A SYNTHESIS OF DIVERSITY, DISTRIBUTION, ABUNDANCE, AGE, SIZE AND DIET OF FISHES IN THE LEASE SALE 193 AREA OF THE NORTHEASTERN CHUKCHI SEA

Final Report

Prepared for:

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

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

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

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EXECUTIVE SUMMARY

[1]B.J. Gallaway, [2]B.L. Norcross

This study provides a synthesis of fish information for the Lease Sale 193 area of the northeastern Chukchi Sea. We identified 22 cruises that sampled demersal fishes in the Chukchi Sea during the period 1959 to 2010. Of these, 16 of the 22 cruises included at least some sampling in the Lease Sale 193 area, but only six (1990 to 2010) provided enough information to allow a focused examination of fish distribution (Chapter 1). An overview of the overall analysis methods we used are described in Chapter 1, and details regarding these analyses are provided in Appendix 1. Appendix 2 provides results of the model analyses and Appendix 3 contains maps and summary tables for the cruises included in this report. Appendix 4 offers a qualitative evaluation of various demersal trawls that have been used to sample fishes in the Lease Sale 193 area.

In Chapter 2, J.T. Priest and S.W. Raborn describe the species composition and assemblage structure of fishes in the study area from collections during 1990 and 2009-2010. Species richness ranged from a low of 19 to a high of 27 species represented in the collections for a given cruise. Cods, especially Arctic cod, were typically the most prevalent family, but sculpins were very common among all the studies. Further, sculpins were also the family with the highest number of species.

Overall, the type of trawl used greatly affected estimates of species richness. The beam trawl collections had between 1.3 and 1.7 species represented in a sample size of 10 individuals, whereas only 0.1 species would be represented in a sample size of 10 individuals collected with the NMFS 83-112 otter trawl. Other factors affecting species richness and assemblage structure, at least in some of the analyses, included diel movements, year, prospect, depth, water temperature, latitude and substrate type. The type of gear used also affected estimates of fish assemblage structure. For more detail, see Chapter 2.

S.T. Crawford and S.W. Raborn describe the distribution and abundance of three important, representative species (Arctic cod, Arctic staghorn sculpin and Bering flounder) in Chapter 3 of this report. Arctic cod, typically the numerically dominant fish in the Chukchi Sea, are an important prey item for a large number of seabird and marine mammal species. Collectively, sculpins represent the second-most abundant family of fishes and the Arctic staghorn sculpin is often the most abundant representative of this family of fishes. Bering flounder are not as abundant as cod and sculpins.

[1] LGL Ecological Research Associates, Inc., Bryan, Texas
[2] University of Alaska Fairbanks, Fairbanks, Alaska

Arctic cod were widely distributed across the study area. Overall, the mean density (number per 1,000 m^2) estimates ranged from a low of 1.9 for collections obtained using a 5-m beam trawl to a high of 32.4 for collections taken using a plumb staff beam trawl collections. Gear type was a significant factor influencing the estimated density of Arctic cod, but little observable impact was observed for other explanatory variables in any of the analyses (with the possible exception of substrate).

In the overall analysis, Arctic staghorn sculpin were most abundant in the Klondike Prospect and vicinity, and exhibited the lowest abundance around the Burger Area. Catches in the plumb staff beam trawl were almost 20 times higher than catches in the NMFS 83-112 otter trawl. When the Barber 1990 NMFS 83-112 data set was excluded, gear impacts were reduced to non-significant levels; i.e., there was not much difference in the estimated density of Arctic staghorn sculpin based upon the type of beam trawl used. Important factors governing Arctic staghorn sculpin abundance included latitude and water depth in at least some of the analyses.

Bering flounder abundance appeared to be highest along the 166˚W meridian. Of the three species examined, it was the only one where gear was not indicated to be an important factor for explaining abundance patterns. Abundance of this species appeared to be negatively associated with longitude (east to west) in one analysis, and prospect was important in another analysis. The highest values of Bering flounder abundance were associated with the western one-half of the Lease Sale 193 area.

Six representative fish species collected during the 2009 and 2010 cruises were subjected to age/length analyses as described by B.L. Norcross, B.A. Holladay, and C. Gleason in Chapter 4. These collections show differences in size/age distributions between years, and we observed differences in length distribution between present and past studies that cannot be attributable to gear differences among studies. We conclude that our sample efforts in recent years captured small fish because the small sizes are numerically dominant in the northeastern Chukchi Sea. The observed inter-annual variability in size/age distributions of Chukchi Sea fishes suggest larger sample sizes are needed to fully understand age-at-length patterns. We recommend 20 otoliths be examined for each 5-mm length interval for each species.

L.E. Edenfield, B.L. Norcross, S.S. Carroll, and B.A. Holladay describe the topic relationships of five demersal fishes of the Chukchi Sea based on collections taken in 2009 and 2010 in Chapter 5. Arctic cod diets included amphipods, copepods, euphausiid/mysids and other small crustaceans over all seasons and areas. Copepods were observed to be extremely important over all areas and seasons. Important prey items of Arctic staghorn sculpin included amphipods and polychaetes; and, averaged over season and area, amphipods and copepods were important prey of the stout eelblenny. The most important component of the polar eelpout diet was amphipods. The Bering founder diet was largely dependent upon amphipods and the euphausiid/mysid prey category. This prey study yielded similar results to those obtained in previous studies conducted in the Alaskan and Canadian Arctic.

The data and models utilized in this investigation provide an important baseline for determining future impacts, if any, resulting from offshore oil and gas exploration and development in the Lease Sale 193 area. The models were set up to be able to define changes resulting from natural shifts in environmental variables separate from effects of oil and gas development. The baseline dataset include data adequate for defining “before” conditions in the Lease Sale 193 area that can later be subdivided into “impact” and “control” areas. Coincident with and following exploration and development, “after” studies can be conducted in the “control” and “reference” areas using gears consistent with the baseline studies to determine impacts.

Lastly, we suggest that future research also focus on developing an understanding of the inter-annual and spatial variability of Arctic cod and the inter-annual variability in recruitment of fishes into the demersal fish community. Such studies should incorporate new gears as necessary to meet these objectives, but should not be conducted at the expense of sampling consistent with the historical baseline data.

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CHAPTER 1 - INTRODUCTION

[1]B.J. Gallaway, [2]B.L. Norcross, [1]R.M. Meyer, [1]S.W. Raborn, [2]B.A. Holladay

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Offshore areas within the northeast Chukchi Sea from Point Hope to Barrow, Alaska were offered for oil and gas leasing in February 2008 (Lease Sale 193) by the United States Minerals Management Service (MMS). This Lease Sale, the second for this region, precipitated an interest in gaining an understanding of the biological communities living in the region. The general consensus was that little was known about offshore ecosystems in the northeast Chukchi Sea in general, and Arctic marine fishes in particular (Johnson 1997; Power 1997; Mecklenburg et al. 2002; MMS 2006). The baseline information describing Chukchi Sea offshore fish communities in the lease area was sparse, making it difficult to predict effects of offshore oil and gas activities, especially considering the potential, confounding impacts that may result from recent atmospheric warming (Arctic Climate Impact Assessment [ACIA] 2004).

For example, the Chukchi Sea presently has an extremely high biomass of benthic invertebrates and other organisms for an Arctic area (Grebmeier and Dunton 2000). Until recently, the northern Bering Sea was also a benthic-dominated ecosystem; i.e., very similar to the Chukchi Sea. Coincident with the recent warming trend, the shallow, northern Bering Sea appears to be shifting from an ice-dominated system in which benthic fauna prevail, to one more dominated by pelagic fauna (Grebmeier et al. 2006). Over time, similar changes could extend northward into the Chukchi Sea. Baseline data were needed to document the presently-existing fish and other biological communities. Baseline information collected now provides the potential to separate impending changes into the relative effects of climate versus anthropogenic effects related to oil and gas development.

ConocoPhillips Alaska, Inc. and Shell Exploration & Production Company began a multidisciplinary baseline investigation of the Lease Sale 193 area in 2008. Fish investigations began in 2009 under the auspices of University of Alaska Fairbanks (UAF) and were continued in 2010 as a joint effort between UAF and LGL Alaska Research Associates, Inc. (LGL). In 2010, investigations were expanded with the addition of another sponsor, Statoil USA E & P, Inc. The 2010 study was also amended to include a synthesis of available fish information suitable for use as baseline information. This report provides the requested synthesis.

[1] LGL Ecological Research Associates, Inc., Bryan, Texas
[2] University of Alaska Fairbanks, Fairbanks, Alaska

1.1 SUMMARY OF HISTORICAL FISH DATA

The Chukchi Sea is outside the range of routine fishery collections. It is north of the regular fish trawl research surveys conducted by the National Oceanic and Atmospheric Administration (NOAA) Alaska Fishery Science Center. To date, there has been no notable effort for commercial fishing in the eastern Chukchi Sea (Arctic FMP 2009). Subsistence fishing in the region is limited to large fishes for human consumption that are taken close to shore. The Chukchi Sea Lease Sale 193 area, which is offshore in the northeastern Chukchi Sea, is, as noted above, under exploration for oil and gas development. From 1959 through 2010, 22 cruises in the Chukchi Sea sampled demersal fish. Collectively, these investigations used 15 different types of demersal trawls (Table 1.1; Norcross et al. 2011). Of those, 16 cruises since 1973 collected fish in the Lease Sale 193 area. All collections occurred in the ice-free months of July – October, and most cruises were in August and September.

Over the historical collection period from 1959 to 2008, >80 taxa of fishes in 19 families were captured (Norcross et al. 2011). More than 90% of the fishes collected were composed of 10 species in four families: smelts – rainbow smelt (*Osmerus mordax*); cods – Arctic cod (*Boreogadus saida*), saffron cod (*Eleginus gracilis*); sculpins – hamecon (*Artediellus scaber*), Arctic staghorn sculpin (*Gymnocanthus tricuspis*), shorthorn sculpin (*Myoxocephalus scorpius*); flatfishes – Bering flounder (*Hippoglossoides robustus*), yellowfin sole (*Limanda aspera*), Alaska plaice (*Pleuronectes quadrituberculatus*). However the dominant species differed among collections depending on the time and place the collections were made.

The composition of fish assemblages in the Chukchi Sea is dominated by a small number of species, although they are not always found in the same proportions. Composition of fish assemblages appears mainly dependent on time and location of sample collection. Multiple fish assemblages were identified in only 7 of the 22 studies conducted during 1959 to 2008 (Norcross et al. 2011). Three of the seven studies identifying multiple assemblages occurred in 1959, 1973 and 2004, years in which no sampling was conducted in the Lease Sale 193 area. Two collections, 1973-Morrrow and 2007b-Norcross (Table 1.1), each identified two distinct assemblages, but only one assemblage in each study occurred within the Lease Sale 193 area. The two remaining studies each identified at least two assemblages within the Lease Sale 193 area. In collection 2007a-Norcross, there were two assemblages in the area of concern. The most complex fish assemblage structure was the 1990-Barber study that identified five distinct fish assemblages, four of which were in the Chukchi Sea Lease Sale 193 area (Norcross et al. 2011). Though fish assemblage differences have been noted for the Lease Sale 193 area, they were not the result of additions and deletions of fish species in the Chukchi Sea over the historical time frame; i.e., there has been no statistical change in composition of fish taxa presence over the 50-year period (Norcross et al. 2011).

Composition of fish assemblages in the northeastern Chukchi Sea is not stable through time. Of interest, it is not the location that most affects fish assemblage structure, but rather the month in which sample collections are made and certain environmental factors (Norcross et al. 2011). The main environmental factors determining demersal fish assemblage structure include temperature, salinity, and sediments. These are factors that are likely to be affected by climate change (ACIA 2004).

With Arctic warming, the composition of marine fish and benthic communities is expected to change. Therefore, changes in distribution of individual fish species, as might be expected with influences of climate change, could restructure the species composition and spatial extent of fish assemblages (Norcross et al. 2011).

1.2 DATA AND MODEL JUSTIFICATION

We restricted our quantitative synthesis effort to studies that were conducted in the Lease Sale 193 area. We relied heavily on Generalized Linear Models (GLMs) for the analyses described below and in the following chapters and in Appendix 1.

1.2.1 Data sets utilized

Whereas 16 of the 22 cruises conducted in the northeastern Chukchi Sea included at least some sampling in the Lease Sale 193 area, not all provided enough information to be useful in the synthesis. Ultimately, the cruise data sets that were included in the quantitative synthesis consisted of Barber 1990; COMIDA 2009; COMIDA 2010; WWW0902; WWW0904; and WWW1003 (see Table 1.1). The composite distribution of samples used in the synthesis analyses are shown by Figure 1.1.

1.2.2 Model selection and justification

The overarching purpose of this study is to better identify and quantify the extant fish populations and communities in the northeast Chukchi Sea, as well as to determine how these communities have changed as a function of time and environmental variables, taking into account the effects of different sampling gears. To that end, we had to first determine what population and community metrics to quantify.

The population densities of species are certainly of interest. Observed frequencies for all species collected are reported in each cruise data set. We use statistical models (see Appendix 1) to more accurately reflect trends for three numerically dominant species. Length frequency distributions are described for species where catches were sufficient for this purpose. However, size distributions are not modeled or correlated with any explanatory variable.

In our study, the data of interest are catch (count of fish) and the effort required to obtain catch. The simplest approach for analyzing such data is to divide each sample‘s catch by the corresponding effort to obtain catch-per-unit-effort (CPUE) and report the averages for each observed combination of categorical variables. Comparing levels of categorical variables in this way can be very misleading if sample sizes were uneven across cells and/or the study design is not a complete factorial; i.e., every combination of cells was not observed. Furthermore, ignoring the influence of continuous variables decreases understanding of the habitat, and, at worst, can lead to deceptive interpretations of comparisons across levels of categorical variables. By modeling the data to obtain predicted CPUEs, missing cells can be filled, uneven sampling can be standardized, and covariates can be added to control for confounding effects.

Historically, this catch was divided by effort to obtain CPUE, a lognormal distribution was assumed, and ANOVA or linear regression analysis were applied, or the two were combined as in analysis of covariance (ANCOVA). Typically, however, CPUE does not have a lognormal distribution and/or contains numerous zero values, which cannot be log-transformed without adding a constant (such as one). Different conclusions can be reached depending on the choice of the constant. Further, dividing by effort weights each tow equally (tows can vary considerably in the volume of water or area of sea floor they sample). False conclusions can be reached when CPUE does not exhibit a lognormal distribution and samples are incorrectly weighted.

To address these issues, we used Generalized Linear Models (GLMs) with discrete probability distributions to compute the likelihood of observing the counts of fish that were collected. These types of GLMs constitute a relatively new approach for analyzing CPUE data (Stefansson 1996; Power and Moser 1999; Terceiro 2003; Minami et al. 2007; Arab et al. 2008; Shono 2008; Dunn 2009).

Community attributes are more difficult to quantify than are most population metrics. This is particularly true for species diversity. Most descriptive reports use metrics such as the Shannon-Wiener index and Simpson’s Index to quantify community diversity. These descriptors attempt to reduce diversity into a single, interpretable number. However, species diversity can be separated into two components—richness (the number of species) and evenness (how evenly distributed the quantity of individuals are across species; Pielou 1977).

Most, if not all, diversity indices combine these components in various ways which confound interpretation of results (Washington 1984). It is not possible to tell from these diversity indices whether one site yields a higher diversity index relative to another because its individuals are more evenly distributed across species, or because it possesses more species. Healthy communities often have a few dominant species and many rare species, which leads to high species richness coupled with low evenness. Disturbed systems typically have fewer species (low richness), but sometimes the species that are present are about equally represented, leading to high evenness. Kimbro and Grosholz (2006) reported that evenness increased with increasing disturbance, while Mackey and Currie (2001) found evenness to be unrelated to disturbance in about half the studies they surveyed. Therefore, we chose not to analyze evenness and focused on species richness, which was also modeled using GLMs.

Another important community level feature is the proportionate mix of species, which can be used to define distinct communities. The degree or magnitude of change in this mix across environmental gradients defines the level of beta diversity for an area. This mix is termed the assemblage structure (sometimes called community structure). For a given sample within which fish are caught, there will be a certain number of species collected (species richness) and each species will have a relative abundance that marks its comparative contribution to the assemblage. A species' relative abundance equals the abundance of that species in the sample divided by the total abundance of all species in the sample. Changes in these values as a function of the explanatory variables was modeled with multinomial GLMs.

1.3 REPORT CONTENT

We have organized the fish synthesis report in six chapters, beginning with this Introduction. Chapter 2 addresses species composition and assemblage structure of Chukchi Sea fishes. The distribution and abundance of dominant and/or selected species is described in Chapter 3. The size and age distribution of key species and their trophic relationships are covered in Chapters 4 and 5, respectively.

The appendices are a critical part of this report. Appendix 1 provides a detailed account of the statistical methods that were used, and the results of the model analyses are provided in Appendix 2. Appendix 3 contains maps and details of fishing activities for those cruises considered in this report. Each Chapter (2–5) relies heavily on the results detailed in these and other appendices. Appendix 4 provides qualitative comparisons of the results obtained from the various gear types that have been used to sample demersal fishes in the northeastern Chukchi Sea. Not all gears sample the same and it is important to be able to separate gear effects from environmental effects.

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Table 1.1. Summary of data collected during 1959–2010 cruises in the Chukchi Sea. Cruise (Chukchi Demersal Fish, CDF) is a unique identifier for each cruise and gear combination that is used in the Chukchi Demersal Fish data base prepared for the Bureau of Ocean Energy Management (Norcross et al. 2011). Headings are abbreviated: Abund = abundance, Temp = temperature, Sal = salinity, Substrate = % grain size. Gear types are abbreviated: OT = otter trawl; PSBT = plumb staff beam trawl. Mesh is the smallest mesh.

Cruise (CDF)	Cruise	Month and year	Fishing gear	Haul area (m^2)	Abund	Biomass	Depth	Temp	Sal	Substrate
1959-Alverson	John N. Cobb 43	Aug 1959	400 eastern OT		X		X	X		
1970-Quast	WEBSEC-70	Sep 1970	3 m OT				X	X	X	
1973-Morrow	Alpha Helix-1973	Jul-Sep 1973	4.9 m OT		[1]		X	[1]		
1976-Pereyra	MF-76-B	Aug-Oct 1976	NMFS 83-112	X	X	X	X	X		
1977-Frost	Glacier-1977	Aug-Sep 1977	4.9 m & 5.8 m OT		X	X	X			
1983a-Fechhelm	Discoverer-1983	Aug-Sep 1983	7.6 m OT		X		X	X	X	
1983b-Fechhelm	Discoverer-1983	Aug-Sep 1983	2.7 m OT		X		X	X	X	
1989-Barber	HX130 (Barber 1989)	Sep 1989	4.9 m OT		X		X	X		
1990-Hokkaido	OS33	Jul-Aug 1990	43 m OT		X	X	X	X	X	
1990-Barber	OH902 (Barber 1990)	Aug-Sep 1990	NMFS 83-112	X	X	X	X	X	X	
1991-Hokkaido	OS38 (Barber 1991)	Jul 1991	43 m OT		X	X	X	X	X	
1991c-Barber	OH91	Aug-Sep 1991	NMFS 83-112	X	X	X	X	X	X	
1992-Hokkaido	OS44 (Barber 1992)	Jul 1991	43 m OT		X	X	X	X	X	
2004-Norcross	RUSALCA-2004	Aug 2004	PSBT	X	X		X	X	X	X
2004-Mecklenburg	RUSALCA-2004	Aug 2004	7.1 m OT		[1]	[1]	X	X	X	X
2007a-Norcross	OS180	Aug 2007	PSBT	X	X	X	X	X	X	X
2007b-Norcross	OD0710	Sep 2007	PSBT	X	X	X	X	X	X	X
2007-Hokkaido	OS180	Aug 2007	43 m OT		X	X	X	X	X	
2008-Norcross	OS190	Jul 2008	PSBT	X	X	X	X	X	X	
2008-Hokkaido	OS190	Jul 2008	43 m OT		X	X	X	X	X	
2009a-Norcross	COMIDA 2009	Jul-Aug 2009	PSBT	X	X	X	X	X	X	X
2009c-Norcross	WWW0902	Aug-Sep 2009	PSBT	X	X	X	X	X	X	X
2009e-Norcross	RUSALCA-2009	Sep 2009	PSBT	X	[1]	[1]	X	X	X	X
2009g-Norcross	WWW0904	Sep-Oct 2009	PSBT	X	X	X	X	X	X	X
2009-Mecklenburg	RUSALCA-2009	Sep 2009	9.1 m OT		[1]	[1]	X	X	X	X
2010a-Gallaway	COMIDA 2010	Jul-Aug 2010	5mBT	X	X	X	X	X	X	X
2010b-Gallaway	WWW1003	Sep 2010	PSBT	X	X	X	X	X	X	X
2010c-Gallaway	WWW1003	Sep 2010	3mBT	X	X	X	X	X	X	X
2010d-Gallaway	WWW1003	Sep 2010	4mBT	X	X	X	X	X	X	X
2010e-Gallaway	WWW1003	Sep 2010	5mBT	X	X	X	X	X	X	X
2010f-Gallaway	WWW1003	Sep 2010	MPSBT	X	X	X	X	X	X	X

[1] data collected but not yet public

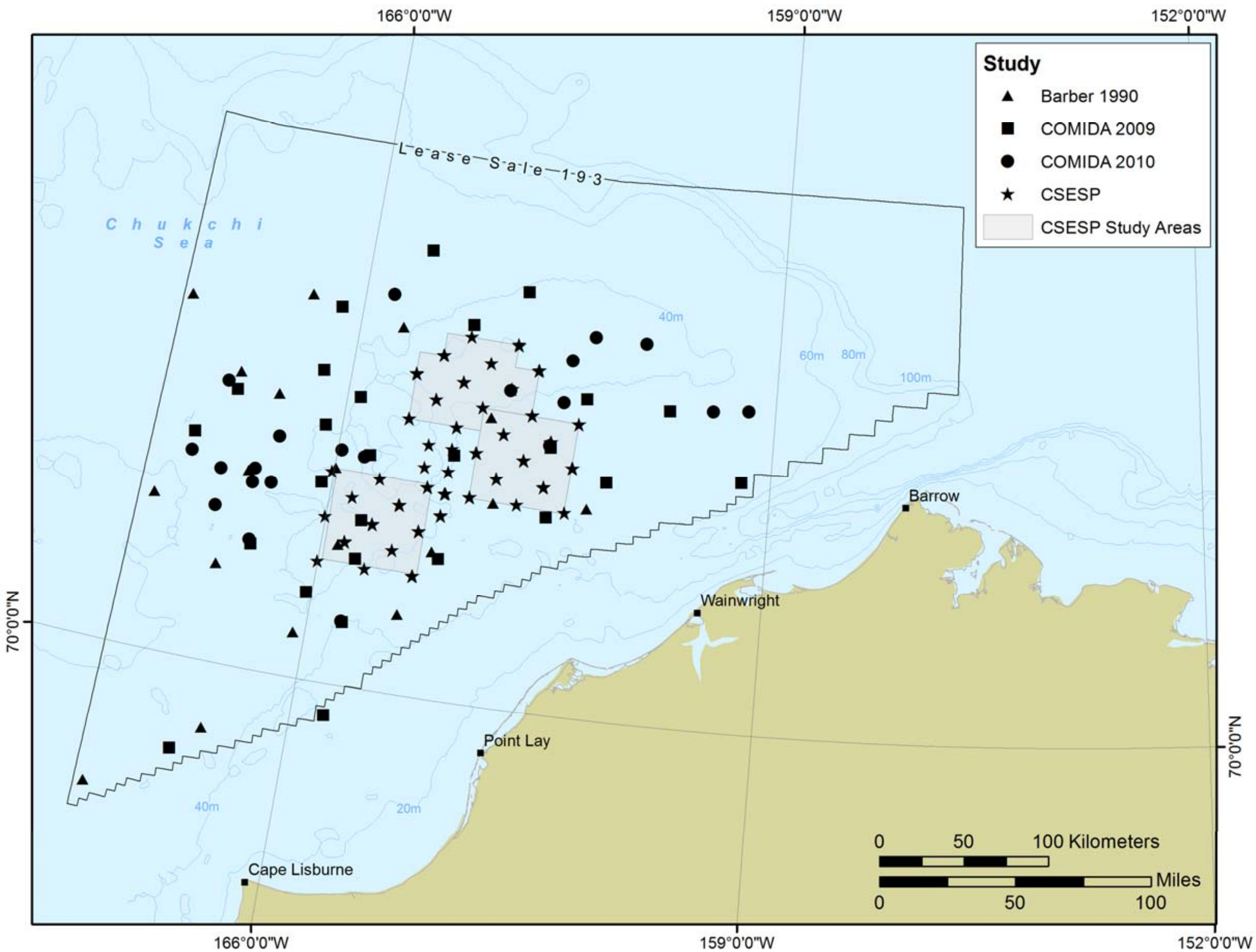

Figure 1.1. Composite distribution of benthic trawl samples used in the synthesis analysis.

CHAPTER 2 - SPECIES COMPOSITION AND ASSEMBLAGE STRUCTURE OF DEMERSAL FISHES IN THE NORTHEASTERN CHUKCHI SEA

[1]J.T. Priest, [2]S.W. Raborn

The sale of offshore oil and gas leases (Lease Sale 193) in 2008 by the United States Minerals Management Service (MMS) in the northeastern Chukchi Sea highlighted the necessity for gathering additional biological data. As a result of Lease Sale 193, several stakeholders (ConocoPhillips Alaska, Inc., Shell Exploration & Production Company, and Statoil USA E & P, Inc.) have sponsored multidisciplinary baseline investigations of oceanographic and biological conditions.

Sampling first occurred during the summer, open-water season of 2008 with fish sampling for the baseline studies program added in 2009 (Norcross et al. 2011). This study was managed by Olgoonik-Fairweather (OLF) as a joint venture between the stakeholders and is referred to as the Chukchi Sea Environmental Studies Program (CSESP).

The CSESP fish studies were complemented by studies of benthic invertebrates, zooplankton, seabirds and marine mammals. Acoustic buoys were also set to passively detect the movement of whales and walrus through the northeastern Chukchi Sea over the course of a year. Physical oceanographic studies were conducted to provide information on large scale water flow and water mass properties that were possibly influencing the biological observations. As all of the biological and physical processes are interrelated, this work represents a major step towards an ecosystem-scale understanding of the Chukchi Sea.

Two cruises were conducted as part of the CSESP in 2009, one in August and the other in September/October. Sampling was conducted at two study areas (Klondike and Burger) on each cruise. Each study area roughly corresponded to a prospective area of development (prospect) leased by one of the stakeholders. The 2009 fish field studies and laboratory analyses were conducted by University of Alaska Fairbanks (UAF) researchers. In 2010, a third study area (Statoil) was added to the study. Fish sampling occurred on only one cruise during September 2010 and was conducted by LGL Alaska Research Associates, Inc (LGL) with the assistance of UAF personnel. Laboratory analyses (diet analysis, age determination based on otoliths, and individual weights) of the 2010 samples are being conducted by UAF. All fish caught by LGL were provided to UAF researchers for further analysis.

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[1] LGL Alaska Research Associates, Inc., Anchorage, Alaska
[2] LGL Ecological Research Associates, Inc., Bryan, Texas

A synthesis of fish studies including data from the CSESP, the Chukchi Offshore Monitoring in the Drilling Area (COMIDA), and historical data was required as part of the 2010 program to provide a baseline for future impact assessments. Historical data (Barber et al. 1994) were reviewed (Chapter 1) and evaluated as part of a synthesis workshop conducted by the team of scientists that had conducted the CSESP fish investigations. Review of the historical data suggested that only Barber's 1990 trawl studies had the requisite spatial overlap with the Lease Sale 193 area and sample documentation necessary for inclusion in the synthesis analyses. Although all studies included pelagic (midwater) sampling, relatively low pelagic catches among all studies meant that we only assessed demersal fish communities.

2.1 SYNTHESIS STUDY OVERVIEW

The synthesis utilizes data from the CSESP study, the COMIDA program (comparable in both location and time), and the historical trawl study of Barber conducted in 1990. Other studies potentially providing additional data were either primarily limited to areas outside the Lease Sale 193 area or lacked the proper metadata for inclusion.

2.1.1 Overview of the CSESP study

Fish sampling for the CSESP cruises occurred at stations in a fixed grid, with stations for fishing selected *a priori*. These stations were grouped into three study areas (prospects). The Klondike and Burger study areas were identical in shape and size at 55.6 x 55.6 km^2 (30 x 30 NM^2; Figure A3.9). These two study areas were non-adjacent and centered about 70 km apart; the northeast corner of Klondike was about 19 km from the southwest corner of Burger. The Statoil study area was not square-shaped and was adjoined to the northwestern edge of Burger. Limited sampling also occurred in the corridor between the Klondike and Burger/Statoil study areas (Transitional stations). In total, the CSESP cruises sampled 26 stations (being those in the Burger and Klondike study areas) in 2009 while in 2010, 43 stations were sampled (Klondike, Burger, Statoil and the Transitional stations). The number of stations in each study area varied; there were 13 in Klondike and Burger, 11 stations in Statoil, and six Transitional stations. The stations sampled in Burger and Klondike in 2010 were the same stations as those sampled in 2009.

In 2009, two CSESP cruises took place during which fish were sampled. Fish sampling occurred during 13–29 August (cruise WWW0902) and again during 25 September–10 October (cruise WWW0904). All of the same stations were sampled on both cruises. In 2010, there was only one cruise from 1–19 September (WWW1003). The sampling in 2010 was of the same 26 stations in Klondike and Burger with 17 additional stations in Statoil and the Transitional stations. Sampling during both years occurred on the R/V *Westward Wind*.

The PSBT and the 3mBT are both beam trawls designed to sample epibenthic invertebrates and demersal fishes living in, on or near the bottom. The PSBT was towed on the bottom for 2 to 3 minutes. This gear was very effective at sampling benthic invertebrates, which greatly limited the length of tows. The 3mBT was usually towed for 30 minutes, though this was occasionally reduced to 10 or 15 minutes if the area was known to have high benthic invertebrate biomass. For both nets, the length of wire deployed was usually twice the water depth (scope = 2.0).

2.1.2 Overview of COMIDA study

The COMIDA study was initiated to provide a wide-scale view of the ecosystem within Lease Sale 193. Fish sampling occurred from 27 July to 11 August 2009. Sampling was conducted entirely with a three-meter plumb staff beam trawl (PSBT) towed for about 2–3 minutes. Fish sampling occurred again in 2010 from 30 July to 15 August. In 2010, sampling was only with a five-meter beam trawl (5mBT) towed for approximately 30 minutes. These two gear types were never used at the time during either year. The chief scientists for both years were Dr. Jackie Grebmeier and Dr. Ken Dunton. Synoptic measurements of temperature, salinity, and substrate analysis occurred at all stations sampled for fish during both years of sampling. Sampling in 2009 was aboard the R/V *Alpha Helix* under the direction of UAF researchers while in 2010 LGL researchers aboard the R/V *Moana Wave* performed the sampling. Protocols for the PSBT and 5mBT as a part of the COMIDA study were the same as those observed for the CSESP study.

2.1.3 Overview of Barber study

As a result of the first sale of offshore leases in the Chukchi Sea, the first broad scale study in the Chukchi Sea was organized. Fish collections occurred during the 16 August–13 September 1990 aboard the R/V *Oshoro Maru*. Sampling also occurred during the 1989 and 1991 field seasons. The data from 1989 and 1991 were excluded from analyses because of a lack of spatial overlap in Lease Sale 193 as well as a lack of tow data being collected (effort data was only available for fish data from 1990). Some sampling from this study occurred nearshore, outside of Lease Sale 193; data from these stations were excluded. All sampling was with a standard NMFS 83-112 otter trawl (Table 1.1) towed for one hour. Further, substrate data was not collected at stations selected for fishing. Further discussion of trawl methods are found in Barber et al. (1994) and Barber et al. (1997).

2.2 MODEL ANALYSES AND ASSUMPTIONS

Models were run for three datasets, producing subtle yet important differences (see Appendix 1 for more details). First, models were created using all studies and data. Because the 1990 study (Barber et al. 1997) did not sample substrate composition, these variables could not be included. For this reason, we then chose to add substrate variables in a separate analysis that excluded the Barber 1990 study. Finally, the models were run using only the CSESP cruises, allowing for the inclusion of “prospect” as a categorical variable. For all three of these approaches, the impact of categorical and continuous variables upon assemblage structure and species richness was analyzed. Appendix 1 includes more discussion of these analyses.

2.2.1 Statistical approaches to community analyses

Community attributes are more difficult to quantify than are most population metrics. This is particularly true for species diversity. Most descriptive reports use metrics such as the Shannon-Wiener index and Simpson’s Index to quantify community diversity. These descriptors attempt to reduce diversity into a single, interpretable number. However, species diversity can be separated into two components—richness (the number of species) and evenness (how evenly distributed individuals are across species; Pielou 1977). Most, if not all, diversity indices combine these components in various ways which confounds interpretation of the results (Washington 1984). It is not possible to tell from these diversity indices whether one site yields a higher diversity index relative to another because its individuals are more evenly distributed across species, or because it possesses more species.

2.2.1.1 Species richness

Healthy communities often have a few dominant species and many rare species, leading to high species richness coupled with low evenness. Disturbed systems typically have fewer species (low richness), but sometimes the species that are present are about equally represented leading to high evenness. Kimbro and Grosholz (2006) reported that evenness increased with increasing disturbance, while Mackey and Currie (2001) found evenness to be unrelated to disturbance in about half the studies they surveyed. Therefore, we chose not to analyze evenness and focused instead on species richness. Richness was standardized to 10 individuals; that is, if a random sample of 10 fish were observed, how many species would be expected in this sample.

2.2.1.2 Assemblage structure

Another important community level feature is the proportional mix of species, which can be used to define distinct communities. The degree or magnitude of change in this mix across environmental gradients defines the level of beta diversity for an area. This mix is termed the assemblage structure (sometimes called community structure). For a given sample with a positive catch, there will be a certain number of species collected (species richness) and each will have a relative abundance that marks its comparative contribution to the assemblage. A species' relative abundance equals the abundance of that species in the sample divided by the total abundance of all species in the sample.

2.2.2 Variables measured

The independent variables used in the analyses are from a variety of sources. For the CSESP and COMIDA cruises, synoptic observations (depth) and measurements of water characteristics (salinity, temperature) occurred at all stations. Substrate analysis from the CSESP cruises is from A. Blanchard (UAF, unpublished data). Substrate analyses from the COMIDA cruises are from M. Guarinello (University of Maryland Center for Environmental Science, Chesapeake Biological Lab, unpublished data). Distance offshore was calculated using ArcMap© 10 software and the spatial analyst extension (ESRI, Inc). Data from the Barber study was calculated using the published results when available (1994) and raw data from the authors.

2.3 RESULTS

2.3.1 Diversity – Number of fish species and families

In total, 32,014 fish from all studies were analyzed (Table 2.1). Of these, 6,098 were from the CSESP cruises (both years combined). A total of 39 fish species were distributed across 11 families (Table 2.1). Species richness of individual cruises ranged from a low of 19 fish species (COMIDA 2010) to a high of 27 species (WWW0904). Cods were the most commonly caught family though sculpins were the family with the highest number of unique species (10).

Unmodeled relative abundances varied widely from study to study, being confounded with gear, effort, and environmental variables (Figure 2.1). The total catch from the 1990 Barber study was composed of 96.5% Arctic cod (*Boreogadus saida*) while from the COMIDA 2009 study it was 6.9% Arctic cod.

Across the studies compared, cods (especially Arctic cod) were the most prevalent family. However, two cruises were an exception: COMIDA 2009 and WWW0904 both caught more sculpins than cods. For the WWW0904 cruise, Arctic cod were the most common species, though this did not hold true for COMIDA 2009 (fourth most common species).

Sculpins were very common among all of the studies, often distributed among several common species (Table 2.1). Sculpins were also the family with the highest number of species present. In addition, sculpins were most common in the COMIDA 2009 and the WWW0904 cruises, exceeding 40% of the total catch.

2.3.2 Measured environmental variables

The Lease 193 study area is entirely offshore; thus most sampling stations were far from land. The lease blocks were sampled more heavily than surrounding areas and were located farther from shore than the rest of the lease area. Sampling distance from shore varied from 55.3 km to 307.0 km.

Much of the northeastern Chukchi Sea is relatively shallow. Maximum depth at sampling stations was relatively uniform, ranging from 20.5–55.0 m. Temperature and salinity are often inextricable because of the water masses. Salinity varied from a low of 30.9 psu to a high of 33.3 psu. Temperatures ranged from -1.8 to 7.9 C. The highest values for temperature and salinity, as well as the lowest value for salinity, were within the CSESP study area.

Substrates varied widely from station to station, often radically different among stations in close proximity. Percent mud ranged from a low of 0% to a high of 98.0%. Percent gravel ranged from a low of 0% to a high of 60.6%. The CSESP substrate data ranged from 0–60.6% gravel and 9.5–92.5% mud.

2.3.3 Statistical analyses

2.3.3.1 Variables affecting richness

Categorical variables

Gear (3mBT, 5mBT, NMFS 83-112, PSBT) as an independent variable was included in all three analyses (Tables A2.1.3, A2.2.3, A2.3.3). There was 100% evidence that gear was affecting richness using both the “all data” and CSESP + COMIDA datasets. When only CSESP data is analyzed and prospect is an independent variable, the percent evidence for gear is only 74% (moderate evidence of influence). The CSESP analysis only compares the 3mBT to the PSBT.

We also examined whether vertical diel movement of fishes affected species richness. That is, whether species present on the bottom during the day might not be present during the night, or vice-versa. Day vs. night sampling was included in all iterations of the model (Tables A2.1.3, A2.2.3, A2.3.3). When all datasets are included, there is 100% evidence of an impact on species richness. For the COMIDA + CSESP dataset, there was 99% evidence. For just the CSESP data, there was only a 24% chance of day vs. night sampling impacting species richness.

For all three iterations, predicted marginal means for day sampling were greater than or equal to night sampling.

Year was only included for two analyses: COMIDA + CSESP and just the CSESP data (Tables A2.2.3, A2.3.3). In both analyses, year was found to have 100% evidence to affect species richness. Predicted marginal means for both of these analyses were very similar and were more than double in 2010 (2.2, CSESP; 2.0 COMIDA + CSESP) than in 2009 (1.0, CSESP; 0.9 COMIDA + CSESP).

The inclusion of prospect as an independent variable was only permissible with just the CSESP data (Table A2.3.3). There was a 100% chance that species richness varied depending on the prospect. The Statoil study area had the highest predicted marginal mean of 1.9, followed by the Burger study area (1.7), and the Klondike study area (1.1).

Continuous variables

In all three iterations of the modeled results, depth was determined to have 100% evidence of impact on species richness (Tables A2.1.4, A2.2.4, A2.3.4). In all cases, increased depth was positively correlated to increased species richness.

Temperature was included in all three datasets (Tables A2.1.4, A2.2.4, A2.3.4). When all data are analyzed, there was a 100% chance of temperature affecting richness and was positively correlated. For the COMIDA + CSESP dataset and just the CSESP data, temperature had lower evidence (96% and 64% respectively) and was negatively correlated.

Likewise, salinity was also included in all datasets (Tables A2.1.4, A2.2.4, A2.3.4). Salinity was never highly correlated to species richness. For all data, salinity had a 74% chance of affecting species richness (moderate probability). For the COMIDA + CSESP dataset and just the CSESP data, salinity had much lower evidence (32% and 24% respectively), thus indicating that there existed little evidence that salinity was affecting species richness.

Latitude and longitude were included in both the all data analysis and in the COMIDA + CSESP dataset but not in the CSESP only analysis to avoid being confounded with prospect (Tables A2.1.4, A2.2.4). The all data analysis showed 93% evidence for latitude and 60% evidence for longitude. The COMIDA + CSESP dataset showed a high likelihood of latitude affecting species richness (93%) but did not ascertain the likelihood of longitude (69%). That is, the evidence was just as likely that longitude affected richness as not. Latitude was positively correlated with richness in both analyses.

Distance offshore (km) was in both the all data analysis and in the COMIDA + CSESP dataset but not in the CSESP only analysis to avoid being confounded with prospect (Tables A2.1.4, A2.2.4). The all data analysis had 58% evidence while the COMIDA + CSESP dataset had 49% evidence.

Substrate was assessed for the COMIDA + CSESP dataset and the only CSESP dataset (Tables A2.2.4, A2.3.4). For the COMIDA + CSESP data and the only CSESP the resulting evidence were the same for both analyses. Both substrate groups were determined to have a very high likelihood of impacting species richness: 100% evidence for percent gravel and 100% evidence for percent mud. Substrate therefore surely affected the species richness. Percent mud and percent gravel were both negatively correlated with species richness.

2.3.3.2 Variables affecting assemblage structure

Categorical variables

For all three analyses there was a 100% chance that gear (3mBT, 5mBT, NMFS 83-112, PSBT) affected assemblage structure (Tables A2.1.2, A2.2.2, A2.3.2). Even for the analysis of just CSESP data (3mBT vs. PSBT), there still remained a 100% chance of impact. All gear types affected assemblage structure.

Assessing whether sampling was during day or night affected proportions of species was done for all three analyses (Tables A2.1.2, A2.2.2, A2.3.2). For all datasets, there was 100% evidence of impact.

Year was included in two analyses (COMIDA + CSESP and only CSESP data; Tables A2.2.2, A2.3.2). Both analyses found 100% evidence for year affecting assemblage structure.

Prospect (Klondike, Burger, or Statoil) as a categorical independent variable was assessed using only just the CSESP data (Table A2.3.2). There was a 100% chance that prospect affected the assemblage structure.

Continuous variables

Depth, water temperature and water salinity were included in all three analyses (Tables A2.1.2, A2.2.2, A2.3.2). In all iterations of the model, temperature, depth, and salinity were found to have 100% evidence of affecting assemblage structure.

Latitude and longitude were included in the all data and COMIDA + CSESP datasets (Tables A2.1.2, A2.2.2). Latitude had 100% evidence of affecting assemblage structure in both models. The results for longitude seemed to indicate that it does not play a role in affecting assemblage structure. For the all data iteration there was 0% evidence while for the COMIDA + CSESP dataset there was 100% evidence of impact. (Having 0% evidence means that there is a 100% chance that salinity did *not* affect assemblage structure for this dataset.)

The distance from shore was included in the all data and COMIDA + CSESP datasets (Tables A2.1.2, A2.2.2). In both iterations, distance offshore was found to have 100% evidence of impacting assemblage structure. Substrate data were included in the COMIDA + CSESP and the CSESP only datasets. Percent gravel was found to have 100% evidence of impact in both iterations. Percent mud was found to have 100% evidence for both the COMIDA + CSESP dataset and the CSESP only dataset.

The nMDS biplots (Figures A2.1–A2.3) showed clustering of both stations and species. Including all datasets, there is a cluster of both samples and species along the vector of 'distance from shore.' The data from Barber are seen to separate from the rest of the data.

2.4 DISCUSSION

2.4.1 Richness and diversity

Total richness among the studies was within similar ranges (19–27). Notably the three CSESP cruises had higher raw species richness than did the other cruises. There were 39 fish species caught among all of the studies. In general, fish species richness is low in the Arctic compared to lower latitudes (Stevens 1996). Eastman (1997) postulated that this is because Arctic fishes are relatively evolutionarily young and have not yet expanded into all niches. Species adapted to survive in other areas have trouble adapting to the extreme environment (cold temperatures, ice cover, and seasonal food supply) of the Arctic. The undifferentiated topography of the northeastern Chukchi Sea provides few unique macro-habitats that are necessary to support diverse biological assemblages. Correspondingly, the lack of piscivorous fishes is likely attributable to low fish density, further suppressing the number of fish species within the ecosystem. These factors all limit Arctic fish diversity.

In all iterations of the model, depth was shown to have 100% chance of affecting species richness. This could be attributable to the depth of the photic zone impacting the benthic community or potentially to a warm, nutrient-high water mass that does not affect deeper waters. Though the causation remains unknown, our results show that species richness increases with depth.

When included, percent gravel and percent mud both had 100% evidence of affecting species richness. Neither of these is particularly surprising; substrate affects the abundance of benthic invertebrates causing food availability to either be enhanced (e.g., polychaete worms) or curtailed (e.g., brittle stars). Latitude showed slightly less, yet still significant evidence, of impacting species richness.

2.4.2 Assemblage structure

Though the proportions of fish species differed among studies, several trends remained similar. Arctic cod dominate the total catches in all cruises except COMIDA 2009. Catches of cod were fairly consistent throughout the stations too, i.e., total numbers were not influenced by sporadic large catches. Though Arctic cod are known to school in large, dense aggregations (Logerwell et al. 2011; Crawford 2010), no schools were observed in any of the COMIDA or CSESP cruises. This is likely because most year-plus Arctic cod schools have been noted at or near the shelf break (<100 m), mostly outside of Lease Sale 193 (Logerwell et al. 2011). Lease blocks slated for prospective development are located away from the shelf break.

Though cods were most often the prevalent family, sculpins were very common among all of the studies, often distributed among several common species. Two cruises (COMIDA 2009 and WWW0904) caught more sculpins than cods. Sculpins were also the family with the highest number of species present. Sculpins were most common in the COMIDA 2009 and the WWW0904 cruises, exceeding 40% of the total catch. Fish sampling in the northwestern Chukchi Sea as part of the RUSALCA study showed higher proportions of sculpins than those found in our study (Mecklenburg et al. 2007), implying an east-west gradient in assemblage structure.

Most of the variables included in the models showed significant evidence of impacting assemblage structure. This demonstrates that assemblage structure, being composed of the proportions of individual species, can be influenced by many factors: a response by a single species to one of the variables would alter the relative abundance. Longitude however, did not have much evidence of impact. The nMDS biplots indicate that while clusters exist that are statistically significant, they may not be biologically significant.

Water flux into the Chukchi Sea transports fishes from the Bering Sea, impacting assemblage structure within the study area. As the northern Bering Sea fish community changes in response to changing environmental conditions (Grebmeier et al. 2006a) this will affect the Chukchi Sea. The northeastern Chukchi Sea could therefore receive different species, proportions and levels of fishes. This impact remains to be studied.

2.4.3 Fish community composition of the northeastern Chukchi Sea

Fish communities of the northeastern Chukchi Sea are benthic based. Almost all species caught were demersal, or at least semi-demersal. While pelagic catches were excluded from our analyses, catches from midwater trawls were magnitudes lower than demersal catches. Almost all fish species present are associated with the sea floor and feed on benthic invertebrates (Barber et al. 1994; Coad and Reist 2004; Chapter 5 of this report). Benthic biomass is very high in the Chukchi Sea as compared to other Arctic seas (Grebmeier et al. 2006b). Even though most of the ecosystem biomass is benthic (Blanchard et al. 2010), a large portion of the biomass is in species that have little or no value as forage (e.g., *Ophiura sarsi*, brittle star). Chapter 5 further discusses food habits of selected species.

Among almost all prior studies in the region, Arctic cod were almost always the most common offshore species. Fish assemblages in the study area are dominated by select species, with many more uncommon fish species. Advection of fish from the Bering Sea may be the source of some of the rare fishes found in the southern Chukchi Sea. Previous studies did not always agree on exact species proportions but were often very similar.

Arctic cod are very important to the ecosystem as they are abundant, high in nutritional value (Piatt et al. 1990), and fed upon by higher trophic levels such as seabirds and marine mammals (Piatt et al. 1990; Frost and Lowry 1983). Additionally, Arctic cod are a ‘generalist’ species: they can feed on a wide variety of benthic and pelagic forage (Hop et al. 1997; Barber et al. 1994) and are uniquely physiologically adapted to the environment (Chen et al. 1997). There are also several benefits to being a semi-demersal species, such as the ability to eat both pelagic and benthic food sources, and the mobility to move to higher food concentrations (e.g., seasonal nearshore to offshore migrations). These present a distinct advantage over competing species that are more limited in diet and habitat.

2.4.3.1 Variables affecting fish communities

The higher predicted marginal means for 2010 compared to 2009 may have been the result of an anomalously large recruitment from 2009. Pelagic catches in 2009 were orders of magnitude higher than in 2010 and were predominantly ichthyoplankton (<40 mm). Higher demersal catches in 2010 could possibly be due to an increased number of young fish. Alternatively, the high pelagic catches in 2009 and high demersal catches in 2010 could be due to another factor such as an atypically high plankton bloom in 2009 with cascading benefits through the food web. These shifts could be due to environmental changes such as a slight shift in water mass boundaries, allowing for a much higher level of nutrients (Weingartner 1997), or transporting plankton into the study area.

Past studies have noted large fluctuations in the age structure of fish in the Chukchi Sea from year to year (Barber et al. 1994; Norcross et al. 2010). The harsh environment of the Chukchi Sea likely causes juvenile fish recruitment to occur sporadically (Barber et al. 1994). Thus, favorable environmental conditions in 2009 may have caused a year of excellent recruitment resulting in an abundance of juvenile fish. Data from several disciplines associated with this project indicate that 2009 may have been an anomalous year. CSESP seabird observations for 2009 were a level of magnitude higher than those seen in either 2008 or 2010; copepod-feeding alcids were seen in record numbers (A. Gall, ABR Inc., unpublished data).

It is quite likely that the 83-112 otter trawl did not effectively sample the fish community that was within a few centimeters of the ocean floor. Thus, the high-rising otter trawl would have proportionally oversampled fish higher in the water column while proportionally undersampling benthic fishes. Data from Barber et al. (1997) show that semi-demersal cods were caught in much higher proportions than were demersal sculpins, as expected if benthic undersampling were occurring. Predicted marginal means (as well as unadjusted CPUE) for samples from the Barber 1990 are much lower than the other studies. This is attributable to the massive amount of effort put forth (one hour tows) as well as the sheer size of the 83-112 otter trawl. Another major difference between the 83-112 otter trawl and the beam trawls used in the other studies is the mesh size: the 83-112 otter trawl used significantly larger mesh (see Appendix 4 for further discussion). The mesh size can cause different fish to stay caught in the net, potentially changing both assemblage structure and the species richness.

2.5 CONCLUSION

Data collected from two years of fish sampling as a component of the Chukchi Sea Environmental Studies Program (CSESP) was compared to concurrent and historical data from the region. These comparisons were examined using generalized linear models (GLMs) to determine whether selected environmental variables statistically affected species richness or assemblage structure. These datasets were modeled in three separate iterations allowing for the inclusion of variables that may not have been measured during all cruises. Data were limited to demersal catches within the Lease Sale 193 area.

In total, catches from six cruises were analyzed, five of which were from the period of 2009–2010. Raw species richness ranged from 19 to 27 per individual cruise with a total of 39 species of fish across 11 families. Cods (Gadidae) were the most common family, though sculpins (Cottidae) were also very common. Catches of cods were mostly of a single species (Arctic cod) while sculpin catches tended to be spread out among the 10 sculpin species.

Results from the GLM showed mixed responses to environmental variables. Assemblage structure was likely affected by vertical diel movement of fishes. Species richness was likely also influenced by this variable, though the response is less clear if the analysis is restricted to just CSESP data. The gear used to capture fish changes the proportions of fish caught (even among just CSESP data). Substrate, especially percent gravel, affected both species richness and fish assemblage structure. Latitude and depth were important to both assemblage structure and species richness. These two variables were both positively correlated to richness (increasing depth or latitude resulted in increased species richness). Notably, demersal assemblage structure and species richness changed from 2009 to 2010.

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Table 2.1. Catch by family and species of studies in the northeastern Chukchi Sea. Totals are of demersal catches only at stations within Lease Sale 193. Bold numbers indicate the totals for each family.

Family	Barber 1990	COMIDA 2009	COMIDA 2010	WWW0902	WWW0904	WWW1003	Total
Agonidae	**4**	**15**	**5**	**26**	**37**	**118**	**205**
Aspidophoroides monopterygius		1		4	8	1	14
Hypsagonus quadricornis						5	5
Ulcina olrikii	3	14	5	22	29	112	185
Agonidae spp.	1						1
Ammodytidae		**12**	**7**		**30**	**2**	**51**
Ammodytes hexapterus		12	7		30	2	51
Clupeidae	**3**						**3**
Clupea pallasii	3						3
Cottidae	**276**	**823**	**179**	**337**	**837**	**518**	**2,970**
Artediellus gomojunovi					1		1
Artediellus ochotensis						1	1
Artediellus scaber	20	27	36	219	160	227	689
Artediellus spp.	7						7
Gymnocanthus tricuspis	131	715	11	50	205	131	1,243
Hemilepidotus papilio	4			1			5
Icelus spatula	1		1	12	14	11	39
Icelus spp.						1	1
Microcottus sellaris	1						1
Myoxocephalus scorpius		79	61	53	438	132	763
Myoxocephalus spp.	108		5				113
Trichocottus brashnikovi					2	1	3
Triglops pingelii	3	2	1	2	17	14	39
Triglops spp.	1						1
Cottidae			64				64
Gadidae	**22,242**	**139**	**338**	**604**	**505**	**884**	**24,712**
Boreogadus saida	22,223	139	337	604	504	884	24,691
Eleginus gracilis	11		1				12
Gadus macrocephalus	8						8
Theragra chalcogramma					1		1
Hemitripteridae		**1**		**1**	**8**	**39**	**49**
Nautichthys pribilovius		1		1	8	39	49
Liparidae	**17**	**65**	**15**	**13**	**22**	**36**	**168**
Liparis gibbus	12		3	8	15	1	39
Liparis tunicatus	1	64	12	5	7	35	124
Liparis spp.	4	1					5
Osmeridae	**2**						**2**
Mallotus villosus	2						2
Pleuronectidae	**218**	**72**	**50**	**35**	**33**	**17**	**425**
Hippoglossoides robustus	213	53	50	35	31	17	399
Limanda aspera		15					15
Limanda proboscidea		4			2		6
Pleuronectes quadrituberculatus	1						1
Reinhardtius hippoglossoides	4						4
Stichaeidae	**16**	**628**	**111**	**686**	**479**	**251**	**2,171**
Anisarchus medius		51	89	529	247	163	1,079
Eumesogrammus praecisus				5	23	11	39
Leptoclinus maculatus		1		1			2
Lumpenus fabricii	16	566	21	149	203	70	1,025
Stichaeus punctatus		10	1	2	6	7	26
Zoarcidae	**282**	**267**	**129**	**242**	**131**	**207**	**1,258**
Gymnelus hemifasciatus		193	6	89	14	34	336
Gymnelus spp.	3						3
Gymnelus viridis		4		17	15	11	47
Lycodes mucosus	5		3	1	5		14
Lycodes palearis		15		1	2	1	19
Lycodes polaris		30	115	107	64	112	428
Lycodes raridens		25	2	27	31	49	134
Lycodes spp.	274						274
Zoarcidae spp.			3				3
All species	23,060	2,022	834	1,944	2,082	2,072	32,014
Number of species	21	22	19	24	27	25	

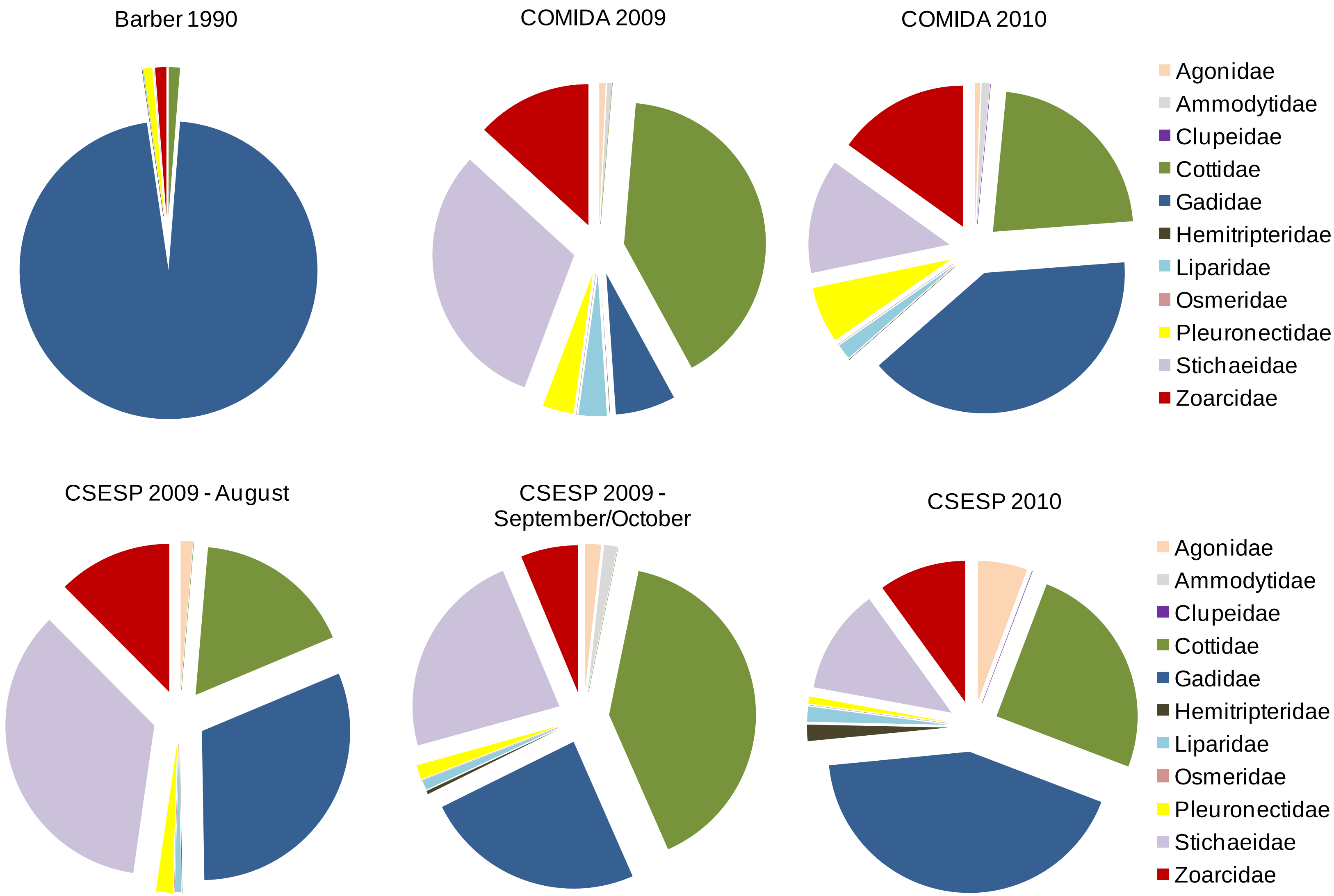

Figure 2.1. Proportions of family catches by cruise in the northeastern Chukchi Sea. All applicable gear types for each cruise are included.

CHAPTER 3 - DISTRIBUTION AND ABUNDANCE OF KEY FISH SPECIES IN THE NORTHEASTERN CHUKCHI SEA, ALASKA

[1]S.T. Crawford, [2]S.W. Raborn

Long-term datasets are useful for tracking changes in fish populations over time (Miller et al. 1991; Bunnell et al. 2006). Long-term datasets enable one to recognize changing trends in abundance and composition of fish communities while also providing perspective on year-to-year variability. However, most studies are of a short duration and while they can record interannual variability, they may not be sufficient to describe changes or trends in populations (Olden et al. 2006).

The Chukchi Sea is a variable environment (Barber et al. 1994). Fish are must cope with a seasonal lack of light, short period of primary production and cold water temperatures. On a yearly basis there are changes in flow patterns of nutrient rich water through Bering Strait from the Bering Sea (Barber et al. 1994). On a long-term basis, there have been notable changes in sea ice (ACIA 2004, www.amap.no/acia; Walsh 2008) and rises in Arctic temperatures over the past couple of decades (Walsh 2008). These factors affect the fish of the Chukchi Sea. The Chukchi Sea is at the limit of the range for a number of species (Barber et al. 1994). It appears that for some species year to year recruitment can vary widely (Barber et al. 1994). For these reasons, the Chukchi Sea fish communities are expected to exhibit both long-term and short-term changes.

One method to monitor changes in an ecosystem is to study indicator species that can be considered to be representative of the larger community (Karr 1981). Mecklenburg et al. (2008) recommend monitoring Arctic cod (*Boreogadus saida*) and Arctic staghorn sculpin (*Gymnocanthus tricuspis*) in the Chukchi Sea. Arctic cod are the primary member of the cryopelagic fish community and have been shown to be the numerically dominant species in the Chukchi Sea (Barber et al. 1994; Norcross et al. 2011). Furthermore, Arctic cod are a valuable part of the Arctic ecosystem and their health and abundance is important for a large number of bird and marine mammal species that feed on them (Frost and Lowry 1980; Piatt et al. 1990). Arctic staghorn sculpin, a member of the demersal fish community, are widespread throughout the Chukchi Sea. Collectively, sculpins (Cottidae) represent the second most abundant family of fishes in the Chukchi Sea (Barber et al. 1994; Norcross et al. 2011). In some areas sculpins are the most numerous family and Arctic staghorn sculpin are the most abundant species (Mecklenburg et al. 2007). Bering flounder (*Hippoglossoides robustus*) were also included in this analysis. While they are not present in as large of numbers as the other two species (Barber et al. 1994; Mecklenburg et al. 2007), Bering flounder are more piscivorous and changes in the

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[1] LGL Alaska Research Associates, Inc., Anchorage, Alaska
[2] LGL Ecological Research Associates, Inc., Bryan, Texas

populations of other species would likely be reflected in changes in abundance and distribution of Bering flounder. In addition, Bering flounder have historically been much more numerous in the southern Chukchi Sea and rising water temperatures may lead to an increased presence in more northern areas of the Chukchi Sea.

In the Chukchi Sea there has historically been a lack of fish data collected and no long-term monitoring of fish populations has been conducted (Mecklenburg et al. 2008). Most studies from the 20th century were spatially limited or exploratory in nature. The majority of studies that have been undertaken were done in response to potential gas and oil exploration and development. In 1990, the Minerals Management Service (MMS) performed a fish study that ranged throughout the northeastern Chukchi Sea including a number of stations in what is now the Lease Sale 193 area (Barber et al. 1994). Recently, fish studies have been undertaken in the Lease Sale 193 area as part of the Chukchi Sea Environmental Studies Program (CSESP) and the Chukchi Offshore Monitoring in a Drilling Area study (COMIDA) conducted in 2009 and 2010. The goal of this paper is to describe and quantify the distribution and abundance of Arctic cod, Arctic staghorn sculpin and Bering flounder populations in the Lease Sale 193 area, as well as how abundances changed as a function of various physiochemical variables routinely amenable to measurement.

3.1 METHODS

Demersal capture data and associated environmental data from the three aforementioned studies were analyzed (Table 3.1). For an overview of these studies, see Section 2.1 in Chapter 2 as well as Section A4.1 in Appendix 4. This study was interested in the Lease Sale 193 area, necessitating the exclusion of some study stations that were sampled by Barber and COMIDA 2009 and 2010, but were outside of the lease area. In total, catches of 24,691 Arctic cod, 1,243 Arctic staghorn sculpin and 399 Bering flounder from 105 study stations were analyzed. Environmental data used in analysis is from the same respective studies as the fish capture data. Distance offshore was calculated using ArcMap© 10 software.

3.1.1 Distribution

Maps for species recent and historical densities were derived using ArcMap© 10 software and the spatial analyst extension (ESRI, Inc). Observed fish density values were linked to a table of fixed sample points throughout the Lease Sale 193 area. The points were then interpreted using the inverse distance weighted method which operates under the assumption that phenomena that are close to each other are more alike than those that are farther apart. This assumption means that each point has an influence on all the other points, but the power of the influence decreases as distance increases.

Maps were drawn for each gear type used. Some studies used the same gear and could be plotted together while other studies had unique gears and were displayed separately. Each gear type had a different ability to catch fish, which could have lead to false conclusions on areas of high or low abundance if all gears were plotted together.

3.1.2 Statistical modeling

The methods for evaluating density and the factors affecting density are discussed in Appendix 1.

3.2 RESULTS

3.2.1 Population density models

Fish densities were estimated using negative binomial models which fit the data better than Poisson models based on QAICc values. There was a considerable amount of uncertainty regarding the best model for each species. For the first set of analysis (all data sets) no model received more than 8.5% weight for any species (Table A2.1.1). For the 2009 and 2010 analysis of the CSESP and COMIDA data, no model received more than 2.6% weight for any species (Table A2.2.1). Similarly, in the CSESP 2009 and 2010 analysis no model for any species received more than 4.7% (Table A2.3.1).

3.2.2 Arctic cod

A number of gears showed high abundance for Arctic cod in the vicinity of 71°N 166°W, near the northwest corner of the Klondike study area (Figures 3.1–3.4). Other areas of high and low abundance were variable between gears. The 1990 sample appears to show a more consistent gradient for density while recent studies have had a much more patchy distribution (Figures 3.1–3.4). Arctic cod were found at all 18 stations sampled in 1990. During the COMIDA cruises in 2009 and 2010 Arctic cod were present in 20 of 27 and 19 of 21 stations, respectively. Arctic cod were present in all 43 stations sampled during CSESP.

3.2.2.1 Historical and present

The marginal means calculated by the GLM for each sample gear ranged from a low with the 5mBT to a high with the PSBT (Table A2.1.3). Observed CPUEs followed the same trend (Table 3.2). The GLM results showed evidence that Arctic cod catches were influenced by the gear type being used. The GLM also showed that distance offshore, depth, bottom water temperature and bottom salinity all most likely had no influence on Arctic cod catches (Table A2.1.4).

3.2.2.2 2009 and 2010

GLM results analyzing 2009 and 2010 catch data from the CSESP and COMIDA studies found that the sample year was not important in explaining Arctic cod catches. Marginal mean catches between years were similar. There was evidence that gear was important in explaining catch data (Table A2.2.3). Most independent variables were found to be not important. The percentage of mud in the substrate may have been important while no other independent variable had better than a 40% chance of being important (Table A2.2.4).

3.2.2.3 CSESP 2009 and 2010

GLM results analyzing CSESP data for 2009 and 2010 found that the sample year was not important in explaining abundance of Arctic cod. Marginal mean catches between both years were similar. Gear was an important factor in explaining Arctic cod density (Table A2.3.3). No independent variables were found to be important (Table A2.3.4).

3.2.3 Arctic staghorn sculpin

The Klondike study area and vicinity tended to have the highest densities of Arctic staghorn sculpin for all gears. Conversely, the area around the Burger study area had low densities for all gears. Two gears showed areas of high density along Hanna Shoal while two gears showed low densities on the shoal (Figures 3.5–3.8). Arctic staghorn sculpin were found in 11 of 18 stations sampled in 1990. During the COMIDA cruises in 2009 and 2010 Arctic staghorn sculpin were present in 12 of 27 and 5 of 21 stations, respectively. Arctic staghorn sculpin were present in 21 of 43 stations sampled during CSESP.

3.2.3.1 Historical and present

The marginal means catches calculated by the GLM for each sample gear was almost 20 times higher for the PSBT than for the NMFS 83-112 otter trawl (Table A2.1.3). Observed CPUEs showed even more discrepancy between the two nets. Excluding stations where Arctic staghorn sculpin were not present the difference between the nets was even more drastic (Table 3.2). The GLM results showed Arctic staghorn sculpin catches were influenced by the gear type being used. There was strong evidence that catches were negatively related to latitude and water depth. Salinity and bottom water temperature likely had no influence on Arctic staghorn sculpin catches in the study area (Table A2.1.4).

3.2.3.2 2009 and 2010

GLM results analyzing 2009 and 2010 catch data for the CSESP and COMIDA studies found that neither the sample year nor the sample gear were important in explaining catches. Marginal mean catches were similar among all three gears (Table A2.2.3). No independent variable had strong evidence that it was important to the abundance of Arctic staghorn sculpin, but there was strong evidence that salinity, bottom water temperature, distance offshore, longitude and percent of the substrate that was gravel were not important in explaining Arctic staghorn sculpin abundance (Table A2.2.4).

3.2.3.3 CSESP 2009 and 2010

GLM results analyzing CSESP data from 2009 and 2010 catch data found that the sample year was not important in explaining abundance of Arctic staghorn sculpin. Marginal mean catches between both years were similar. Prospect was important in explaining Arctic staghorn sculpin density with the highest values coming from the Klondike prospect (Table A2.3.3). No independent variables were found to be important (Table A2.3.4).

3.2.4 Bering flounder

Bering flounder abundance tended to be highest along the 166°W meridian, in the eastern half of the Lease Sale 193 area. For all gears the Burger study area had the lowest observed densities (Figures 3.9–3.12). Bering flounder were found in 13 of 18 stations sampled in 1990. During the COMIDA cruises in 2009 and 2010 Bering flounder were present in 14 of 27 and 12 of 21 stations, respectively. Bering flounder were present in 16 of 43 stations sampled during CSESP.

3.2.4.1 Historical and present

The marginal means calculated by the GLM for each sample gear were fairly consistent. Observed CPUEs were 10 times larger for PSBT than the 3mBT (Table A2.1.3). Excluding stations where no Bering flounder were sampled the observed CPUEs were lowest for the NMFS 83-112 otter trawl and highest for the PSBT (Table 3.2). The GLM results showed Bering flounder catches were not influenced by sampling gear. The GLM also showed that latitude, distance offshore, bottom salinity, bottom water temperature and depth all most likely had no influence on Bering flounder catches (Table A2.1.4).

3.2.4.2 2009 and 2010

GLM results analyzing 2009 and 2010 catch data found that neither the sample year nor the sample gear were important in explaining catches. Marginal mean catches were lowest for

5mBT and 3mBT and highest for the PSBT (Table A2.2.3). There was strong evidence for longitude being negatively correlated with Bering flounder abundance. Water depth, distance offshore, latitude and bottom water temperature were not important in explaining abundance (Table A2.2.4).

3.2.4.3 CSESP 2009 and 2010

GLM results analyzing CSESP data from 2009 and 2010 catch data found that the sample year was not important in explaining abundance of Bering flounder. Marginal mean catches between both years were similar. Prospect was important in explaining Bering flounder density with the highest values coming from the Klondike prospect (Table A2.3.3). No independent variables were found to be important (Table A2.3.4).

3.3 DISCUSSION

No species showed a strong northward expansion that may be expected with rising Arctic Ocean water temperatures. Arctic cod were widely distributed throughout the study area. Barber et al. (1994) found higher densities of cod at the southern stations that were outside the Lease Sale 193 area. We saw no abundance gradient among any of our samples. Arctic staghorn sculpin and Bering flounder showed more distinct distribution patterns. Both species were rare near the Burger study area and with the exception of Bering flounder catches in the 3mBT in 2010 they were both rare in the Statoil study area as well. Klondike may be along the edge of a current of nutrient rich Bering Shelf water that flows north through the Central Channel between Herald and Hanna shoals (Weingartner 2008). The Burger study area (the most eastern of the three study areas) may be composed of Resident Chukchi Water (Weingartner 1997) which Wyllie-Echevarria et al. (1997) found to be an important limiting factor to Bering flounder distribution.

The amount of area sampled by each net varied considerably which has an effect on the observed presence of fish in areas of low abundance. The NMFS 83-112 otter trawl is larger than the sample gears and at each station it sampled approximately 11, 20 and 180 times as much area as the 5mBT, 3mBT and PSBT, respectively. Inversely, the PSBT sampled such a small area that fish had to be somewhat of a high density or else the area sampled would not large enough to capture them. This is shown in table 3.1 where CPUE for PSBT at only the stations where each species was captured are much higher than the CPUE from all samples. The other nets by fishing a larger area can capture species present in low densities. Thus, though recent surveys show a smaller proportion of the stations containing some species of fish this is likely the result of sampling bias rather than range reduction.

There appears to have been little shift in the abundance of any of the three species we analyzed. While the use of different gears makes direct comparisons impossible the marginal means for the NMFS 83-112 otter trawl were within the range of the more recent nets or in the case of Arctic staghorn sculpin only 0.1 fish per 1,000 m^2 lower than the 5mBT. Similarly, year was not an important variable in either of the analyses using recent data. This suggests that these fish populations are likely stable despite noted variations in year-to-year juvenile abundance (Barber et al. 1994; Norcross et al. 2011; Priest et al. 2011).

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Table 3.1. Studies used for analysis and their associated gears and fish catches. Note: The total number of stations does not equal the number of stations because many sites were sampled in both 2009 and 2010 years.

				Analysis					
Study	Year	Gear	Number of Stations	Historical and Present	2009 and 2010	CSESP 2009 and 2010	Arctic cod	Arctic staghorn sculpin	Bering flounder
CSESP	2009	PSBT	26	X	X	X	1,108	255	66
	2010	PSBT, 3mBT	43	X	X	X	884	131	17
COMIDA	2009	PSBT	27	X	X		139	715	53
	2010	5mBT	21	X	X		337	11	50
Barber	1990	NMFS 83-112 otter trawl	18	X			22,223	131	213
Total			105				24,691	1,243	399

Table 3.2. Mean catches for three species of fish calculated using different methods. All numbers are fish per 1,000 m^2. Data are for all studies from Lease Sale 193 area in the northeastern Chukchi Sea.

	Marginal mean CPUE			All stations observed CPUE			Only stations present CPUE		
Gear	Arctic cod	Arctic staghorn sculpin	Bering flounder	Arctic cod	Arctic staghorn sculpin	Bering flounder	Arctic cod	Arctic staghorn sculpin	Bering flounder
3mBT	3.7	0.3	0.7	3.4	0.5	0.0	3.5	1.9	0.2
5mBT	1.9	0.2	0.7	2.0	0.1	0.4	2.2	0.4	0.8
NMFS 83-112 otter trawl	10.9	0.1	0.7	15.3	0.1	0.2	15.3	0.2	0.2
PSBT	32.4	1.9	1.0	27.5	4.4	4.2	30.9	10.3	11.2

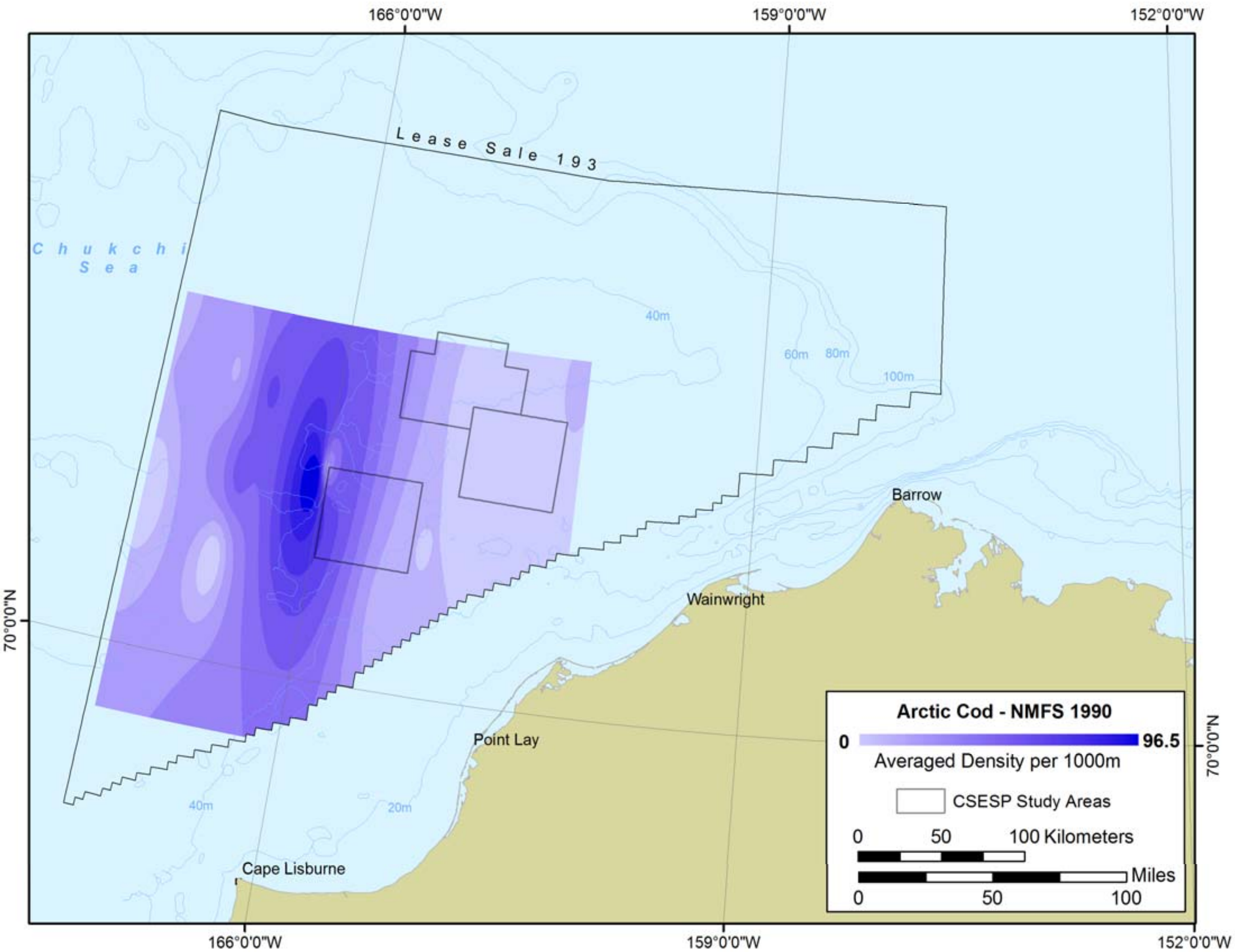

Figure 3.1. Observed density of Arctic cod from the NMFS 83-112 trawl in the northeastern Chukchi Sea.

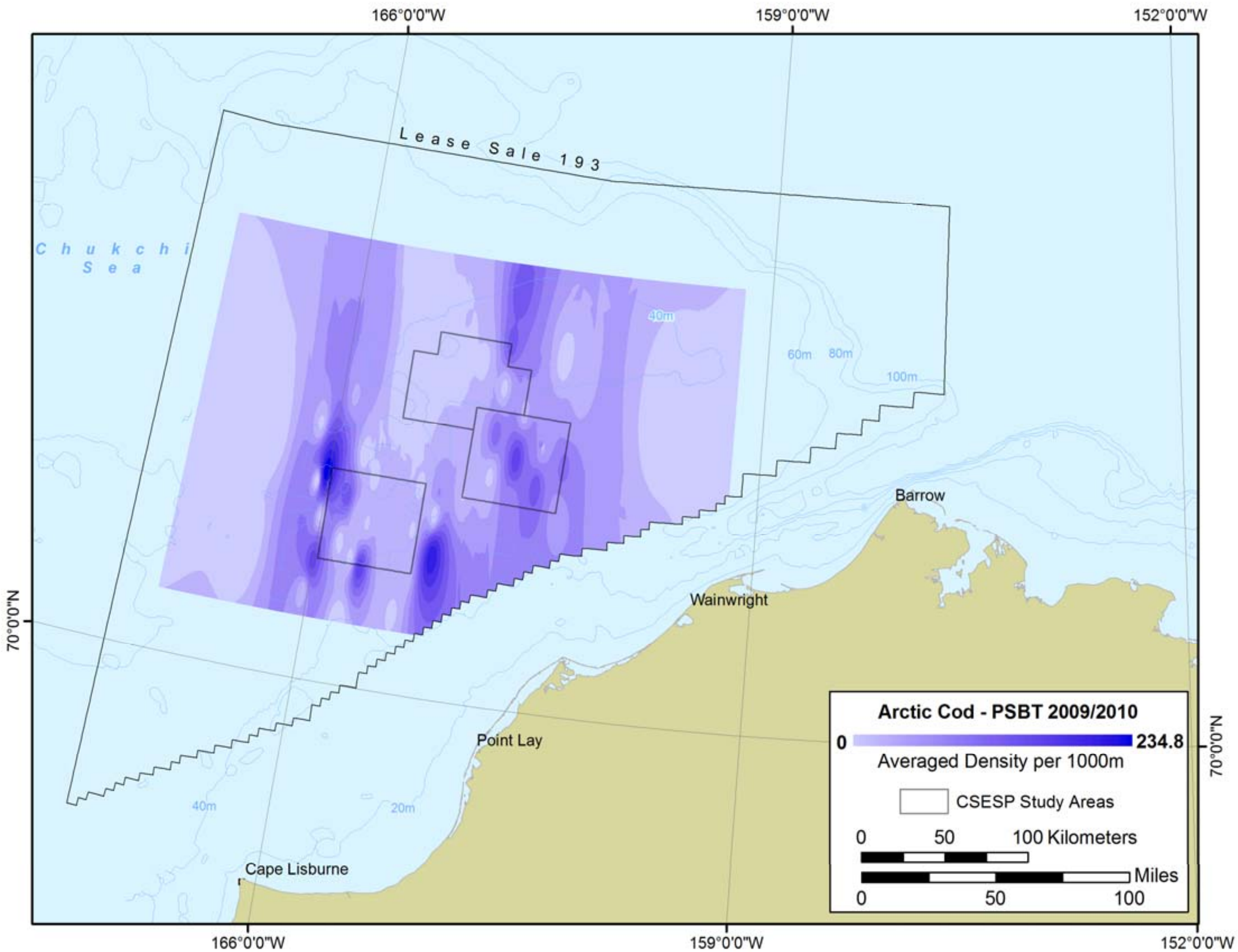

Figure 3.2. Observed density of Arctic cod from the PSBT in the northeastern Chukchi Sea.

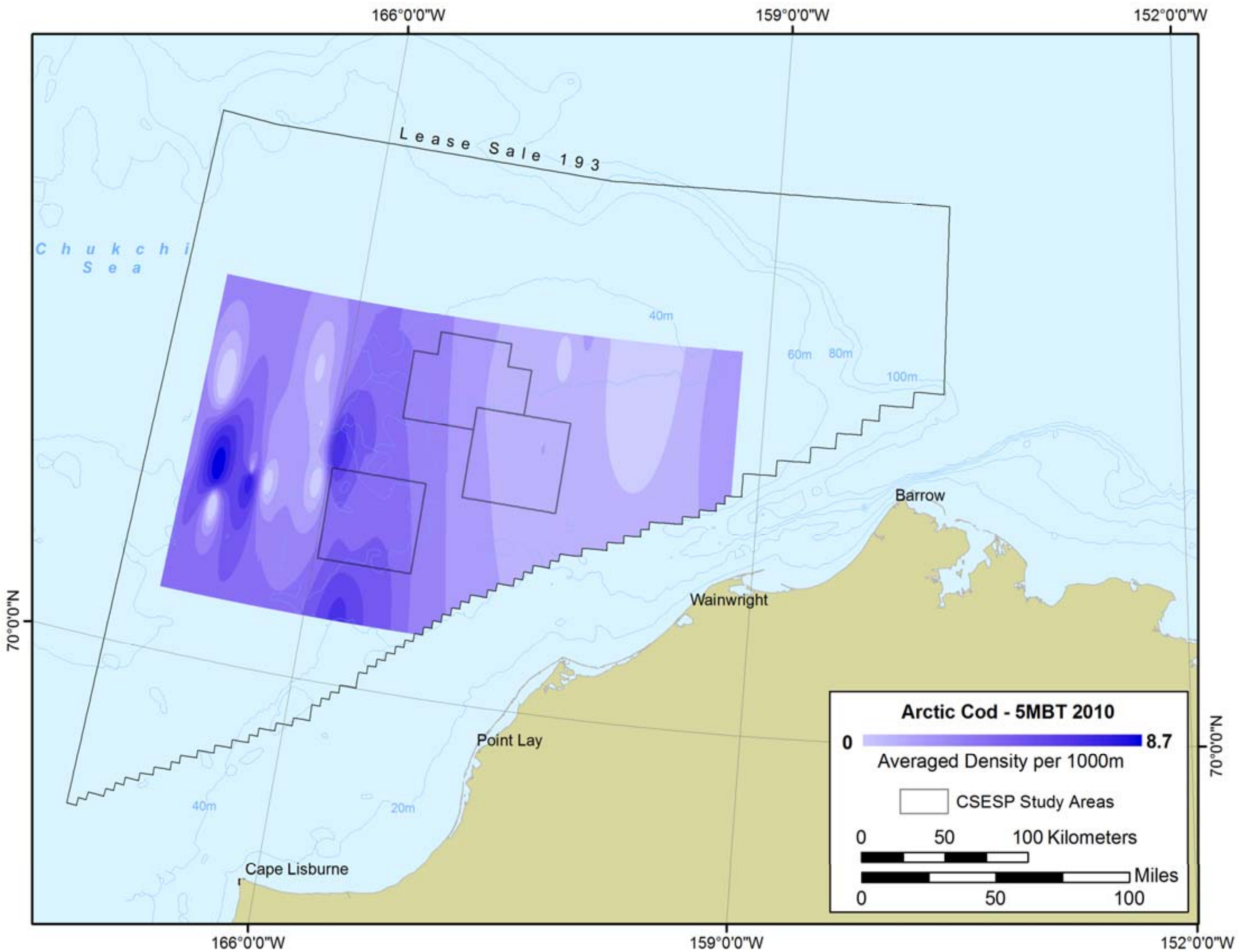

Figure 3.3. Observed density of Arctic cod from the 5mBT in the northeastern Chukchi Sea.

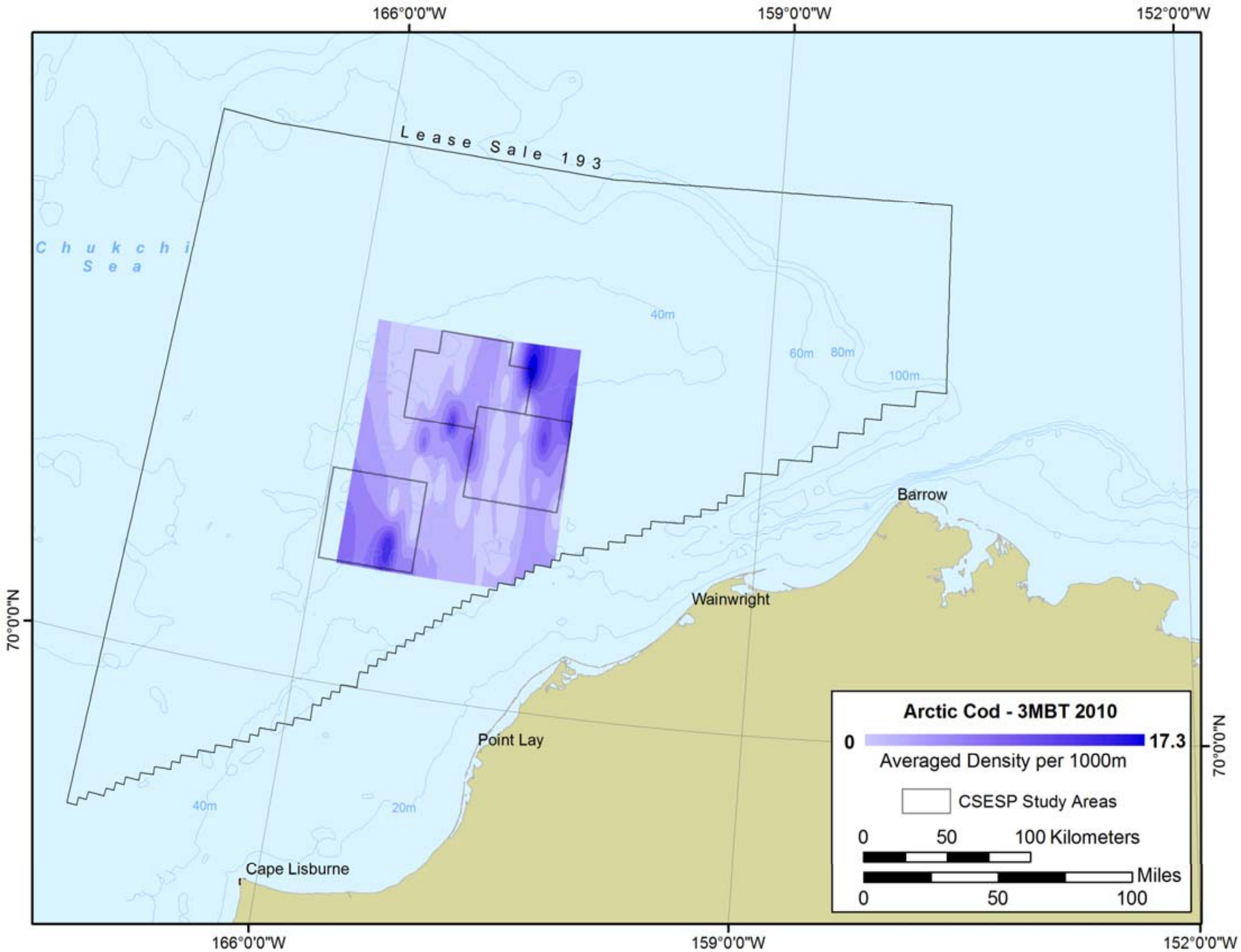

Figure 3.4. Observed density of Arctic cod from the 3mBT in the northeastern Chukchi Sea.

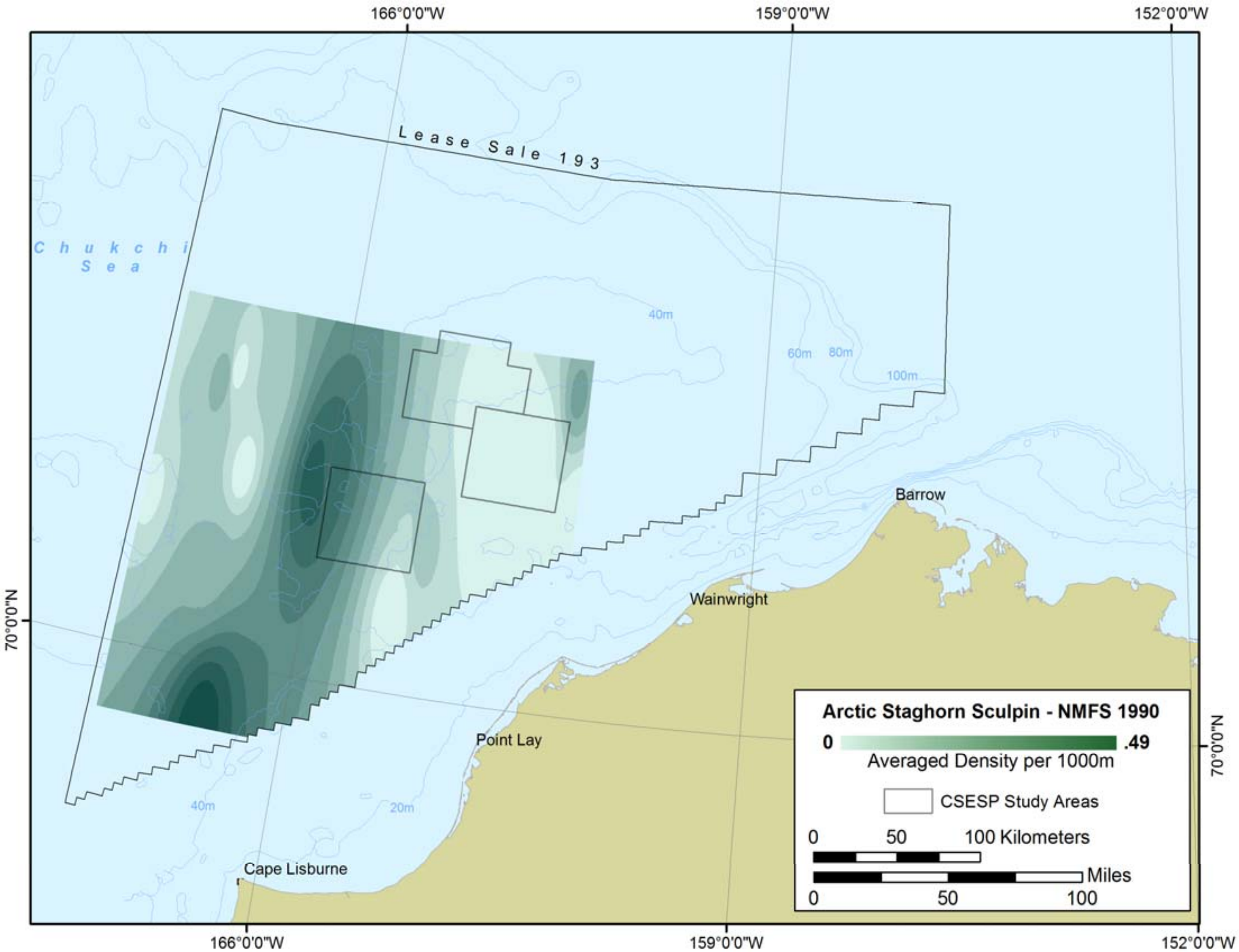

Figure 3.5. Observed density of Arctic staghorn sculpin from the NMFS 83-112 trawl in the northeastern Chukchi Sea.

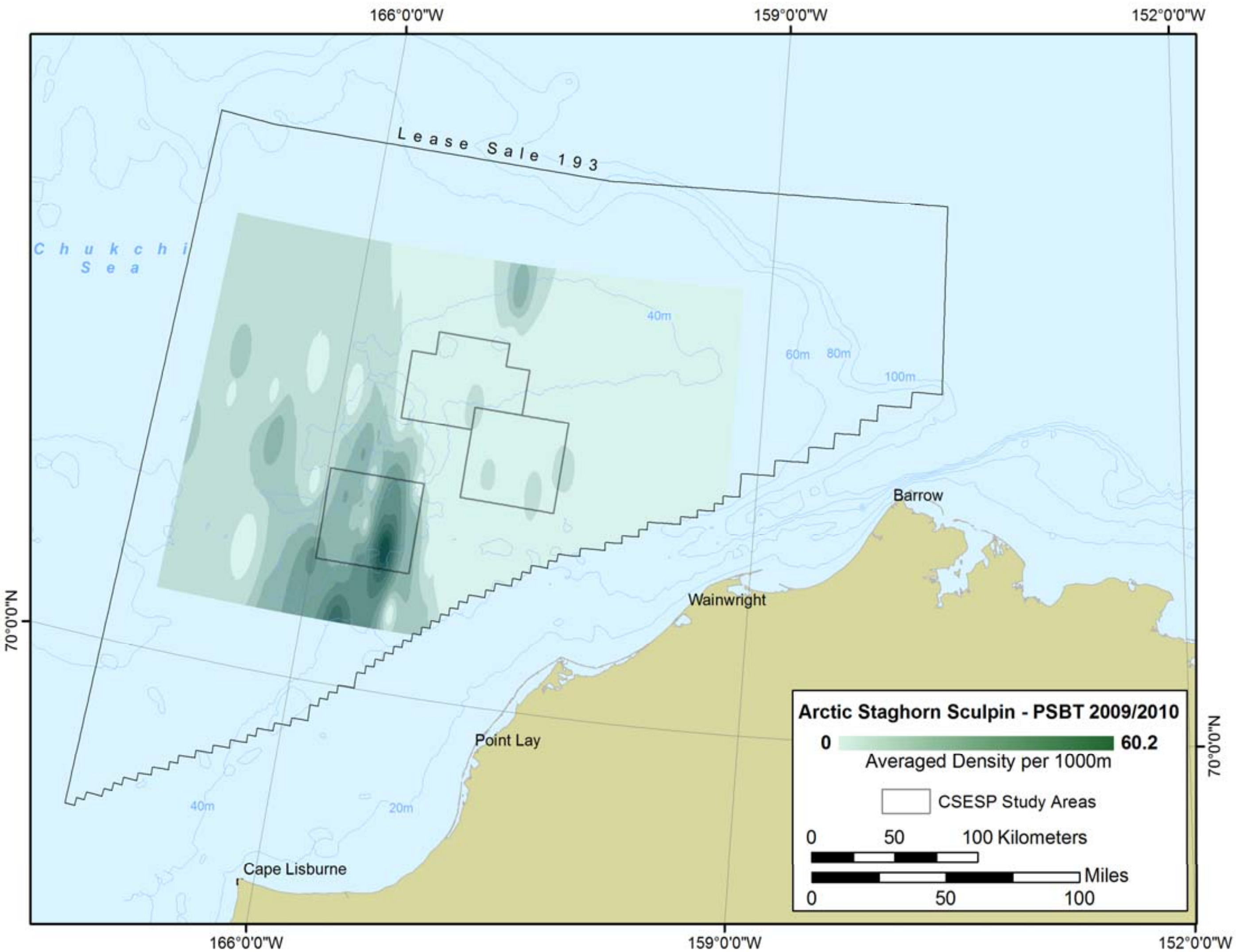

Figure 3.6. Observed density of Arctic staghorn sculpin from the PSBT in the northeastern Chukchi Sea.

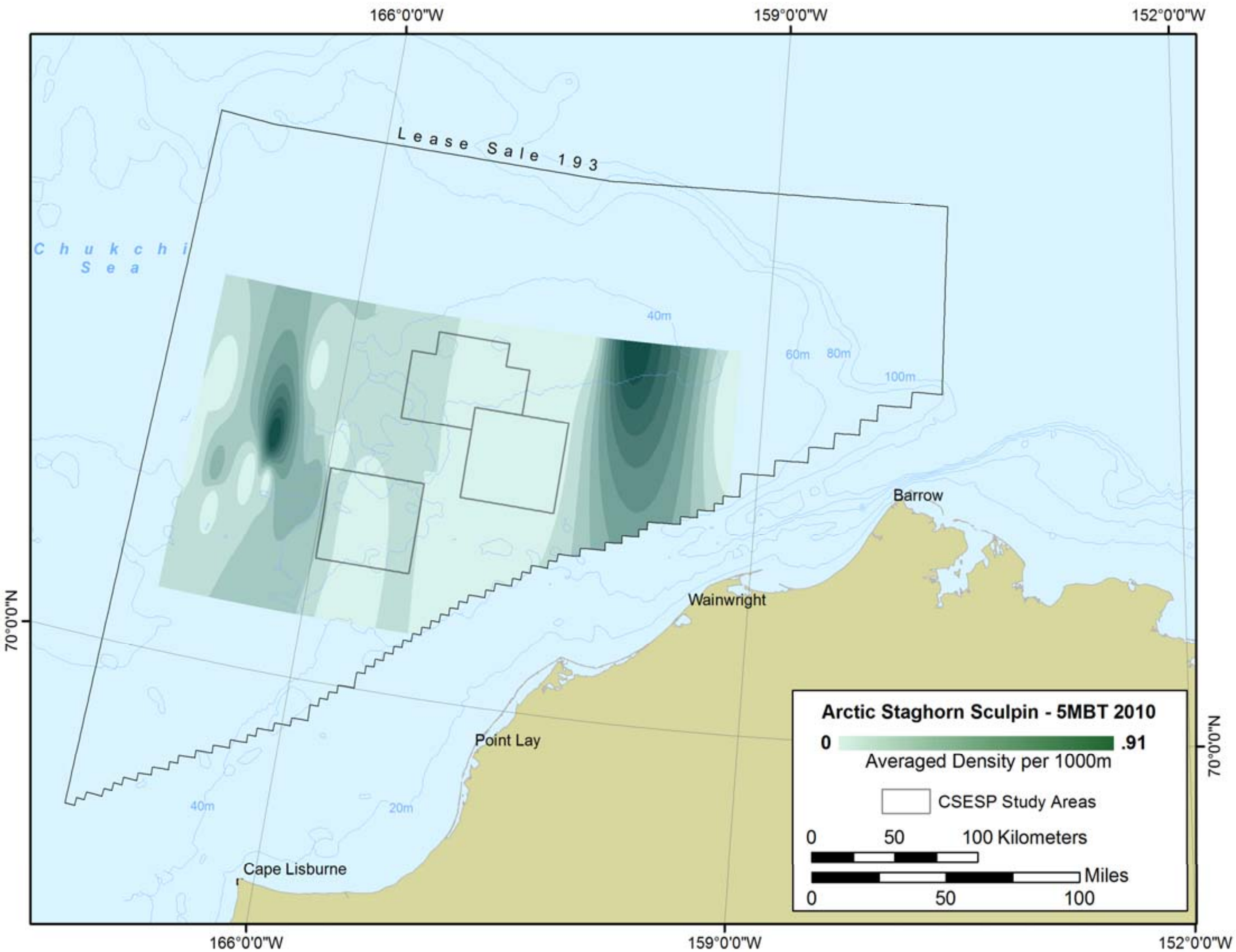

Figure 3.7. Observed density of Arctic staghorn sculpin from the 5mBT in the northeastern Chukchi Sea.

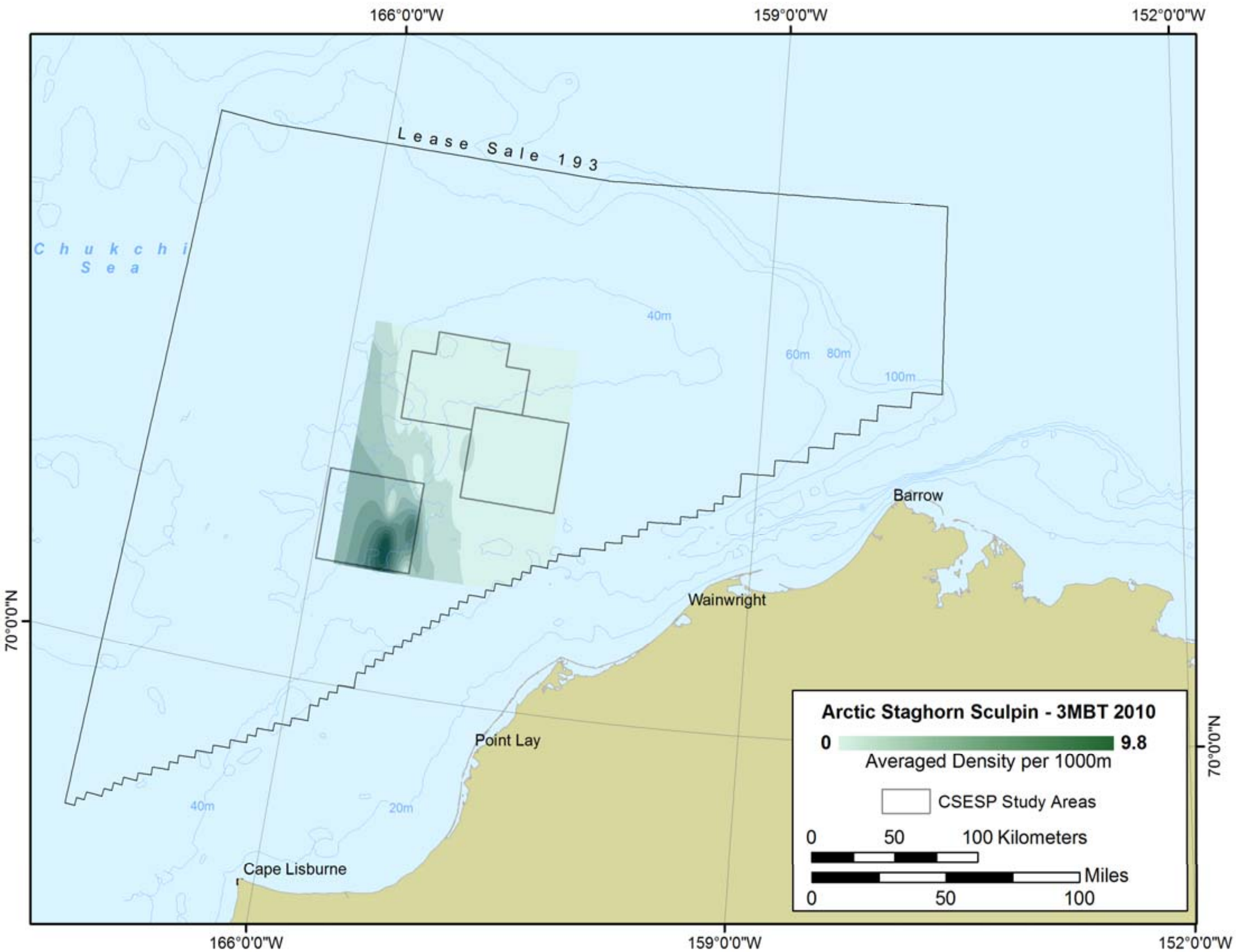

Figure 3.8. Observed density of Arctic staghorn sculpin from the 3mBT in the northeastern Chukchi Sea.

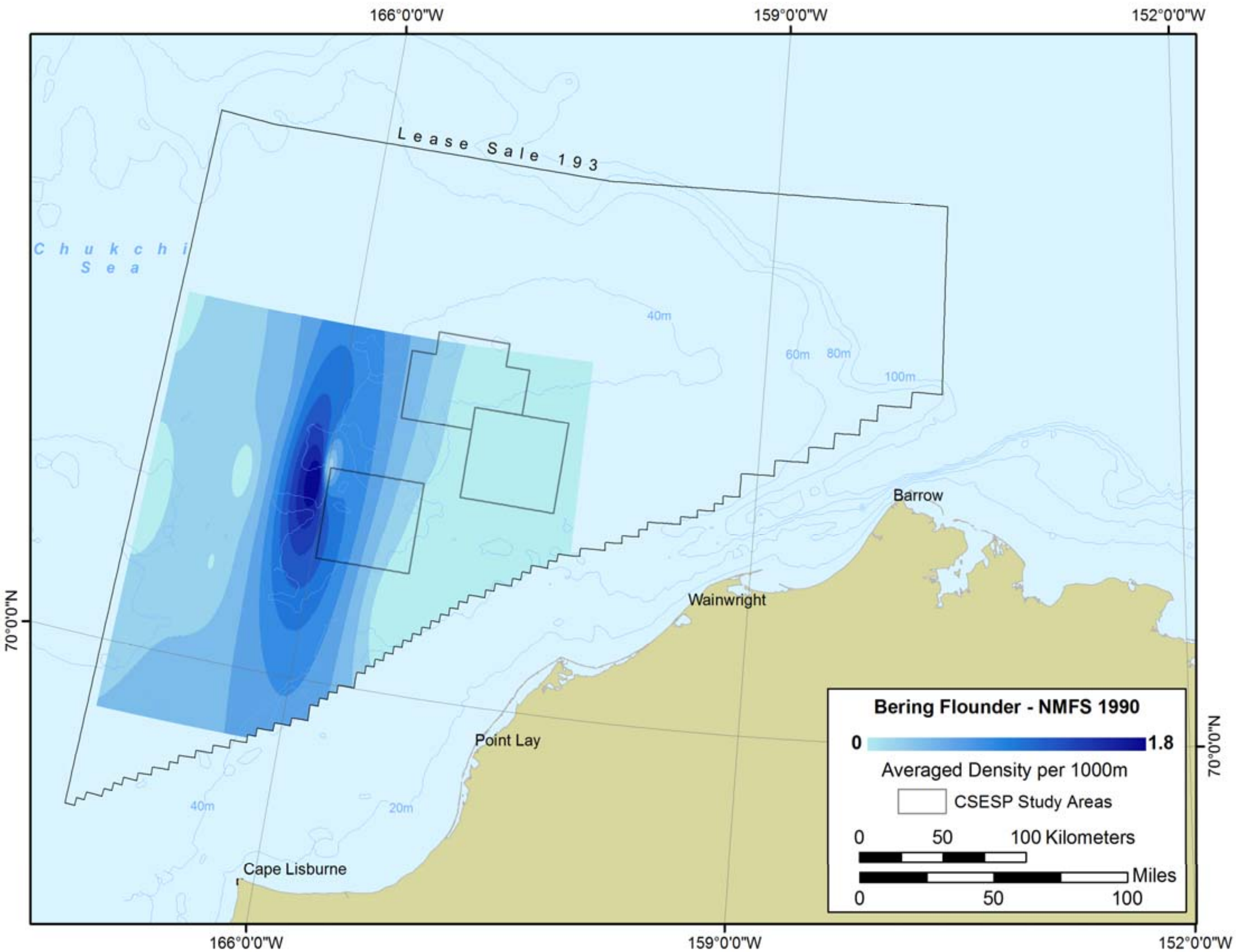

Figure 3.9. Observed density of Bering flounder from the NMFS 83-112 trawl in the northeastern Chukchi Sea.

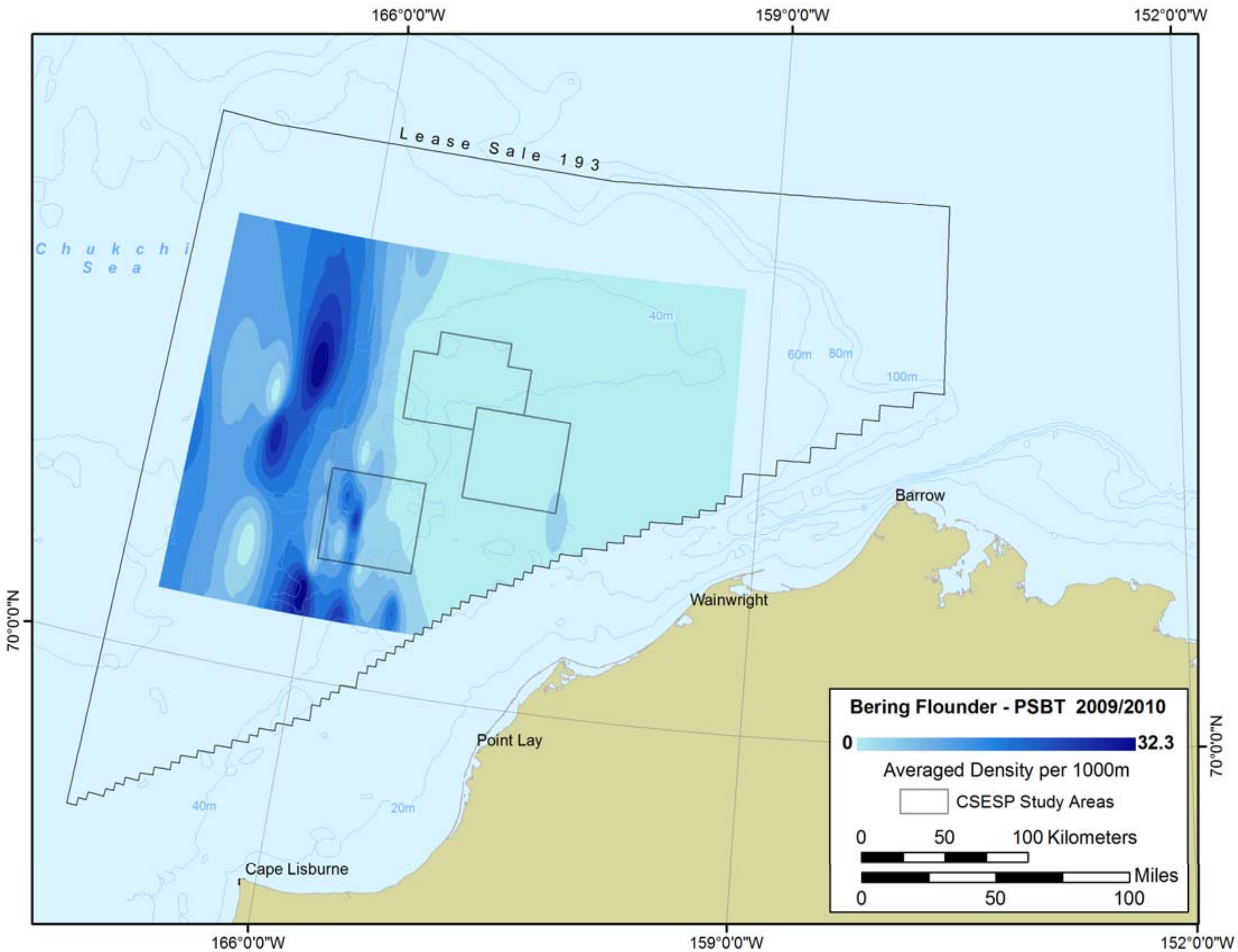

Figure 3.10. Observed density of Bering flounder from the PSBT in the northeastern Chukchi Sea.

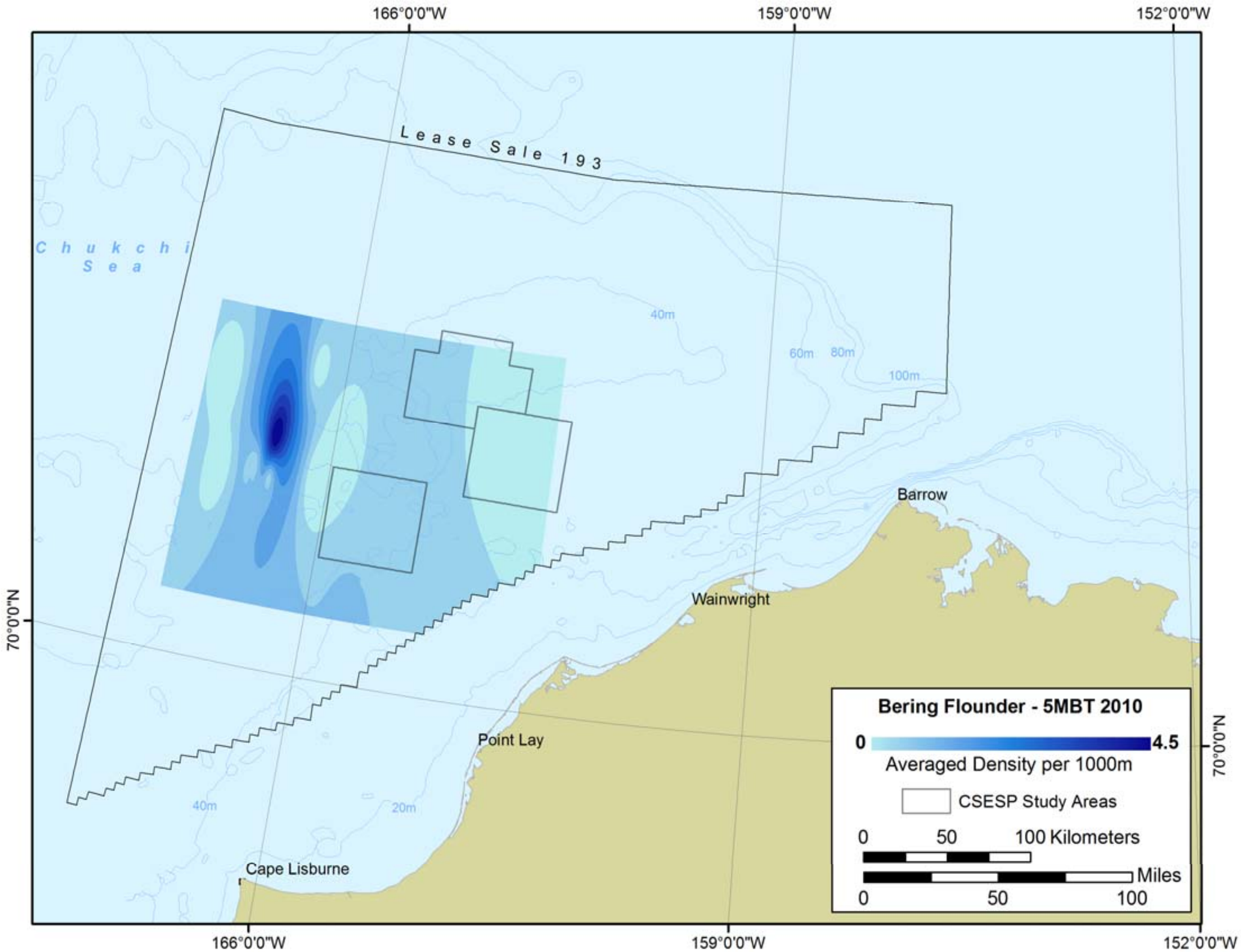

Figure 3.11. Observed density of Bering flounder from the 5mBT in the northeastern Chukchi Sea.

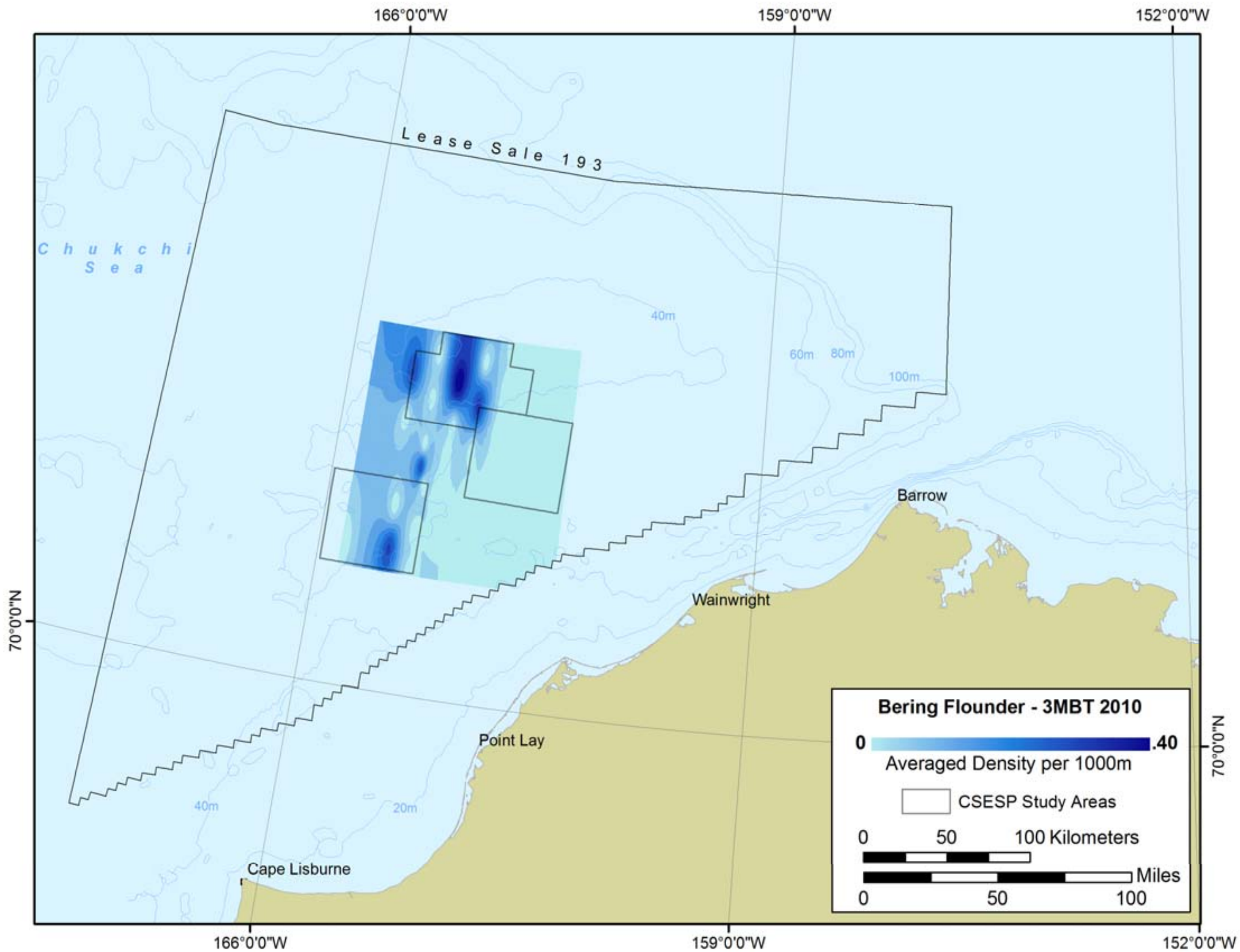

Figure 3.12. Observed density of Bering flounder from the 3mBT in the northeastern Chukchi Sea.

CHAPTER 4 - LENGTH-WEIGHT-AGE RELATIONSHIPS OF DEMERSAL FISHES IN THE CHUKCHI SEA

[1]B.L. Norcross, [1]B.A. Holladay, [1]C. Gleason

4.1 INTRODUCTION

Because of the potential for oil and gas development, interest is increasing in fishes in the US Arctic waters. Many historic (Frost and Lowry 1983; Barber et al. 1997) and recent (Norcross et al. 2010; Norcross et al. 2011) investigations 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.

There is detailed information about only a few Arctic marine fishes. Little is known about species that are not of commercial or cultural interest (Power 1997) or not important in the eastern Arctic. Arctic cod (*Boreogadus saida*), which is called polar cod in the eastern Arctic, is an abundant circumpolar species (Mecklenburg et al. 2011). Because of its numeric and geographic importance more information exists about length, weight and age of Arctic cod than for other Alaskan Arctic fish species. In the 1970s and early 1990s fish surveys in Chukchi Sea contributed knowledge about Arctic cod (Frost and Lowry 1983; Gillispie et al. 1997); the latter survey also provided information about Arctic staghorn sculpin (*Gymnocanthus tricuspis*; Smith et al. 1997a) and Bering flounder (*Hippoglossoides robustus*; Smith et al. 1997b).

This study not only compares life history parameters from the present study to those of past studies, but it also contributes information about species for which nothing has been previously been published.

4.2 METHODS

Fishes used in this study were collected offshore in the northeastern Chukchi Sea during 2009 and 2010. The collections occurred during cruises conducted by the Chukchi Sea Environmental Studies Program (CSESP) sponsored by ConocoPhillips Alaska, Inc., Shell Exploration & Production Company (Shell), and Statoil USA E & P, Inc., and through Shell's support of fishing research during cruises by the Chukchi Sea Offshore Monitoring in Drilling

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[1] University of Alaska Fairbanks, Fairbanks, Alaska

Area (COMIDA) that is sponsored by the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE). Fishes were collected during July/August 2009 (2 cruises), September/October 2009 (1 cruise), July/August 2010 (1 cruise) and September 2010 (Figure 4.1). Three separate areas were selected as the CSESP areas of interest for intensive research, including Klondike, Burger, and Statoil study areas. The COMIDA 2009 and 2010 cruises encompassed a larger geographic area than the CSESP cruises. Fishes were collected using a combination of bottom and midwater trawls. Bottom collections were made with a 3-m plumb staff beam trawl (3mPSBT) with a 4-mm codend liner in 2009 and 2010; in 2010 a 5-m plumb staff beam trawl (5mPSBT), 3-m (3mBT) and 5-m (5mBT) beam trawls with 12-mm liners were also used (Meyer and Holladay, Appendix 4). Bottom trawls were open a minimum of 1 m above the footrope (Meyer and Holladay, Appendix 4). The mouths of the bottom trawl nets were open throughout deployment, and it is possible that fish were collected in the water column while moving toward and away from the sea floor, as well as the target collections on the bottom. Midwater collections were made with an Isaacs-Kidd Midwater Trawl (IKMT) with a mouth 1.5 m wide by 1.8 m high and 3-mm mesh (Norcross et al. 2011).

At sea processing was not identical for all cruises. In all 2009 collections, all fishes were retained for laboratory analysis with the exception of particularly numerous size classes of a species. When a species was represented by N>25 individuals of an obvious length class, a subsample of 25 individuals were counted and measured while the rest of the individuals of that length class were counted but not measured. Subsamples were frozen and sent to Fairbanks for further processing. Therefore the 2009 lengths examined here are not representative of the length frequency of the entire catch; they are instead the percentage of fishes measured in the lab. Fishes caught during COMIDA 2010 were measured in 10 mm length bins and discarded; weight was not recorded. On the CSESP cruise in September 2010 all fishes were frozen and sent to the Fisheries Oceanography lab in Fairbanks for processing.

Fishes captured during the 2009 and 2010 field seasons, with the exception of COMIDA 2010, were transported to the University of Alaska Fisheries Oceanography Laboratory. Each fish was thawed, total length was measured to the nearest mm, and wet weight was measured to the nearest 0.1 g for larger fish and 0.0001 g for smaller fish on an Orion series HR200 precision balance.

Weight-length regressions were calculated using the standard relationship (Ricker 1975):

$$W = aL^b$$

where W = total weight (g) and L = total length (mm), and the parameters a and b are constants estimated by a linear transformation of this equation. Length and weight were log-transformed and fitted with least squares regressions using Microsoft® Excel 2010. Weight-length regressions only were calculated for species for which >30 individuals were collected.

A subset of six fish species collected during 2009 and 2010 cruises were selected for additional analysis based on their prevalence on the sampling grounds and because they represent major fish taxonomic families present in the Chukchi Sea. The selected species were Arctic cod (*Boreogadus saida*, Family Gadidae, Cods), Arctic staghorn sculpin and shorthorn sculpin (*Gymnocanthus tricuspis* and *Myoxocephalus scorpius*, respectively, Family Cottidae, Sculpins), polar eelpout (*Lycodes polaris*, Family Zoarcidae, Eelpouts), stout eelblenny (*Anisarchus medius*, Family Stichaeidae, Pricklebacks), and Bering flounder (*Hippoglossoides robustus*, Family Pleuronectidae, Flatfishes). Each of these species was analyzed from bottom trawl catches, but Arctic cod was the only species sufficiently numerous to merit length analysis from midwater trawl catches.

Standard length-frequency histograms were plotted as a percentage of individuals in 3-mm length classes, except for COMIDA 10 where fish lengths were recorded in 10-mm increments. Composite length-frequency histograms for each species were created from only the four cruises for which fish were measured in 1-mm increments. Examination of length distributions by area and season could only be conducted for the three cruises in the defined study area for which repeated sampling was standardized.

Otoliths were dissected from the fish and prepared for aging. Two sagittal otoliths were removed from the frozen fish, cleaned, and stored in centrifuge tubes. One otolith was mounted in Crystalbond thermoplastic glue onto a 1 in x 3 in glass slide and thin sectioned using a Buehler isomet low speed saw. If juvenile and larval fish otoliths had little concavity, otoliths from these fish were mounted and polished on the sagittal plane. Otoliths were reheated to place the flat edge of the otolith on the glass. Each sample was ground down to a thickness of 200–400 µm and was periodically checked for clarity of the growth rings under 100 X on a compound scope while grinding the otolith on a Buehler rotating wheel. The rotating wheel sprayed water over the surface of the lapping film (9 and 15 µm) to keep a clean grinding surface and prevent breakage of the otolith. The second otolith was prepared if the first otolith was illegible for aging or had broken off during processing; if not used, it was stored.

Otolith ages were assessed. Otoliths were photographed using a Leica DM1000 compound microscope and documented in a database. Otoliths were aged by comparing the photograph of transmitted light stored on the computer to the mounted otoliths viewed under the reflected light using a Leica M165C dissecting microscope. Age of the fish was determined by paired light summer and dark winter growth zones. Age-0 fish had daily rings representing summer growth without having a winter growth annulus present on the margin. Age-1 fish had summer growth plus a winter growth annulus. The dark winter growth zones were annuli, i.e., marking each year of age of the fish. A scale bar in a Leica microscope program was used to measure age-0 and age-1 growth zones, which aided consistent identification of the early growth patterns. We found the ages of Arctic cod were more reliably legible if the otoliths were underpolished so as to have less translucency. Otoliths ages were assessed by at least two different technicians referred to as readers. If the assigned ages of the readers disagreed, then the disputed otoliths were assessed again by both readers without prior knowledge of their original assessments. If an age was still not agreed upon, a third independent reader was used to assess the age of the otolith.

Verification of ages of fishes collected from the Chukchi Sea was necessary because Arctic species have rarely been aged and literature is limited (Lønne and Gulliksen 1989; Smith et al. 1997a, 1997b). Gillispie et al. (1997) used two different methods to read otoliths: transmitted light to define the translucent summer zone and break and burn to define the dark winter zone. To verify our assessments, we sent otoliths prepared by the UAF Fisheries Oceanography Lab to state and federal laboratories. A subset of 21 otoliths from five key species, Arctic cod (n=8), Arctic staghorn sculpin (n=3), Polar eelpout (n=3), stout eelblenny (n=4), and Bering flounder (n=3), from 2009 and 2010 OLF cruises were randomly selected to be assessed by Kristen Munk, Fishery Biologist, at the Alaska Department of Fish and Game (ADF&G) Age Determination Unit in Juneau, AK in November 2010. Kristen Munk has experience aging Alaskan fishes, but not these species. Specimen numbers, species, and month of capture were made available to the ADF&G Lab.

Ages provided by ADF&G (Appendix 5) were reviewed by UAF fisheries technicians with previous aging experience, Paige Drobny and Christine Gleason. Drobny is a fisheries technician who holds a M.S. in Fisheries Oceanography, and has experience reading daily and annuli on squid statoliths (a similar structure to otoliths) and annuli in marine fish otoliths in the UAF Fisheries Oceanography Lab. Gleason is an M.S. student in Fisheries Oceanography and has experience reading annuli on fish scales, otoliths, vertebrae of over 20 marine and freshwater species in the UAF Fisheries Oceanography Lab and with ADF&G. Drobny and Gleason had the most agreement with Munk at ADF&G for Arctic staghorn sculpin. They had partial agreement for Arctic cod, Polar eelpout, and Bering flounder, and did not agree with any ages assigned by ADF&G for stout eelblenny. Age-0 fish were commonly agreed upon by UAF and ADF&G labs; older ages proved to be the most difficult.

Assessing ages of Arctic cod was more difficult than for other species. Previous studies of Arctic cod indicate relatively young age assignments for this Arctic species (Lønne and Gulliksen 1989; Gillispie et al. 1997), but initial readings by the UAF Fisheries Oceanography and the ADF&G Age Determination Unit recorded ages up to 11. Arctic cod otoliths had numerous growth rings that could have been misread as annuli, thus initial UAF and ADF&G Lab readers could have overestimated the ages. Therefore a third assessment was needed. A subset of Arctic cod (n=23) of prepared otoliths were sent to Tom Helser, Manager of the Age and Growth Program at NOAA/National Marine Fisheries Service (NMFS) Alaska Fisheries Science Center (AFSC) in Seattle, WA in May 2011 after we received the analysis from ADF&G. The Arctic cod specimens were from a separate fish research cruise (RUSALCA) in the Chukchi Sea in September 2009. Specimen numbers, species, and capture date were made available to the AFSC Lab. Scientists at the AFSC lab have experience aging fish collected in the Beaufort Sea in 2008 (Rand and Logerwell 2011). In Seattle, the Arctic cod otoliths were read independently by two technicians. There was 87% agreement between the two AFSC technicians (Appendix 6). The age assignments between AFSC and UAF technicians had 83% agreement. Both AFSC and UAF Labs readers found it helpful to verify thin sectioned Arctic cod otoliths with a whole or a piece of an otolith polished flat from the same specimen.

Final age estimations by Fisheries Oceanography technicians were subjected to QA/QC review. All otolith ages from the key species (Arctic cod, Arctic staghorn sculpin, Shorthorn sculpin, Polar eelpout, stout eelblenny, and Bering flounder) were reviewed by experienced readers, Paige Drobny and Christine Gleason. Ages assigned previously by technicians were graphed in age vs. length plot by species to determine potentially erroneous age assignments. Drobny and Gleason chose potentially erroneous samples to be re-aged. Drobny and Gleason each aged these samples separately and then jointly examined otoliths for which their age estimations disagreed. Discussion and rereading of otolith rings continued until agreement was reached on age assignment.

QA/QC of ages assigned to otoliths revealed many discrepancies. Arctic staghorn sculpin had the most legible and precise assigned ages from the initial submission. Drobny and Gleason had a larger range of ages for Shorthorn sculpin than the initial submissions. Arctic cod, Polar eelpout, stout eelblenny, and Bering flounder, proved to be the most challenging species to age due to the numerous growth rings and large range of ages. The two experienced technicians reread otoliths Arctic cod, shorthorn sculpin, polar eelpout, stout eelblenny, and Bering flounder. This was necessary as these species exhibited the most precision error among readers. The database was updated with age values based on the new readings; the age data were reanalyzed.

4.3 RESULTS

In 2009 and 2010, approximately 50 fish species belonging to approximately 10 families were captured. More than 30 individuals were caught of each of the 18 species for which length-weight regressions were calculated (Table 4.1). The number of specimens per species ranged over two orders of magnitude. All length-weight regressions were highly significant (p<0.0001); for only two of the 18 regressions was r^2 <0.90. The estimated parameters for all species were similar. All intercepts (a) were negative and within a narrow range of about 0.1 separating the largest and smallest. Likewise, the range of slopes (b) was limited to 3.53–2.99.

Length-frequency plots appeared to clearly differentiate age-0 from older fish for four of the six species examined (Figures 4.2 and 4.3). Arctic cod captured in midwater and bottom, Arctic staghorn sculpin, and shorthorn sculpin catches were dominated by the smallest, apparently age-0 individuals.

Overlap of age-at-length was common for all the species examined (Figures 4.2 and 4.3). Small (15–75 mm) specimens of age 0 Arctic cod were captured in midwater. Arctic cod in the bottom trawl, while mostly <75 mm were as large as 182 mm. The large peak of 51–60 mm fish was age 0. The smaller peak at 75–105 mm was made up of ages 1-2, with two individual as old as age-3 (Figure 4.2). Specimens of Arctic staghorn sculpin were 33–115 mm. Most were <90 mm and 0–3 years old. Shorthorn sculpin was the only species with all specimens <100 mm assessed as ages 0-2. Polar eelpout had a distinct size spike of age-0 at 39–45 mm; a few of these were assessed as age-1 (Figure 4.3). The total length and age range of polar eelpout was greater than that of the other species, up to 200 mm and ages 0-10. There were few age-0, -1 or -2 stout eelblenny. The size peak was 87–114 mm for ages 3-6. Stout eelblenny >129 mm were ages 6-10. The smallest specimens of Bering flounder (15–23 mm) were all age-0. Bering flounder of 36–60 mm were age 1 and >60 mm were ages 2-5.

The length distributions of Arctic cod displayed vertical, seasonal and interannual patterns. Arctic cod caught by the midwater trawl were smallest (20–30 mm) and in the largest numbers in July/August in both 2009 and 2010 (Figure 4.4). By September 2010 the modal size increased approximately 20 mm. However, while that size range was similar in September 2010, extremely low catches of Arctic cod made comparisons unreliable. Conversely, the largest collection of Arctic cod by bottom trawl was in September 2010 (Figure 4.5). The smallest sizes found in the bottom trawl were 38–45 mm in July/August 2009, 15–20 mm larger than those in the midwater at the same time. In July/August 2010 the Arctic cod were caught with a net having a mesh three times larger than that of July/August 2009. By September 2009 and 2010, the smallest mode of Arctic cod in bottom collections increased to 50–60 mm, about 10 mm larger than that in the midwater collections. The size range of this mode was broader in 2009 than in 2010. In 2010 a second range of sizes was seen between 75 and 93 mm, but a similar pattern was not clear in 2009.

The other species also showed seasonal and interannual patterns in length distributions. Arctic staghorn sculpin had three modal peaks (27, 42, and 63 mm) in the July/August 2009 cruise (Figure 4.6). In the cruise immediately following, only a fifth as many fish were caught and had a mode of 72 mm. During the same time period in 2010, the modal size was 40 mm, the mode also found in September/October 2009. The difference in size distributions in September between the two years was that there was a second mode at 57 mm seen in 2010. Shorthorn sculpin had length modes that increased over season from 30 mm in July/August 2009 to 39 mm a few weeks later (Figure 4.7). By September/October 2009 the mode was 45 mm, identical to that in 2010; however the modal peak was sharper in 2010. In July/August 2010 the mode was 70 mm, which may be attributable to a different net being used. Polar eelpout perhaps had the most interesting length-frequency configurations because its size range was greater than that of the other species and because more modes were apparent (Figure 4.8). There was a marked difference in size (36 vs. 66 mm) of polar eelpout in the July/August and the August cruises in 2009. The larger size corresponded to the mode captured in July/August 2010. In September of both years the smallest mode increased to 45 mm and a second mode was evident at 75 mm; large fish were captured, but the modes were not as clear. Few small stout eelblenny were captured (Figure 4.9). Though there was a mode at 54 mm, the largest mode in two of the time periods in 2009 was 90 mm and was followed by a mode at 115 mm. In September 2010 there was a single mode at 102 mm though the size range was greater than in the previous year. Despite comparatively small numbers of Bering flounder caught in each cruise, more than one mode was found in each of the length distributions (Figure 4.10). The smallest mode was 40 mm in all three collections in July/August. A very small size mode (18 mm) in September 2010 indicated newly settled age-0 Bering flounder that were not captured at any other time.

Examination of length-frequency graphs for individual species revealed trends across time and across space. Arctic cod in the midwater trawl were the same size (30 mm) in both Klondike and Burger in July/August 2009 (Figure 4.11). By September/October 2009, fewer Arctic cod were caught in Klondike as in Burger, but they were larger. In September 2010, Arctic cod were not in the midwater in any study area. The bottom trawl never captured Arctic cod as small as were found in the midwater trawl. However, small Arctic cod (45 mm) were found in the bottom trawl in Klondike in July/August 2009; small Arctic cod were not found in Burger at that time (Figure 4.12). By September in 2009 and 2010 in all three study areas, the Arctic cod were larger, 45–60 mm. Arctic staghorn sculpin was caught only rarely in Burger and never in Statoil (Figure 4.13). It was most numerous in September at a size of 36–40 mm. Like Arctic staghorn sculpin, shorthorn sculpin was mostly caught in Klondike where its modal size was 43–48 mm in all seasons (Figure 4.14). Polar eelpout had a broad range of sizes and relatively modest numbers of fish over all three time periods and two of the study areas (Figure 4.15). In Statoil, small (42–45 mm) polar eelpout dominated. A modal size of 90 mm dominated stout eelblenny length distribution for all collections in 2009 (Figure 4.16). In contrast, in 2010 the mode increased to 105 mm for all three study areas. Numbers of Bering flounder collected were negligible in Burger (n=2) and Statoil (n=16), and the length distribution of those caught in Klondike did not provide insightful patterns regarding size (Figure 4.17).

Other fish species were captured in numbers too small to allow examination over time and space. However composite length/frequency plots provided baseline information on sizes of 30 species of Chukchi Sea fishes (Appendix 7).

4.4 DISCUSSION

This study provides updated life history information for some important and ecologically representative demersal fish species in Chukchi Sea. Real differences were seen between length distributions of these species in the present and past studies that cannot be attributed to gear, as the same bottom trawl was used consistently during four of the five collection periods that we considered. At first glance it appeared that the small size and small mesh of the 3mPSBT biased fish catches to individuals <80 mm, however almost all stout eelblenny were >80 mm, thus diffusing that argument. Likewise it appeared that this trawl was not effective at catching fish

>120 mm, but the length distribution of polar eelpout proved that conclusion to be invalid. We conclude that our sample efforts captured small fish because the small sizes are numerically dominant in the northeastern Chukchi Sea.

The modal size of Arctic cod was always larger in bottom trawl collections than in midwater collections. As Arctic cod got larger they descended in the water column and were more predominant in bottom catches than in midwater tows, e.g., September 2010. Arctic cod <105 mm are more abundant in water 40–100 m than in water deeper than that (Lowry and Frost 1981). The sample depths of <100 m may be one factor affecting the predominance of small size of Arctic cod that we captured in this study. Gear avoidance by Arctic cod older than age-0 also may be a factor affecting catches, particularly for the small midwater IKMT net that likely pushes a pressure wave in advance of the trawl.

Arctic cod size increased over season. The size distribution of Arctic cod appeared to be more linked to season than to area of capture. The exception to that is that is the absence of small Arctic cod in Burger in July/August 2009. The absence of small Arctic cod may support the hypothesis that they spawn further south and are transported northward as larvae (Wyllie-Echeverria et al. 1997). Interannual variability in northward transport of water and larvae would then account for the observed difference in the present study.

The size of Arctic cod captured in the Alaskan Arctic seems to vary greatly. In the late 1970s Arctic cod ranged from 54 to 257 mm in nearshore waters in the central Beaufort Sea (Craig et al. 1982) and from 45 to 180 mm in the western Beaufort Sea and northeastern Chukchi Sea (Frost and Lowry 1983). In the early 1990s they ranged from 75 to 228 mm (Gillispie et al. 1997). In this study we captured Arctic cod from 9 to 187 mm. Each of these studies used different types of nets to catch the fish. Craig et al. (1982) used a 67 m fyke net with a 12 mm mesh trap. Frost and Lowry (1983) used 4.9 m and 5.8 m otter trawls with a 6 mm codend liner mesh. Gillispie et al.'s (1997) fish were captured with a NMFS 83-112 trawl with a 32 mm liner. The gears considered by the present study had 3 mm mesh in the midwater trawl that was used both years, 4 mm in the only bottom trawl used during 2009 and used as one of the bottom trawls during the 2010 CSESP cruise, and 12 mm used during each 2010 cruise. There does not appear to be a direct relationship between mesh size and the minimum and maximum lengths of Arctic cod captured. It is logical that our gear, which had the smallest mesh, caught the smallest Arctic cod. The confounding factors of sampling decade, location, and gear are difficult to attribute.

The ages that we estimated for Arctic cod were comparable to other areas and times. The age-at-length that we assessed for Arctic cod was comparable to those of the eastern Arctic where all specimens 59–168 mm were assessed as ages 1 and 2 (Lønne and Gulliksen 1989). In the Barents Sea and north of Svalbard 25 years ago, age-1 Arctic cod had mean sizes of 82 mm and 102 mm respectively. In the Beaufort Sea in 1977–80 age-1 fish made up 46% and fish ages 4-6 composed only 7% (Craig et al. 1982). Of the Arctic cod taken in the Chukchi Sea in 1990, 59% were age-1 and 16% were ages 4-8 (Gillispie et al. 1997). In the Chukchi Sea 30 years ago, the mean length of Arctic cod was 88 mm, and ranged as big as 184 mm (Lowry and Frost 1981). In that study, 81% of the Arctic cod were age-1, and many of the larger fish were quite young. In the western Beaufort Sea in 2008 age-0 Arctic cod were 25–50 mm and age-1 were 70–180 mm (Parker-Stetter et al. 2011). In the eastern Beaufort Sea in 2009 ages 0-3 fish were 30–130 mm (A. Majewski, Canada DFO, pers. comm.). In comparison, for lengths 20–187 mm we determined Arctic cod to be ages 0-3.

Our age estimates of Arctic staghorn sculpin generally agreed with those from 1990–1991 catches in the Chukchi Sea (Smith et al. 1997a). That analysis of mean length at age showed age-1 was ~50 mm, age-2 ~65 mm and age-3 ~80 mm, as did their older length-at-age estimates. In this study the mean size at age was similar to that of 20 years ago. Age distributions differed markedly in the two years of sampling leading the authors to suggest that a recruitment failure all but eliminated a year class (Smith et al. 1997a). We found differences in interannual and seasonal distribution of lengths of Arctic staghorn sculpin, but they could not be interpreted as missing year classes. In contrast to Arctic staghorn sculpin we only found ages-0 to -2 shorthorn sculpin despite a large length distribution. The apparent faster growth can be seen in the seasonal sampling in 2009. More information is needed to compare these two sculpins.

We conducted an in-depth study of polar eelpout and stout eelblenny as they are abundant species in the study area and lack previous age and size information. Unfortunately that means there is no earlier research with which to compare them. Polar eelpout and stout eelblenny had very different length distributions. Polar eelpout were to 30–200 mm at ages 0-10. Their length distributions showed marked peaks at the smallest sizes indicating a distinct age-0 year class, which was confirmed by age assessments. However, the second peak was a mix of ages 1-4. Stout eelblenny displayed the opposite pattern, with most individuals being >80 mm without distinct size peaks to indicate separate age classes. There were few stout eelblenny ages 0-2 captured, which could indicate either lack of recruitment or that their spawning location is at a distance and they do not inhabit this offshore location until they are larger and older. The information that we discovered about the age-length distributions of these two species is valuable in that it is the most comprehensive examination to date for these species.

Bering flounder sizes and ages were smaller in our collections than in collections in 1990–1991, when the sizes of Bering flounder asymptotes were 211 mm for males and 241 mm for females (Smith et al. 1997b). Maximum was age-8 for males and age-11 for females; >40% of the 133 fish examined were age-5. These larger fish were captured with a NMFS 83-112 net (Table 1.1; Barber et al. 1997; Smith et al. 1997b). We did not capture any Bering flounder over 130 mm and age-5. That could be a consequence of sampling with smaller mesh than during 1990–1991. However the Bering Sea in 2003, the 3mPSBT successfully captured flatfishes 131–497 mm (Norcross and Holladay 2005). It is likely that the difference is due to the location of the sample areas. In 1990 most Bering flounder were captured west of Klondike (Figures 3.9). The largest Bering flounder were captured in our study during July/August 2009 and 2010, though the latter collection used a larger net with bigger mesh.

Length-frequency distributions portray an interaction of rates of reproduction, recruitment, growth and mortality of ages that are present (Anderson and Neumann 1996). These distributions can change over time; such change may provide insight into the dynamics of fish populations and underlying problems. Fish larger than the mean sizes captured in this study are known to have been present in the Chukchi Sea during 1990–1991 (Gillespie et al. 1997; Smith et al. 1997a, 1997b). However other studies did not capture age-0 fishes, which are an important ecological component, as we were able to do.

It is obvious that despite measuring over 3,300 specimens of fish from six species and assessing their ages from over 1,100 otoliths, patterns are not easy to discern and even larger numbers of fish need to be examined to fully understand age-at-length distribution, and particularly to assess habitats occupied by age-0 fish, when the fish are especially vulnerable and the strength of the year class is established. External age lab assessments proved how difficult it is to assign an age these under-studied Arctic species. We recommend examining 20 otoliths per 10 mm length range of each species. Determining changes over time in age at length would be difficult without assessing ages of greater numbers of fishes. Interannual variability in vertical and seasonal sizes of fishes needs to be investigated further. Getting inconsistent results in two years of sampling makes it difficult to make definitive statements about size and age distribution of these important fish species in the Chukchi Sea now, other than noting that year-to-year variability occurs.

4.5 ACKNOWLEDGMENTS

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Table 4.1. Estimated parameters of length-weight relationships ($W = aL^b$) for 18 species of fish for which >30 individuals were captured. N = number of fish examined.

Family and common name	Scientific name	N	*a*	SE (a)	*b*	SE (b)	r^2
Cods							
Arctic cod	*Boreogadus saida*	3648	-5.4802	0.0184	3.1055	0.0113	0.95
Sculpins							
hamecon	*Artediellus scaber*	492	-5.3853	0.0506	3.3278	0.0304	0.96
Arctic staghorn sculpin	*Gymnocanthus tricuspis*	574	-5.9031	0.0460	3.5156	0.0273	0.97
shorthorn sculpin	*Myoxocephalus scorpius*	1023	-5.6090	0.0439	3.3626	0.0276	0.94
ribbed sculpin	*Triglops pingelii*	36	-5.6109	0.2263	3.1836	0.1284	0.95
Sailfin sculpins							
eyeshade sculpin	*Nautichthys pribilovius*	55	-5.5160	0.1759	3.3436	0.1073	0.95
Poachers							
Arctic alligatorfish	*Ulcina olrikii*	224	-6.0377	0.1397	3.4837	0.0838	0.89
Snailfishes							
kelp snailfish	*Liparis tunicatus*	64	-5.3822	0.1587	3.2354	0.0953	0.96
Eelpouts							
halfbarred pout	*Gymnelus hemifasciatus*	150	-5.7344	0.1187	3.1359	0.0626	0.94
fish doctor	*Gymnelus viridis*	41	-6.0362	0.3115	3.3053	0.1558	0.92
polar eelpout	*Lycodes polaris*	311	-5.7900	0.0569	3.2056	0.0307	0.97
marbled eelpout	*Lycodes raridens*	129	-5.7140	0.0978	3.1934	0.0522	0.97
Pricklebacks							
stout eelblenny	*Anisarchus medius*	871	-5.5382	0.0572	2.9946	0.0288	0.93
fourline snakeblenny	*Eumesogrammus praecisus*	41	-6.1816	0.1973	3.5295	0.0990	0.97
slender eelblenny	*Lumpenus fabricii*	959	-5.7634	0.0519	3.0874	0.0279	0.93
Arctic shanny	*Stichaeus punctatus*	88	-5.9718	0.0772	3.3492	0.0470	0.98
Sand lances							
Pacific sand lance	*Ammodytes hexapterus*	226	-6.4727	0.1659	3.4669	0.1000	0.85
Flatfishes							
Bering flounder	*Hippoglossoides robustus*	175	-5.6671	0.0710	3.2779	0.0404	0.97

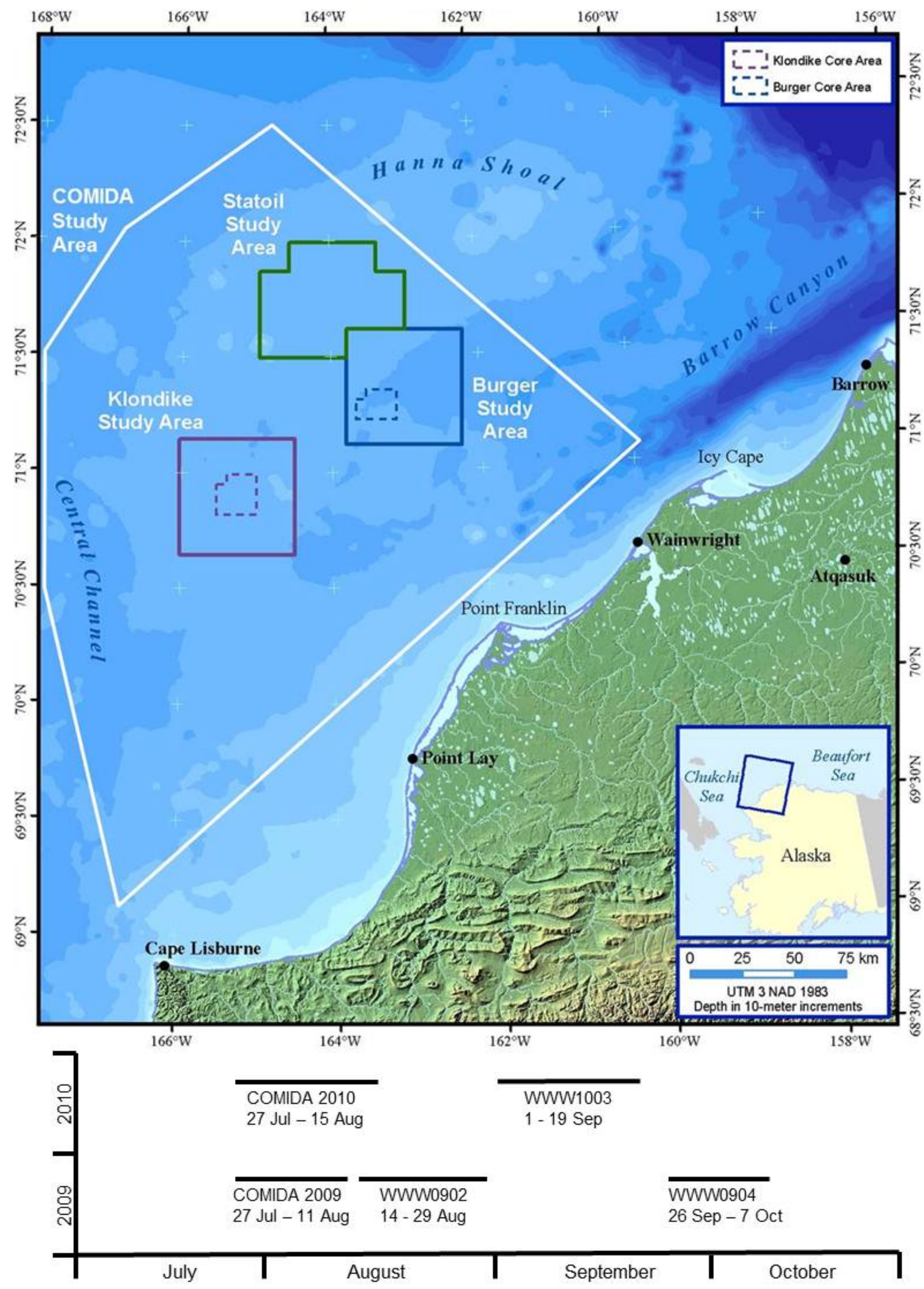

Figure 4.1. Map of 2009 and 2010 study areas and time frame of sampling in the Chukchi Sea. The three CSESP cruises are WWW0902, WWW0904, WWW1003.

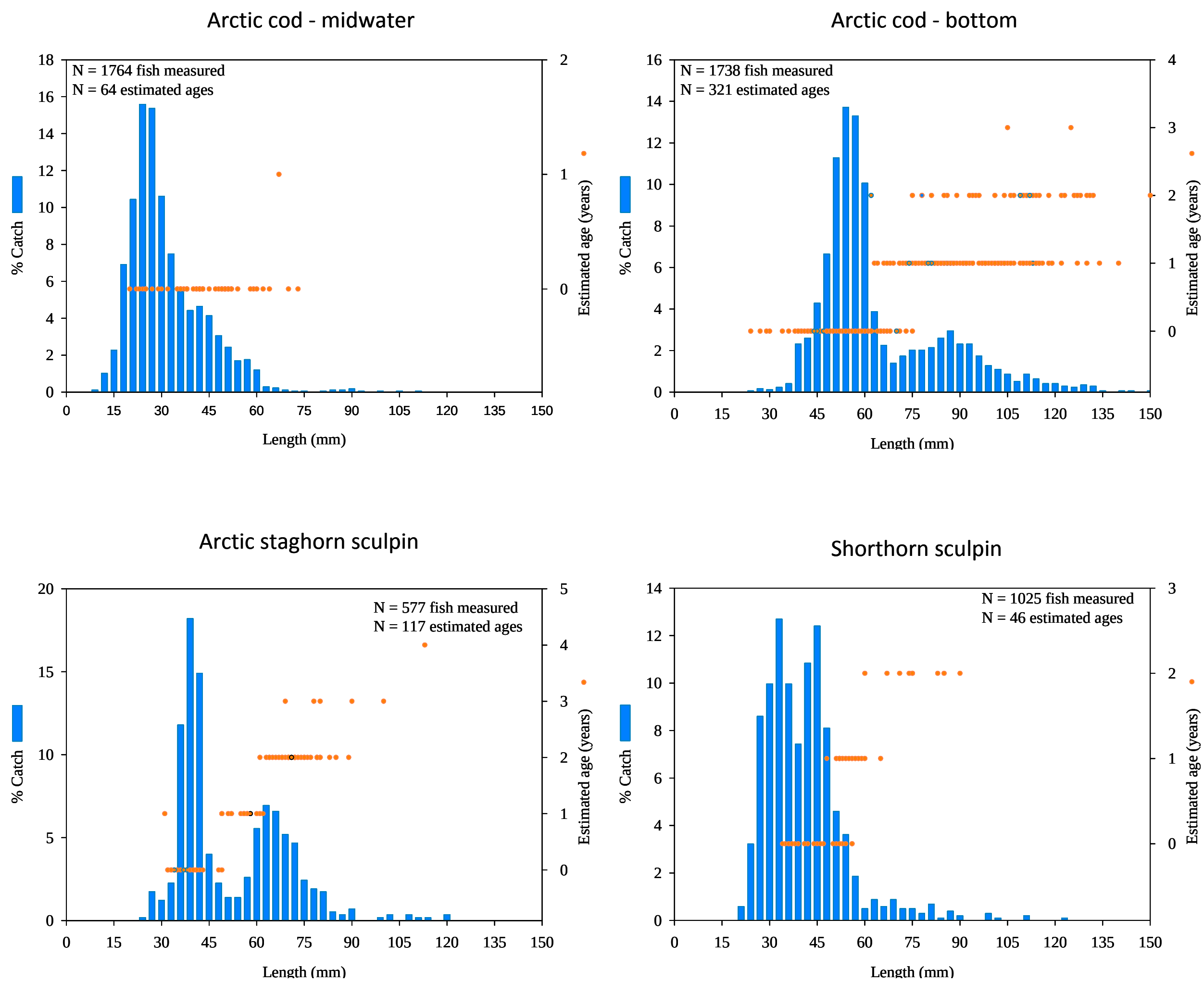

Figure 4.2. Age-at-length of Arctic cod (midwater and bottom trawls), Arctic staghorn sculpin and shorthorn sculpin combined over collections July/August 2009, September/October 2009, and September 2010.

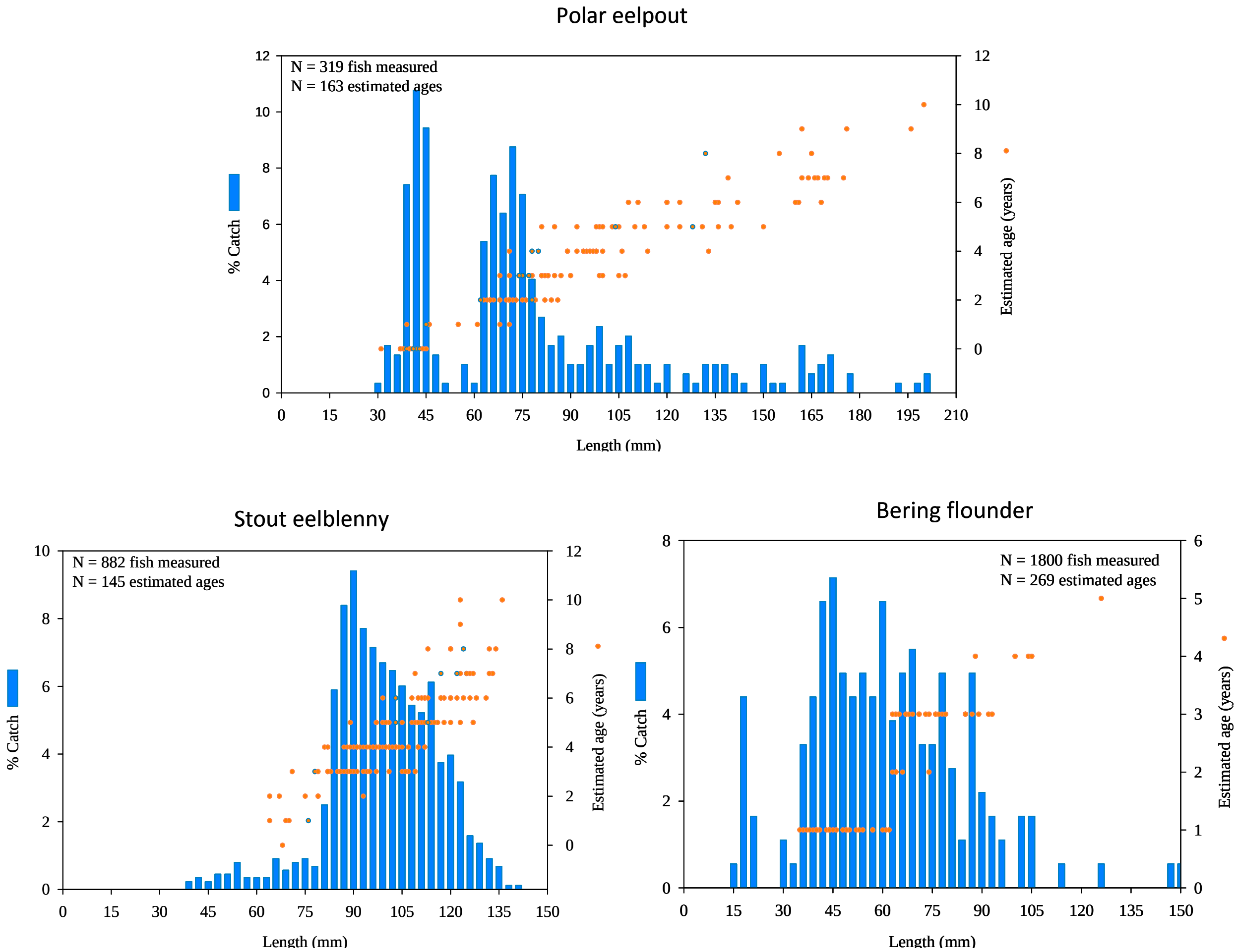

Figure 4.3. Age-at-length of polar eelpout, stout eelblenny and Bering flounder combined over collections July/August 2009, September/October 2009, and September 2010.

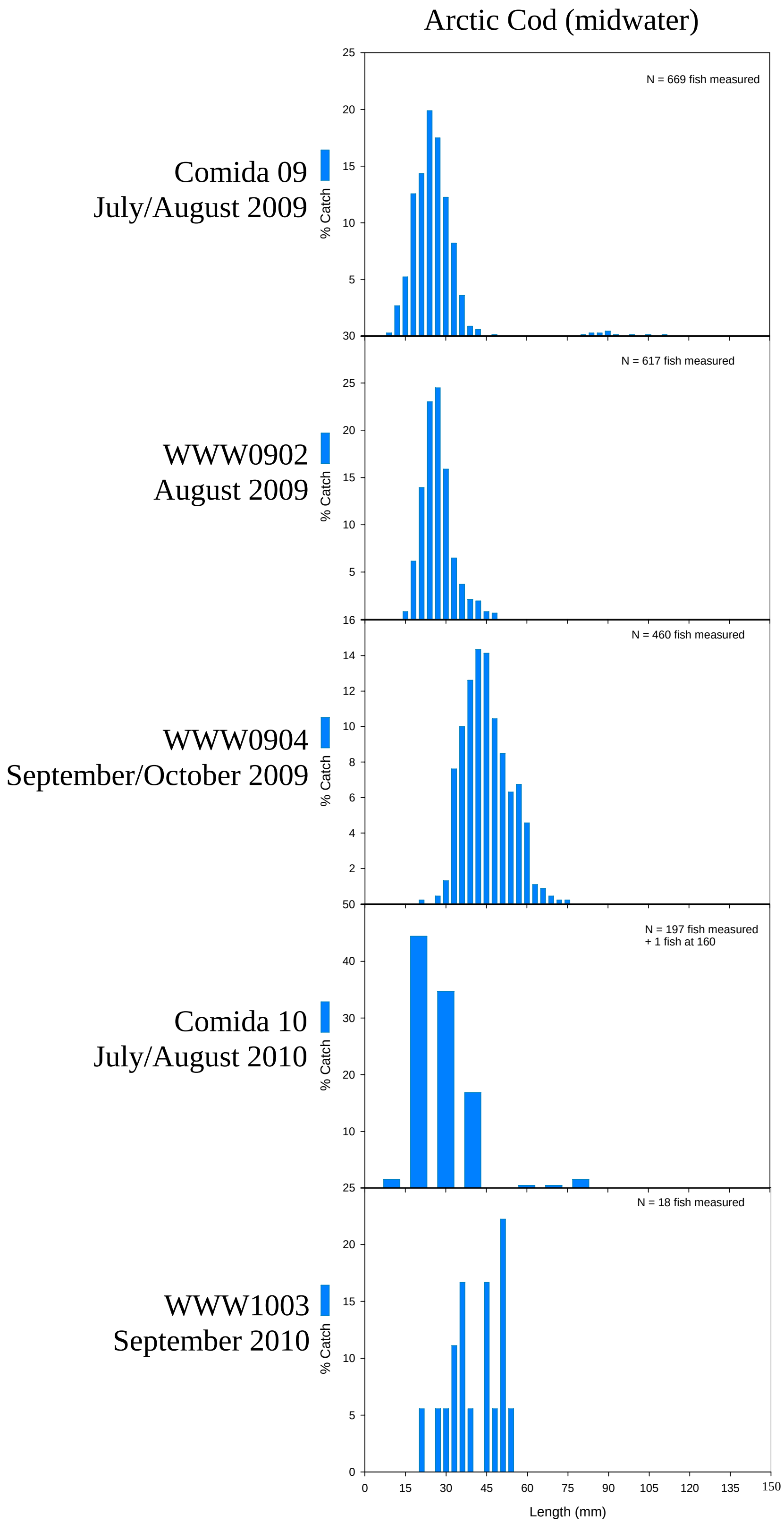

Figure 4.4. Frequency of Arctic cod lengths from collections by midwater trawl on each of five cruises.

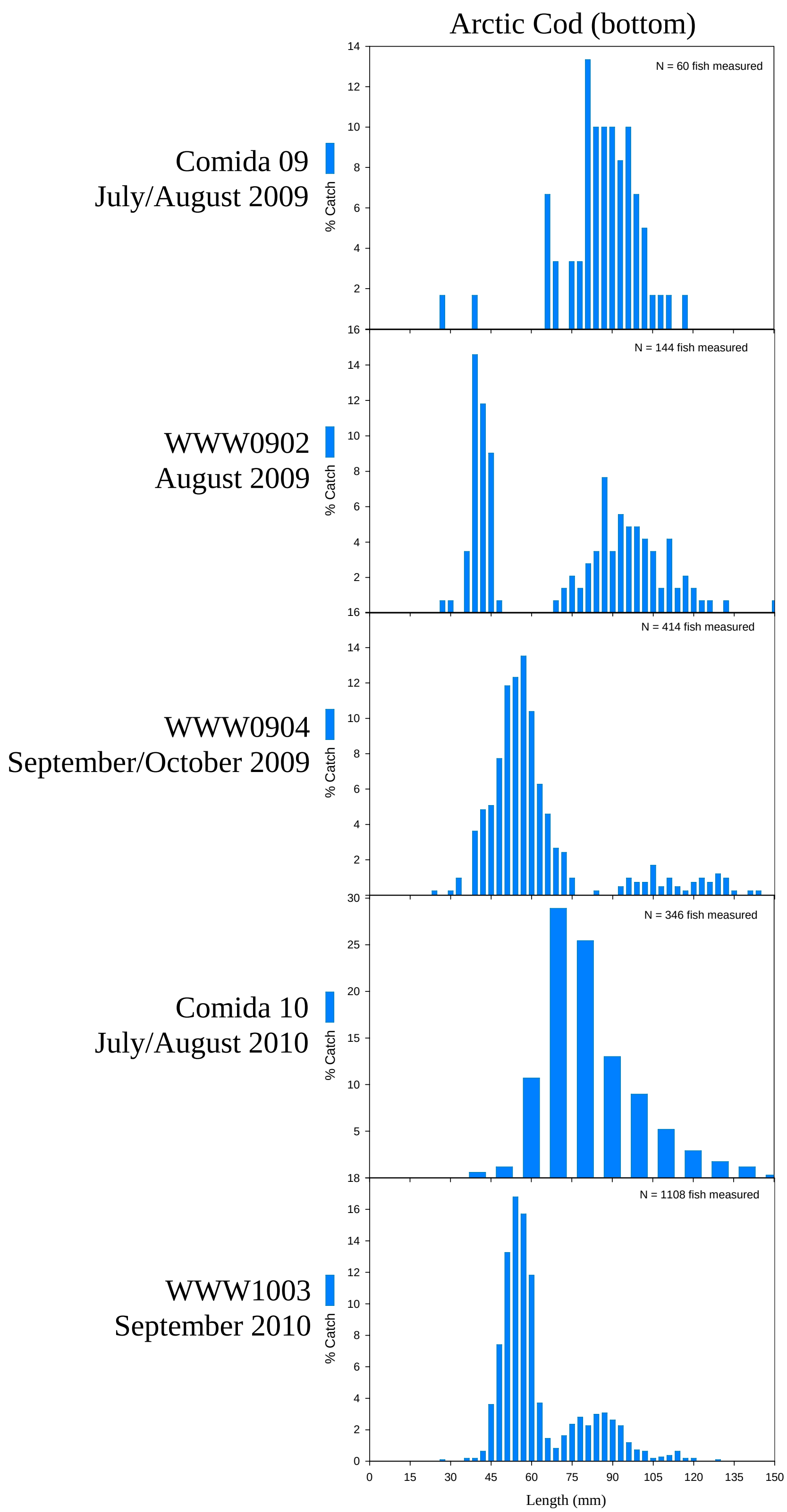

Figure 4.5. Frequency of Arctic cod lengths from collections by bottom trawl on each of five cruises.

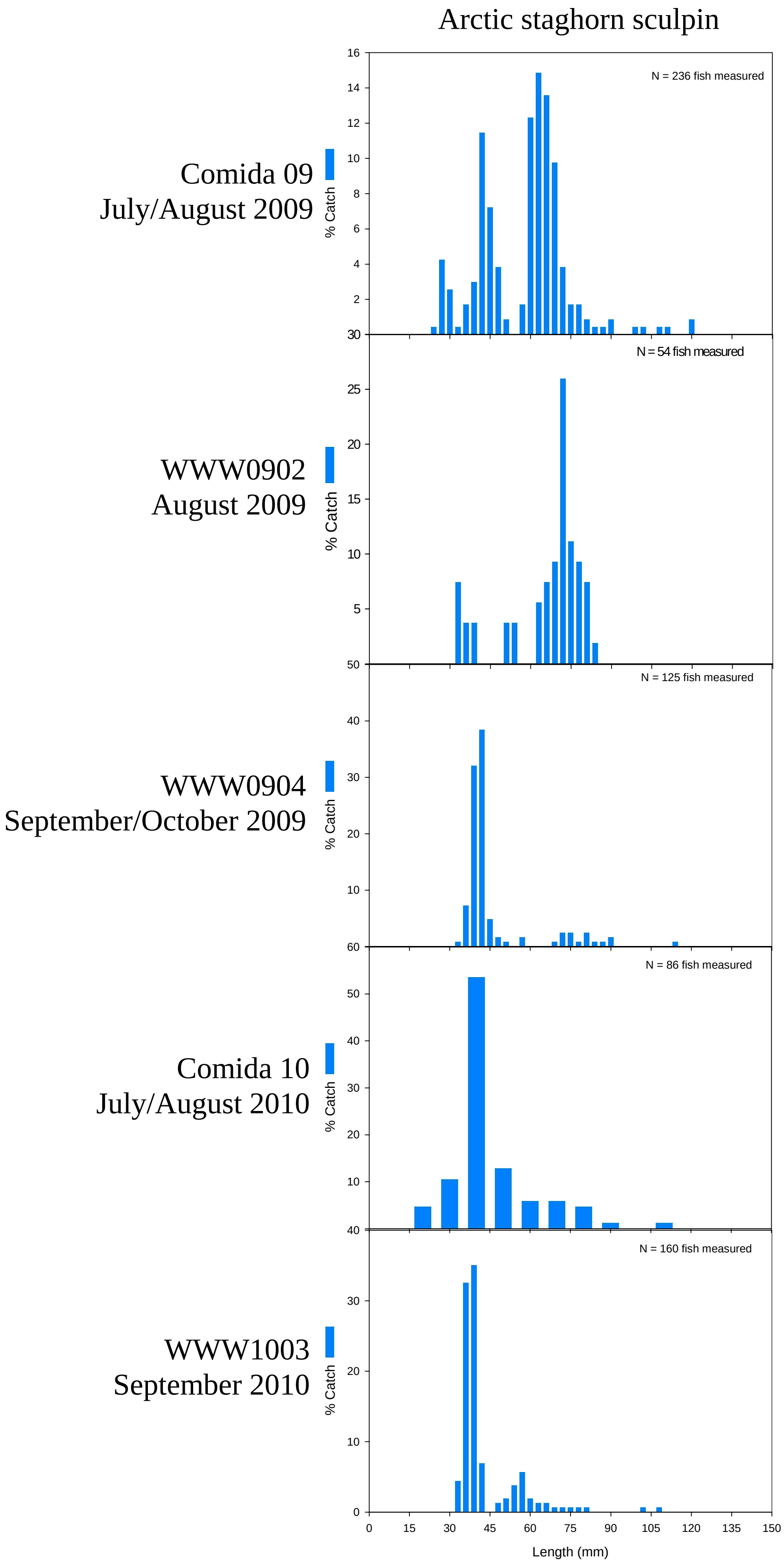

Figure 4.6. Frequency of Arctic staghorn sculpin lengths from collections by bottom trawl on each of five cruises.

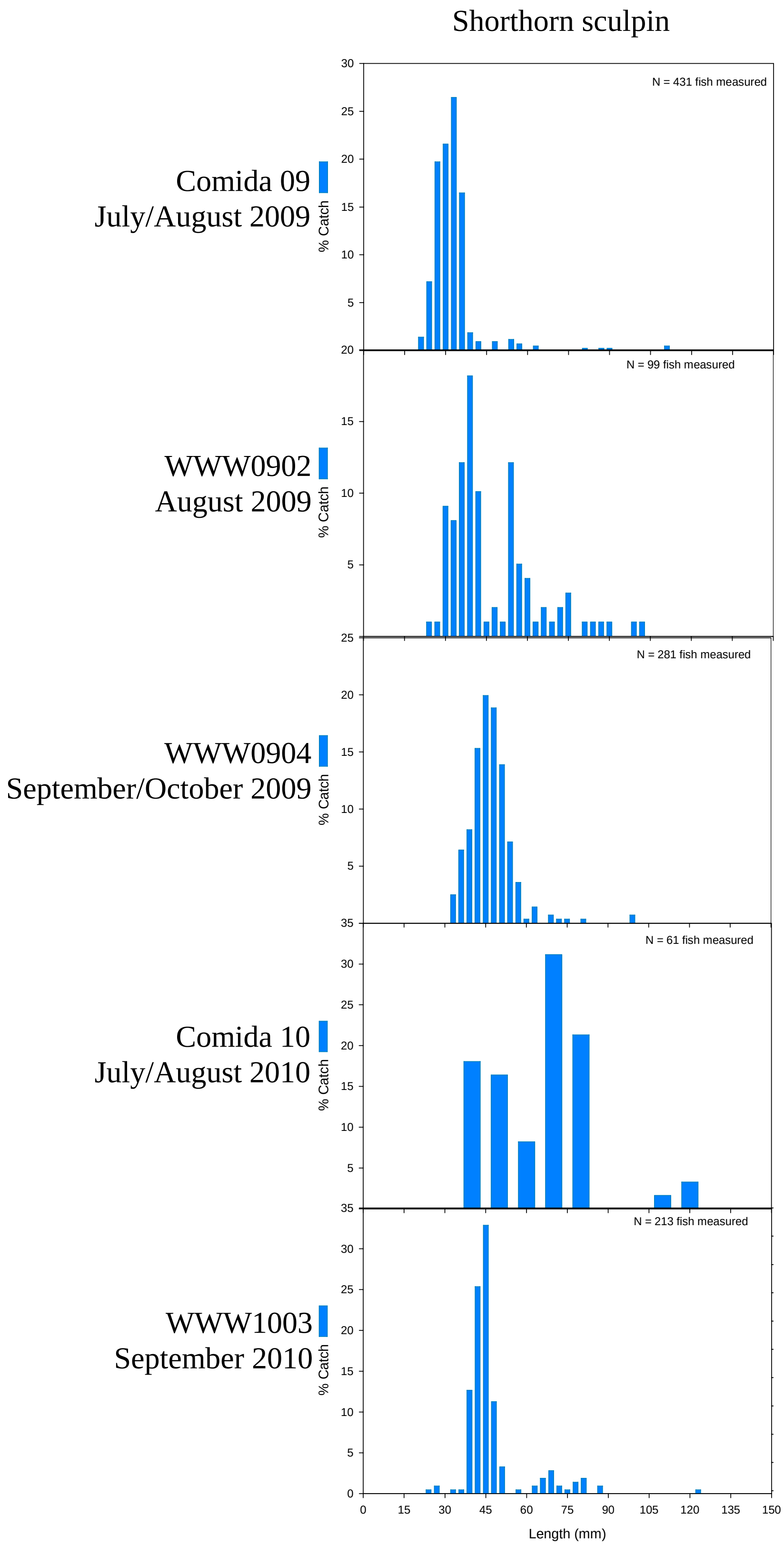

Figure 4.7. Frequency of shorthorn sculpin lengths from collections by bottom trawl on each of five cruises.

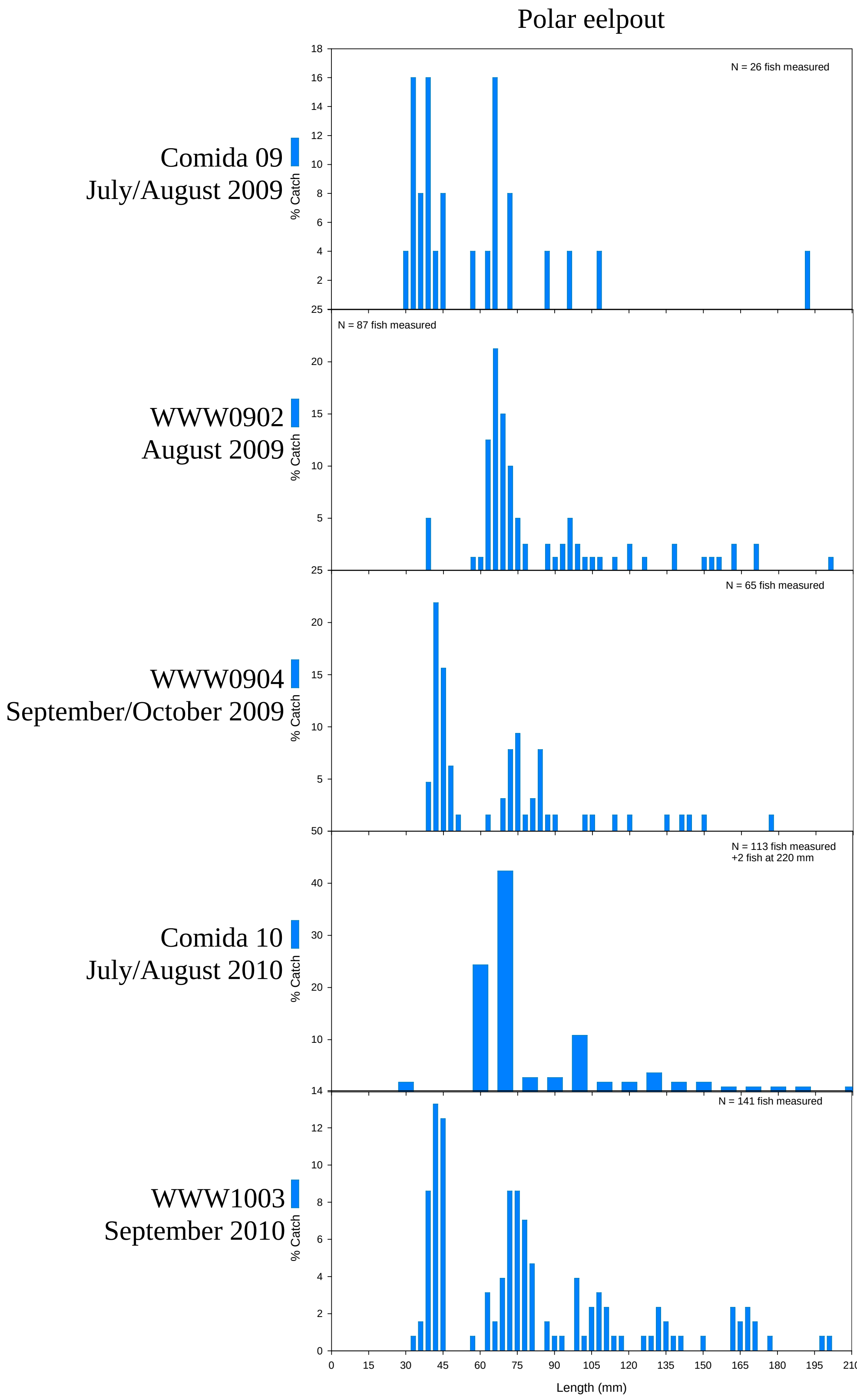

Figure 4.8. Frequency of polar eelpout lengths from collections by bottom trawl on each of five cruises.

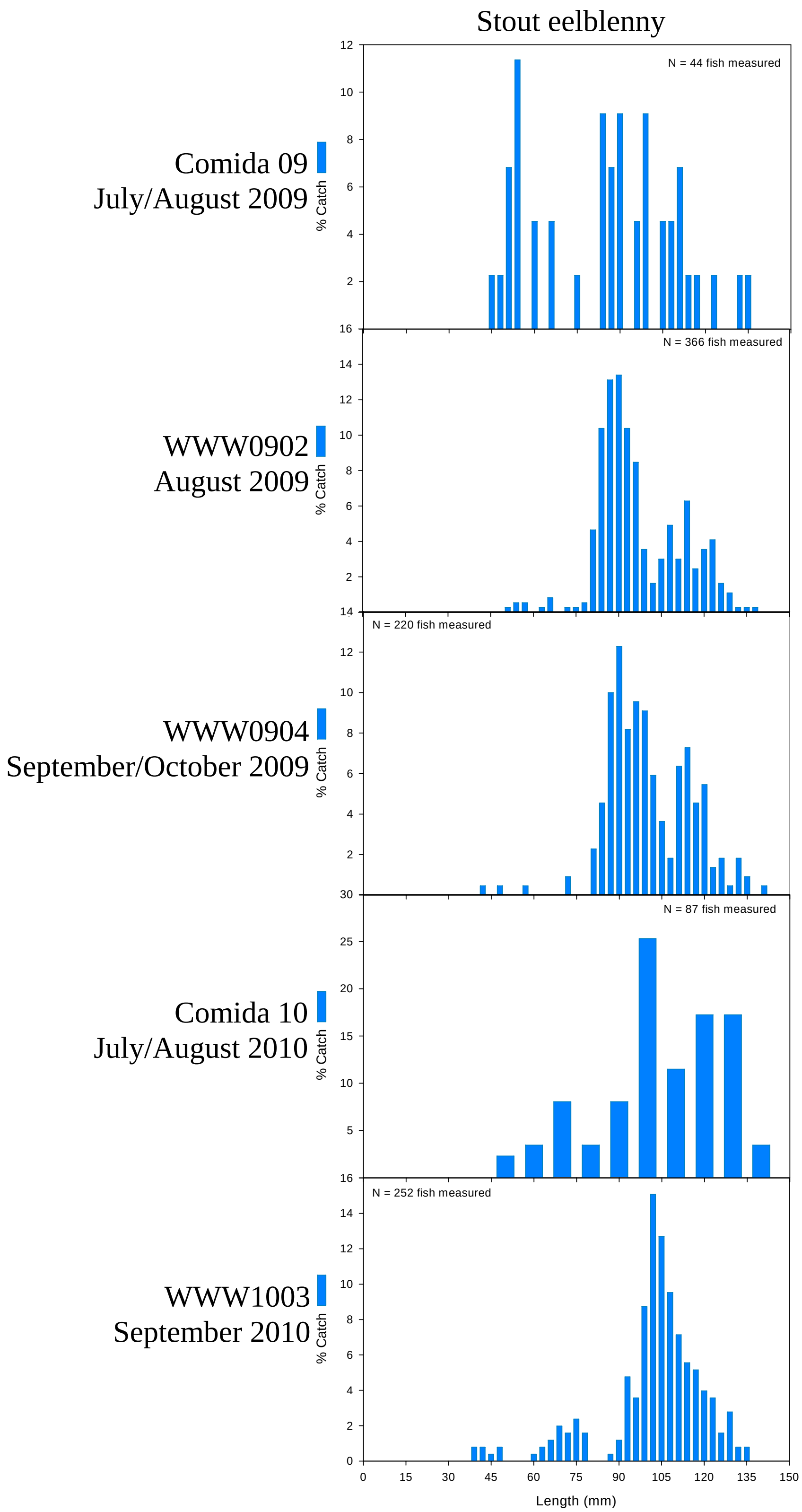

Figure 4.9. Frequency of stout eelblenny lengths from collections by bottom trawl on each of five cruises.

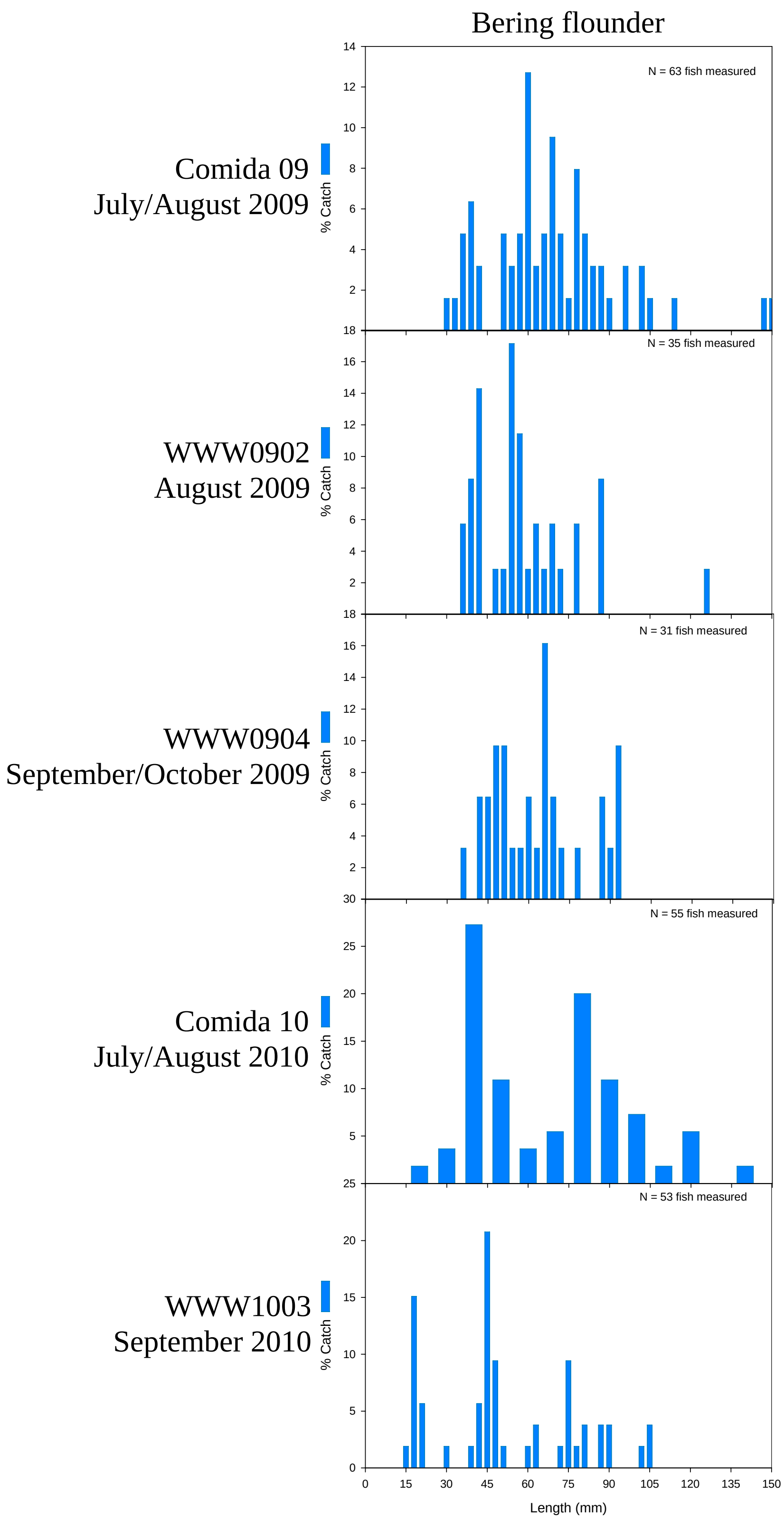

Figure 4.10. Frequency of Bering flounder lengths from collections by bottom trawl on each of five cruises.

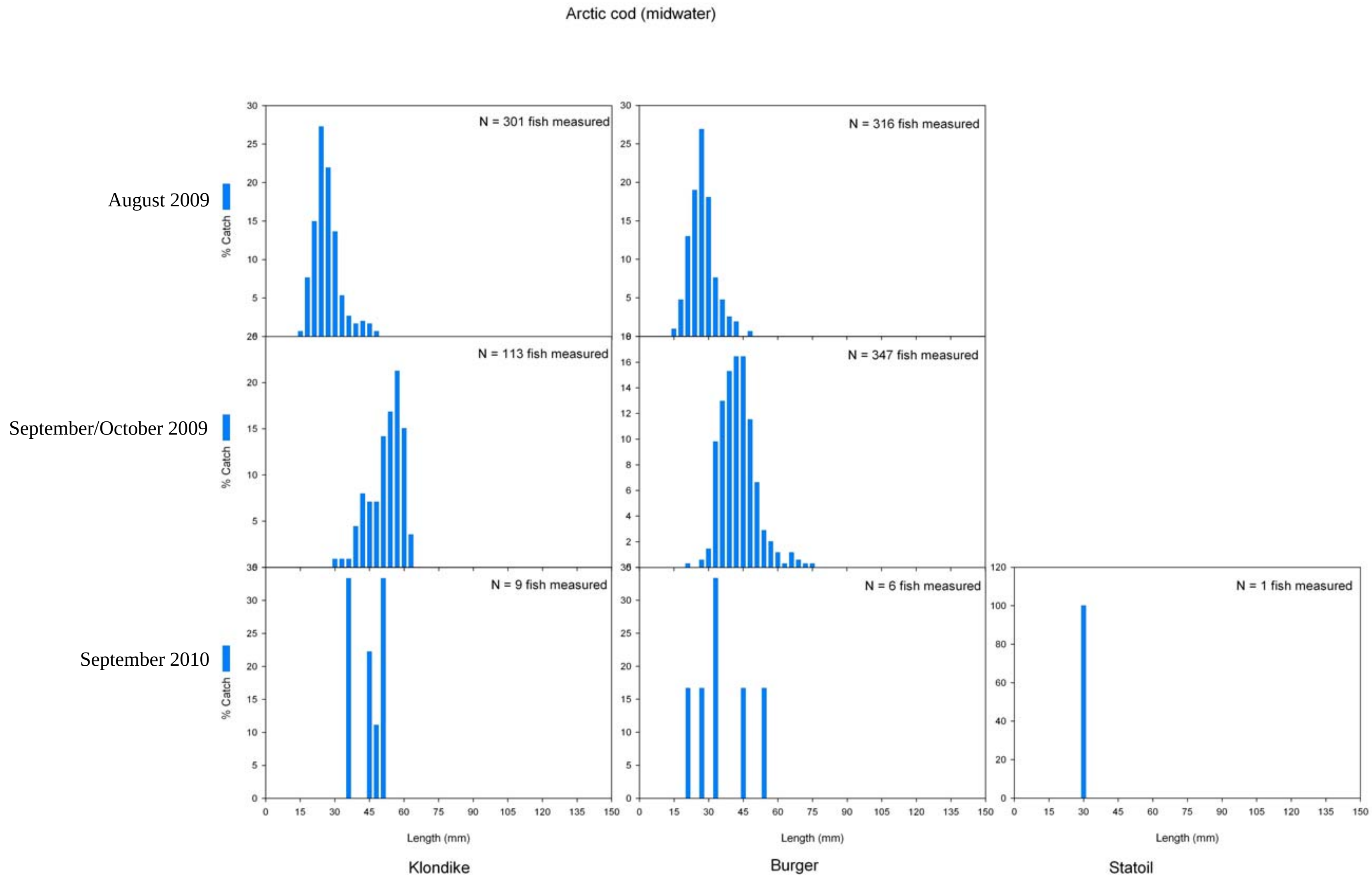

Figure 4.11. Frequency of Arctic cod lengths from collections by midwater trawl in each season and study area.

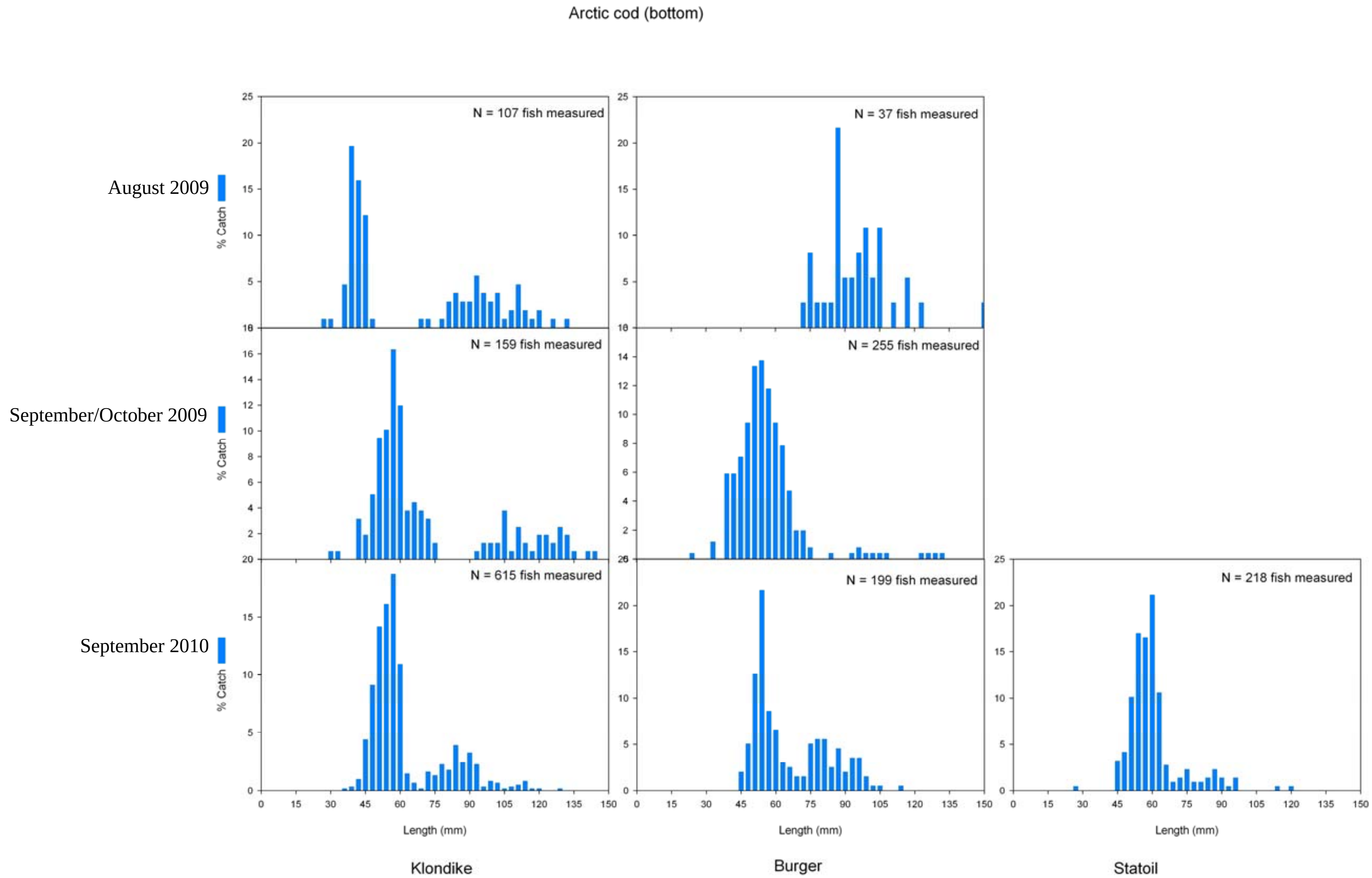

Figure 4.12. Frequency of Arctic cod lengths from collections by bottom trawl in each season and study area.

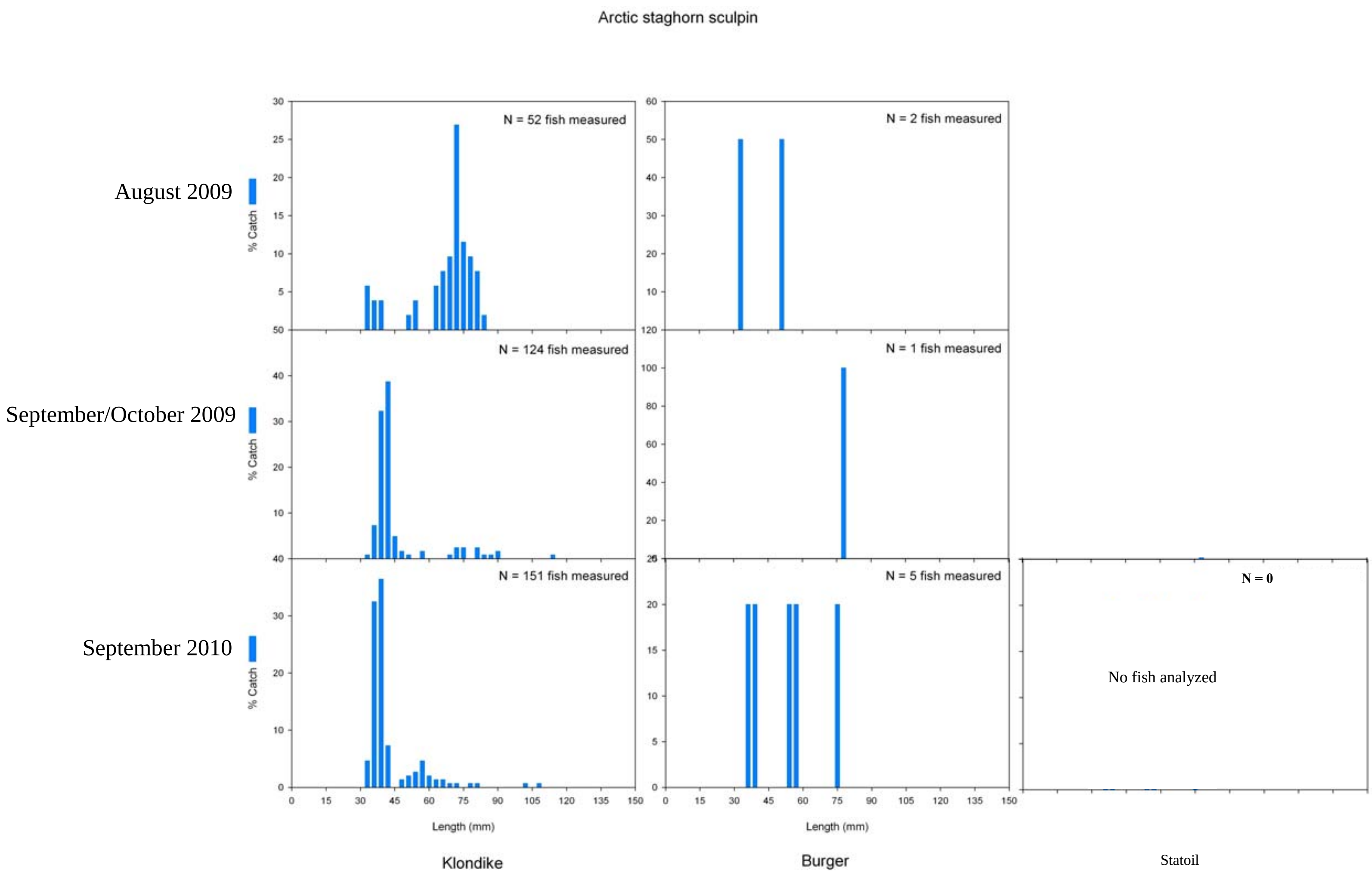

Figure 4.13. Frequency of Arctic staghorn sculpin lengths in each season and study area.

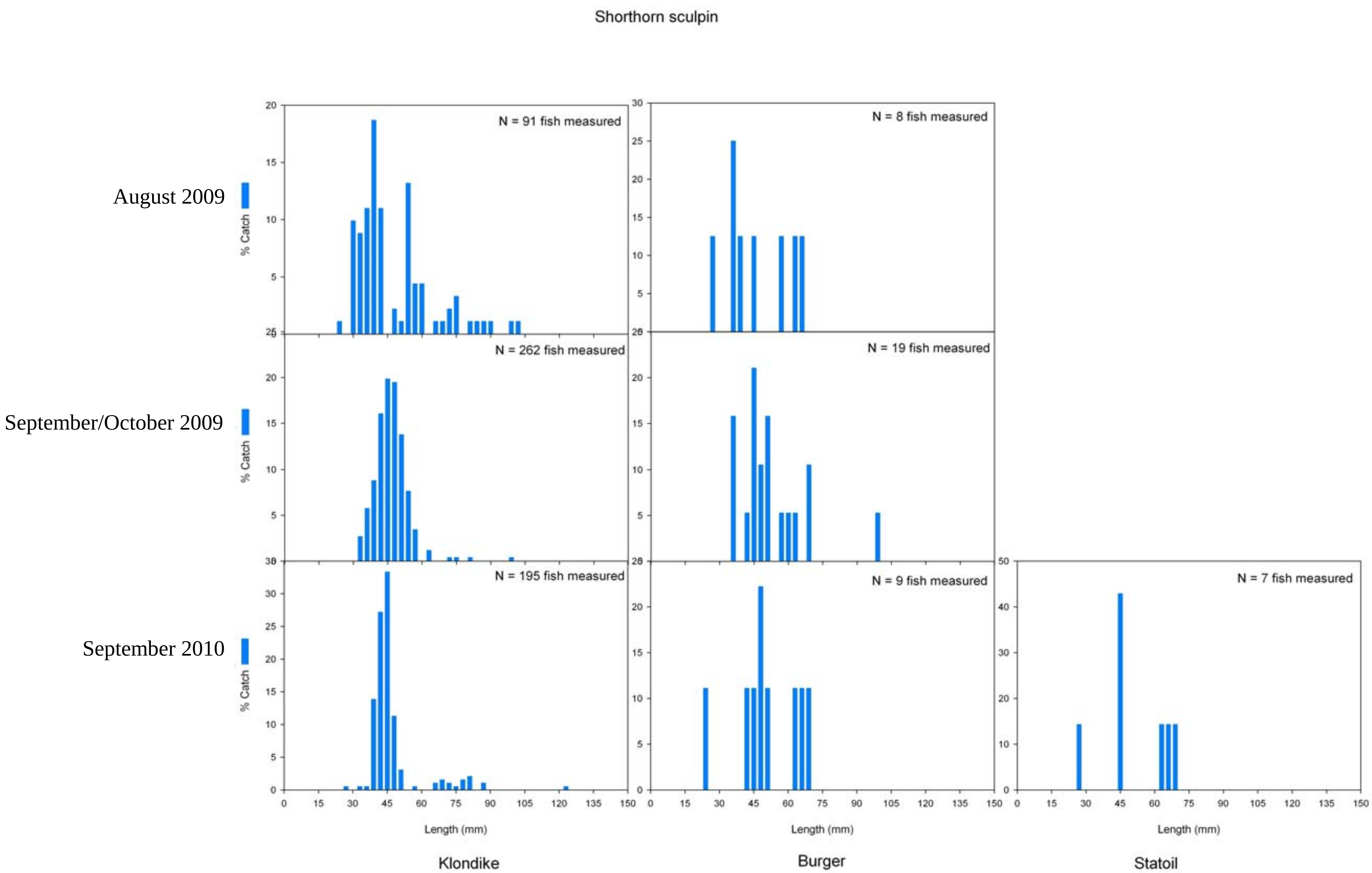

Figure 4.14. Frequency of shorthorn sculpin lengths in each season and study area.

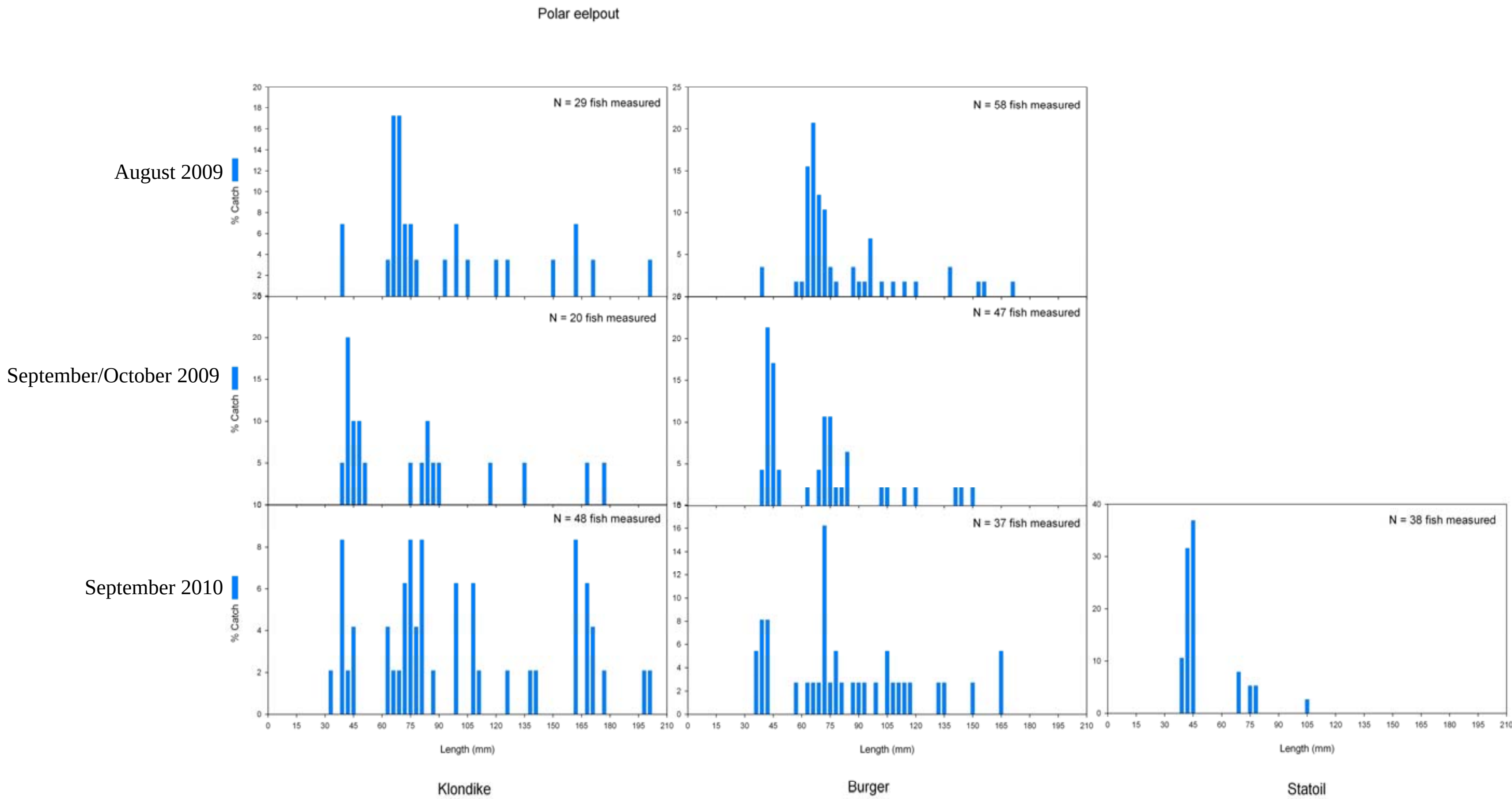

Figure 4.15. Frequency of polar eelpout lengths in each season and study area.

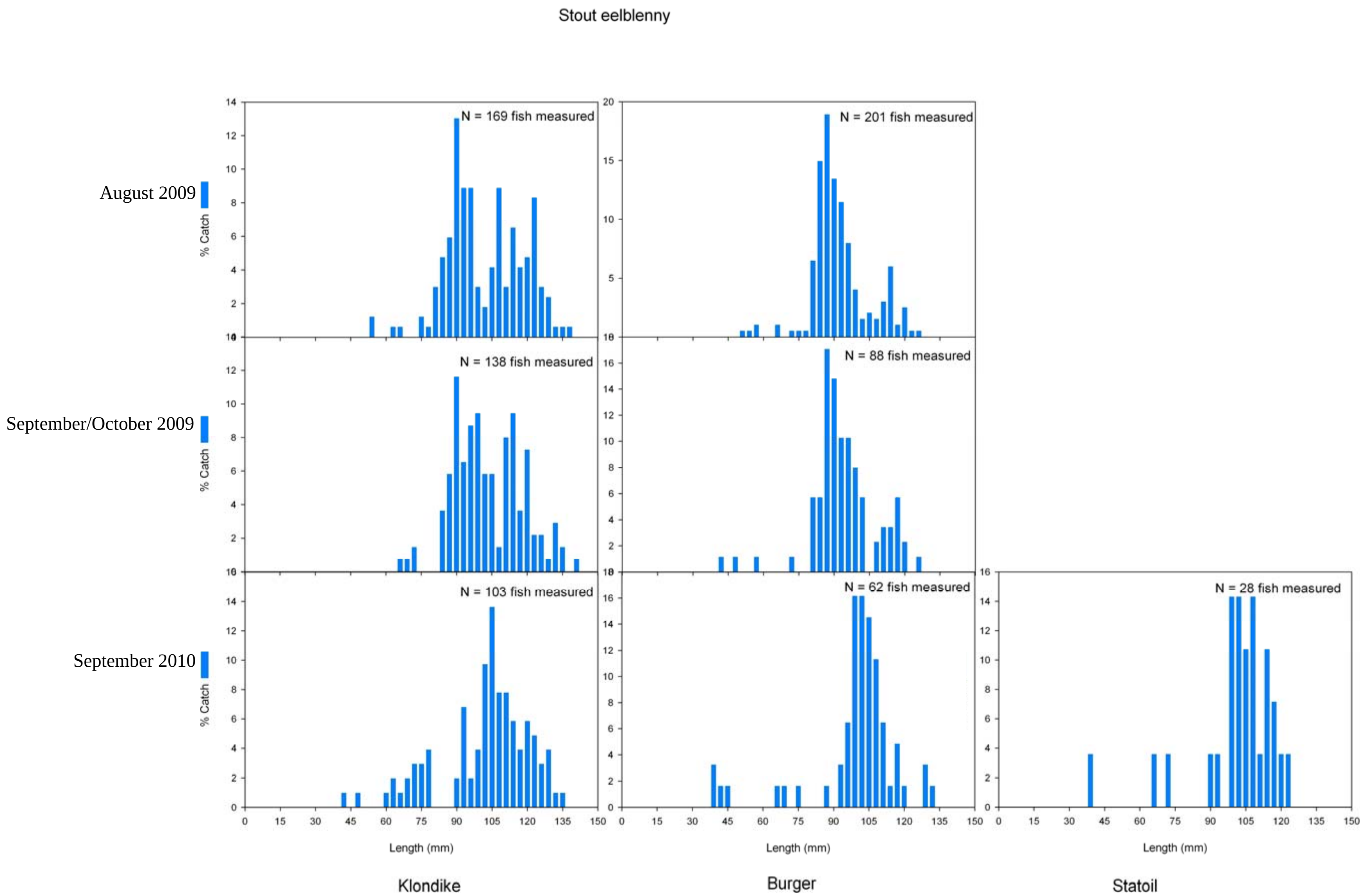

Figure 4.16. Frequency of stout eelblenny lengths in each season and study area.

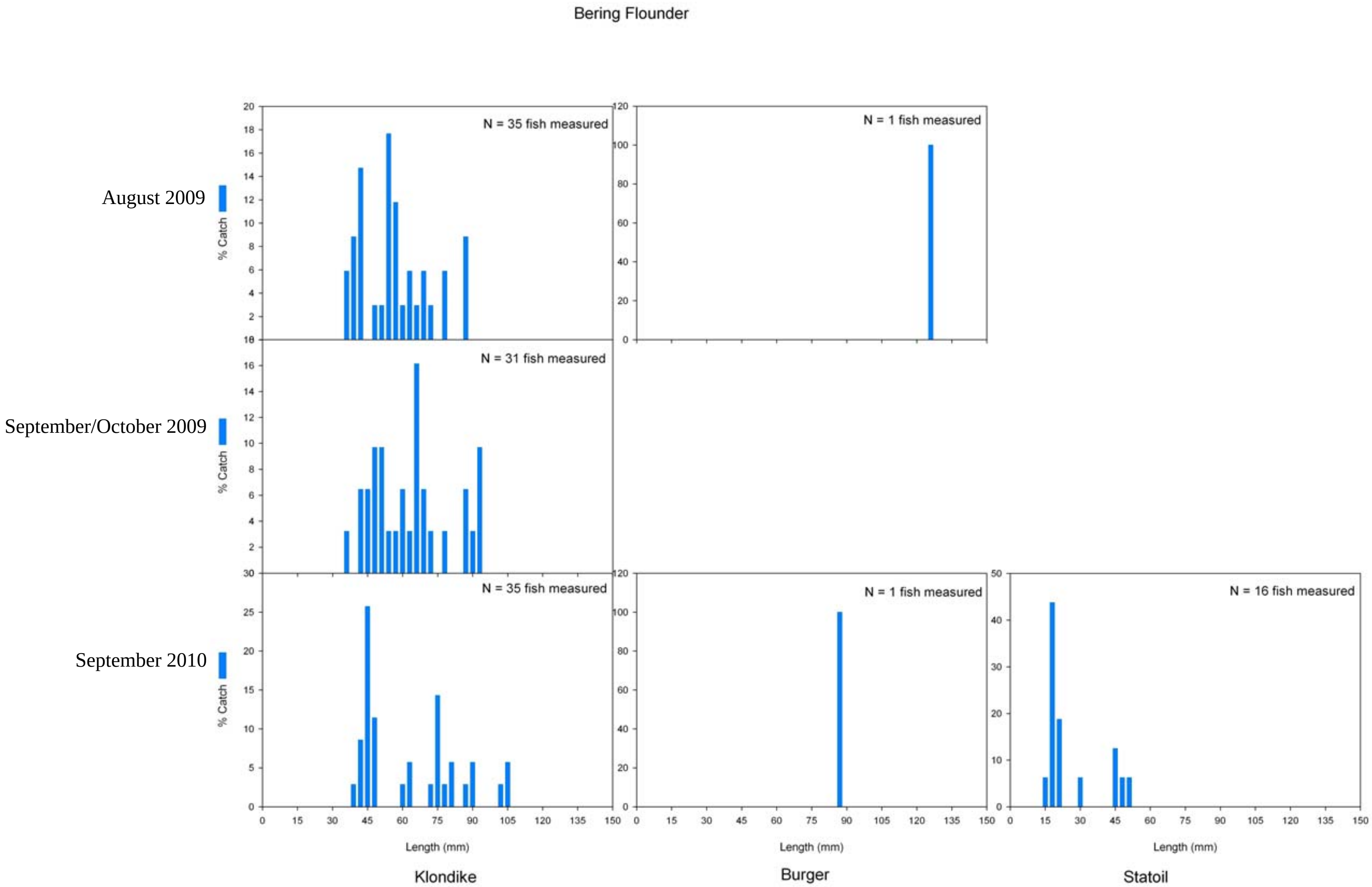

Figure 4.17. Frequency of Bering flounder lengths in each season and study area.

CHAPTER 5 - TROPHIC RELATIONSHIPS OF FIVE SPECIES OF DEMERSAL FISHES IN THE NORTHEASTERN CHUKCHI SEA, 2009–2010

[1]L.E. Edenfield, [1]B.L. Norcross, [1]S.S. Carroll, [1]B.A. Holladay

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5.1 INTRODUCTION

Fishes are an important component in the Arctic food web. They provide a link between lower level organisms, such as zooplankton and some invertebrates, and higher level predators, such as seabirds, marine mammals and subsistence users. There have been far more observations in Arctic regions of lower and higher trophic levels than of fishes (Craig and McCart 1976; Craig et al. 1982, 1984; Frost and Lowry 1981, 1983, 1984; Grebmeier and Dunton 2000). A current paucity of information on fish distribution and ecology (Johnson 1997; Power 1997; Mecklenburg et al. 2002; MMS 2006) is a critical gap in the knowledge of the changing Arctic ecosystem. A clear understanding of the trophic ecology is necessary to better assess ecosystem changes through time and to forecast potential changes in the Arctic food web.

The Chukchi Sea has an extremely high biomass of benthic organisms for an Arctic area (Grebmeier and Dunton 2000). However, fish prey resource information is limited for the Chukchi Sea. Furthermore, because of impending climate change and offshore drilling for oil and gas, it is vital to establish a baseline of fish resources. Knowledge of prey resources available to fish as predators, or of fish as a prey resource for higher trophic levels, is valuable in determining potential effects of changes of natural or anthropogenic origin that could influence trophic levels.

Diets of the most abundant species of marine fishes in the Arctic waters of Alaska reveal that fishes feed on benthic and pelagic animals of several trophic levels. Stomach analyses of Arctic cod (*Boreogadus saida*) from the eastern Chukchi and western Beaufort Seas reveal that their diets consist primarily of epibenthic and pelagic amphipods and copepods (Lowry and Frost 1981; Lønne and Gulliksen 1989) along with other crustaceans and fish tissue. In the northeastern Chukchi Sea, saffron cod (*Eleginus gracilis*) eat epibenthic and benthic prey (Coyle et al. 1997). Arctic staghorn sculpin (*Gymnocanthus tricuspis*) eat benthic polychaetes and molluscs (Coyle et al. 1997). In the Canadian Arctic, Arctic staghorn sculpin consume mostly amphipods, along with other crustaceans, polychaetes, and molluscs (Atkinson and Pearcy 1992). Arctic alligatorfish (*Ulcina olrikii*) and slender eelblenny (*Lumpenus fabricii*) have a highly diverse diet of benthic polychaetes, amphipods, and molluscs, while ribbed sculpin

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[1] University of Alaska Fairbanks, Fairbanks, Alaska

(*Triglops pingelii*) feed almost exclusively on zooplankton. Polar eelpout (*Lycodes polaris*) prey mainly upon molluscs, but have regional differences in consumption of copepods, amphipods, polychaetes, and fish tissue. Flatfishes in the eastern Bering Sea eat benthic crustaceans, molluscs, and polychaetes (Zhang et al. 1998), and additionally consume brittle stars in the Chukchi Sea (Jewett and Feder 1980). Bering flounder (*Hippoglossoides robustus*) diets from the Chukchi Sea consist mainly of crustaceans and fish (Coyle et al. 1997).

Stable isotopes are complementary to stomach analyses. Whereas stomach contents portray dietary information for a snapshot in time, stable isotopes provide information over an integrated time period by reflecting assimilated food. Stable isotopes in muscle tissue describe integrated diet for 5–8 months in summer flounder (*Paralichthys dentatus*; Buchheister and Latour 2010). Stable nitrogen and carbon isotope ratios have been used to identify likely dietary sources for Arctic species (Hobson and Welch 1992; Dehn et al. 2006). Stable nitrogen isotope ratios are indicative of the trophic level at which an individual feeds. As an organism consumes nutrients, it preferentially uses the lighter nitrogen isotope (^{14}N) for metabolic processes and integrates the heavier isotope (^{15}N) into tissues, leading to a stepwise enrichment of ^{15}N in the food web (e.g., Kelly 2000). Carbon-13 typically provides information on carbon source and benthic versus pelagic foraging (Dehn et al. 2007; Horstmann-Dehn et al. 2011). Benthic algae become enriched in the heavier carbon isotope (^{13}C) because they have minimal replenishment of the lighter isotope (^{12}C) through the benthic boundary layer, while planktonic algae are likely to experience increased water turbulence and be depleted in ^{13}C (France 1995). Predators feeding on benthic organisms will be enriched in ^{13}C relative to predators feeding on pelagic organisms.

The Chukchi Sea Environmental Studies Program (CSESP) sponsored by ConocoPhillips Alaska, Inc., Shell Exploration & Production Company, and Statoil USA E & P, Inc. provided a valuable and rare opportunity to assess the trophic ecology of fishes within the framework of a comprehensive environmental and ecological research program. The objective of the present study is to document the relative importance of prey taxa in the diet of demersal fishes through examination of stomach contents. Further objectives are to assess diets among and within species, and to detect differences in diet relative to fish species, length, season, and location of capture. Additionally, we analyze stable nitrogen and carbon isotope ratios of fish muscle and prey to describe trophic structure for the same parameters used in the diet analysis.

5.2 METHODS

5.2.1 Fish collections

Fishes used in this study were collected offshore in the northeastern Chukchi Sea during CSESP and COMIDA cruises in 2009 and 2010. Two collections were during July/August 2009 (cruises COMIDA 2009 and WWW0902), one was during September/October 2009

(WWW0904), and one was during September 2010 (WWW1003; Figure 5.1). Three separate areas were selected as the CSESP areas of interest for intensive research, including Klondike, Burger, and Statoil study areas. Some COMIDA 2009 stations were outside of the study area boundaries; fishes collected at those stations were assigned to a study area based on longitude. Fish collected on the COMIDA 2009 cruise west of 164° W were analyzed with Klondike fish, and fish collected on the COMIDA 2009 cruise east of 164° W were considered with Burger fish. Fishes were collected using a combination of bottom and midwater trawls. Five species were selected for diet analysis based on their prevalence on the sampling grounds and because they are representative of major taxonomic families present in the Chukchi Sea. The selected species were Arctic cod (family Gadidae, cods), Arctic staghorn sculpin (family Cottidae, sculpins), polar eelpout (family Zoarcidae, eelpouts), stout eelblenny (*Anisarchus medius*; family Stichaeidae, pricklebacks), and Bering flounder (family Pleuronectidae, flatfishes).

5.2.2 Laboratory procedures

Fishes were frozen at sea and transported to the University of Alaska (UAF) Fisheries Oceanography Laboratory in Fairbanks, Alaska. In the laboratory, each fish was thawed and total length was measured to the nearest millimeter. Where available, stomach contents were examined from at least 30 fish and muscle tissue was examined by stable isotope analyses from five individuals of each species, season (July/August 2009, September/October 2009, and September 2010), area (Klondike, Burger, and Statoil; Figure 5.1), and length class (0–50 mm, 51–75 mm, 76–100 mm, and ≥101 mm). Although the field sampling design was geographically balanced (Figure 5.1), fish populations were less so; thus there were many combinations of species, season, area, and length class with insufficient quantities of fishes to achieve these goals.

Stomachs were excised from the whole fish, covered in water, and frozen until processing. When thawed, stomachs were blotted on lens paper and wet weight of the stomach was measured to the nearest 0.0001 g on an Orion series HR200 precision balance. Prey were removed from the stomach and the empty weight and approximate percent fullness of the stomach were recorded (0–100%). Prey items from each stomach were sorted into class- or family-level taxonomic groupings. Each whole prey item, determined by the presence of a head, was counted. All prey of the same taxonomic group were blotted on lens paper and weighed to the nearest 0.0001 g. Fragments of organisms were included in this weight when it was possible to definitively identify to a taxonomic group. The presence of prey fragments was assigned a count of one only where no whole animals were observed. This process was repeated for each taxonomic group of prey in every stomach. Prey were grouped into broad taxonomic groupings for analysis (Table 5.1) Prey taxa taken from the thawed stomachs were retained frozen for stable isotope analysis. Voucher specimens of prey taxa in good condition were archived in 50% isopropyl alcohol.

A total of 476 fishes and 444 fish prey items were prepared for stable nitrogen and carbon isotope analysis. Two 10 mg subsamples of muscle tissue were taken from the dorsal region of each fish, stored in vials and frozen at -20 C. Individual prey items collected from the stomachs of multiple fish collected in the same season and area, regardless of fish species, were pooled together to increase prey sample mass (>0.2 mg after being freeze dried). Each sample was stored in a vial that was labeled by season and area, and frozen at -20 C. Samples were freeze dried for approximately 24 hrs using a VirTis BTKES freeze dryer.

Fish muscle samples were processed to assess non-lipid-extracted $^{15}N/^{14}N$ ratios and lipid-extracted $^{13}C/^{12}C$ ratios. Extracting lipids from samples removes the carbon signature of lipids, leaving only the carbon signature of the tissue, but can confound the nitrogen signature (Pinnegar and Polunin 1999; Sweeting et al. 2006). Therefore, the nitrogen signatures used in our analysis were determined from non-lipid-extracted samples while carbon signatures were taken from lipid-extracted samples. One muscle sample from each fish was lipid extracted using the methods of Bligh and Dyer (1959) as modified by Logan et al. (2008). Dried samples were immersed in a 2:1 chloroform:methanol mixture with a solvent volume about three times the sample volume. Samples soaked for approximately eight hours, the solvent containing lipids was removed, and fresh solvent was added. This process was repeated three times. Lipid-extracted samples were freeze dried for an additional 24 hrs. Non-lipid-extracted and lipid-extracted muscle samples were homogenized prior to stable nitrogen and carbon isotope analysis.

Fish prey samples were processed to assess non-treated $^{15}N/^{14}N$ ratios and acid fumed/lipid-extracted $^{13}C/^{12}C$ ratios. Exoskeleton carbonates of invertebrates can lead to biased stable carbon isotope results (Søreide et al. 2006). Therefore, fish prey were treated to remove carbonates and lipids. Prey tissues were fumed at saturated HCl vapors for four hours in a vacuum chamber. Samples were then soaked in 2:1 chloroform:methanol mixture for approximately four hours, the solvent was removed, and fresh chemicals were added. This process was repeated three times and the samples were freeze dried for an additional 24 hrs before analyzing stable nitrogen and carbon isotopes.

5.2.3 Diet analysis

A total of 999 stomachs was examined across five species of fish, three seasons, three areas, and four length classes (Table 5.2). Empty stomachs were recorded (N=69 empty stomachs; Table 5.2) but were not considered further. To analyze diets of fishes, frequency of occurrence (FO) and index of relative importance (IRI) were calculated for prey taxa in each stomach and averaged over category (species, season, area, and length class). When a prey taxon occurred in less than five stomachs that prey taxon was excluded from FO and IRI analyses, which further reduced the diet analysis sample size by seven stomachs. This resulted in a total sample size of 923 stomachs across all categories.

FO considers a single element of fish dietary importance, presence of a prey taxon, and is calculated for each prey taxon in a stomach:

%FO= 1 / N,

where N is the number of prey taxa present.

In contrast to %FO, the IRI considers three measures of fish prey dietary importance (occurrence, numerical abundance, and weight) and takes into account the effect of more than one dimension of prey. The IRI is a useful tool for having a balanced analysis of diet contents, as %N is biased toward prey that are numerous but small (i.e., copepods) while %W is biased toward prey that are relatively rare but large (i.e., fish tissue; Hyslop 1980; Liao et al. 2001). IRI was calculated for each prey taxon:

IRI = (%N+%W) / %FO,

where %N is the percentage by count of a certain prey taxon, %W is the percentage of the weight of the prey taxon, and %FO is the frequency of occurrence as described above (Pinkas et al. 1971).

Pie charts indicating the %FO and %IRI of prey taxa within categories of predator species, season and area were created using Microsoft® Excel (2010).

5.2.4 Diet relationships among and within species

To better understand whether one or more of the factors of species, length class, area and season affected predator diet, %FO and %IRI were examined in relation to each of these factors and each combination of factors. The same statistical analyses were performed separately on %FO and %IRI data using the statistical package PRIMER +PERMANOVA (Anderson et al. 2008). Statistical tests are explained by Blanchard (in prep) and briefly detailed here. Mean values of %FO and %IRI were calculated separately over the target group of predators, i.e., each of 5 fish species x 4 length categories (≤50 mm, 51–75 mm, 76–100 mm, ≥101 mm) x 2.5 areas (Klondike, Burger in 2009; these plus Statoil in 2010) x 3 seasons (July/August 2009, September/October 2009, September 2010), for a maximum of 30 groups for each predator species. Data were transformed to 4th root to reduce the influence of large values, and a Bray-Curtis similarity index was calculated. A four-factor PERMANOVA test was designed using predator species, length class, area and season. Sum of squares was set to Type III (partial) and the permutation of residuals was performed under a reduced model. Each factorial that indicated a significant difference ($p<0.05$) was analyzed via a pairwise test.

Non-metric multidimensional scaling plots (MDS; Kruskal 1964) were used to display patterns among sample groups. MDS ordination plots have no 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 <0.2 is considered to be a good fit. MDS ordination of fish species by area was used to examine the relationship with physical variables if a significant cluster was found (MDS, PRIMER v. 6).

Indices quantifying the diversity and evenness of diet of each predator sample were calculated using the DIVERSE function in PRIMER (Clarke and Gorley 2006). When sampling effort and methodology are carefully controlled, as in this study, the Shannon index is the appropriate measure of diversity (Leonard et al. 2006). Shannon's diversity index measures the diversity of diet within a sample of predators:

$$H' = -\Sigma_i \, p_i \log_2(p_i),$$

where p_i is the proportion of the total prey belonging to the ith species. Log_2 was used, following methods described by Coyle et al. (1997).

Pielou's evenness index measures how evenly the prey species are distributed among the predator samples:

$$J' = H' / \log S,$$

where S is the total number of prey taxa in sample.

Diversity and evenness of diet were examined for each predator species two ways: as a whole without regard for length, area and season, and for length categories within each species. Separate average values were calculated over the %FO and IRI of each predator category (i.e., species x season x area x length class), which weighted each predator category equally.

5.2.5 Stable isotope analysis

Fishes (Table 5.3) and fish prey (Table 5.4) were analyzed for stable nitrogen and carbon isotope ratios at the Alaska Stable Isotope Facility at UAF. A 0.2–0.4 mg subsample of ground fish muscle or prey was weighed in tin crucibles using a micro-balance (Sartorius Model MP2). Stable nitrogen and carbon isotope ratios were determined using a Finnigan MAT DeltaPlusXP Isotope Ratio Mass Spectrometer (IRMS) directly coupled to a Costech Elemental Analyzer (ESC 4010). The $^{15}N/^{14}N$ and $^{13}C/^{12}C$ compositions were expressed in conventional delta (δ) notation, relative to the levels of ^{15}N in atmospheric nitrogen and ^{13}C in Vienna Pee Dee Belemnite. Peptone was used as a laboratory-working standard. The precision of analysis for both $\delta^{15}N$ and $\delta^{13}C$ was ± 0.2‰. More positive values of both $\delta^{15}N$ and $\delta^{13}C$ ratios are referred to as enriched.

Effect of species, length class, season or area on trophic level and carbon source were tested using $\delta^{15}N$ and $\delta^{13}C$ values for fish muscle and fish prey. Tests of Shapiro-Wilk Normality and Equal Variance were run to determine the appropriate statistical examination. For fish muscle, a one way ANOVA (F) was used if assumptions for normality and equal variance were met; if neither assumption was met, a Kruskal-Wallis (H) one way analysis of variance on ranks was used. When a significant difference was found among groups, within group differences were examined using the corresponding pairwise multiple comparisons, i.e., Tukey Test (q) or Dunn's Method (Q). For fish prey, mean values of $\delta^{15}N$ and $\delta^{13}C$ values were calculated for broad taxonomic groupings, i.e., amphipod, copepod, crab, euphausiids/mysid, fish, mollusc, nematode, other crustacean, polychaete, or shrimp, by area or by season. As assumptions for normality and equal variance were not met, a Kruskal-Wallis (H) one way analysis of variance on ranks was used followed by Dunn's Method (Q). A two way ANOVA (F) general linearized model (GLM) examined fish prey groupings considering area or season followed by a Tukey Test. All statistical analyses were performed with SigmaPlot (Sigmaplot 2011). An α less than 0.05 was considered significant.

5.3 RESULTS

5.3.1 Diet and stable isotope summaries by fish species

5.3.1.1 Arctic cod

Frequency of occurrence and index of relative importance of prey for Arctic cod, averaged over each category of species, area and season (length class disregarded), both emphasized copepods. Prey of 349 Arctic cod stomachs consisted of amphipods, copepods, euphausiid/mysids, and other crustaceans for all seasons and areas (Figure 5.2). Fish tissues were also consumed in all areas and seasons except for Statoil in 2010. Shrimps were consumed in all areas and seasons except for Klondike in September/October 2009 and 2010, while polychaetes were only consumed in Klondike in September/October 2009 and 2010. Molluscs and crabs were consumed only in Klondike in 2009. Average IRI indicated that copepods were extremely important for all areas and seasons (Figure 5.3). Shrimps were somewhat important in Klondike in July/August 2009, in Burger in September/October 2009, and in Statoil in September 2010. Amphipods were important in 2009 in Klondike, whereas fishes were somewhat important in Burger in 2009.

Differences were found among length classes, area and season for stable nitrogen and carbon isotope ratios of Arctic cod muscle. For each pair of length classes (0–50 mm, 51–75 mm, 76–100 mm, and ≥101 mm), the larger length class was more enriched in ^{15}N ($p<0.001$, Table 5.5, Figure 5.4). However, there was no difference in $\delta^{15}N$ between 76–100 mm and ≥101 mm length classes. For stable carbon isotope ratios among length classes, Arctic cod ≥101 mm were more enriched in ^{13}C than those 0–50 mm ($p=0.007$, Table 5.5, Figure 5.4). Though there were no differences in nitrogen isotope ratios for Arctic cod when comparing by area, Arctic cod muscle was more enriched in ^{13}C at Klondike than in Burger (p=0.003, Table 5.6, Figure 5.5). Seasonal differences were not found for stable nitrogen isotope ratios (Table 5.7). Arctic cod collected during July/August 2009 and September 2010 were more enriched in ^{13}C than those collected during September/October 2009 (p<0.001, Table 5.7).

5.3.1.2 Arctic staghorn sculpin

The same prey were both frequently occurring and relatively important in the stomachs of 123 Arctic staghorn sculpin observed. Fish collected at Klondike in all seasons preyed upon amphipods, copepods, euphausiid/mysids, molluscs, polychaetes, shrimps, other crustaceans and other miscellaneous prey (Figure 5.6). This species also preyed upon fish at Klondike in September/October 2009 and fish and crabs in September 2010. Arctic staghorn sculpin captured at Burger in July/August 2009 contained amphipods, euphausiid/mysids, fish tissue, polychaetes, other crustaceans and miscellaneous prey. Only one Arctic staghorn sculpin was collected at Burger in September/October 2009 and it had other miscellaneous prey present in its stomach. Fish stomachs collected at Burger in 2010 contained amphipods, polychaetes, and other miscellaneous prey. There were no Arctic staghorn sculpin collected at Statoil in September 2010. Amphipods and polychaetes were important in all categories of Arctic staghorn sculpin, except for the single fish captured at Burger in September/October 2009 (Figure 5.7).

Differences were found for stable nitrogen and carbon isotope ratios among length classes of Arctic staghorn sculpin (nitrogen p<0.001, carbon p=0.001, Table 5.8), but not for area (Table 5.9) or for season (Table 5.10). Each of the larger length classes was more enriched in ^{15}N than fish 0–50 mm (Figure 5.4). There were no significant differences in stable nitrogen isotope ratios among other length class pairings. Arctic staghorn sculpin 51–75 mm and 76–100 mm were more enriched in ^{13}C than fish 0–50 mm.

5.3.1.3 Stout eelblenny

The 199 stout eelblenny stomachs examined revealed a variety of prey consumed. Stout eelblenny stomachs contained amphipods, copepods, molluscs, nematodes, polychaetes, and other crustaceans across all areas and seasons (Figure 5.8). Fish tissue was consumed by stout eelblenny collected at Klondike in July/August 2009 and September 2010 and other miscellaneous prey were found for all areas and seasons except Burger in September/October 2009. IRI averaged over area and season indicated that amphipods and copepods were important for all categories, while polychaetes, nematodes, and molluscs played an important role in some categories (Figure 5.9).

Stout eelblenny had significant differences for stable nitrogen and carbon isotope ratios among length classes (nitrogen p<0.001, carbon p=0.002, Table 5.11) and for nitrogen isotope ratios between two seasons (p=0.038, Table 5.12). The largest length classes, 76–100 and ≥101 mm, were more enriched in ^{15}N than for either the 0–50 or 51–75 mm classes, but the largest length classes were not different from each other. Stout eelblenny ≥101 mm were more enriched in ^{13}C than were fish 0–50 or 51–75 mm (Figure 5.4). No other differences for $\delta^{13}C$ were found among length classes. No significant differences were found among areas for stable nitrogen or carbon isotope values (Table 5.13). Stout eelblenny collected during September 2010 were enriched in ^{15}N compared to those collected during July/August 2009 (Figure 5.5). No other significant differences were found among seasons for stable nitrogen or carbon isotope values.

5.3.1.4 Polar eelpout

There was a marked difference in of FO and IRI patterns of prey consumed by polar eelpout. For all area and season categories, the 144 polar eelpout stomachs contained amphipods, copepods, and other crustaceans (Figure 5.10). Polar eelpout collected in 2010 also contained polychaetes and molluscs across all three areas, as well as euphausiid/mysids at Burger and shrimp at Klondike. Euphausiid/mysids occurred at Burger in September/October 2009, while molluscs were consumed by stout eelblenny from Burger in July/August 2009. Average IRI showed that amphipods were the most important component of polar eelpout diet, except in Statoil in 2010, where polychaetes and copepods were the most important food items (Figure 5.11).

Polar eelpout had significant differences in stable nitrogen isotope ratios among length classes ($p<0.001$, Table 5.14, Figure 5.4), and area ($p=0.002$, Table 5.15). The three larger length classes (51–75, 76–100 and ≥101 mm) were each more enriched in ^{15}N than 0–50 mm fish, but were not significantly different from each other (Table 5.14). No differences in $\delta^{13}C$ were found among any length classes. Polar eelpout collected in Burger and Statoil were more enriched in ^{15}N than Klondike, but were not significantly different from each other values. No differences were found for $\delta^{13}C$ when comparing by areas. Polar eelpout collected during July/August 2009 and September 2010 were more enriched in ^{15}N than those collected during September/October 2009, but were not different from each other (Table 5.16). Polar eelpout collected during July/August 2009 were more enriched in ^{13}C than those collected during September/October 2009 (Figure 5.6). No other significant differences were found among seasons.

5.3.1.5 Bering flounder

The distribution of Bering flounder did not extend across all sample areas. Stomachs from 107 Bering flounder were analyzed from all three areas in 2010 and from Klondike only in 2009 (Figure 5.12). However, only one fish from Burger and one from Statoil was available in 2010. In 2010 at Burger, the fish consumed only euphausiid/mysids, and at Statoil, the single fish consumed amphipods, copepods, and euphausiid/mysids. From the Klondike area, Bering flounder consumed amphipods, copepods, euphausiid/mysids, polychaetes, and other crustaceans in all three seasons. They also consumed fish, molluscs, and other miscellaneous prey in 2009.

Amphipods and euphausiid/mysids appeared to be the most important food items overall for Bering flounder, based on IRI (Figure 5.13).

Many differences were found for stable nitrogen and carbon isotope ratios among length classes of Bering flounder (nitrogen p<0.001, carbon p<0.001, Table 5.17), but none were found for season (Table 5.18). The three largest length classes were each more enriched in ^{15}N than the smallest length class (Figure 5.4). Additionally, Bering flounder ≥101 mm were more enriched in ^{15}N than either the 51–75 mm or the 76–100 mm length classes. No differences were found for $\delta^{15}N$ between the two middle length classes. The ≥101 mm length class and the 51–75 mm length class were each more enriched in ^{13}C than the 0–50 mm length class (Figure 5.4). No other significant differences were found among length classes. Bering flounder were only examined from Klondike, so we were not able to compare among areas.

5.3.2 Contrasts among and within species

Non-metric multidimensional scaling (MDS) plots displayed patterns among predator categories, i.e., combinations of species, length class, area and season. The stress values of <0.2 indicated that the 2-dimensional MDS plots were a good fit for relationships among samples. Species tended to group together for both FO and IRI when plotted on a multi-dimensional scale using all predator categories. Although MDS plots did not signify statistical significance, they were an indicator that the combination of these factors resulted in similar FOs and IRIs within a species (Figures 5.14 and 5.15).

5.3.2.1 Frequency of occurrence

There were significant differences in prey occurrence in stomachs between Arctic cod and polar eelpout and between stout eelblenny and polar eelpout (p=0.014). There was relatively low similarity for frequency of occurrence of diet items among all species (<30% similarity, Table 5.19). In addition, there was low similarity within and among areas (Table 5.20). Arctic cod consumed primarily copepods while amphipods, and euphausiid/mysids, shrimp, other crustaceans and fish occurred with less frequency. Stout eelblenny fed on a diverse, but even, diet consisting of all prey categories except for crabs and shrimp. Polar eelpout prey occurrence was mostly amphipods, with copepods, polychaetes, and fish tissue occasionally consumed. Frequency of prey occurrence in Arctic cod differed between the 51–75 mm and ≥101 mm length classes (p=0.039). Percent similarity between the two smaller length classes was higher than percent similarity between all other pairs of length classes (Table 5.21). Stout eelblenny were found to have some differences in FO among season (p=0.012), area (p=0.006), and length class (p=0.007), as well as when area and length class were combined (p=0.016). Percent similarities for frequency of occurrence of diet items for stout eelblenny among areas, seasons and length classes were high, except when comparing the smallest length class to the larger length classes (Tables 5.22–5.24). The low percent similarity of the smallest length class when compared to other length classes was true for all areas (Tables 5.25–5.27). Differences in FO of prey were found for polar eelpout between Klondike and Burger areas (p=0.020), although percent similarity was greater between Burger and Statoil than between either Burger and Klondike or Klondike and Statoil (Table 5.28).

5.3.2.2 Index of relative importance

As with frequency of occurrence, differences were found among areas (p=0.022) and between Arctic cod and polar eelpout (p=0.011) and stout eelblenny and polar eelpout (p=0.016). Percent similarity of IRI was generally low between species (<35% similarity, Table 5.29) with the exception of Arctic staghorn sculpin and polar eelpout, which had 48% similarity, and was low among and within areas (Table 5.30). The most important prey taxon for Arctic cod was copepods, followed distantly by amphipods, fish, and shrimp. In contrast, the most important prey taxon for polar eelpout was amphipods. Fish, shrimp and copepods were also important in polar eelpout diets, although the percentage of index of relative importance for these prey taxa were much smaller than for amphipods. Stout eelblenny had a larger number of prey items that were important and had less disparity between the most important (by percent IRI) prey item, copepods, and additional important prey items, such as amphipods, other crustaceans, polychaetes, and shrimp. The importance of particular prey taxa differed between Arctic cod of 51–75 mm and ≥101 mm length classes (p=0.045). Percent similarity between the two smallest length classes was higher than among the other length classes (Table 5.31). Significant differences were found in stout eelblenny prey IRI collected in July/August 2009 compared to September 2010 (p=0.043). Additionally, differences were found in stout eelblenny prey between area (p=0.013), length class (p=0.009) and area and length class together (p=0.020). Percent similarity for stout eelblenny was high among seasons, areas, and the two largest length classes (Tables 5.32–5.34). Within areas, percent similarity of IRI for stout eelblenny varied greatly, but increased as the length class increased (Tables 5.35–5.37). Differences in percent IRI of prey were found for polar eelpout between Klondike and Burger areas (p=0.018), although there was less percent similarity between the other areas (Table 5.38).

5.3.2.3 Stable isotopes

There were significant differences among species for $\delta^{15}N$ and $\delta^{13}C$ values (nitrogen p<0.001, carbon p<0.001, Table 5.39). The mean values of $\delta^{15}N$ in increasing order for the five species were: Arctic cod < Bering flounder < Arctic staghorn sculpin < stout eelblenny < polar eelpout (Figure 5.16). Only three of the 10 pairings of species were not significantly different: polar eelpout and stout eelblenny, Bering flounder and Arctic cod, and Bering flounder and Arctic staghorn sculpin. The mean values of $\delta^{13}C$ were in the same increasing order for the five species as the ^{15}N values: Arctic cod < Bering flounder < Arctic staghorn sculpin < stout eelblenny < polar eelpout (Figure 5.16). All species pairings were significantly different for $\delta^{13}C$ values except for polar eelpout and stout eelblenny, and Bering flounder and Arctic staghorn sculpin.

5.3.3 Diversity and evenness

Patterns in diet diversity and evenness indices were found among predator species. Taken as a whole without consideration of subcategories, stout eelblenny and Bering flounder had the highest indices of diet diversity and evenness (Table 5.40). Arctic cod, Arctic staghorn sculpin and polar eelpout had comparatively lower indices of diversity and evenness. When length categories were considered within a species, the patterns were not as uniform. Diversity and evenness indices increased for both %FO and IRI with increased length of Arctic cod. This pattern of both indices increasing with increasing fish length was not seen in any other species. Percent FO diversity increased with increasing length of stout eelblenny, and %FO evenness increased with increasing length of Arctic staghorn sculpin and Bering flounder.

A total of 923 stomachs was examined of four length categories in each of five fish species, though numbers were not evenly distributed across categories (Table 5.2). The limiting factor was the number of fish collected of each species in each length class and in Burger and Statoil study areas. For Arctic staghorn sculpin and Bering flounder $\geq$101 mm and stout eelblenny 0–50 mm, fewer than five individuals were available for analysis of stomach contents. When so few individuals were examined, the number of prey in those species-length classes was <5. The low numbers translated to indices of diversity and evenness that did not follow the patterns described in the preceding paragraph. However when more than 100 individuals were examined of Arctic cod 51–75 mm and stout eelblenny $\geq$101 mm, there was not a corresponding increase in the number of prey taxa and the trend of increasing index values with fish length was clearly seen.

5.3.4 Stable isotope analysis of fish prey

There were few significant differences in $\delta^{15}N$ and $\delta^{13}C$ between pairs of prey groups (nitrogen $p<0.001$, carbon $p<0.001$, Table 5.41). The mean values of ^{15}N in decreasing order for the 10 prey groups were: nematodes > polychaetes > fish > shrimp > molluscs > euphausiids > amphipods > copepods > other crustaceans > crabs (Figure 5.16). Nematodes were more enriched in ^{15}N than every group except polychaetes and fish. Polychaetes were more enriched in ^{15}N than amphipods, copepods, other crustaceans and crabs. Allowing for the effects of cruise in GLM, the same pairings were significantly different and even more pairings were different ($F = 20.664$, $p<0.001$). Fish differed from the same four groups as polychaetes. Allowing for the effect of season in GLM, there was one less significant difference than in a one way ANOVA (F

= 19.188, p<0.001); there was no difference between nematodes and molluscs. The decreasing order of the median values was not the same for $\delta^{13}C$ as for $\delta^{15}N$, but rather it was: other crustaceans > molluscs > nematodes > polychaetes > shrimp > amphipods > fish > copepods > euphausiids (Figure 5.16). There were also fewer significant differences between pairings of prey groups. Other crustaceans were more enriched in ^{13}C than amphipods, fish, copepods and euphausiids.

5.4 DISCUSSION

The most striking results are seen when comparing diets and stable isotope findings between species. Diet findings were similar to previous studies in the Alaskan (Lowry and Frost 1981; Lønne and Gulliksen 1989; Coyle et al. 1997) and Canadian Arctic (Atkinson and Pearcy 1992) and the stable isotope results are similar to previously published values (France 1995; Schell et al. 1998; Iken et al. 2010; Feder et al. 2011). Stable isotopes describe integrated diet thus a mixture of possible prey items should be considered. Comparing stomach contents to stable isotope results allows for fine tuning species trophic resolution and adds further insight when assessing integration of prey (Dehn et al. 2007; Horstmann-Dehn et al. 2011). We observed a clear trophic hierarchy within the five fish species examined using nitrogen and carbon isotopic signatures of fish tissue and associated diet items.

Arctic cod and Bering flounder have similar trophic level and feeding habitat classifications. Of all species examined, Arctic cod are the least enriched in nitrogen, meaning that they feed on lower trophic levels, and in carbon, meaning that they rely on pelagic prey (Schell et al. 1998; Dehn et al. 2007; Iken et al. 2010; Feder et al. 2011). Copepods are an integral part of Arctic cod diet (Lowry and Frost 1981; Lønne and Gulliksen 1989; Atkinson and Pearcy 1992; Coyle et al. 1997), and have a pelagic carbon signature and a low-trophic level nitrogen signature (Schell et al. 1998; Dehn et al. 2007). Bering flounder have the next highest level of enrichment for both nitrogen and carbon isotopes. The Bering flounder diet in this study consists mainly of amphipods and euphausiids. Amphipods and euphausiids, which can be found throughout the water column, have slightly higher carbon nitrogen signature than copepods, but are still lower than other prey items found in other species (Schell et al. 1998). These differences between diets of Arctic cod (copepods) and Bering flounder (amphipods/euphausiids) lead to Arctic cod being classified as less enriched and lower trophically than Bering flounder.

In terms of enrichment in nitrogen and carbon, Arctic staghorn sculpin were the next highest after Bering flounder. Bering flounder and Arctic staghorn sculpin have similar isotopic signatures, as do amphipods and euphausiids. The observed diet of Arctic staghorn sculpin is similar to previous studies (Lowry and Frost 1981; Lønne and Gulliksen 1989; Atkinson and Pearcy 1992; Coyle et al. 1997) and is similar to the diet observed in Bering flounder, except that amphipods are more important to Arctic staghorn sculpin than to Bering flounder. Amphipods are slightly more enriched in carbon than euphausiids, indicating a more benthic habitat (Schell et al. 1998; Dehn et al. 2007). The difference in importance of amphipods in the diet allows Arctic staghorn sculpin to be classified higher trophically and more benthically than Bering flounder.

In contrast, stout eelblenny and polar eelpout were both classified at high trophic levels and as benthic feeders. Stout eelblenny are classified higher trophically than the three previous species, based on nitrogen signatures of the fish tissue. This species also has more enriched carbon signatures than the three previous species, indicating that they feed more benthically than pelagically (Schell et al. 1998; Dehn et al. 2007). Although the diet of stout eelblenny includes copepods and amphipods, they also have a highly diverse diet, which is similar to previous studies of slender eelblenny, a closely related species (Atkinson and Pearcy 1992). It is the other prey items, i.e., fish, nematodes, polychaetes, molluscs, and shrimp, consumed that give stout eelblenny a high-trophic and benthic-feeding classification, because these items are integrated in a way that is reflected in the isotopic signatures of the fish tissue. A similar relationship is observed between the diet items and the tissue of polar eelpout, which are ranked as the highest trophic level and the most benthically feeding species examined by this research. Polar eelpout diet consists of amphipods, shrimp, fish, molluscs, and polychaetes (Atkinson and Pearcy 1992; Coyle et al. 1997). The cumulative diet results in enriched nitrogen and carbon signatures (Schell et al. 1998; Dehn et al. 2007), indicating that polar eelpout prey upon benthic prey that are high in the trophic scheme.

As fish length increases, the stable isotope signatures of nitrogen become more enriched, indicating predation at higher trophic levels. Larger fish can eat larger prey such as other fish, shrimp, molluscs, and polychaetes (Gibson and Ezzi 1987). In addition to feeding at higher trophic levels, larger fish transition to consuming more benthic prey, such as crabs, molluscs, nematodes, other crustaceans, shrimp, and polychaetes (France 1995; Schell et al. 1998; Dehn et al. 2007).

There are very few differences between area and season. Fish tissue collected from Klondike Arctic cod is enriched in carbon compared to Burger, indicating that cod are preying on more benthic sources. Differences in diets are seen in high-trophic/benthic-feeding species, such as stout eelblenny and polar eelpout, among areas and only in stout eelblenny among seasons. However, a corresponding difference in stable isotope signatures was not seen in stout eelblenny and polar eelpout among areas. Additionally, seasons do not display a similar pattern of enrichment for these two benthic foragers. Although differences were found in both isotopes and diets among species, there were no relationships linking these results; thus, we cannot explain them.

The present study found differences between diets of the fish species and the associated trophic level of the fish species. Despite examining 999 stomachs, the sample sizes within a category were sometimes small due to the number of factors considered (species by length class by area by season), which could result in a sample size as small as N=1. Increasing the sample size to a minimum of 30 fish in each 4-factor category in future studies is recommended. Because this is the only study that examined diet and trophic level of these key species in the Chukchi Sea, the results are important in describing the trophic structure of this ecologically and economically significant area.

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Table 5.1. Groupings of fish prey taxa used in this diet analysis.

Group	Taxa
Amphipod	
	Ampeliscidae
	cf. *Monoculodes crassirostris*
	Gammarid amphipod
	Hyperiidea
	Melita spp.
	Monoculodes spp.
	Themisto libellula
Copepod	
	Calanoid copepod
	Copepod
	Cyclopoid
	Harpacticoid copepod
	Pseudocalanus spp.
Crab	
	Hermit crab zoea
	Crab
	Crab megalops
	Crab zoea
Euphausiid/Mysid	
	cf. *Neomysis* sp.
	Euphausiid
	Mysid
	Thysanoessa raschii
Fish	
	Boreogadus saida
	Fish, whole
	Fish scales
	Fish tissue
	Otoliths
Mollusc	
	Bivalve
	Bivalve siphons
	Bivalve veliger
	Gastropod
	Nuculana spp.
	Pteropod
	Limacina helicina
Nematode	
	Nematode
Other	
	Brittle star
	cf. Larvacean
	Foraminifera
	Harpacticoid copepod
	Holothuroidea
	Invertebrate eggs, misc.
	Plant tissue
	Pteropod
	Sponge
	Squid
	Unid. Tissue
Other Crustacean	
	Barnacle
	Barnacle (cyprid)
	Unid. Crustacean
	Cumacean
	Isopod
	Leucon spp.
	Ostracod
	Tanaid
Polychaete	
	Maldanidae
	Polychaete worm
	Scaleworm
Shrimp	
	Caridean shrimp
	Crangonid shrimp
	Hippolytid shrimp
	Pandalid shrimp

Table 5.2. Summary of stomachs analyzed in each category of predator length class, season and area. Numbers in parenthesis indicate the number of empty stomachs for that category, followed by the number of stomachs removed from that category because they contained only rare prey.

	July/August 2009		September/October 2009		September 2010		
	Burger	**Klondike**	**Burger**	**Klondike**	**Burger**	**Klondike**	**Statoil**
Arctic cod							
0–50 mm	-	15	7 (3)	7 (1)	16 (1)	36 (1)	19 (1)
51–75 mm	6	1	3 (1,1)	8 (1)	33	28	37 (1)
76–100 mm	7 (1)	27 (1)	2	1 (1)	24	33 (5)	14 (1)
≥101 mm	3 (1)	16	3	17	3	-	2
Arctic staghorn sculpin							
0–50 mm	2	2	-	8 (2)	-	30 (2)	-
51–75 mm	11	21 (1)	-	4	3	9 (1)	-
76–100 mm	1	7	1	8	-	3	-
≥101 mm	2	1	-	17 (2)	-	1	-
Stout eelblenny							
0–50 mm	1	2	-	-	-	5	-
51–75 mm	5	4	-	-	-	15 (1)	1
76–100 mm	11 (1)	12	7	13 (2)	12 (2)	4	5
≥101 mm	4	17	2	23 (1)	19	31	13
Polar eelpout							
0–50 mm	2 (1)	3 (1)	13 (10)	7 (5)	1	3 (0,1)	15
51–75 mm	14	6	12 (2)	-	5 (0,2)	8 (1)	3
76–100 mm	11 (1)	3 (2)	5	4	7	8 (4)	2
≥101 mm	7	7	5	2	6 (1)	16 (0,2)	1 (0,1)
Bering flounder							
0–50 mm	-	24	-	-	-	10	1
51–75 mm	-	32 (1)	-	9 (1)	-	7 (1)	-
76–100 mm	-	11	-	5	1	6	-
≥101 mm	1 (1)	3 (1)	-	-	-	2 (1)	-

Table 5.3. Summary of fish tissue analyzed in each category of predator species, length class, season, and area for stable isotope analysis (nitrogen, carbon).

	July/August 2009		**September/October 2009**		**September 2010**		
	Burger	**Klondike**	**Burger**	**Klondike**	**Burger**	**Klondike**	**Statoil**
Arctic cod							
0–50 mm	-, -	9, 9	7, 7	7, 7	5, 5	10, 10	5, 5
51–75 mm	5, 4	4, 4	8, 8	9, 10	5, 5	7, 7	4, 4
76–100 mm	6, 6	5, 5	5, 5	5, 3	5, 5	4, 4	5, 5
≥101 mm	6, 6	6, 6	3, 3	7, 5	3, 3	5, 5	2, 2
Arctic staghorn sculpin							
0–50 mm	1, 1	8, 8	-, -	7, 7	-, -	4, 4	-, -
51–75 mm	3, 5	5, 5	-, -	5, 5	2, 2	4, 4	-, -
76–100 mm	1, 1	5, 5	1, 1	5, 5	-, -	3, 3	-, -
≥101 mm	1, 2	-, -	-, -	1, 1	-, -	1, 1	-, -
Stout eelblenny							
0–50 mm	3, 3	1, 1	2, 2	-, -	-, -	1, 1	-, -
51–75 mm	5, 4	5, 4	2, 1	-, -	2, 2	5, 5	2, 2
76–100 mm	6, 6	5, 5	8, 8	5, 5	5, 5	5, 5	5, 5
≥101 mm	4, 4	6, 6	8, 8	5, 5	5, 5	5, 5	5, 5
Polar eelpout							
0–50 mm	1, -	1, 1	4, 5	4, 5	1, 1	5, 5	5, 5
51–75 mm	5, 5	5, 5	5, 5	-, -	4, 4	5, 5	5, 5
76–100 mm	5, 5	3, 3	5, 5	5, 5	5, 5	5, 5	2, 2
≥101 mm	4, 4	5, 5	6, 6	2, 2	5, 5	7, 7	1, 1
Bering flounder							
0–50 mm	-, -	5, 5	-, -	5, 4	-, -	6, 6	1, 1
51–75 mm	-, -	5, 5	-, -	5, 5	-, -	5, 5	-, -
76–100 mm	-, -	2, 2	-, -	5, 1	-, -	2, 2	-, -
≥101 mm	1, 1	1, 1	-, -	-, -	-, -	1, 1	-, -

Table 5.4. Summary of prey taxa analyzed in each season and area for stable isotope analysis (nitrogen, carbon).

	July/August 2009		**September/October 2009**		**September 2010**		
	Burger	**Klondike**	**Burger**	**Klondike**	**Burger**	**Klondike**	**Statoil**
Amphipod	24, 15	44, 39	12, 8	32, 21	7, 6	23, 18	8, 3
Copepod	6, 3	12, 11	1, -	8, 1	3, 2	18, 8	16, 14
Crab	-, -	6, -	-, -	-, -	-, -	-, -	-, -
Euphausiid/Mysid	2, 1	19, 14	2, 1	8, 3	3, 2	8, 5	7, 5
Fish	1, -	3, 2	4, 3	7, 7	-, -	1, -	-, -
Mollusc	2, 2	-, -	1, 1	-, -	-, -	2, 1	2, -
Nematode	2, -	3, 1	-, -	3, -	2, 1	5, 1	1, 1
Other Crustacean	10, 2	26, 13	1, 1	14, 1	2, 2	17, 6	2, 1
Polychaete	7, 5	12, 6	6, 4	10, 6	1, -	6, 4	3, 1
Shrimp	-, -	5, 2	2, 2	3, 3	-, -	2, 2	1, 1

Table 5.5. Stable isotope differences between length classes of Arctic cod. Upper half of the table is nitrogen, lower half is carbon. Symbol for statistic indicates test that was performed ("F"= ANOVA, "H"=Kruskal-Wallis, "Q"=Dunn's Method, "q"= Tukey Test).

Nitrogen, $H=94.516$, $p<0.001$, Q

	0–50 mm	**51–75 mm**	**76–100 mm**	**≥101 mm**
0–50 mm		3.65	7.92	8.25
51–75 mm			4.41	4.83
76–100 mm				0.50
≥101 mm	4.52			

Carbon, $F=4.233$, $p=0.007$, q

Table 5.6. Stable isotope differences between areas for Arctic cod. Upper half of the table is nitrogen, lower half is carbon. Symbol for statistic indicates test that was performed ("F"= ANOVA, "H"=Kruskal-Wallis, "Q"=Dunn's Method, "q"= Tukey Test).

Nitrogen, $H=2.753$, $p=0.252$

	Klondike	**Burger**	**Statoil**
Klondike			
Burger	4.85		
Statoil			

Carbon, $F=5.955$, $p=0.003$, q

Table 5.7. Stable isotope differences between seasons for Arctic cod. Upper half of the table is nitrogen, lower half is carbon. Symbol for statistic indicates test that was performed ("F"= ANOVA, "H"=Kruskal-Wallis, "Q"=Dunn's Method, "q"= Tukey Test).

	Nitrogen, H=1.172, p=0.556, Q		
	July/August 2009	**September/October 2009**	**September 2010**
July/August 2009			
September/October 2009	3.72		
September 2010		3.99	
	Carbon, H=19.841, p<0.001, Q		

Table 5.8. Stable isotope differences between length classes of Arctic staghorn sculpin. Upper half of the table is nitrogen, lower half is carbon. Symbol for statistic indicates test that was performed ("F"= ANOVA, "H"=Kruskal-Wallis, "Q"=Dunn's Method, "q"= Tukey Test).

	Nitrogen, H=26.442, p<0.001, Q			
	0–50 mm	**51–75 mm**	**76–100 mm**	**≥101 mm**
0–50 mm		2.86	4.46	3.50
51–75 mm	4.40			
76–100 mm	4.37			
≥101 mm				
	Carbon, H=26.564, p=0.001, q			

Table 5.9. Stable isotope differences between areas for Arctic staghorn sculpin. Upper half of the table is nitrogen, lower half is carbon. Symbol for statistic indicates test that was performed ("F"= ANOVA, "H"=Kruskal-Wallis, "Q"=Dunn's Method, "q"= Tukey Test).

	Nitrogen, H=2.766, p=0.096		
	Klondike	**Burger**	**Statoil**
Klondike			
Burger			
Statoil			
	Carbon, H=1.071, p=0.301		

Table 5.10. Stable isotope differences between seasons for Arctic staghorn sculpin. Upper half of the table is nitrogen, lower half is carbon. Symbol for statistic indicates test that was performed ("F"= ANOVA, "H"=Kruskal-Wallis, "Q"=Dunn's Method, "q"= Tukey Test).

	Nitrogen, H=0.111, p=0.946		
	July/August 2009	**September/October 2009**	**September 2010**
July/August 2009			
September/October 2009			
September 2010			
	Carbon, H=0.831, p=0.660		

Table 5.11. Stable isotope differences between length classes of stout eelblenny. Upper half of the table is nitrogen, lower half is carbon. Symbol for statistic indicates test that was performed ("F"= ANOVA, "H"=Kruskal-Wallis, "Q"=Dunn's Method, "q"= Tukey Test).

	Nitrogen, H=40.886, p<0.001, Q			
	0–50 mm	**51–75 mm**	**76–100 mm**	**≥101 mm**
0–50 mm			4.72	4.44
51–75 mm			4.60	4.16
76–100 mm				
≥101 mm	2.97	2.91		
	Carbon, H=14.742, p=0.002, q			

Table 5.12. Stable isotope differences between seasons for stout eelblenny. Upper half of the table is nitrogen, lower half is carbon. Symbol for statistic indicates test that was performed ("F"= ANOVA, "H"=Kruskal-Wallis, "Q"=Dunn's Method, "q"= Tukey Test).

	Nitrogen, H=15.176, p<0.001		
	July/August 2009	**September/October 2009**	**September 2010**
July/August 2009			3.89
September/October 2009			
September 2010			
	Carbon, H=3.127, p=0.209, Q		

Table 5.13. Stable isotope differences between areas for stout eelblenny. Upper half of the table is nitrogen, lower half is carbon. Symbol for statistic indicates test that was performed ("F"= ANOVA, "H"=Kruskal-Wallis, "Q"=Dunn's Method, "q"= Tukey Test).

	Nitrogen, H=6.534, p=0.038		
	Klondike	**Burger**	**Statoil**
Klondike			
Burger			
StatOil			
	Carbon, H=4.800, p=0.091		

Table 5.14. Stable isotope differences between length classes of polar eelpout. Upper half of the table is nitrogen, lower half is carbon. Symbol for statistic indicates test that was performed ("F"= ANOVA, "H"=Kruskal-Wallis, "Q"=Dunn's Method, "q"= Tukey Test).

	Nitrogen, H=19.774, p<0.001, Q			
	0–50 mm	**51–75 mm**	**76–100 mm**	**≥101 mm**
0–50 mm		4.40	3.08	2.68
51–75 mm				
76–100 mm				
≥101 mm				
	Carbon, F=2.186, p=0.094, q			

Table 5.15. Stable isotope differences between areas for polar eelpout. Upper half of the table is nitrogen, lower half is carbon. Symbol for statistic indicates test that was performed ("F"= ANOVA, "H"=Kruskal-Wallis, "Q"=Dunn's Method, "q"= Tukey Test).

	Nitrogen, H=12.767, p=0.002, Q		
	Klondike	**Burger**	**Statoil**
Klondike		2.43	3.28
Burger			
StatOil			
	Carbon, F=2.697, p=0.072, q		

Table 5.16. Stable isotope differences between seasons for polar eelpout. Upper half of the table is nitrogen, lower half is carbon. Symbol for statistic indicates test that was performed ("F"= ANOVA, "H"=Kruskal-Wallis, "Q"=Dunn's Method, "q"= Tukey Test).

	Nitrogen, F=18.442, p<0.001, q		
	July/August 2009	**September/October 2009**	**September 2010**
July/August 2009		5.90	
September/October 2009	3.72		8.45
September 2010			
	Carbon, F=2.411, p=0.095		

Table 5.17. Stable isotope differences between length classes of Bering flounder. Upper half of the table is nitrogen, lower half is carbon. Symbol for statistic indicates test that was performed ("F"= ANOVA, "H"=Kruskal-Wallis, "Q"=Dunn's Method, "q"= Tukey Test).

	Nitrogen, F=14.358, p<0.001, Q			
	0–50 mm	**51–75 mm**	**76–100 mm**	**≥101 mm**
0–50 mm		4.65	5.87	8.31
51–75 mm	3.66			5.63
76–100 mm				4.18
≥101 mm	3.17			
	Carbon, H=18.827, p<0.001, q			

Table 5.18. Stable isotope differences between seasons for Bering flounder. Upper half of the table is nitrogen, lower half is carbon. Symbol for statistic indicates test that was performed ("F"= ANOVA, "H"=Kruskal-Wallis, "Q"=Dunn's Method, "q"= Tukey Test).

	Nitrogen, H=5.055, p=0.080		
	July/August 2009	**September/October 2009**	**September 2010**
July/August 2009			
September/October 2009			
September 2010			
	Carbon, H=0.887, p=0.642		

Table 5.19. Similarity table for frequency of occurrence of prey taxa consumed by each predator species across all areas and seasons.

	Arctic cod	Arctic staghorn sculpin	Stout eelblenny	Polar eelpout	Bering flounder
Arctic cod	43.56				
Arctic staghorn sculpin	24.00	47.44			
Stout eelblenny	22.97	28.44	63.15		
Polar eelpout	27.49	46.43	34.64	48.95	
Bering flounder	27.30	28.50	27.62	30.05	38.49

Table 5.20. Similarity table for frequency of occurrence of diet items across areas for all species and seasons.

	Klondike	Burger	Statoil
Klondike	36.01		
Burger	33.08	31.65	
Statoil	33.37	33.52	38.36

Table 5.21. Similarity table for frequency of occurrence of diet items across length classes for Arctic cod collected from all areas and seasons.

	0–50 mm	51–75 mm	76–100 mm	≥101 mm
0–50 mm	60.35			
51–75 mm	57.21	51.54		
76–100 mm	31.77	42.40	55.38	
≥101 mm	30.15	37.95	48.81	39.83

Table 5.22. Similarity table for frequency of occurrence of diet items across areas for stout eelblenny collected over all seasons.

	Klondike	Burger	Statoil
Klondike	65.81		
Burger	64.23	61.70	
Statoil	62.34	58.71	61.97

Table 5.23. Similarity table for frequency of occurrence of diet items across seasons for stout eelblenny collected from all areas.

	July/August 2009	September/October 2009	September 2010
July/August 2009	54.77		
September/October 2009	60.83	75.02	
September 2010	59.49	71.61	70.35

Table 5.24. Similarity table for frequency of occurrence of diet items across length classes for stout eelblenny collected from all areas and seasons.

	0–50 mm	**51–75 mm**	**76–100 mm**	**≥101 mm**
0–50 mm	35.92			
51–75 mm	41.00	61.50		
76–100 mm	31.05	65.17	78.65	
≥101 mm	29.48	61.66	75.97	71.10

Table 5.25. Similarity table for frequency of occurrence of diet items across length classes for stout eelblenny collected in Klondike across all seasons.

	0–50 mm	**51–75 mm**	**76–100 mm**	**≥101 mm**
0–50 mm	-			
51–75 mm	45.08	61.70		
76–100 mm	36.29	68.85	84.42	
≥101 mm	31.31	61.63	82.20	79.53

Table 5.26. Similarity table for frequency of occurrence of diet items across length classes for stout eelblenny collected in Burger across all seasons.

	0–50 mm	**51–75 mm**	**76–100 mm**	**≥101 mm**
0–50 mm	-			
51–75 mm	34.19	-		
76–100 mm	23.89	78.81	76.46	
≥101 mm	23.50	72.27	73.84	68.03

Table 5.27. Similarity table for frequency of occurrence of diet items across length classes for stout eelblenny collected in Statoil.

	51–75 mm	**76–100 mm**	**≥101 mm**
51–75 mm	-		
76–100 mm	59.74	-	
≥101 mm	49.28	76.89	-

Table 5.28. Similarity table for frequency of occurrence of diet items across areas for polar eelpout collected from all seasons.

	Klondike	**Burger**	**Statoil**
Klondike	52.73		
Burger	45.54	50.70	
Statoil	42.09	57.60	70.10

Table 5.29. Similarity table for index of importance of diet items across species for all areas and seasons.

	Arctic cod	Arctic staghorn sculpin	Stout eelblenny	Polar eelpout	Bering flounder
Arctic cod	44.36				
Arctic staghorn sculpin	22.58	48.13			
Stout eelblenny	21.14	27.48	61.10		
Polar eelpout	25.36	47.22	34.06	49.02	
Bering flounder	24.05	28.49	25.65	30.01	37.78

Table 5.30. Similarity table for index of relative importance of diet items across areas for all species and seasons.

	Klondike	Burger	Statoil
Klondike	35.56		
Burger	32.60	31.31	
Statoil	30.36	30.65	34.70

Table 5.31. Similarity table for index of relative importance of diet items across length classes for Arctic cod collected from all areas and seasons.

	0–50 mm	51–75 mm	76–100 mm	≥101 mm
0–50 mm	61.35			
51–75 mm	58.36	52.42		
76–100 mm	35.80	44.40	52.42	
≥101 mm	31.71	38.47	47.15	38.48

Table 5.32. Similarity table for index of relative importance of diet items across seasons for stout eelblenny collected from all areas.

	July/August 2009	September/October 2009	September 2010
July/August 2009	53.78		
September/October 2009	58.56	72.01	
September 2010	57.47	69.30	67.94

Table 5.33. Similarity table for index of relative importance of diet items across areas for stout eelblenny collected over all seasons.

	Klondike	Burger	Statoil
Klondike	63.91		
Burger	60.87	59.15	
Statoil	63.03	57.37	63.85

Table 5.34. Similarity table for index of relative importance of diet items across length classes for stout eelblenny collected from all areas and seasons.

	0–50 mm	51–75 mm	76–100 mm	≥101 mm
0–50 mm	38.24			
51–75 mm	43.72	61.93		
76–100 mm	32.82	63.21	74.81	
≥101 mm	29.39	59.18	72.56	67.88

Table 5.35. Similarity table for index of relative importance of diet items across length classes for stout eelblenny collected in Klondike across all seasons.

	0–50 mm	51–75 mm	76–100 mm	≥101 mm
0–50 mm	-			
51–75 mm	45.77	59.76		
76–100 mm	37.54	66.72	80.96	
≥101 mm	32.26	59.32	79.13	76.20

Table 5.36. Similarity table for index of relative importance of diet items across length classes for stout eelblenny collected in Burger across all seasons.

	0–50 mm	51–75 mm	76–100 mm	≥101 mm
0–50 mm	-			
51–75 mm	37.42	-		
76–100 mm	27.09	72.38	72.44	
≥101 mm	26.00	68.48	69.92	68.03

Table 5.37. Similarity table for index of relative importance of diet items across length classes for stout eelblenny collected in Statoil.

	51–75 mm	76–100 mm	≥101 mm
51–75 mm	-		
76–100 mm	66.76	-	
≥101 mm	51.44	73.35	-

Table 5.38. Similarity table for index of relative importance of diet items across areas for polar eelpout collected from all seasons.

	Klondike	Burger	Statoil
Klondike	55.22		
Burger	46.99	50.86	
Statoil	37.38	52.91	63.29

Table 5.39. Stable isotope differences between fish species. Upper half of the table is nitrogen, lower half is carbon. Symbol for statistic indicates test that was performed ("F"= ANOVA, "H"=Kruskal-Wallis, "Q"=Dunn's Method, "q"= Tukey Test).

	Nitrogen, H=294.600, p<0.001, Q				
	Arctic cod	**Arctic staghorn sculpin**	**Stout eelblenny**	**Polar eelpout**	**Bering flounder**
Arctic cod		4.80	12.90	14.81	
Arctic staghorn sculpin	6.65		5.42	6.79	
Stout eelblenny	12.53	3.68			7.14
Polar eelpout	13.69	4.42			8.39
Bering flounder	4.44		4.34	4.98	
	Carbon, H=245.424, p<0.001, Q				

Table 5.40. Shannon's diversity and Pielou's evenness indices for diets of each predator species and length class.

	N fish	N prey taxa	Diversity		Evenness	
			%FO	IRI	%FO	IRI
Arctic cod	**352**	**17**	**2.39**	**1.87**	**0.59**	**0.46**
0–50 mm	93	6	0.96	0.86	0.37	0.33
51–75 mm	113	9	1.55	1.06	0.49	0.33
76–100 mm	99	14	2.38	1.79	0.63	0.47
≥101 mm	47	14	3.03	2.65	0.80	0.70
Arctic staghorn sculpin	**115**	**13**	**2.34**	**2.02**	**0.63**	**0.54**
0–50	47	9	1.86	1.60	0.59	0.50
51–75 mm	48	9	2.03	1.56	0.64	0.49
76–100 mm	16	7	2.03	1.76	0.72	0.63
≥101 mm	4	3	1.38	0.61	0.87	0.39
Polar eelpout	**147**	**15**	**2.24**	**1.88**	**0.57**	**0.48**
0–50 mm	27	7	2.01	1.84	0.72	0.65
51–75 mm	45	9	1.98	1.53	0.63	0.48
76–100 mm	33	10	2.19	1.81	0.66	0.54
≥101 mm	42	10	1.69	1.20	0.51	0.36
Stout eelblenny	**195**	**18**	**3.31**	**2.67**	**0.79**	**0.64**
0–50 mm	3	4	1.91	1.63	0.95	0.81
51–75 mm	15	12	2.65	1.74	0.74	0.48
76–100 mm	69	15	3.31	2.70	0.85	0.69
≥101 mm	108	18	3.37	2.53	0.81	0.61
Bering flounder	**114**	**17**	**3.01**	**2.26**	**0.74**	**0.55**
0–50 mm	43	11	2.40	1.78	0.69	0.51
51–75 mm	45	17	2.84	1.94	0.69	0.47
76–100 mm	23	14	2.82	1.95	0.74	0.51
≥101 mm	3	4	1.63	1.19	0.81	0.59

Table 5.41. Stable isotope differences between fish prey taxa. Upper half of the table is nitrogen, lower half is carbon. Symbol for statistic indicates test that was performed ("F"= ANOVA, "H"=Kruskal-Wallis, "Q"=Dunn's Method, "q"= Tukey Test).

Nitrogen, H=126.218, p<0.001, Q

	Amphipod	Copepod	Crab	Euphausiid/ Mysid	Fish	Mollusc	Nematode	Other Crustacean	Polychaete	Shrimp
Amphipod							6.59		6.78	
Copepod							7.20		7.36	
Crab							4.59		3.72	
Euphausiid/ Mysid							5.05			
Fish										
Mollusc							3.33			
Nematode								7.22		3.14
Other Crustacean	5.17	6.11		5.48	3.36				7.44	
Polychaete										
Shrimp										

Carbon, H=58.027, p<0.001, Q

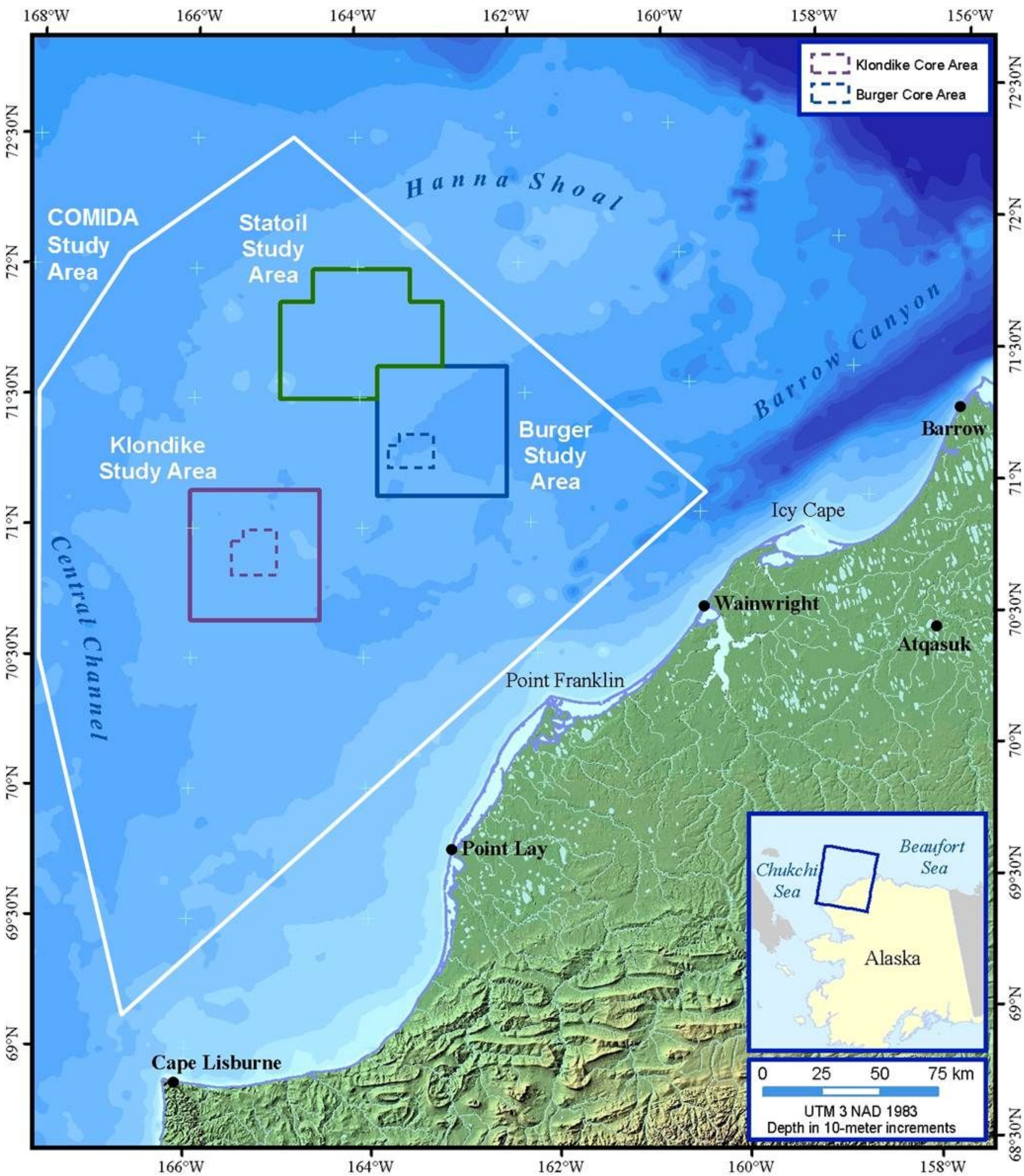

Figure 5.1. Map of COMIDA, Klondike, Burger, and Statoil study areas in the Chukchi Sea.

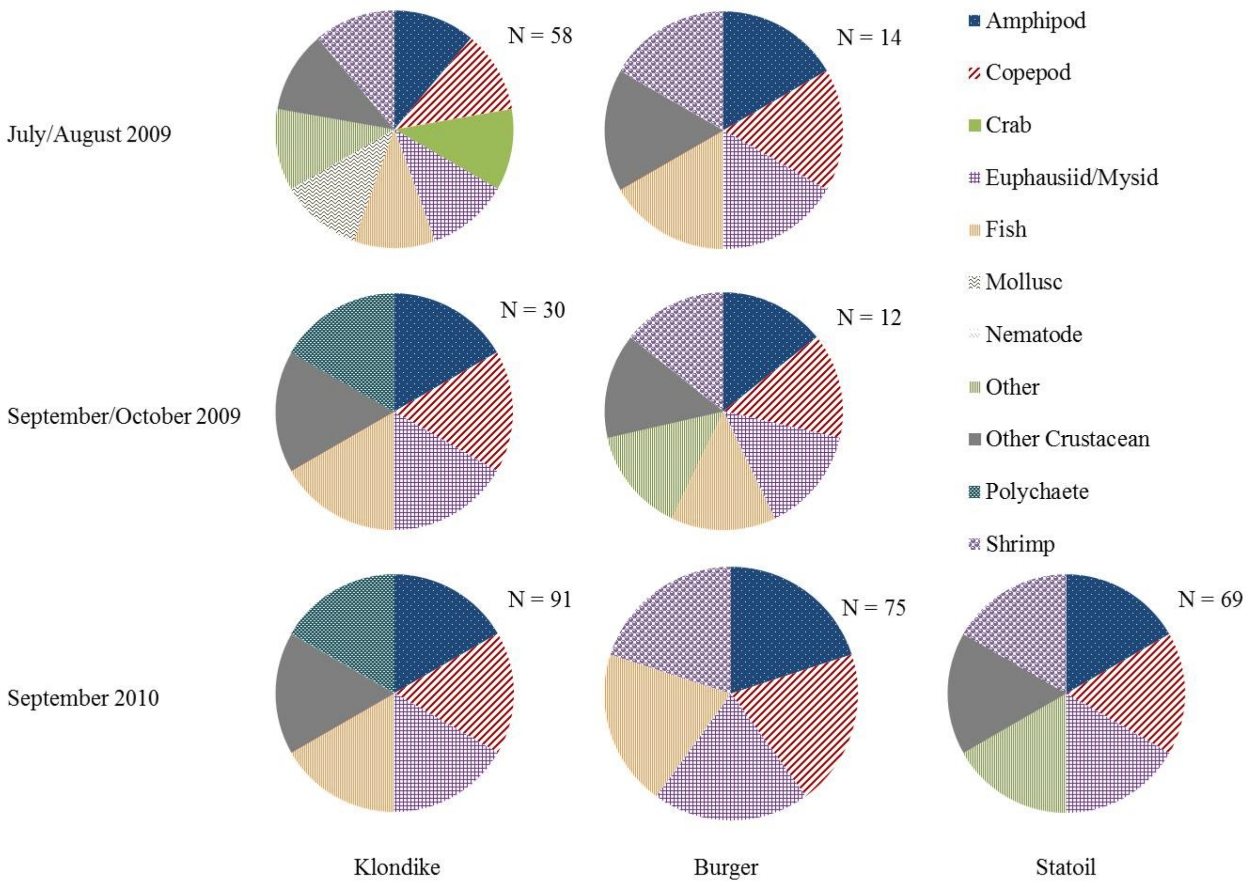

Figure 5.2. Frequency of occurrence of prey consumed by Arctic cod collected in the Chukchi Sea in 2009–2010.

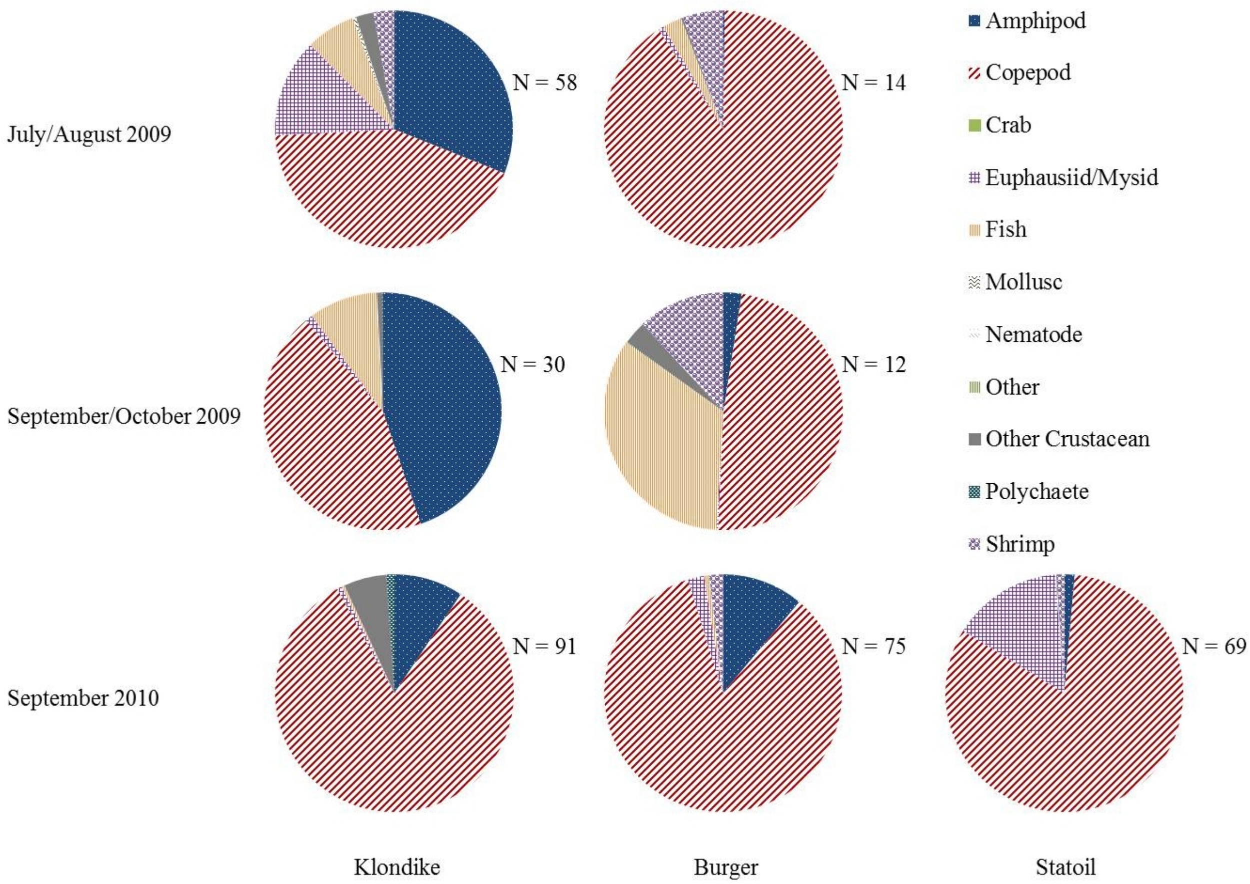

Figure 5.3. Index of relative importance, by percent, of prey consumed by Arctic cod collected in the Chukchi Sea in 2009–2010.

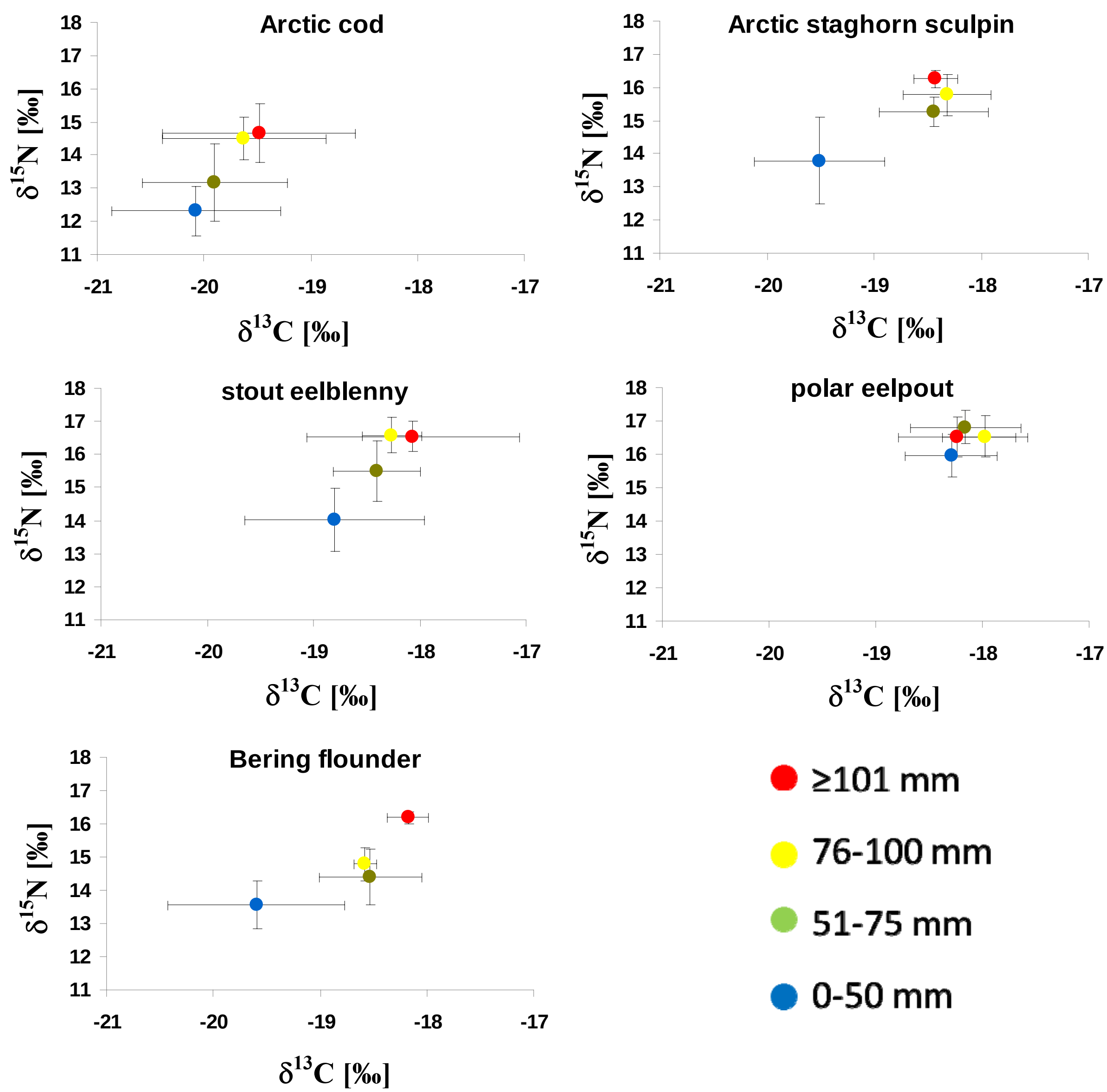

Figure 5.4. Average $\delta^{15}N$ and $\delta^{13}C$ values for each fish species by length class.

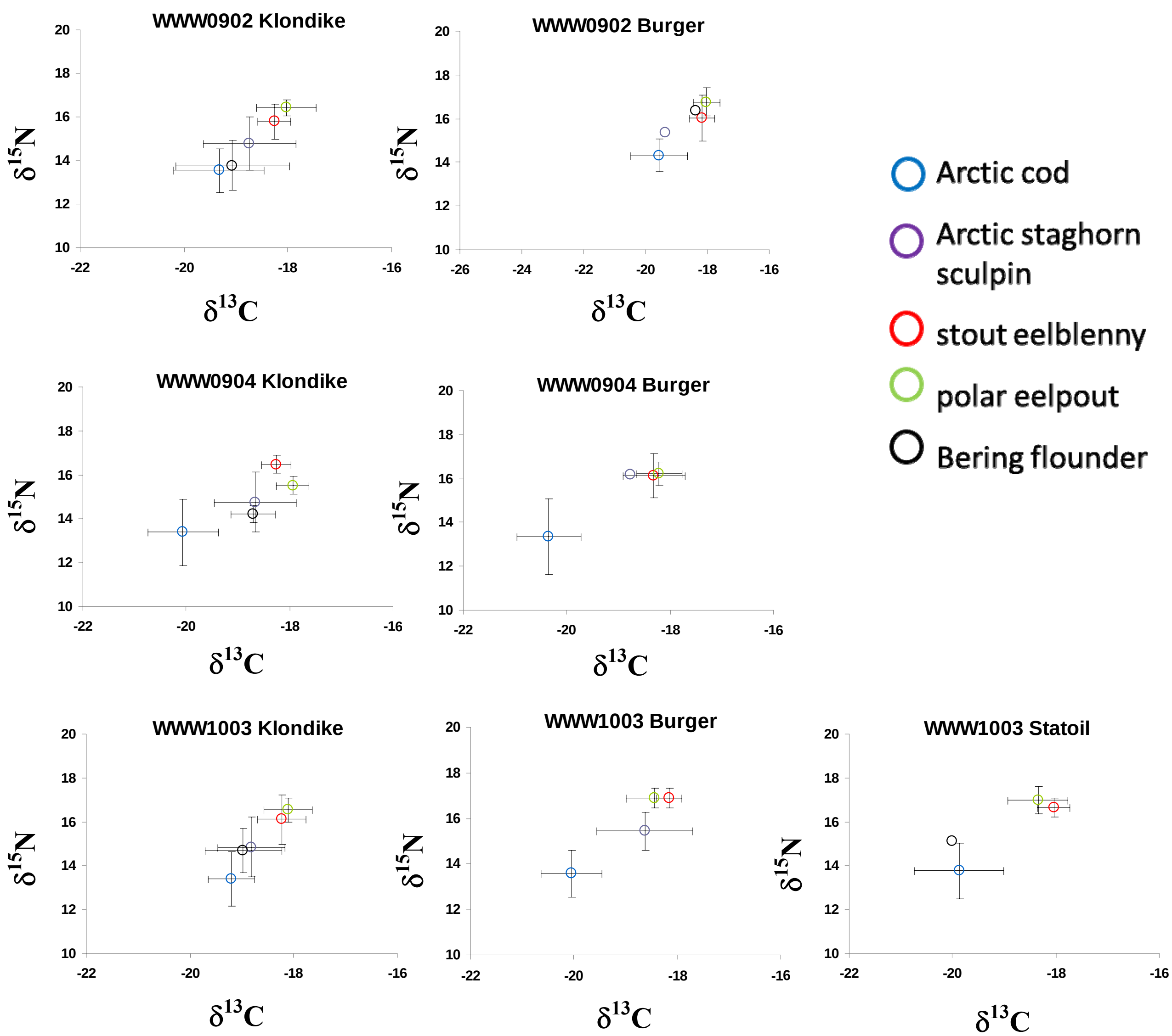

Figure 5.5. Average δ^{15}N and δ^{13}C values for each fish species by season and area.

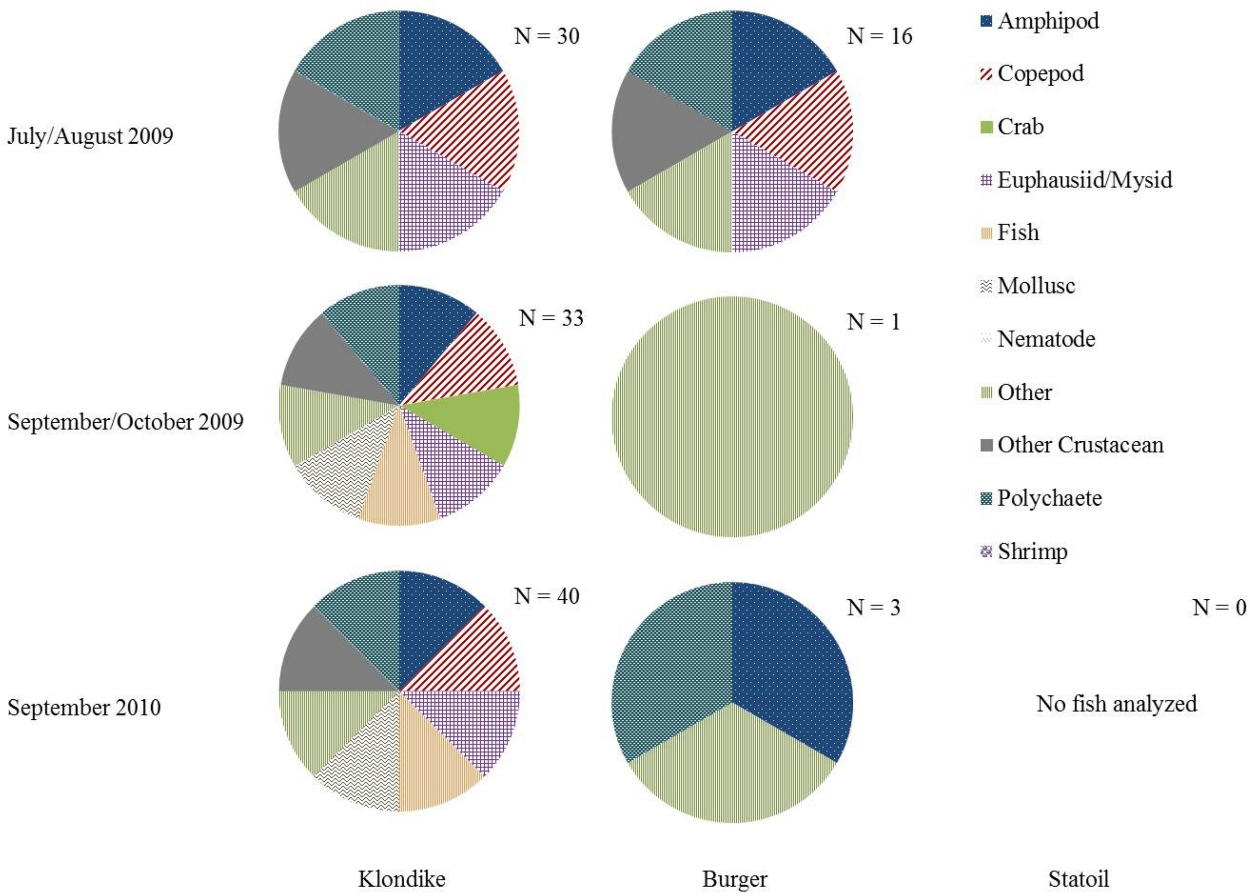

Figure 5.6. Frequency of occurrence of prey consumed by Arctic staghorn sculpin collected in the Chukchi Sea in 2009–2010.

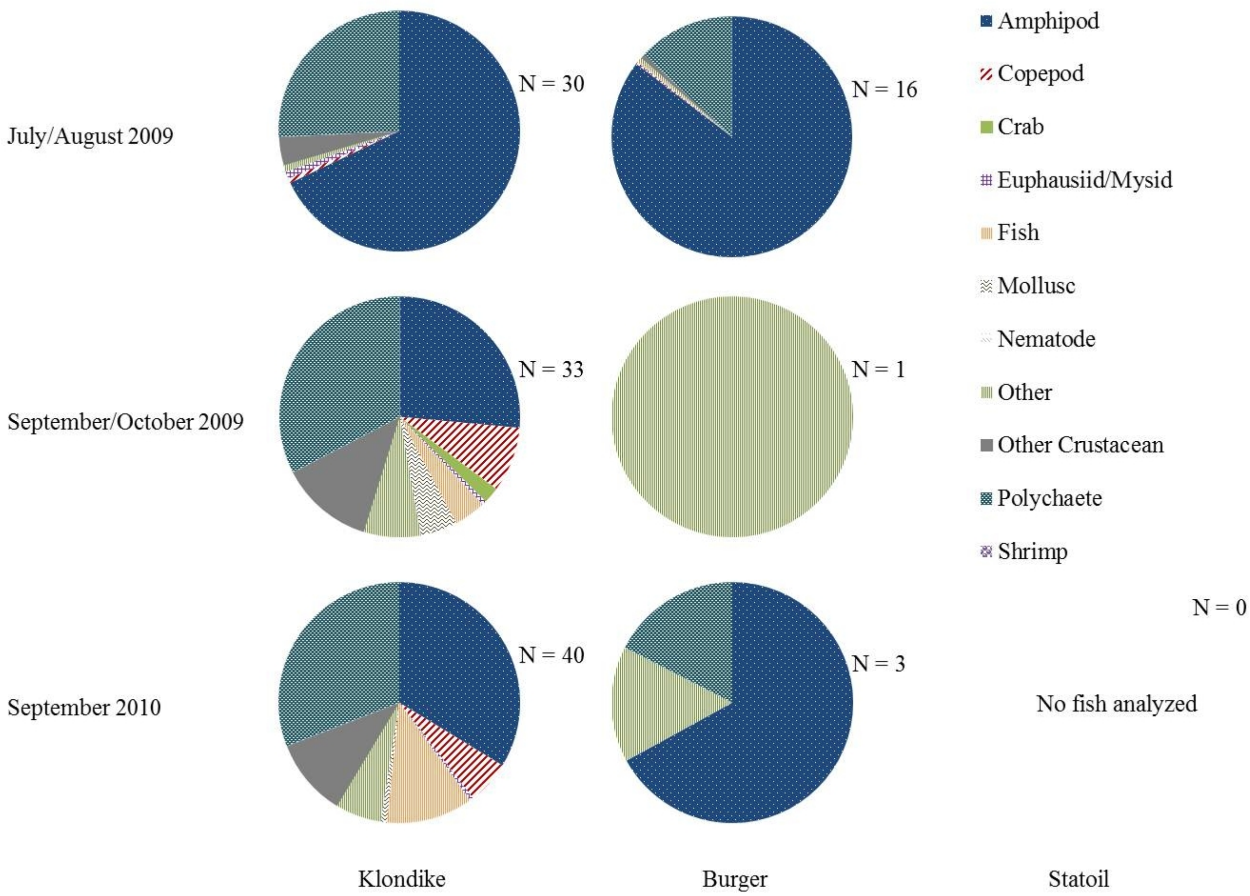

Figure 5.7. Index of relative importance, by percent, of prey consumed by Arctic staghorn sculpin collected in the Chukchi Sea in 2009–2010.

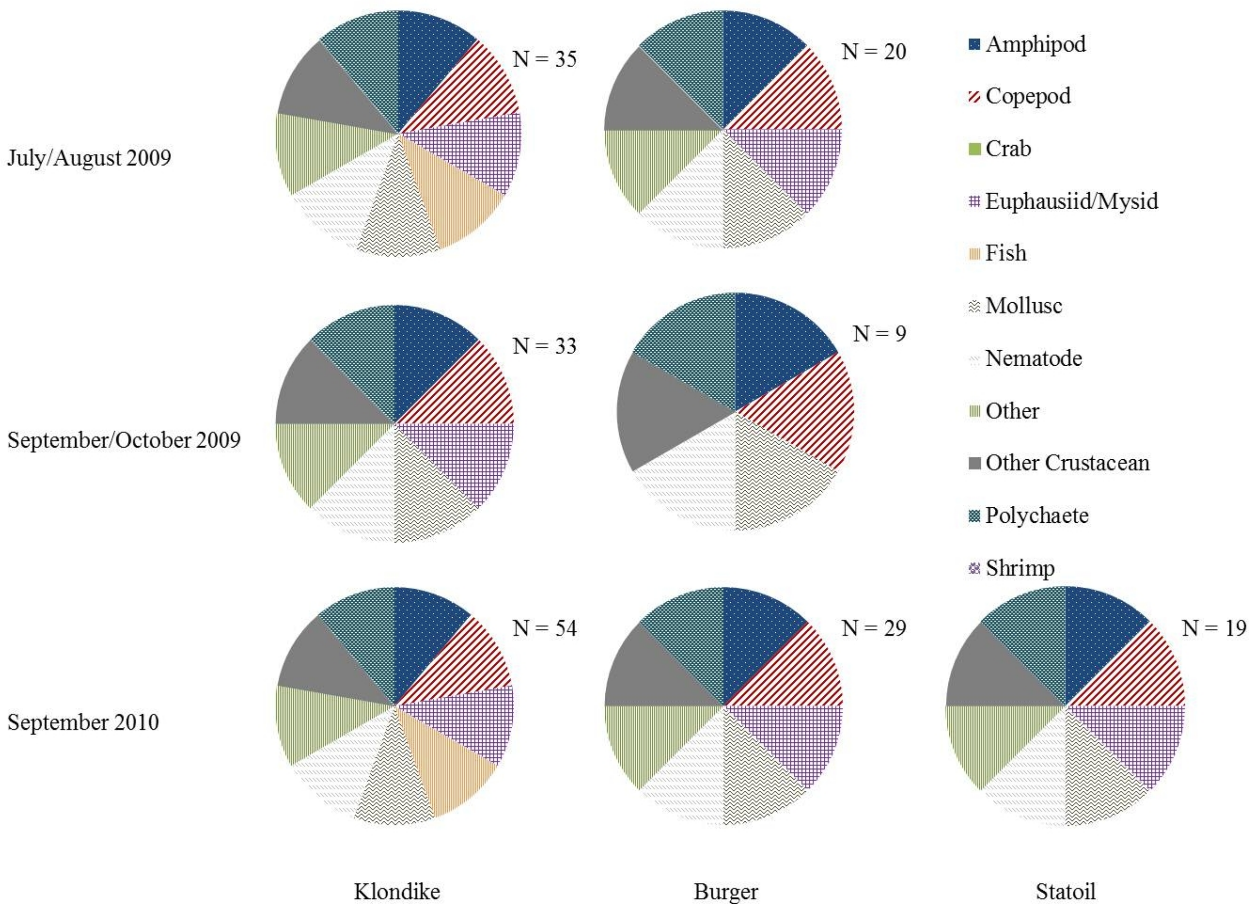

Figure 5.8. Frequency of occurrence of prey consumed by stout eelblenny collected in the Chukchi Sea in 2009–2010.

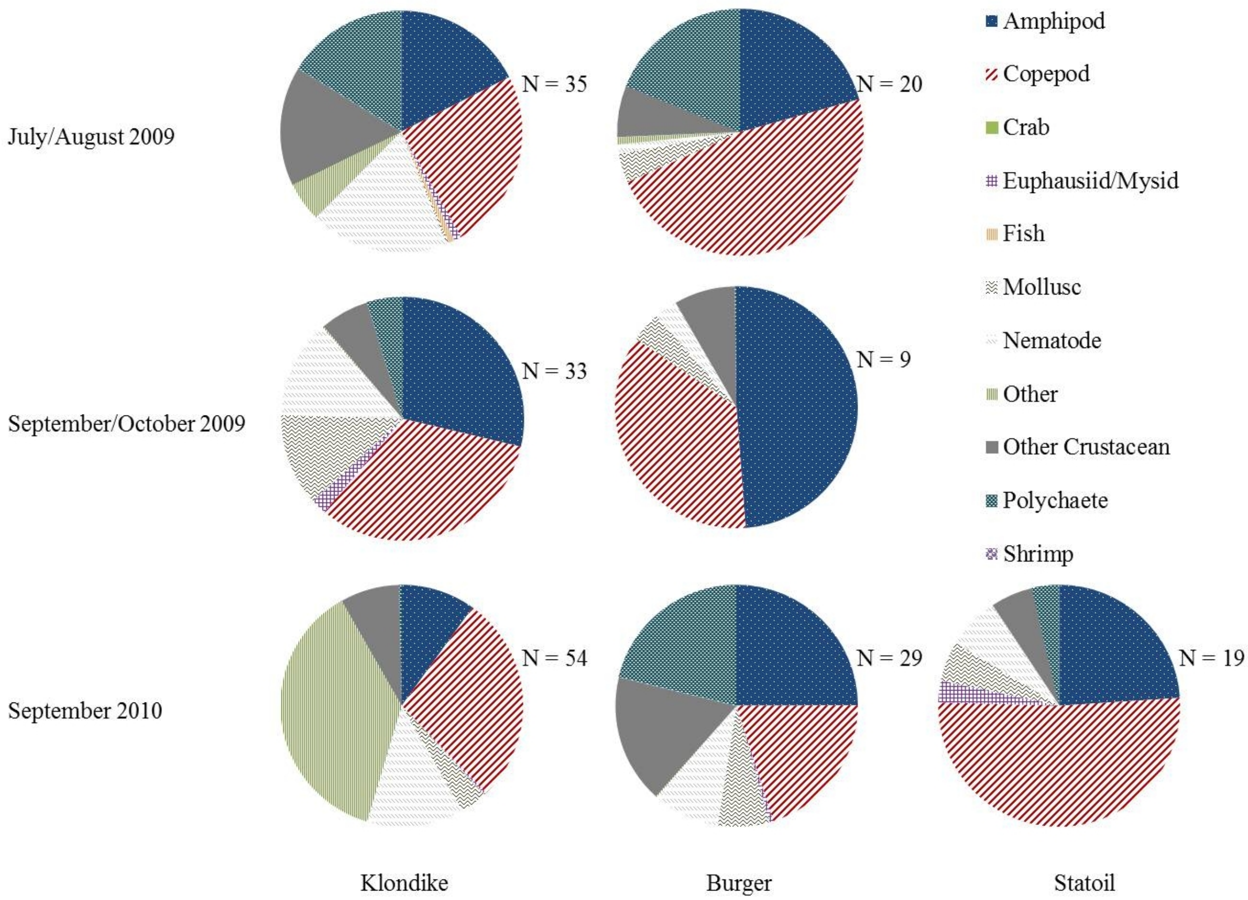

Figure 5.9. Index of relative importance, by percent, of prey consumed by stout eelblenny collected in the Chukchi Sea in 2009–2010.

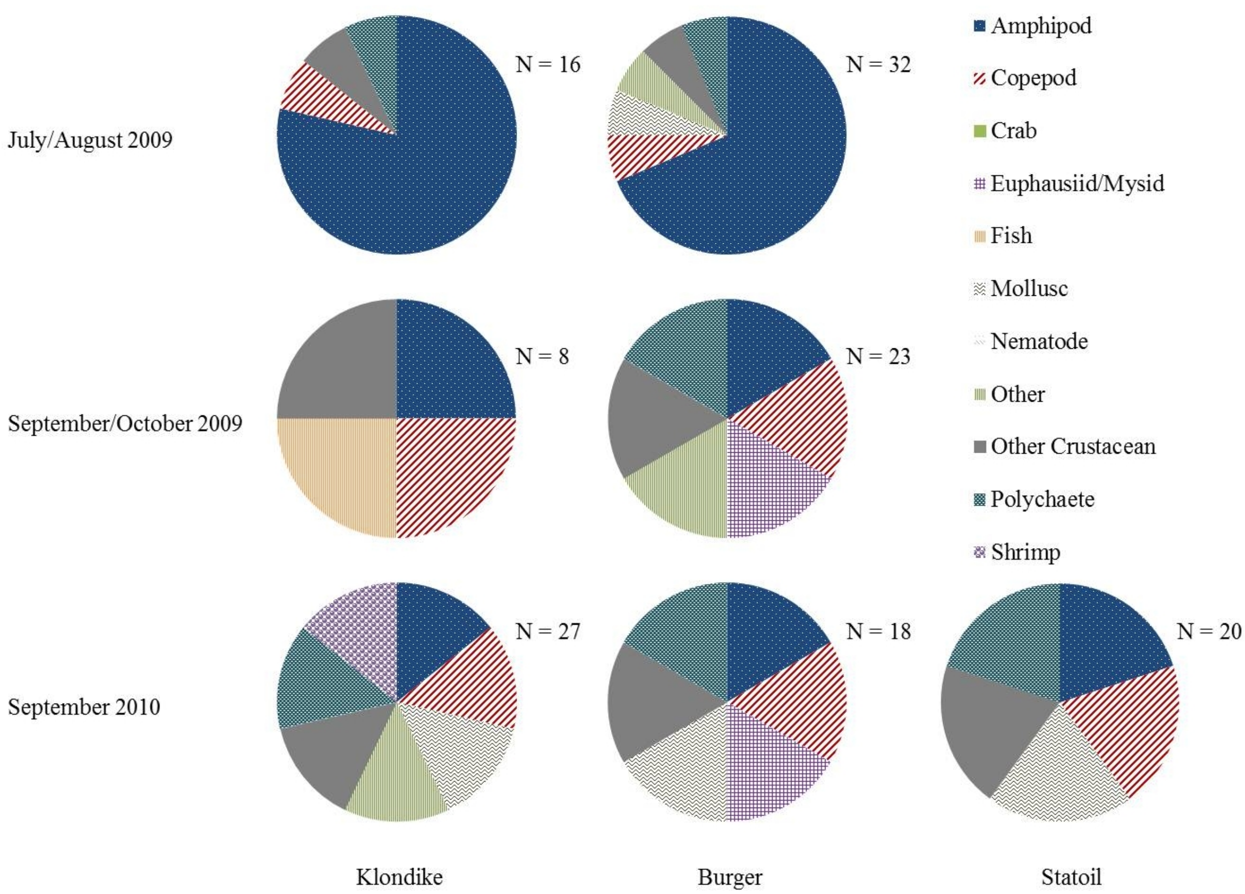

Figure 5.10. Frequency of occurrence of prey consumed by polar eelpout collected in the Chukchi Sea in 2009–2010.

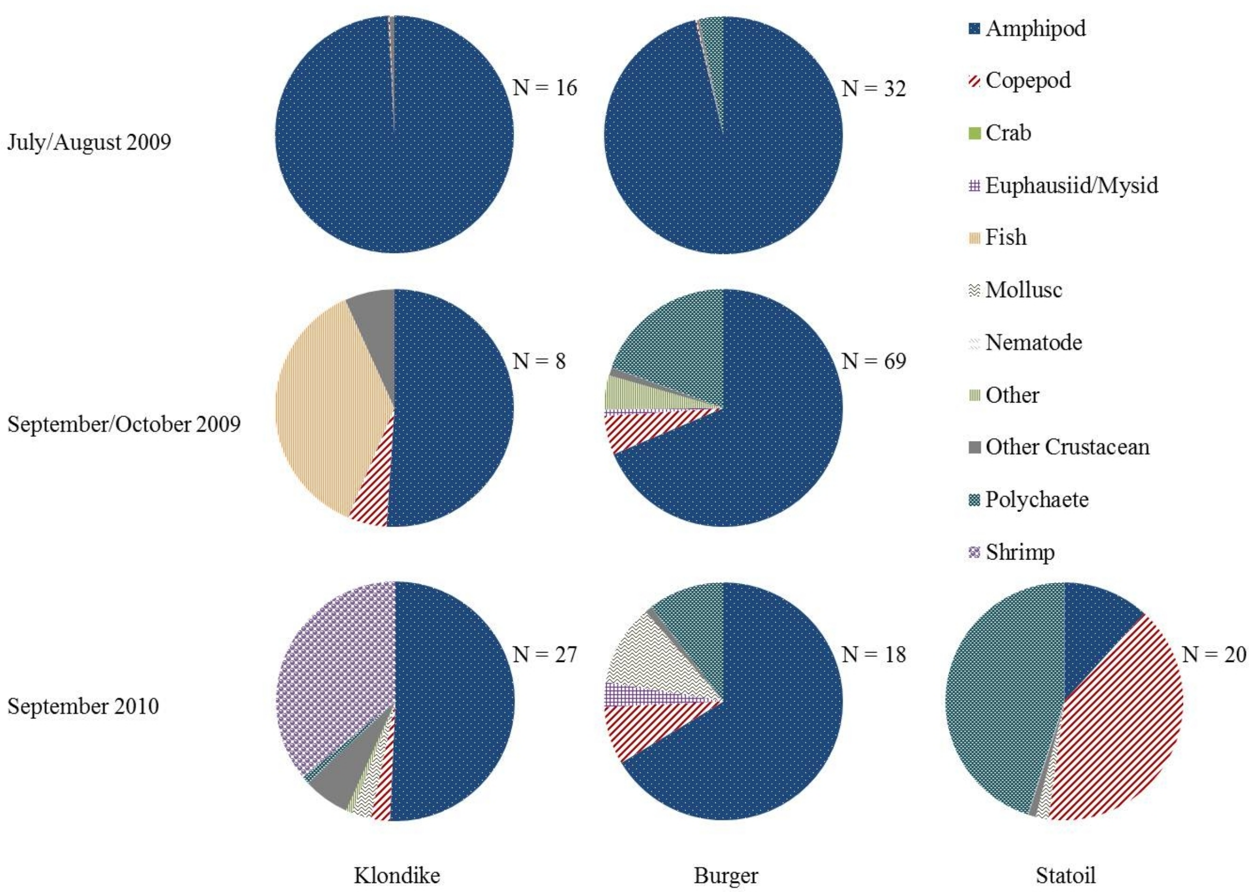

Figure 5.11. Index of relative importance, by percent, of prey consumed by polar eelpout collected in the Chukchi Sea in 2009–2010.

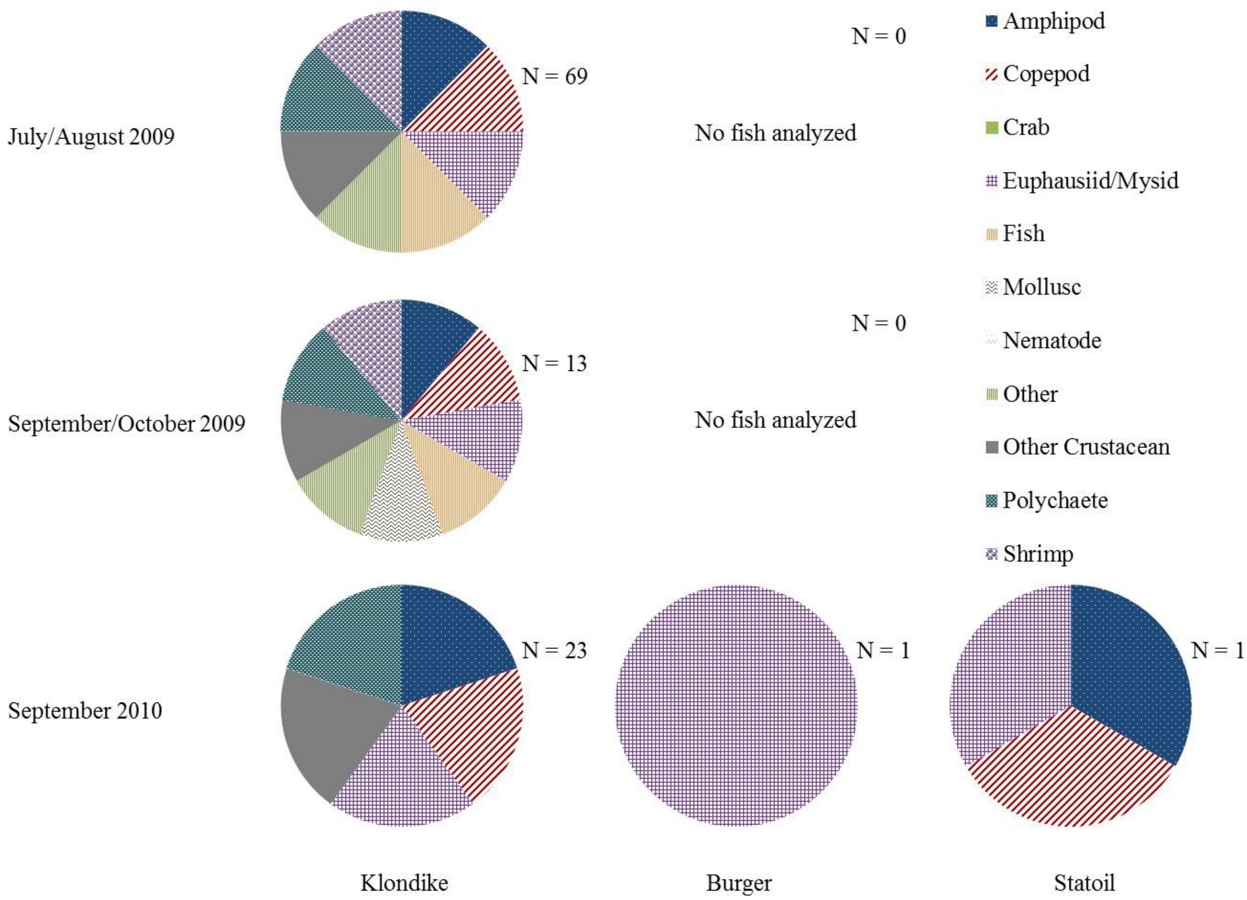

Figure 5.12. Frequency of occurrence of prey consumed by Bering flounder collected in the Chukchi Sea in 2009–2010.

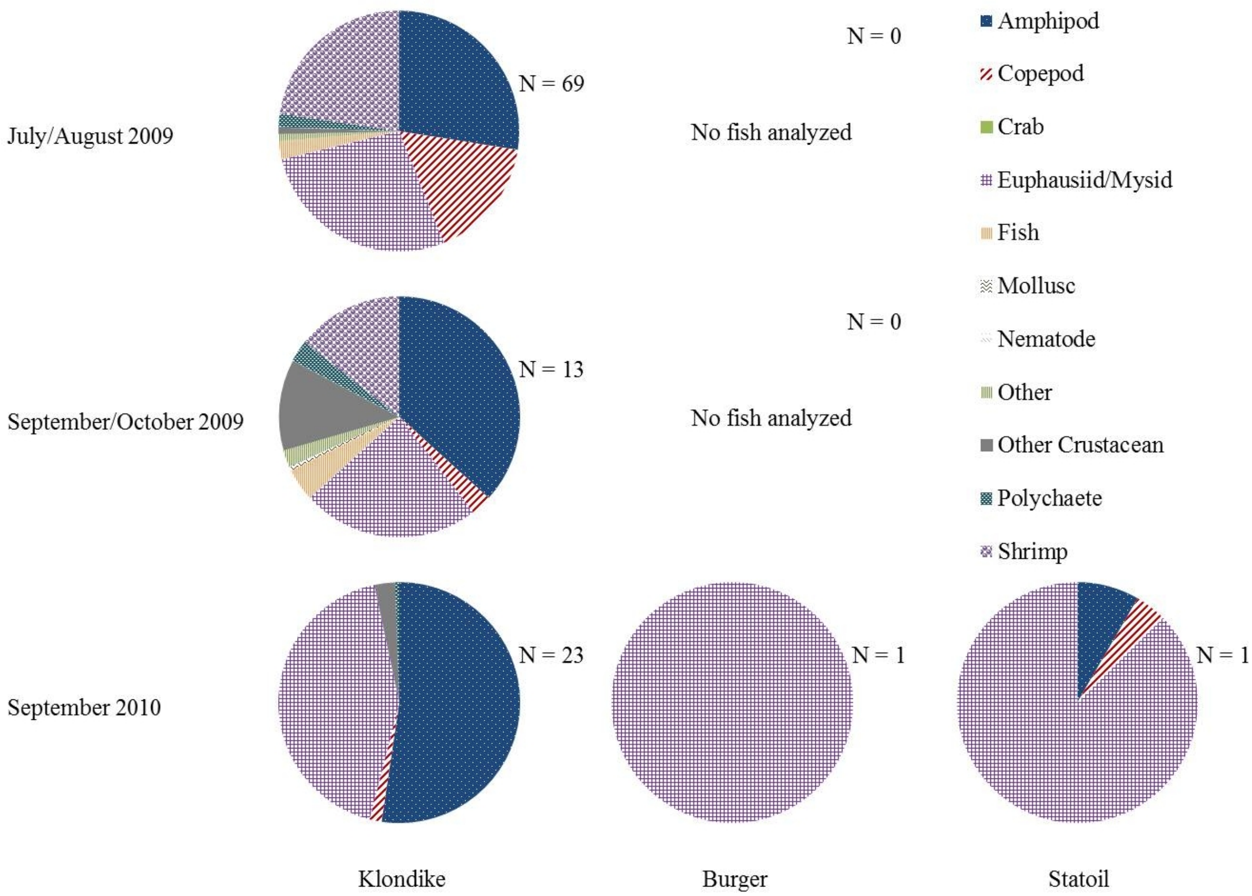

Figure 5.13. Index of relative importance, by percent, of prey consumed by Bering flounder collected in the Chukchi Sea in 2009–2010.

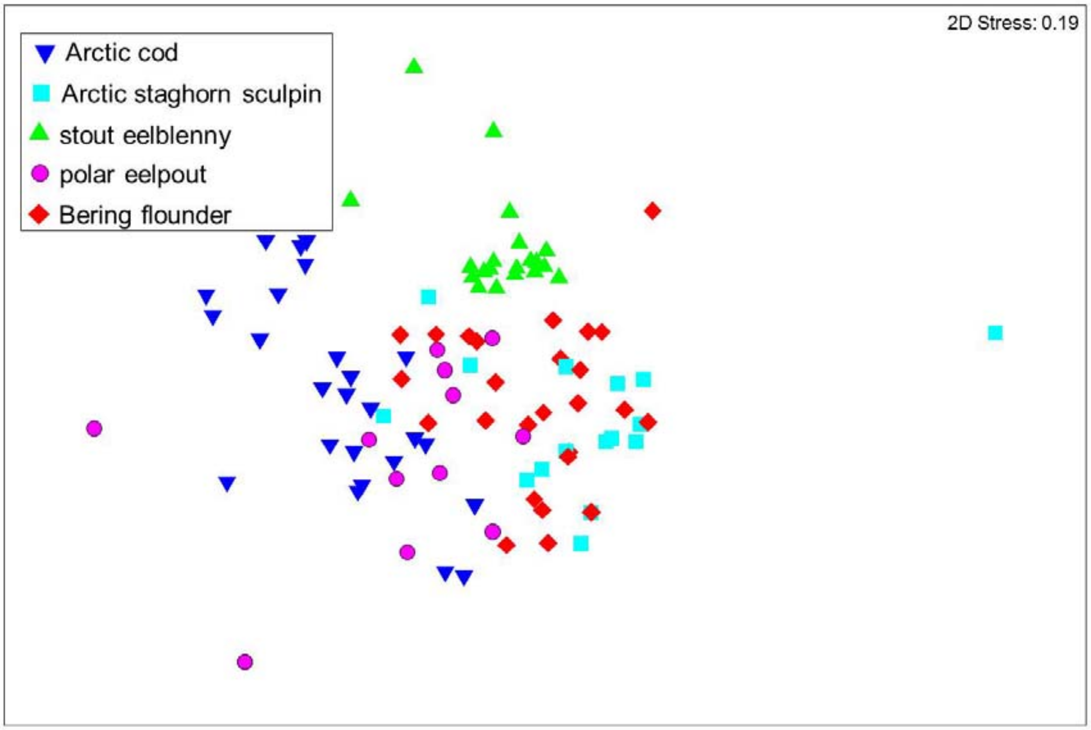

Figure 5.14. MDS plot for frequency of prey taxon occurrence in each predator species. Each point is a category of length class, area and season.

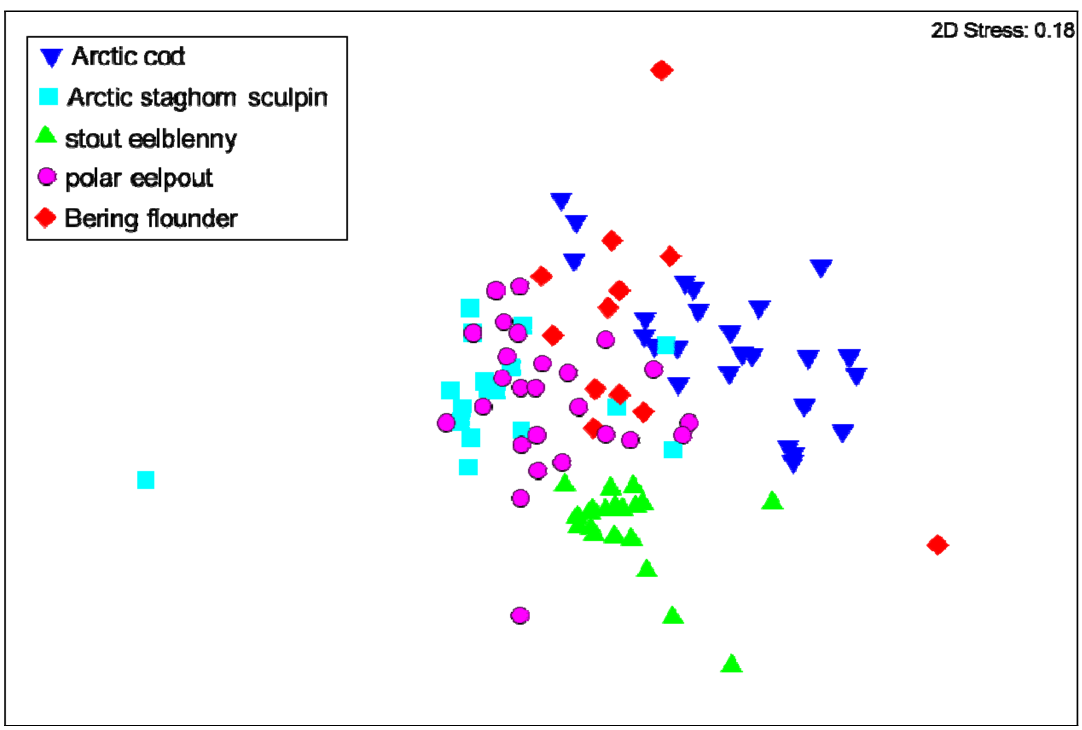

Figure 5.15. MDS plot for index of relative prey taxon importance in each predator species. Each point is a category of length class, area and season.

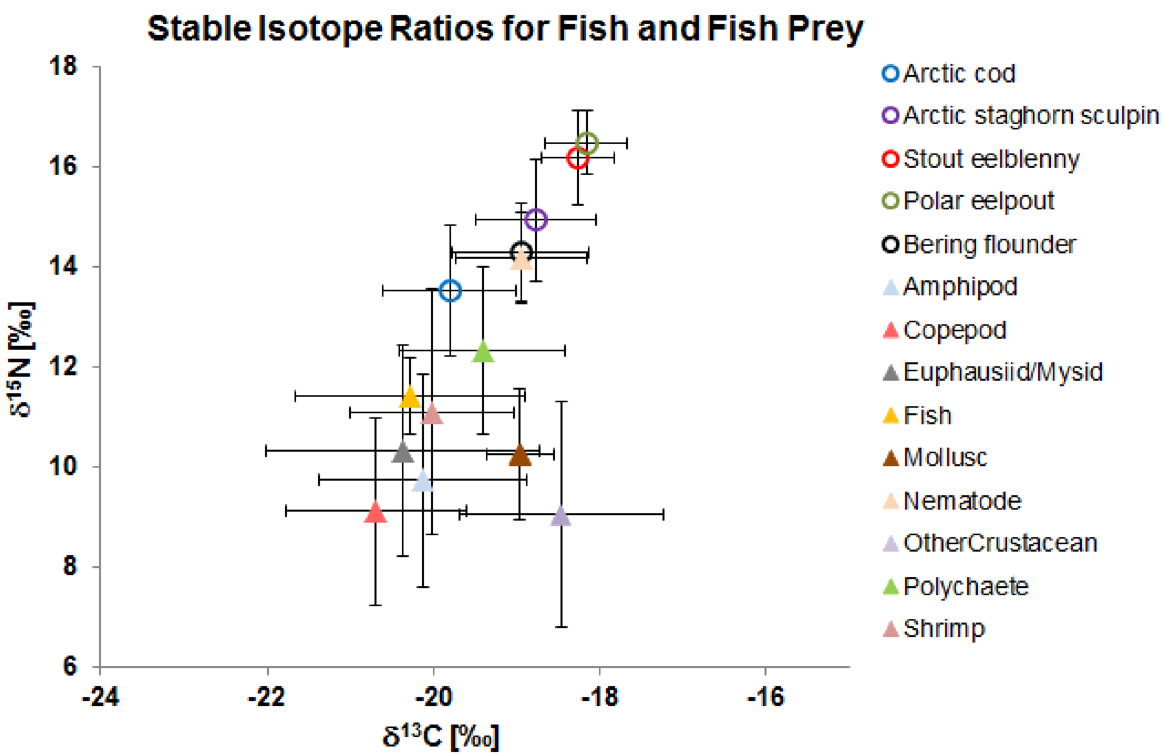

Figure 5.16. Average $\delta^{15}N$ and $\delta^{13}C$ values for fishes and their prey.

APPENDIX 1 - STATISTICAL METHODS FOR MODELING SPECIES DENSITIES AND SPECIES DIVERSITY

[1]S.W. Raborn

A1.1 DATASETS AND VARIABLES OF INTEREST

Three datasets were used during the course of the analysis: (1) all surveys in all years, (2) all surveys in years 2009 and 2010, and (3) only CSESP surveys in 2009 and 2010.

Response variables were restricted to the multinomial variable, *Assemblage Structure*, and the univariates: *Species Richness*, *Arctic cod density*, *Arctic staghorn sculpin density*, and *Bering flounder density*. *Assemblage Structure* is unit-less as it represents the proportionate mix of species, whereas species densities were reported as per 1,000 m^2. *Species Richness* proved more challenging to standardize than the species densities (see below).

Explanatory variables included four categorical variables: *Gear*, *Year*, *Prospect*, and *Night-versus-Day-Sampling*. There were eight continuous variables: *Distance-from-shore, Latitude*, *Longitude*, *Depth*, *Bottom-Temperature*, *Bottom-Salinity*, *Percent-Gravel* in the substrate, and *Percent-Mud*. We also measured the percent sand in the substrate, but as the three substrate types summed to 100%, only two were needed. Because sand and mud were the most correlated (inversely) we dropped percent sand instead of percent gravel to reduce multicolinearity. Note that we could have just as well dropped *Percent-Mud* instead of sand and accomplished the same thing.

Dataset 1 was the most comprehensive as it included 1990-Barber, COMIDA 2009, COMIDA 2010, WWW0902, WWW0904 and WWW1003 (Table 1.1). Barber et al.'s 1990 data (1997) was missing the substrate data. Consequently, substrate variables were not included in this analysis nor were Prospect or Year. There is nothing biologically inherent in the variable Prospect, and we reasoned that the variables Latitude, Longitude, and Distance-from-shore were more appropriate for capturing any environmental gradients among Prospects. The Barber et al. (1997) data represent a 1990 baseline of the demersal fish communities in the northeastern Chukchi Sea as sampled by a NMFS 83-112 otter trawl. Unfortunately, this gear was not used in 2009 or 2010; thus, the causal mechanisms behind any differences between Barber et al. (1997) and more recent data will be confounded. That is, we do not know whether differences were due to changes in the fish community since 1990 or because different gears were used.

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[1] LGL Ecological Research Associates, Inc., Bryan, Texas

Dataset 2 was a reduced version of dataset 1; it included COMIDA 2009, COMIDA 2010, WWW0902, WWW0904 and WWW1003 (Table 1.1). The value of analysis on this dataset is that it included the substrate variables, though at the expense of dropping Barber et al.'s (1997) data from the analysis. As the larger-scale COMIDA collections were included in this dataset, *Prospect* was not included in this analysis.

Dataset 3 used only the CSESP data, WWW0902, WWW0904 and WWW1003, as the primary question of concern was how *Prospects* differed in their respective fish communities. Because it would be redundant to have *Prospect* along with *Latitude*, *Longitude*, and *Distance-from-shore* in the same model, the latter three were dropped from Dataset 3.

A1.2 STANDARDIZING SPECIES RICHNESS

Richness is the number of fish species or taxa and is usually standardized to an area or some level of effort as an index of diversity. The usual practice is to standardize samples to the same number of individuals before making comparisons using a technique known as rarefaction analysis (Sanders 1968). This approach allows comparison of samples that have different levels of effort, but does not allow the inclusion of covariates or categorical variables (e.g., temperature, salinity, etc.). In our analysis, *Species Richness* was initially modeled on a per 1,000 m^2 basis using generalized linear models (GLMs; see further explanation below) instead of on a per individual basis with rarefaction analysis (Priest et al. 2011). This allowed us to control for various covariates and to make comparisons taking several categorical variables into account. Modeling *Species Richness* in this way is becoming increasingly more prevalent in the literature (e.g., Lobo and Martin-Piera 2002; O'Hara 2005). However, the results from this analysis were not interpretable.

The plumb staff beam trawl (PSBT) exhibited a greater number of species per sampling effort (1,000 m^2) as compared to the 3-m beam trawl (3mBT; Priest et al. 2011). This finding could have been because the PSBT disturbed the substrate more causing the catchability of demersal species to increase. While this hypothesis may be valid, we suspect the degree of difference between the two gears (PSBT: 3mBT ≈ 9:1) was at least partially inflated due to the sampling protocol. The PSBT was only fished for about three minutes versus the 3mBT, which was fished for about 30 minutes. The shorter tow times for the PSBT was necessary because the number of invertebrates and quantity of sediment increased due to greater scouring of the substrate; sampling any longer was not logistically feasible. Sampling technique with the 3mBT was different as it mostly did not contact substrate while being towed, which drastically reduced invertebrates and sediment, and in turn afforded a much longer tow time. As mentioned above, there were a limited number of species available to be caught. If at least one individual from all species at a station was collected quickly, e.g., in the first three minutes of the tow, then the difference between the two gears with respect to *Species Richness* may have only been a function of the longer sampling time for the 3mBT. In other words, both gears were sampling what was there in the first few minutes, but there were only so many species that could be caught, and the longer sampling time for the 3mBT caused the denominator (effort) to increase, while the numerator (*Species Richness*) had reached an asymptote in the first few minutes. We were able to avoid this bias by standardizing *Species Richness* to a per individual basis instead of per area in the statistical models. This latter approach is the same strategy as using rarefaction analysis, but with the added benefit of allowing explanatory variables to be included in the model.

A1.3 MODEL PARAMETERIZATION

We used Generalized Linear Models (GLMs) with discrete probability distributions to compute the likelihood of observing the counts that were collected. These types of GLMs constitute a relatively new approach for analyzing CPUE data (Stefansson 1996; Power and Moser 1999; Terceiro 2003; Minami et al. 2007; Arab et al. 2008; Shono 2008; Dunn 2009). This approach involved three steps:

1) constructing a model with variables of interest to predict the catch rate (CPUE) for all the observations;
2) multiplying the predicted CPUE from step (1) by the observed effort (called an offset), to obtain the predicted (expected) catch comparable to the observed catch;
3) computing the likelihood of the observed catch given the expected catch assuming some discrete distribution.

These alternate distributions correctly model data that are generated from the *Poisson* process of counting individuals. They allow for zero counts, but never generate negative values, which are impossible with count data. Step (2) correctly weights each observation's contribution to the overall likelihood.

The response variables required different GLMs. For *Species Richness* and the individual species densities, we considered both *Poisson* and negative binomial regressions. Both utilized a global linear log link function to portray the predicted catch rate:

$$\log_e(\lambda_i) = \mu + x_i\beta \qquad (1)$$

where, λ_i = predicted CPUE for the i^{th} sample tow, μ = overall mean, x_i = the vector of explanatory variables, and β their corresponding vector of coefficients. All independent variables were considered fixed effects and were parameterized with the GLIMMIX Procedure in the SAS Version 9.2 statistical package (SAS Institute Inc. 2008) by maximizing their respective log likelihoods, which were the sums of the likelihoods for each i^{th} observation:

Poisson
$$l_i = w_i\left(y_i \log_e\{\lambda_i\} - \lambda_i - \log_e\{\Gamma(y_i + 1)\}\right) \qquad (2)$$

Negative binomial $$l_i = y_i \log e\left\{\frac{k\lambda_i}{w_i}\right\} - \left(\frac{y_i + w_i}{k}\right)\log_e\left\{1 + \frac{k\lambda_i}{w_i}\right\} + \log_e\left\{\frac{\Gamma(y_i + w_i/k)}{\Gamma(w_i/k)\Gamma(y_i + 1)}\right\} \quad (3)$$

where, the predicted catch rate (λ_i) comes from Equation (1), w_i defines the element size (also called weight or offset), which was the area sampled (m^2) for species densities and the total number of individuals in the sample for *Species Richness*, y_i=the observed catch for the i^{th} sample tow, and k=the negative binomial dispersal coefficient (an additional parameter that allows for inflated variance and requires estimation). Akaike's Information Criterion (AICc; Burnham and Anderson 2002) was used to determine which of the two distribution types was most appropriate for the data being considered. The result was that *Poisson* was best for *Species Richness* and the negative binomial was best for species densities.

Assemblage Structure was modeled as a nominal multinomial distribution, which utilized the generalized logit link function:

$$\log_e\left[\frac{\Pr(y = j|x_i)}{\Pr(y = k|x_i)}\right] = \mu_{jk} + x_i\beta_{jk} \quad (4)$$

where, all j^{th} nominal categories were referenced to a particular category k (in our study we used the most numerically dominant species for k), x_i=the vector of explanatory variables, and μ_{jk} and β_{jk} were parameters specific to the j^{th} category and referenced to k. Hence, we modeled the log odds of a fish in the *Assemblage Structure* being in the j^{th} category as compared to being in the reference category, k, and this relationship was allowed to change with the explanatory variables. The likelihood for each i^{th} observation was given as:

$$l_i = \sum_{j=1}^{J} y_{ij} \log_e\{\mu_{ij}\} \quad (5)$$

where, J=total number of species in the analysis, y_{ij}=the number of individuals in the j^{th} species and i^{th} sample, and μ_{ij}=the predicted number of individuals in the j^{th} species and i^{th} sample.

A1.4 INFORMATION-THEORETIC APPROACH AND MODEL AVERAGING

In addition to the global model, all nested combinations of independent variables were compared using the Information-Theoretic Approach as recommended by Burnham and Anderson (2002). The number of models (including the null model) given the number of predictor variables (k) is 2^k, i.e., 256 for Dataset 1, 2048 for Dataset 2, and 512 for Dataset 3. Weights were assigned to each model based upon their AIC values. AIC values were modified to AICc values to account for small sample size. When the negative binomial model was used, AICc values were further adjusted to QAICc by dividing the log-likelihood for each model by the variance inflation factor from the global model as recommended by Burnham and Anderson (2002) as a means to account for over dispersion. Of the suite of models investigated, Akaike weights sum to one and indicate how probable one model is compared to all others considered. The percent chance that an independent variable affected the response was given by summing the weights of all models that contained the variable in question and expressed as a percentage (100 minus this value represents the weight of evidence against that variable affecting the response).

The Information-Theoretic Approach is more straightforward with respect to interpretation of results than classic hypothesis testing. The p-values rendered by the latter represent the percentage of times the data would be randomly selected given that the null hypothesis is true, i.e., no difference among treatments. If this probability is larger than the *a priori* level of α, which is typically set to 0.05, then differences among treatments are deemed statistically insignificant. Further power analyses are required to move the interpretation beyond "failure to reject the null hypothesis" to the probability that the null would have been rejected had there been real differences of arbitrary levels. This approach is theoretically flawed and many statisticians and quantitative biologists strongly oppose the use of *post hoc* power analyses (Goodman and Berlin 1994; Gerard et al. 1998; Hoenig and Heisey 2001; Anderson et al. 2001; Burnham and Anderson 2002). The Information-Theoretic Approach directly estimates the probability of each hypothesis being true given the observed data and the suite of hypotheses being tested. Thus, the Information-Theoretic Approach is more in keeping with the idea of multiple working hypotheses (Chamberlin 1965; Burnham and Anderson 2002).

A1.5 QUANTIFYING EFFECT SIZE

Effect size across levels of the categorical variables was determined for *Species Richness* and species densities by comparing marginal means, e.g., means that arise when giving equal weight to all levels of all other categorical variables and holding continuous variables constant at their observed averages across all samples. For Dataset 3 continuous variables were averaged within each level of the categorical variable *Prospect*; for Datasets 1 and 2 continuous variables were averaged across the entire dataset. Continuous effect sizes were reported as the change multiplier that must be applied to the response in linear space given a one unit increase in the continuous variable.

The effect size from the multinomial model (*Assemblage Structure* response) is difficult, if not impossible, to reduce to a single value. However, ordination techniques are commonly used to reduce species × site matrices to a few dimensions. A common procedure that allows the simultaneous inclusion of environmental variables is canonical correspondence analysis (CCA), a form of direct gradient analysis (ter Braak and Prentice 1988). However, this ordination technique is sensitive to excessive zeroes in the dataset (McCune and Mefford 2006); the only remedy is to drop species and samples from the analysis, which invokes an arbitrary decision as to how many zeroes are too many. A method of choice for such datasets is non-metric Multidimensional Scaling (nMDS), a nonparametric ordination based on ranks that is insensitive to zeroes (Shepard 1962; Kruskal 1964). This approach is called an indirect gradient analysis because covariates must be correlated with ordination axes *post hoc*. The resulting biplot helps to visualize (1) how sampling stations compared with respect to *Assemblage Structure,* (2) how species compared to their distributions across sampling stations, and (3) how both were correlated with environmental variables. The percent of variance in *Assemblage Structure* explained by the ordination was determined using the Bray-Curtis distance measure. We reduced the number of independent variables included in the final biplot based on the results of the multinomial GLM; we only included variables receiving a 75% chance or more of being important. Catches were converted to species relative abundances prior to ordination. All ordinations were performed with the statistical software PC-ORD (McCune and Mefford 2006).

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APPENDIX 2 - RESULTS OF THE STATISTICAL ANALYSES: TABLES AND FIGURES

[1]S.W. Raborn

Table A2.1.1. Top ten models for each of the six response variables using the dataset that included all surveys. An "X" indicates that the term was present in the model; the weight of evidence (expressed as a percentage) is reported for each model.

Categorical variables		Continuous variables						
Gear	Nightday	Distance from shore	Salinity	Depth	Water temperature	Latitude	Longitude	Evidence for model (% chance)
Assemblage structure								
X	X		X	X	X	X		100.0%
X	X	X	X	X	X	X	X	0.0%
X	X	X		X	X	X		0.0%
X	X	X	X	X	X		X	0.0%
X	X	X	X	X		X		0.0%
X	X	X		X	X	X	X	0.0%
X	X	X	X	X		X	X	0.0%
X	X	X	X	X	X	X	X	0.0%
X	X	X		X	X		X	0.0%
X	X	X	X	X		X	X	0.0%
Species richness								
X			X			X		29.4%
X		X	X				X	29.3%
X			X	X		X		10.2%
X	X		X			X		10.2%
X			X		X	X		8.6%
X		X	X			X		4.4%
X			X			X	X	3.4%
X		X	X	X			X	2.2%
X	X	X	X				X	1.8%
X		X	X		X		X	0.2%
Arctic cod								
X					X			6.5%
X				X				4.8%
X			X				X	3.9%
X	X						X	3.9%
X					X		X	3.3%
X		X				X	X	2.6%
X			X					2.4%
X		X		X		X		2.3%
X		X						2.2%
X	X							2.2%
Arctic staghorn sculpin								
X						X	X	8.1%
X			X			X		5.4%
X		X				X		5.2%
X	X					X		4.5%
X					X	X		4.5%
X		X	X	X	X		X	3.6%
X			X	X	X	X	X	2.8%
X		X		X	X	X	X	2.6%
X		X	X	X		X	X	2.5%
X	X			X	X	X	X	2.5%
Bering flounder								
			X	X			X	5.4%
					X	X	X	3.2%
				X	X		X	2.9%
	X		X				X	2.9%
			X		X		X	2.9%
	X				X		X	2.8%
		X	X			X		2.7%
		X				X	X	2.2%
	X	X					X	2.1%
		X		X			X	2.0%

[1] LGL Ecological Research Associates, Inc., Bryan, Texas

Table A2.1.2. Evidence (expressed as a percentage) for each independent variable affecting each response variable (100 minus the reported value would indicate the evidence against the variable in question) using the dataset that included all surveys. Assemblage structure refers to the proportionate mix of species and is unit-less; species richness and the three species densities were compared as per 1,000 m^2. All possible models were used and averaged as per Burnham and Anderson (2002) to derive the percentages.

		Response variable				
Type of data	Independent variable	Assemblage structure	Species richness	Arctic cod	Arctic staghorn sculpin	Bering flounder
Categorical	Gear	100%	100%	100%	92%	17%
	Day versus night sampling	100%	100%	26%	26%	29%
Continuous	Latitude	100%	93%	50%	75%	32%
	Longitude	0%	60%	43%	48%	44%
	Water temperature	100%	100%	27%	30%	29%
	Salinity	100%	75%	26%	31%	31%
	Depth	100%	100%	30%	80%	28%
	Distance from shore	100%	58%	33%	44%	31%

Table A2.1.3. Predicted responses for all levels of categorical variables to gauge effect size using the dataset that included all surveys. Predicted marginal mean values (i.e., the means that are estimated while holding all other variables constant) from the generalized linear models are reported as the count of each response variable per 1,000 m^2 for the species densities and per 10 individuals for Richness. All possible models were used and averaged as per Burnham and Anderson (2002).

Categorical variable	Evidence for	Level	Predicted marginal mean
		Richness	
Gear	100%	3mBT	1.3
		5mBT	1.7
		NMFS83-112	0.1
		3m PSBT	1.5
Day versus night	100%	Day	1.3
		Night	1.0
		Arctic cod	
Gear	100%	3mBT	3.7
		5mBT	1.9
		NMFS83-112	10.9
		3m PSBT	32.4
Day versus night	26%	Day	12.2
		Night	12.3
		Arctic staghorn sculpin	
Gear	92%	3mBT	0.3
		5mBT	0.2
		NMFS83-112	0.1
		3m PSBT	1.9
Day versus night	26%	Day	0.6
		Night	0.6
		Bering flounder	
Gear	17%	3mBT	0.7
		5mBT	0.7
		NMFS83-112	0.7
		3m PSBT	1.0
Day versus night	29%	Day	0.9
		Night	0.7

Table A2.1.4. Model averaged coefficients for the continuous variables estimated with the generalized linear models using the dataset that included all surveys. Coefficient values are for the linear predictor, while the 1-unit-change-multiplier indicates how much the predicted response must be scaled given a one unit change in each continuous variable. The range in continuous each variable across the study is given (Highest observed-Lowest observed=Range across study), which was used to render the Across-study-multiplier. This metric facilitates comparison of the continuous variables with respect to effect size.

Continuous variable	Evidence for	Coefficient	Lowest observed	Highest observed	Range across study	1 unit change multiplier	Across study multiplier
				Richness			
Distance	58%	-0.001	55.3	307.0	251.8	1.00	0.83
Latitude	93%	0.600	69.2	72.4	3.2	1.82	6.94
Longitude	60%	0.047	-168.8	-159.4	9.4	1.05	1.55
Salinity	75%	-0.165	30.9	33.3	2.5	0.85	0.67
Depth	100%	0.033	20.5	55.0	34.5	1.03	3.13
Water temperature	100%	0.091	-1.8	7.9	9.6	1.10	2.40
				Arctic cod			
Distance	33%	0.001	55.3	307.0	251.8	1.00	1.42
Latitude	50%	-0.356	69.2	72.4	3.2	0.70	0.32
Longitude	43%	-0.038	-168.8	-159.4	9.4	0.96	0.70
Salinity	26%	-0.024	30.9	33.3	2.5	0.98	0.94
Depth	30%	0.009	20.5	55.0	34.5	1.01	1.35
Water temperature	27%	0.005	-1.8	7.9	9.6	1.01	1.05
				Arctic staghorn sculpin			
Distance	44%	-0.006	55.3	307.0	251.8	0.99	0.25
Latitude	75%	-1.717	69.2	72.4	3.2	0.18	0.00
Longitude	48%	-0.293	-168.8	-159.4	9.4	0.75	0.06
Salinity	31%	0.202	30.9	33.3	2.5	1.22	1.64
Depth	80%	-0.176	20.5	55.0	34.5	0.84	0.00
Water temperature	30%	-0.029	-1.8	7.9	9.6	0.97	0.76
				Bering flounder			
Distance	31%	0.001	55.3	307.0	251.8	1.00	1.40
Latitude	32%	-0.388	69.2	72.4	3.2	0.68	0.29
Longitude	44%	-0.545	-168.8	-159.4	9.4	0.58	0.01
Salinity	31%	0.497	30.9	33.3	2.5	1.64	3.40
Depth	28%	0.001	20.5	55.0	34.5	1.00	1.05
Water temperature	29%	-0.042	-1.8	7.9	9.6	0.96	0.67

Table A2.2.1. Top ten models for each of the five response variables using the dataset that included only the 2009 and 2010 surveys. An "X" indicates that the term was present in the model; the weight of evidence (expressed as a percent chance that this model was the most appropriate versus all other considered) is reported for each model.

Categorical variables			Continuous Variables								
Gear	Nightday	Year	Distance from shore	Salinity	Depth	Water temperature	Latitude	Longitude	% Gravel	% Mud	Evidence for model (% chance)
					Assemblage structure						
X	X	X	X	X	X	X	X	X	X	X	100.0%
X	X	X	X		X	X	X	X	X	X	0.0%
X	X	X	X	X	X	X	X		X	X	0.0%
X	X	X	X	X	X	X	X	X	X		0.0%
X	X	X	X	X	X	X	X		X		0.0%
X	X		X	X	X	X	X		X	X	0.0%
X	X	X	X		X	X	X		X	X	0.0%
X	X	X		X	X	X	X	X	X	X	0.0%
X	X		X	X	X	X	X	X	X	X	0.0%
X	X	X	X	X	X	X		X	X	X	0.0%
					Species richness						
X	X	X			X	X	X	X	X	X	26.9%
X	X	X	X		X	X	X	X	X	X	15.9%
X	X	X	X		X	X	X		X	X	12.6%
X	X	X		X	X	X	X	X	X	X	12.3%
X	X	X	X	X	X	X	X	X	X	X	6.8%
X	X	X			X	X	X		X	X	6.0%
X	X	X	X	X	X	X	X		X	X	5.7%
X	X	X	X		X	X		X	X	X	2.9%
X	X	X		X	X	X	X		X	X	2.4%
X	X	X	X	X	X	X		X	X	X	1.5%
					Arctic cod						
X	X									X	2.6%
X					X	X				X	2.2%
X			X			X				X	1.8%
X						X			X		1.3%
X				X		X				X	1.3%
X						X		X		X	1.2%
X		X								X	1.1%
X				X					X		1.1%
X					X				X		1.1%
X					X					X	1.0%
					Arctic staghorn sculpin						
X					X		X	X	X		1.4%
X				X	X		X		X		1.3%
X	X				X		X			X	1.3%
		X			X		X		X	X	1.2%
		X	X		X		X			X	1.2%
		X			X		X	X		X	0.9%
		X		X	X		X			X	0.8%
		X			X	X	X			X	0.6%
					X		X	X		X	0.6%
			X		X		X			X	0.6%
					Bering flounder						
		X	X					X	X		2.0%
		X		X				X	X		1.9%
		X					X	X	X		1.4%
		X						X	X	X	1.2%
X			X	X				X		X	1.2%
X				X		X		X		X	1.2%
X	X			X				X		X	1.1%
X				X			X	X		X	1.0%
X	X				X			X	X		1.0%
X			X				X		X		0.8%

Table A2.2.2. The weight of evidence (expressed as a percent chance that this variable was important) for each independent variable affecting each response variable (100 minus the reported value would indicate the evidence against the variable in question) using the dataset that included only the 2009 and 2010 surveys. Assemblage structure refers to the proportionate mix of species and is unit-less; species richness was compared on a per individual basis (i.e., number of species per 10 individuals), and the three species densities were compared as per 1,000 m^2. All possible models were used and averaged as per Burnham and Anderson (2002) to derive the percentages.

		Response variable				
Type of data	Independent variable	Assemblage structure	Species richness	Arctic cod	Arctic staghorn sculpin	Bering flounder
Categorical	Year	100%	100%	18%	23%	34%
	Gear	100%	100%	81%	22%	53%
	Day versus night sampling	100%	99%	18%	9%	18%
Continuous	Latitude	100%	93%	21%	51%	17%
	Longitude	100%	69%	18%	17%	70%
	Water temperature	100%	96%	34%	12%	20%
	Salinity	100%	32%	19%	12%	28%
	Depth	100%	100%	18%	48%	17%
	% gravel	100%	100%	38%	28%	48%
	% mud	100%	100%	61%	35%	35%
	Distance from shore	100%	49%	16%	16%	18%

Table A2.2.3. Predicted responses for all levels of categorical variables to gauge effect size using the dataset that included all 2009 and 2010 surveys only. Predicted marginal mean values (i.e., the means that are estimated while holding all other variables constant) from the generalized linear models are reported as the count of each response variable per 1,000 m^2 for the species densities and per 10 individuals for Richness. All possible models were used and averaged as per Burnham and Anderson (2002).

Categorical variable	Evidence for	Level	Predicted marginal mean
	Richness		
Year	100%	2009	0.9
		2010	2.0
Gear	100%	3mBT	1.5
		5mBT	0.8
		3m PSBT	2.0
Day versus night	92%	Day	1.6
		Night	1.3
	Arctic cod		
Year	17%	2009	12.7
		2010	12.3
Gear	83%	3mBT	3.1
		5mBT	1.7
		3m PSBT	32.6
Day versus night	16%	Day	12.4
		Night	12.6
	Arctic staghorn sculpin		
Year	22%	2009	1.4
		2010	0.8
Gear	22%	3mBT	0.8
		5mBT	1.0
		3m PSBT	1.4
Day versus night	12%	Day	1.0
		Night	1.2
	Bering flounder		
Year	36%	2009	0.8
		2010	0.4
Gear	62%	3mBT	0.3
		5mBT	0.3
		3m PSBT	1.1
Day versus night	21%	Day	0.6
		Night	0.5

Table A2.2.4. Model averaged coefficients for the continuous variables estimated with the generalized linear models using the dataset that included all 2009 and 2010 surveys only. Coefficient values are for the linear predictor, while the 1-unit-change-multiplier indicates how much the predicted response must be scaled given a one unit change in each continuous variable. The range in continuous each variable across the study is given (Highest observed-Lowest observed=Range across study), which was used to render the Across-study-multiplier. This metric facilitates comparison of the continuous variables with respect to effect size.

Continuous variable	Evidence for	Coefficient	Lowest observed	Highest observed	Range across study	1 unit change multiplier	Across study multiplier
Richness							
Distance	39%	0.000	55.3	255.5	200.2	1.00	0.94
Latitude	97%	0.587	69.5	72.4	2.9	1.80	5.58
Longitude	50%	-0.038	-168.3	-159.4	8.9	0.96	0.72
Salinity	27%	-0.024	30.9	32.9	2.1	0.98	0.95
Depth	100%	0.057	20.5	55.0	34.5	1.06	7.06
Water temperature	74%	-0.046	-1.8	7.9	9.6	0.96	0.64
%Gravel	97%	-0.007	0.0	98.0	98.0	0.99	0.51
%Mud	100%	-0.012	0.0	92.5	92.5	0.99	0.33
Arctic cod							
Distance	17%	0.001	55.3	255.5	200.2	1.00	1.11
Latitude	23%	-0.152	69.5	72.4	2.9	0.86	0.64
Longitude	21%	-0.014	-168.3	-159.4	8.9	0.99	0.88
Salinity	18%	0.020	30.9	32.9	2.1	1.02	1.04
Depth	19%	0.007	20.5	55.0	34.5	1.01	1.26
Water temperature	26%	0.033	-1.8	7.9	9.6	1.03	1.38
%Gravel	36%	0.002	0.0	98.0	98.0	1.00	1.26
%Mud	70%	0.011	0.0	92.5	92.5	1.01	2.85
Arctic staghorn sculpin							
Distance	18%	-0.007	55.3	255.5	200.2	0.99	0.26
Latitude	52%	-2.238	69.5	72.4	2.9	0.11	0.00
Longitude	19%	-0.219	-168.3	-159.4	8.9	0.80	0.14
Salinity	11%	0.059	30.9	32.9	2.1	1.06	1.13
Depth	45%	-0.158	20.5	55.0	34.5	0.85	0.00
Water temperature	12%	0.012	-1.8	7.9	9.6	1.01	1.13
%Gravel	30%	0.005	0.0	98.0	98.0	1.00	1.56
%Mud	38%	-0.012	0.0	92.5	92.5	0.99	0.32
Bering flounder							
Distance	19%	-0.001	55.3	255.5	200.2	1.00	0.90
Latitude	19%	0.006	69.5	72.4	2.9	1.01	1.02
Longitude	77%	-0.975	-168.3	-159.4	8.9	0.38	0.00
Salinity	36%	0.665	30.9	32.9	2.1	1.94	3.94
Depth	16%	-0.010	20.5	55.0	34.5	0.99	0.70
Water temperature	22%	0.006	-1.8	7.9	9.6	1.01	1.06
%Gravel	44%	0.002	0.0	98.0	98.0	1.00	1.21
%Mud	44%	-0.002	0.0	92.5	92.5	1.00	0.84

Table A2.3.1. Top ten models for each of the five response variables using the dataset that included the 2009 and 2010 CSESP surveys only. An "X" indicates that the term was present in the model; the weight of evidence (expressed as a percent chance that this model was the most appropriate versus all other considered) is reported for each model.

Categorical variables				Continuous variables					
Gear	Nightday	Year	Prospect	Salinity	Depth	Water temperature	% Gravel	% Mud	Evidence for model (% chance)
Assemblage structure									
X	X	X	X	X	X	X	X	X	100.0%
X	X		X	X	X	X	X	X	0.0%
	X	X	X	X	X	X	X	X	0.0%
X	X	X	X	X		X	X	X	0.0%
X	X		X	X		X	X	X	0.0%
X	X	X	X	X	X	X	X		0.0%
X	X	X	X	X	X		X	X	0.0%
X	X		X	X	X	X	X		0.0%
	X		X	X	X	X	X	X	0.0%
	X	X	X		X	X	X	X	0.0%
Species richness									
X		X	X		X	X	X	X	27.8%
X		X	X		X		X	X	14.6%
X		X	X	X	X	X	X	X	8.5%
		X	X		X	X	X	X	8.5%
X	X	X	X		X	X	X	X	8.4%
		X	X		X		X	X	5.6%
X	X	X	X		X		X	X	4.6%
X		X	X	X	X		X	X	4.6%
		X	X	X	X	X	X	X	2.7%
	X	X	X		X	X	X	X	2.6%
Arctic cod									
X		X				X		X	4.7%
X			X					X	3.3%
X		X				X	X	X	3.1%
X	X							X	2.7%
X					X	X			2.4%
X	X				X				2.4%
X				X		X		X	2.0%
X					X			X	2.0%
X		X						X	1.9%
X				X				X	1.7%
Arctic staghorn sculpin									
X	X		X	X	X				3.7%
			X			X			3.7%
X	X		X				X		2.8%
			X					X	2.8%
X	X	X	X						2.4%
	X	X	X						1.6%
X	X	X	X		X				1.6%
X	X		X		X			X	1.6%
X	X		X		X	X			1.5%
X	X		X			X			1.5%
Bering flounder									
			X			X	X		3.0%
X		X	X	X					2.2%
X			X	X		X			2.1%
X	X		X	X					1.9%
X			X			X	X		1.8%
X		X	X				X		1.8%
		X	X			X			1.7%
			X	X	X		X		1.6%
X			X				X	X	1.6%
	X	X	X						1.6%

Table A2.3.2. The weight of evidence (expressed as a percent chance that this variable was important) for each independent variable affecting each response variable (100 minus the reported value would indicate the evidence against the variable in question) using the dataset that included the 2009 and 2010 CSESP surveys only. Assemblage structure refers to the proportionate mix of species and is unit-less; species richness was compared on a per individual basis (i.e., number of species per 10 individuals), and the three species densities were compared as per 1,000 m^2. All possible models were used and averaged as per Burnham and Anderson (2002) to derive the percentages.

		Response variable				
Type of data	Independent variable	Assemblage structure	Species richness	Arctic cod	Arctic staghorn sculpin	Bering flounder
Categorical	Year	100%	100%	27%	30%	31%
	Gear	100%	74%	100%	62%	45%
	Day versus night sampling	100%	24%	30%	41%	22%
	Prospect	100%	100%	100%	100%	100%
Continuous	Water temperature	100%	64%	38%	26%	29%
	Salinity	100%	24%	26%	29%	39%
	Depth	100%	100%	31%	45%	29%
	% gravel	100%	97%	37%	28%	27%
	% mud	100%	100%	51%	27%	30%

Table A2.3.3. Predicted responses for all levels of categorical variables to gauge effect size using the dataset that included the 2009 and 2010 CSESP surveys only. Predicted marginal mean values (i.e., the means that are estimated while holding all other variables constant) from the generalized linear models are reported as the count of each response variable per 1,000 m^2 for the species densities and per 10 individuals for Richness. All possible models were used and averaged as per Burnham and Anderson (2002).

Categorical variable	Evidence for	Level	Predicted marginal mean
	Richness		
Year	100%	2009	1.0
		2010	2.2
Gear	74%	3mBT	1.4
		3m PSBT	1.7
Day versus night	24%	Day	1.6
		Night	1.6
Prospect	100%	Klondike	1.1
		Burger	1.7
		StatOil	1.9
	Arctic cod		
Year	27%	2009	20.9
		2010	19.5
Gear	100%	3mBT	3.7
		3m PSBT	36.7
Day versus night	30%	Day	21.4
		Night	19.0
Prospect	18%	Klondike	20.5
		Burger	20.3
		StatOil	19.8
	Arctic staghorn sculpin		
Year	30%	2009	2.5
		2010	2.0
Gear	62%	3mBT	1.4
		3m PSBT	3.0
Day versus night	41%	Day	1.8
		Night	2.6
Prospect	100%	Klondike	6.4
		Burger	0.2
		StatOil	0.0
	Bering flounder		
Year	31%	2009	0.7
		2010	0.5
Gear	45%	3mBT	0.4
		3m PSBT	0.8
Day versus night	22%	Day	0.6
		Night	0.6
Prospect	91%	Klondike	1.4
		Burger	0.1
		StatOil	0.3

Table A2.3.4. Model averaged coefficients for the continuous variables estimated with the generalized linear models using the dataset that included the 2009 and 2010 CSESP surveys only. Coefficient values are for the linear predictor, while the 1-unit-change-multiplier indicates how much the predicted response must be scaled given a one unit change in each continuous variable. The range in continuous each variable across the study is given (Highest observed-Lowest observed=Range across study), which was used to render the Across-study-multiplier. This metric facilitates comparison of the continuous variables with respect to effect size.

Continuous variable	Evidence for	Coefficient	Lowest observed	Highest observed	Range across study	1 unit change multiplier	Across study multiplier
Richness							
Salinity	24%	-0.002	30.9	32.8	2.0	1.00	1.00
Depth	100%	0.092	32.7	45.3	12.5	1.10	3.17
Water temperature	64%	-0.043	-1.5	7.9	9.4	0.96	0.67
%Gravel	97%	-0.008	0.0	60.6	60.6	0.99	0.60
%Mud	100%	-0.014	9.5	92.5	83.0	0.99	0.32
Arctic cod							
Salinity	26%	0.009	30.9	32.8	2.0	1.01	1.02
Depth	31%	0.023	32.7	45.3	12.5	1.02	1.34
Water temperature	38%	0.045	-1.5	7.9	9.4	1.05	1.53
%Gravel	37%	0.006	0.0	60.6	60.6	1.01	1.43
%Mud	51%	0.009	9.5	92.5	83.0	1.01	2.03
Arctic staghorn sculpin							
Salinity	29%	-0.196	30.9	32.8	2.0	0.82	0.68
Depth	45%	-0.095	32.7	45.3	12.5	0.91	0.30
Water temperature	26%	-0.010	-1.5	7.9	9.4	0.99	0.91
%Gravel	28%	-0.004	0.0	60.6	60.6	1.00	0.79
%Mud	27%	-0.002	9.5	92.5	83.0	1.00	0.84
Bering flounder							
Salinity	39%	0.749	30.9	32.8	2.0	2.11	4.31
Depth	29%	0.054	32.7	45.3	12.5	1.06	1.96
Water temperature	29%	-0.022	-1.5	7.9	9.4	0.98	0.82
%Gravel	27%	-0.006	0.0	60.6	60.6	0.99	0.72
%Mud	30%	0.007	9.5	92.5	83.0	1.01	1.72

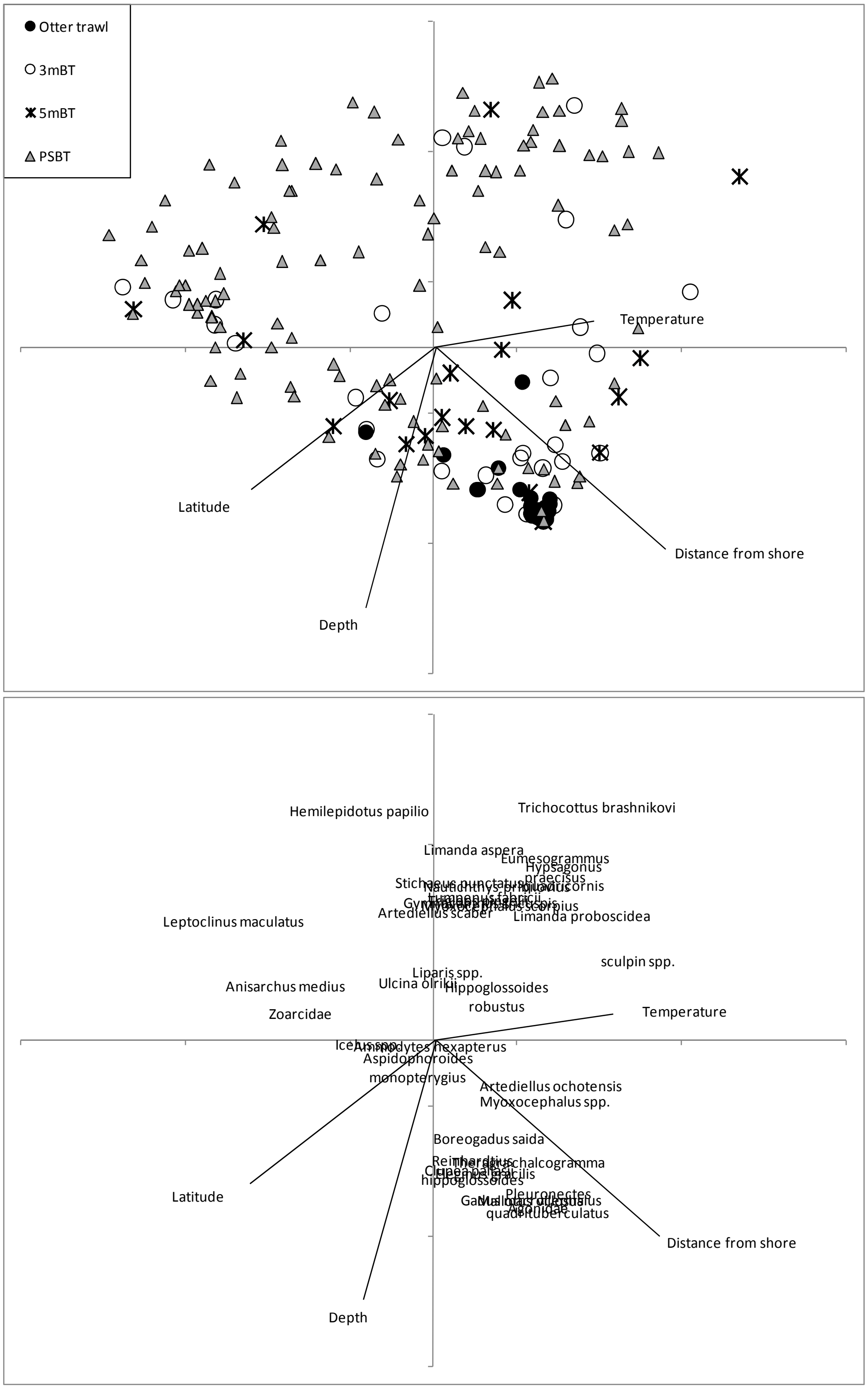

Figure A2.1.1. Axes 1 and 2 from the nonmetric multidimensional scaling (nMDS) ordination of stations and species relative abundances using the dataset that included all surveys. Covariate coordinates were determined via Pearson's product moment correlations with axes. Various marker types in the top panel indicate different levels of the categorical variable *Gear*. The ordination was successful in explaining 48% of the changes in assemblage structure based on the Bray-Curtis (city-block) distance measure.

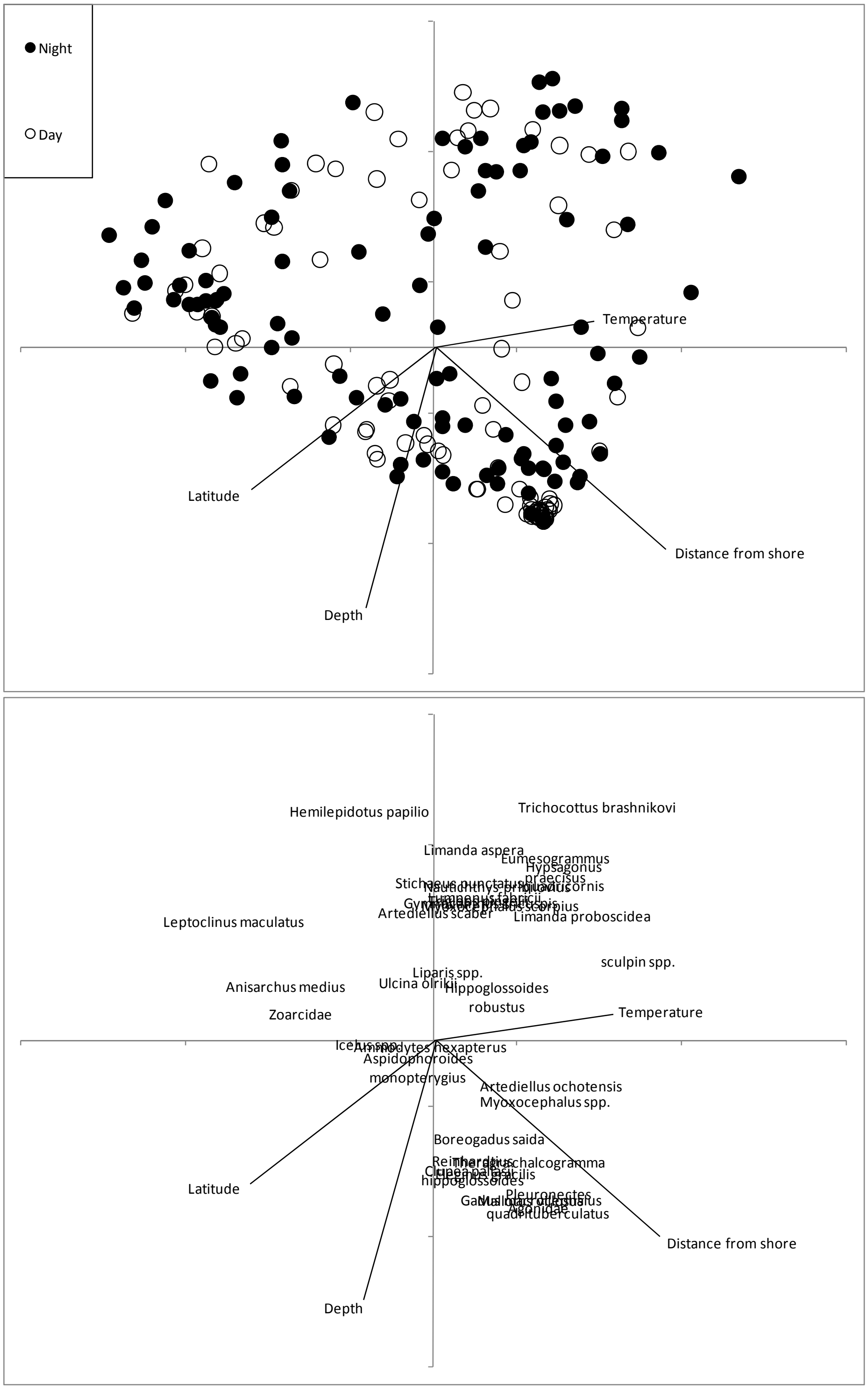

Figure A2.1.2. Axes 1 and 2 from the nonmetric multidimensional scaling (nMDS) ordination of stations and species relative abundances using the dataset that included all surveys. Covariate coordinates were determined via Pearson's product moment correlations with axes. Various marker types in the top panel indicate different levels of the categorical variable *Night-versus-Day*. The ordination was successful in explaining 48% of the changes in assemblage structure based on the Bray-Curtis (city-block) distance measure.

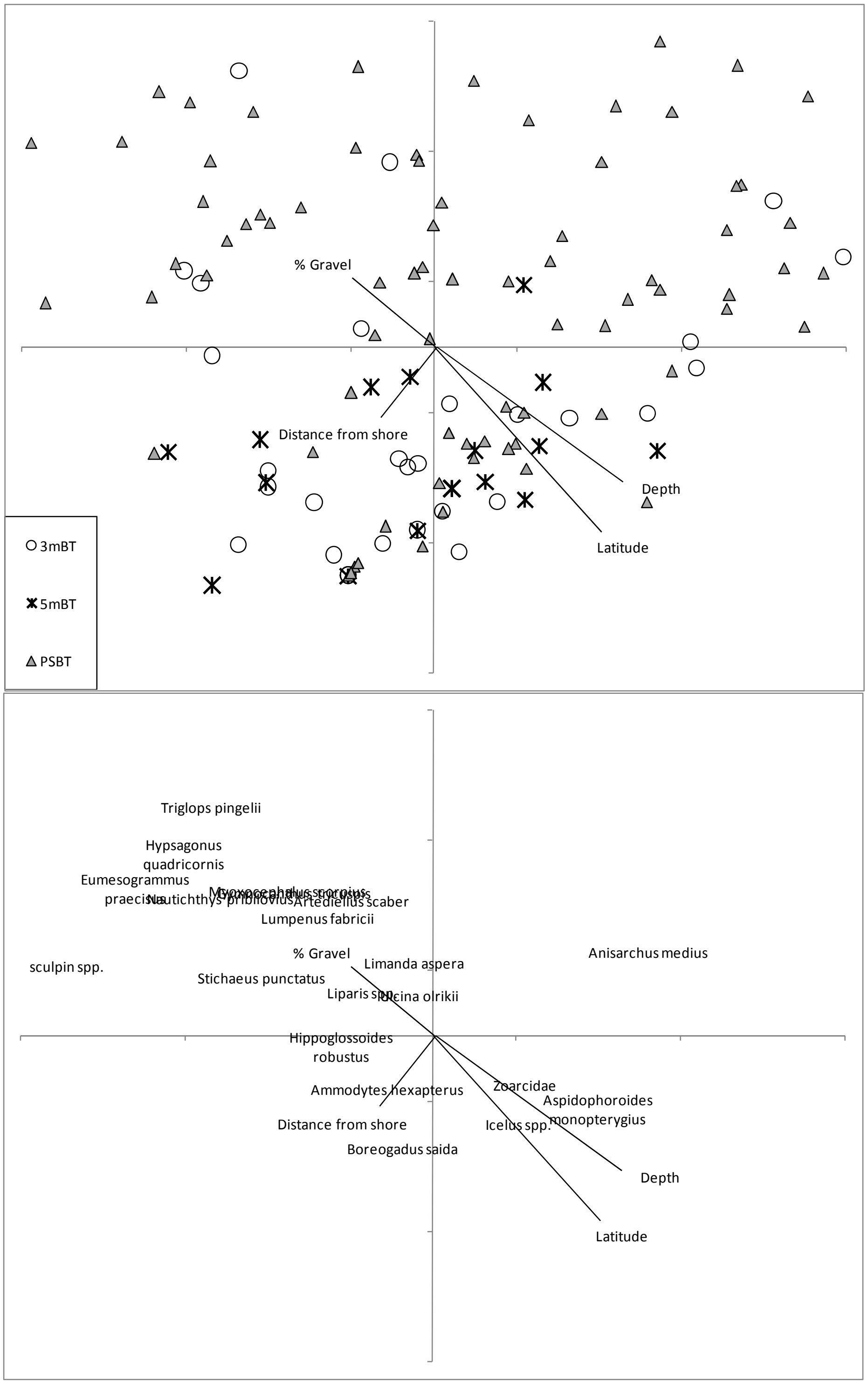

Figure A2.2.1. Axes 1 and 2 from the nonmetric multidimensional scaling (nMDS) ordination of stations and species relative abundances using the dataset that included all 2009 and 2010 surveys only. Covariate coordinates were determined via Pearson's product moment correlations with axes. Various marker types in the top panel indicate different levels of the categorical variable *Gear*. The ordination was successful in explaining 49% of the changes in assemblage structure based on the Bray-Curtis (city-block) distance measure.

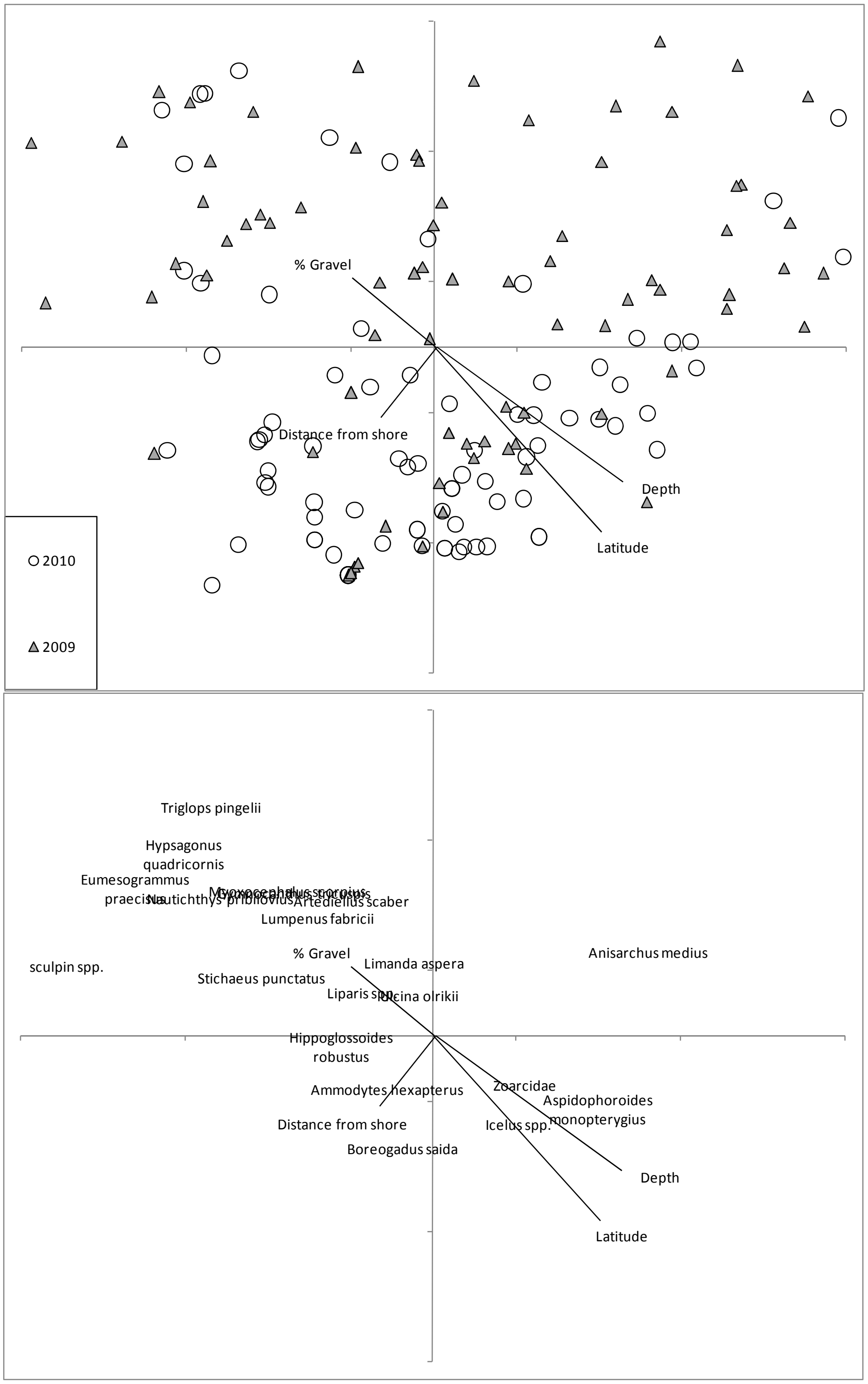

Figure A2.2.2. Axes 1 and 2 from the nonmetric multidimensional scaling (nMDS) ordination of stations and species relative abundances using the dataset that included all 2009 and 2010 surveys only. Covariate coordinates were determined via Pearson's product moment correlations with axes. Various marker types in the top panel indicate different levels of the categorical variable *Year*. The ordination was successful in explaining 49% of the changes in assemblage structure based on the Bray-Curtis (city-block) distance measure.

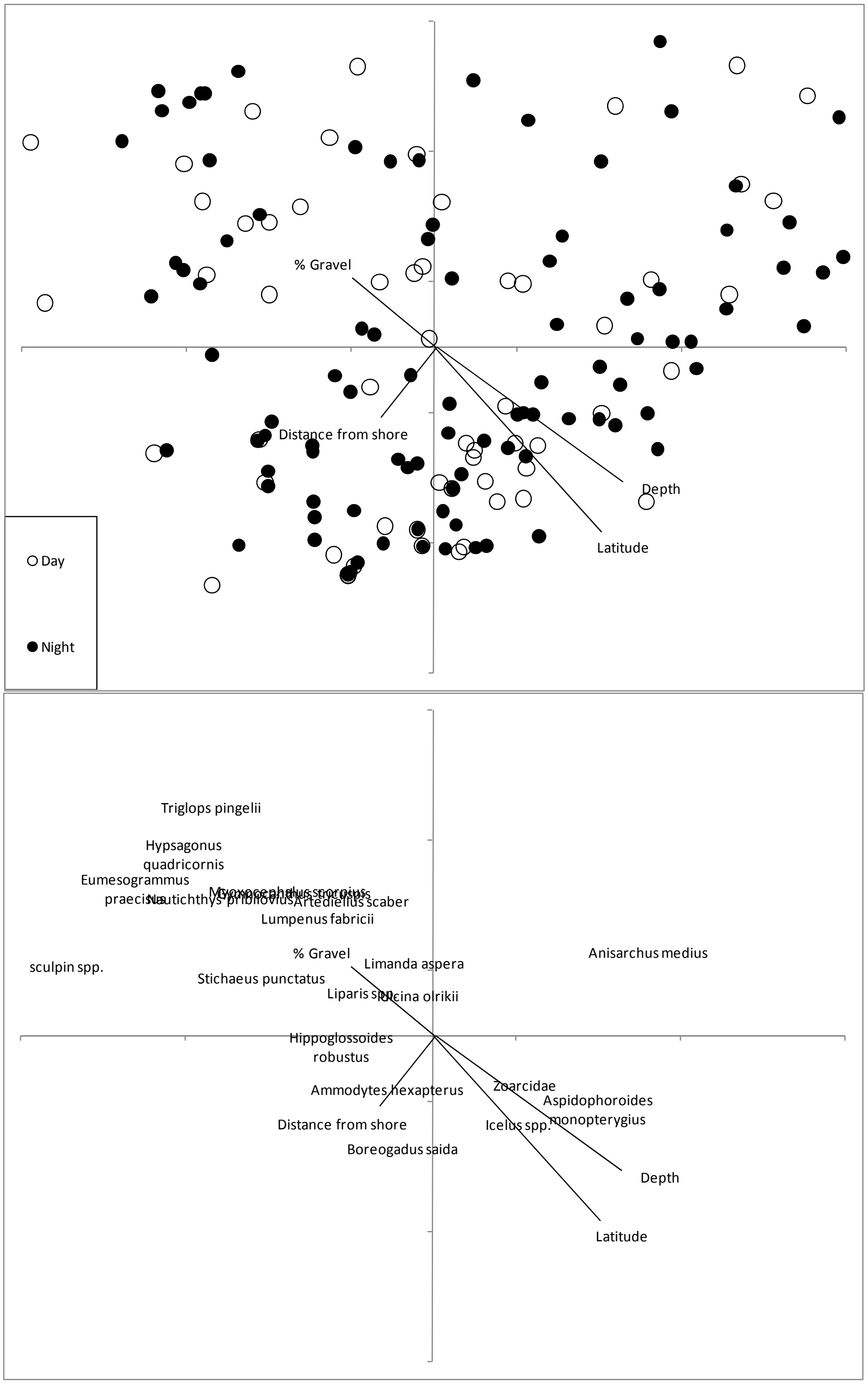

Figure A2.2.3. Axes 1 and 2 from the nonmetric multidimensional scaling (nMDS) ordination of stations and species relative abundances using the dataset that included all 2009 and 2010 surveys only. Covariate coordinates were determined via Pearson's product moment correlations with axes. Various marker types in the top panel indicate different levels of the categorical variable *Night-versus-Day*. The ordination was successful in explaining 49% of the changes in assemblage structure based on the Bray-Curtis (city-block) distance measure.

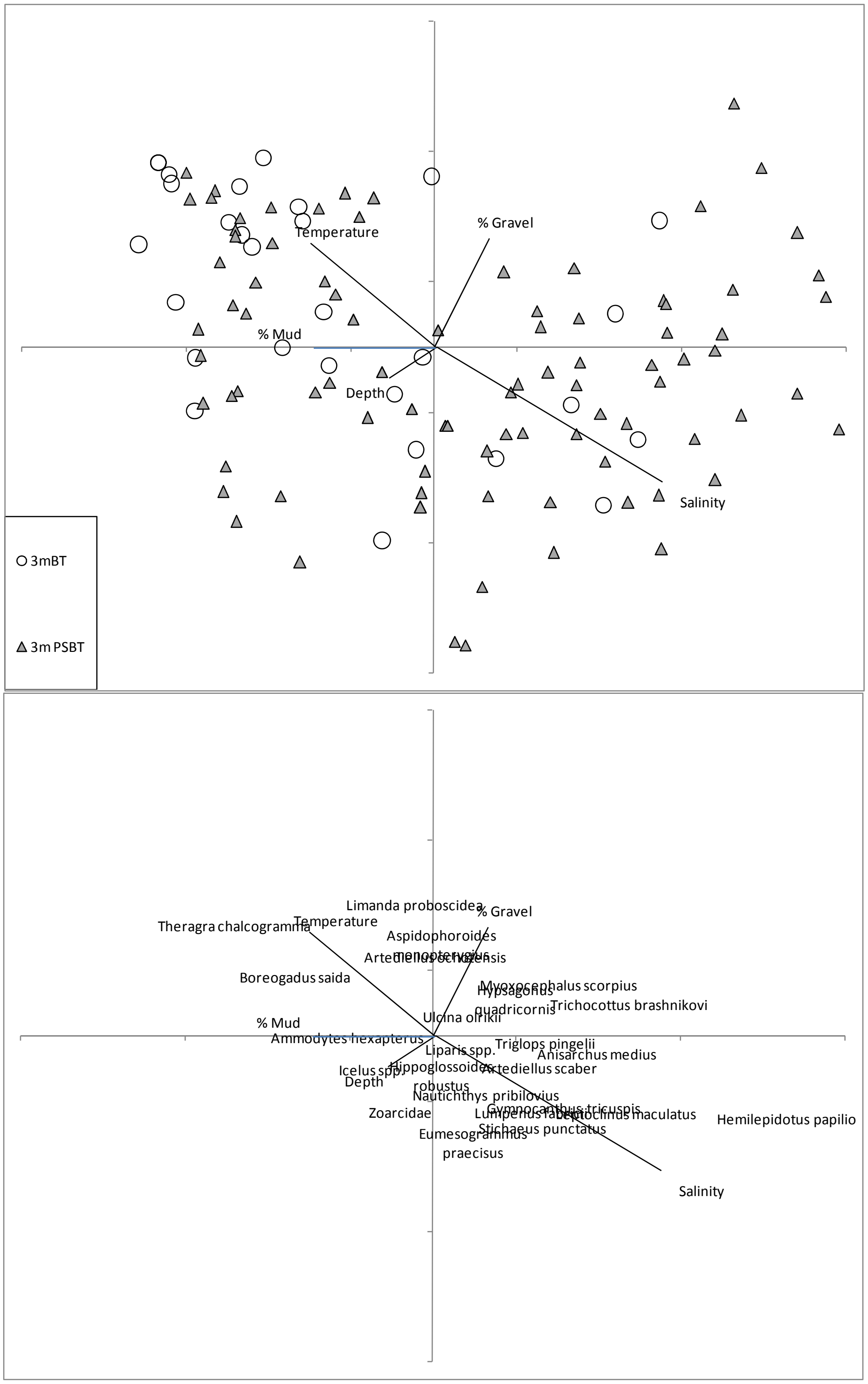

Figure A2.3.1. Axes 1 and 2 from the nonmetric multidimensional scaling (nMDS) ordination of stations and species relative abundances using the dataset that included the 2009 and 2010 CSESP surveys only. Covariate coordinates were determined via Pearson's product moment correlations with axes. Various marker types in the top panel indicate different levels of the categorical variable *Gear*. The ordination was successful in explaining 73% of the changes in assemblage structure based on the Bray-Curtis (city-block) distance measure.

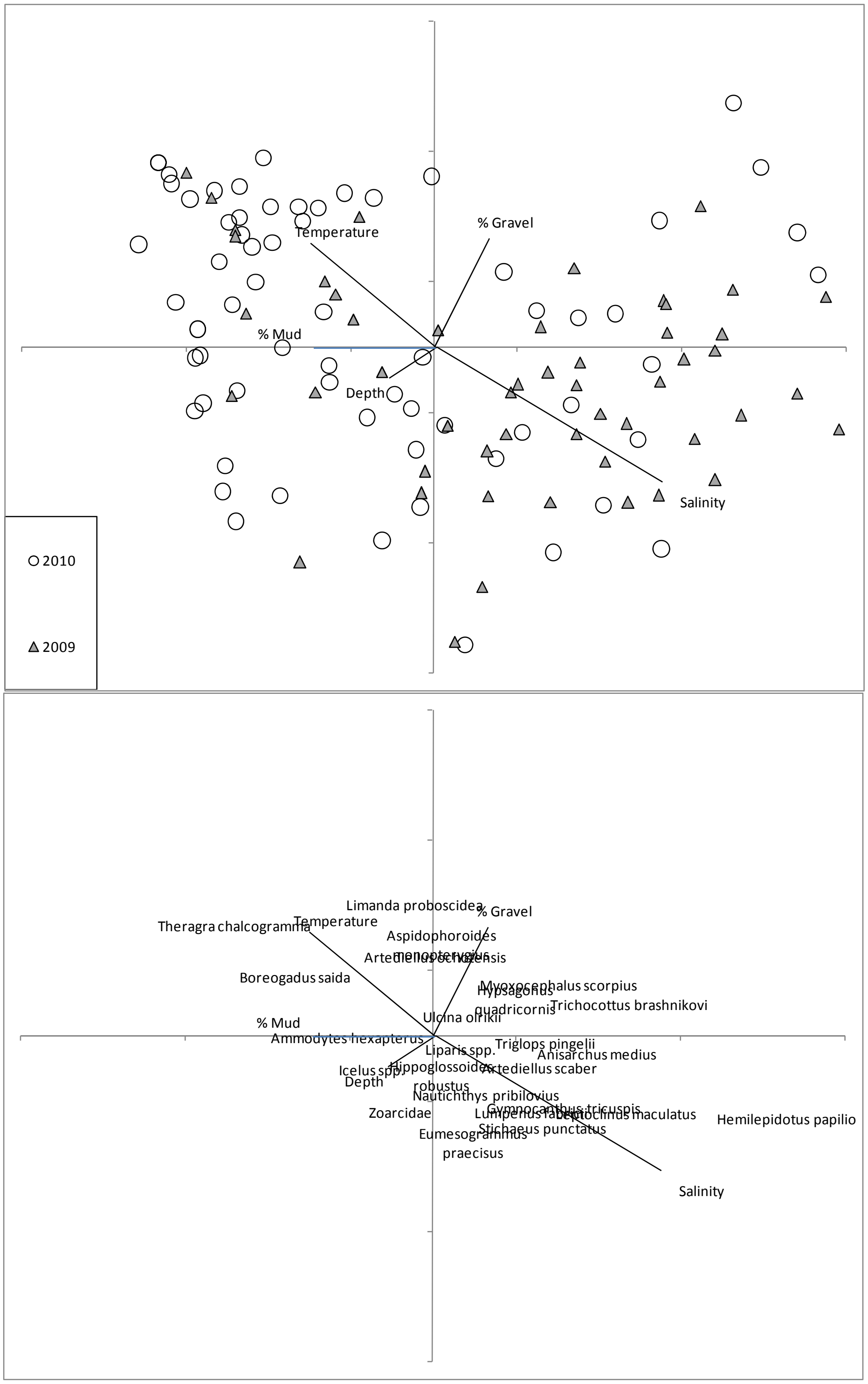

Figure A2.3.2. Axes 1 and 2 from the nonmetric multidimensional scaling (nMDS) ordination of stations and species relative abundances using the dataset that included the 2009 and 2010 CSESP surveys only. Covariate coordinates were determined via Pearson's product moment correlations with axes. Various marker types in the top panel indicate different levels of the categorical variable *Year*. The ordination was successful in explaining 73% of the changes in assemblage structure based on the Bray-Curtis (city-block) distance measure.

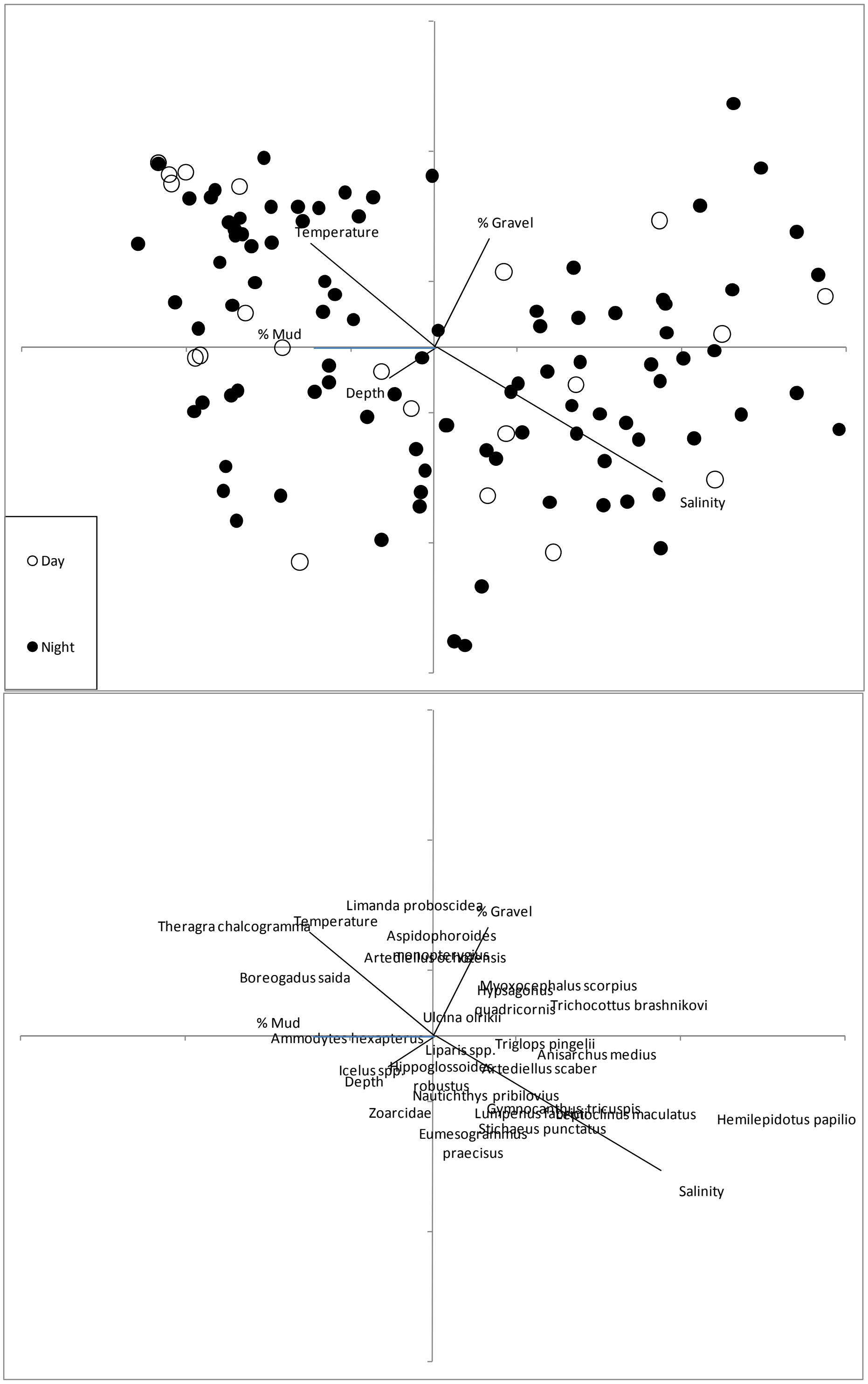

Figure A2.3.3. Axes 1 and 2 from the nonmetric multidimensional scaling (nMDS) ordination of stations and species relative abundances using the dataset that included the 2009 and 2010 CSESP surveys only. Covariate coordinates were determined via Pearson's product moment correlations with axes. Various marker types in the top panel indicate different levels of the categorical variable *Night-versus-Day*. The ordination was successful in explaining 73% of the changes in assemblage structure based on the Bray-Curtis (city-block) distance measure.

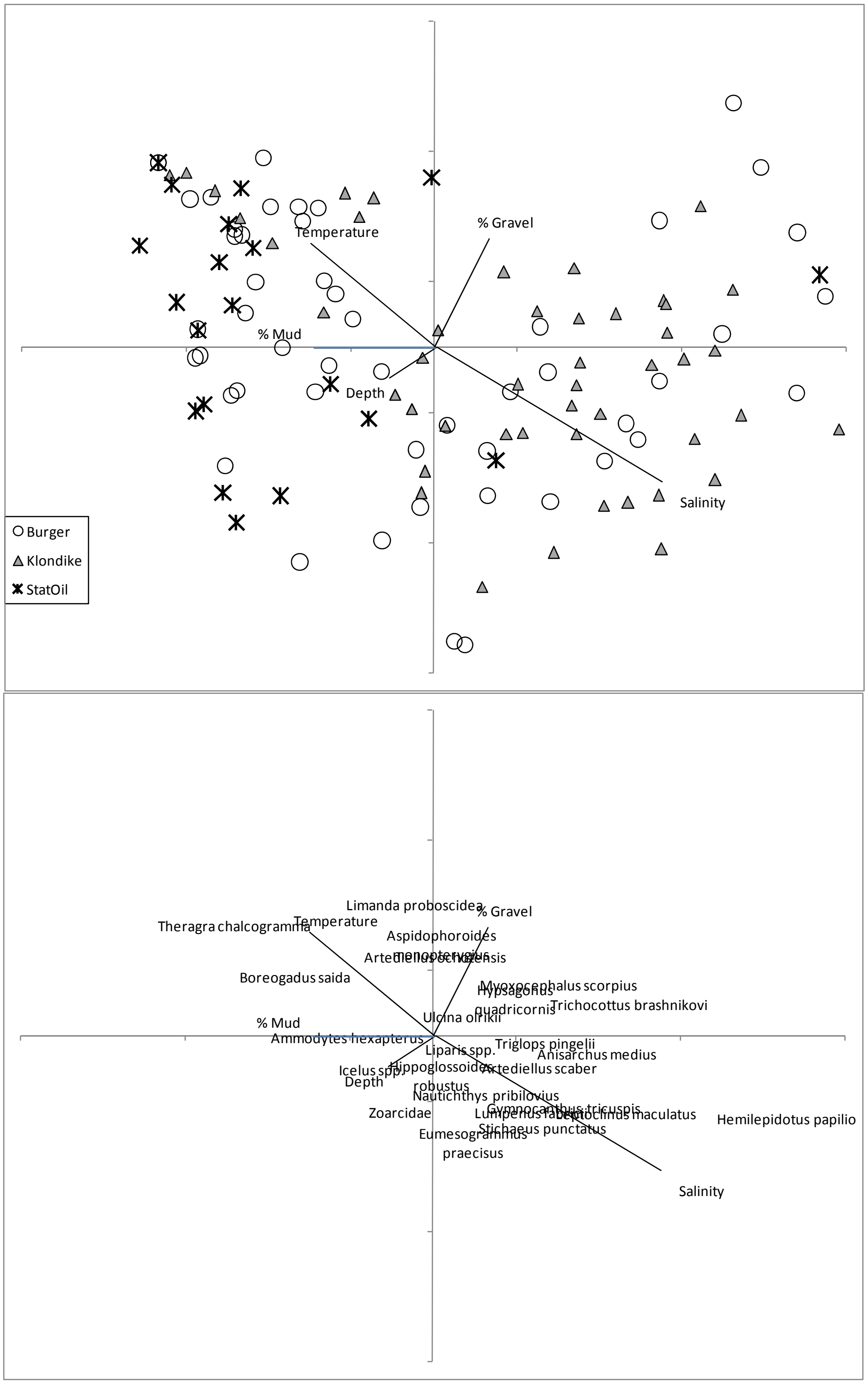

Figure A2.3.4. Axes 1 and 2 from the nonmetric multidimensional scaling (nMDS) ordination of stations and species relative abundances using the dataset that included the 2009 and 2010 CSESP surveys only. Covariate coordinates were determined via Pearson's product moment correlations with axes. Various marker types in the top panel indicate different levels of the categorical variable *Prospect*. The ordination was successful in explaining 73% of the changes in assemblage structure based on the Bray-Curtis (city-block) distance measure.

A2.1 REFERENCES

Burnham KP, Anderson DR (2002) Model selection and multimodel inference: a practical information-theoretic approach, 2nd edition. Springer-Verlag, New York.

APPENDIX 3 - SAMPLING STATIONS AND DATA OVERVIEW FOR EACH OF NINE CRUISES (1989–2010)

[1]B.A. Holladay, [1]B.L. Norcross

This appendix provides maps, a brief description of fishing collections, and citations of source data for the nine collections of fishes that are considered within the chapters and appendices of this report. Cruise names are as in Chapter 1 Table 1.1 of this report.

[1] University of Alaska Fairbanks, Fairbanks, Alaska

A3.1 BARBER 1989

The cruise we refer to as Barber 1989 was reported previously as HX130. Data from the Barber 1989 cruise contributed to Appendix 4 of this report.

Vessel: R/V *Alpha Helix*.
N=25 stations. Only the northernmost 14 stations were analyzed in Appendix 4 of this report.
Demersal fishing gear: 6.1-m otter trawl with 35-mm mesh, no codend liner; coded 6mOT in this report.
Fish data: Counts of fish per haul.
Source of fish data:
Barber et al. (1994: Appendix 1) –*Cruise report of collection methods and counts of fish*.

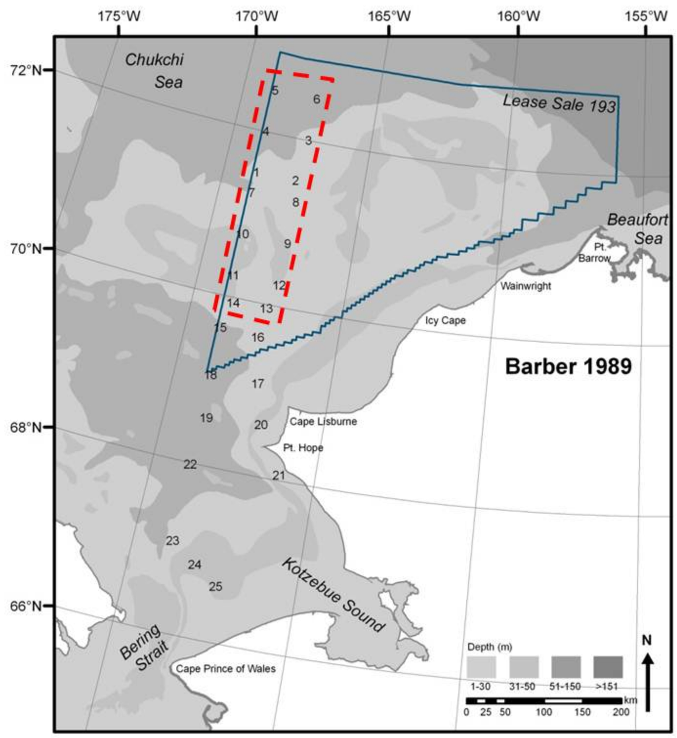

Figure A3.1. Map of fishing stations during Barber 1989. Labels indicate station names. The 14 stations surrounded with a dashed line were analyzed in Appendix 4 of this report.

A3.2 BARBER 1990

The cruise we refer to as Barber 1990 has been referred to elsewhere as OH902. Data from the Barber 1990 cruise contributed to Chapters 2–3 and Appendix 4 of this report.

Vessel: F/V *Ocean Hope III*.
N=48 stations.
Demersal fishing gear: 83-112 Eastern otter trawl with 32-mm codend liner; Scanmar mensuration equipment recorded horizontal and vertical opening during each haul; coded 83-112OT in this report.
Fish data: Counts and biomass of fish per area; lengths of fish specimens.
Sources of fish data:
Barber et al. (1997) –*Summaries of abundance, biomass and length data; detailed information for a subset of species at a subset of stations*.
NODC Accession 9400061 http://www.nodc.noaa.gov/cgi-bin/OAS/prd/accession/details/9400061 –*Electronic data files of fish abundance and biomass for all species and stations*.

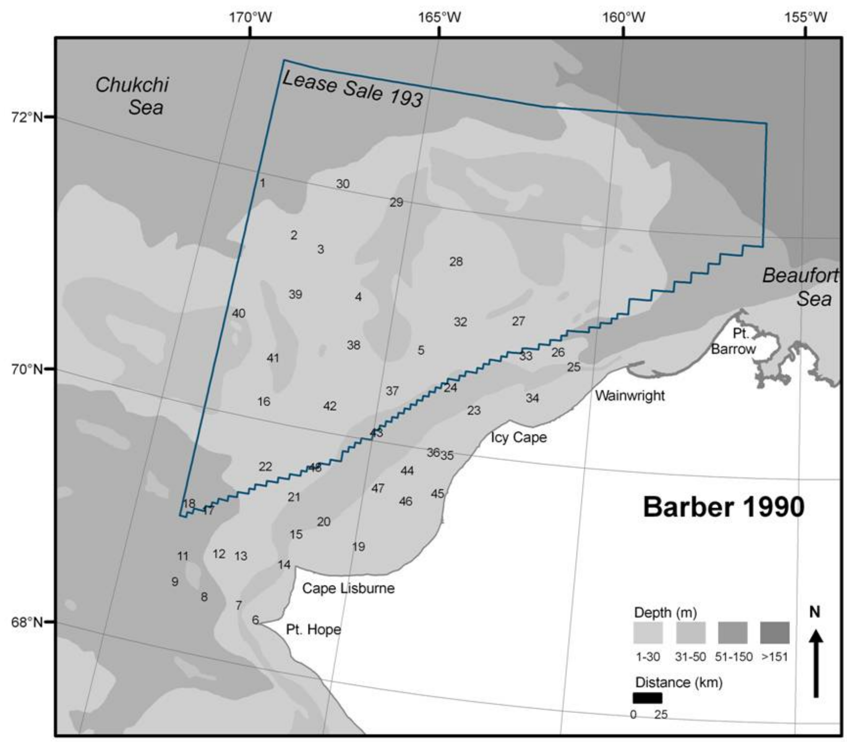

Figure A3.2. Map of fishing stations sampled during Barber 1990. Labels indicate station names.

A3.3 BARBER 1991

The cruise we refer to as Barber 1991 has been referred to elsewhere as OS38 and Hokkaido 1991. Data from the Barber 1991 cruise contributed to Appendix 4 of this report.

Vessel: T/S *Oshoro-Maru*.
N=19 stations.
Demersal fishing gear: 43-m otter trawl with 90-mm codend mesh, no codend liner; coded 6mOT in this report.
Fish data: Counts of fish per haul.
Source of fish data:
Barber et al. (1994: Appendix 4) –*Cruise report with collection methods and counts of fish*.

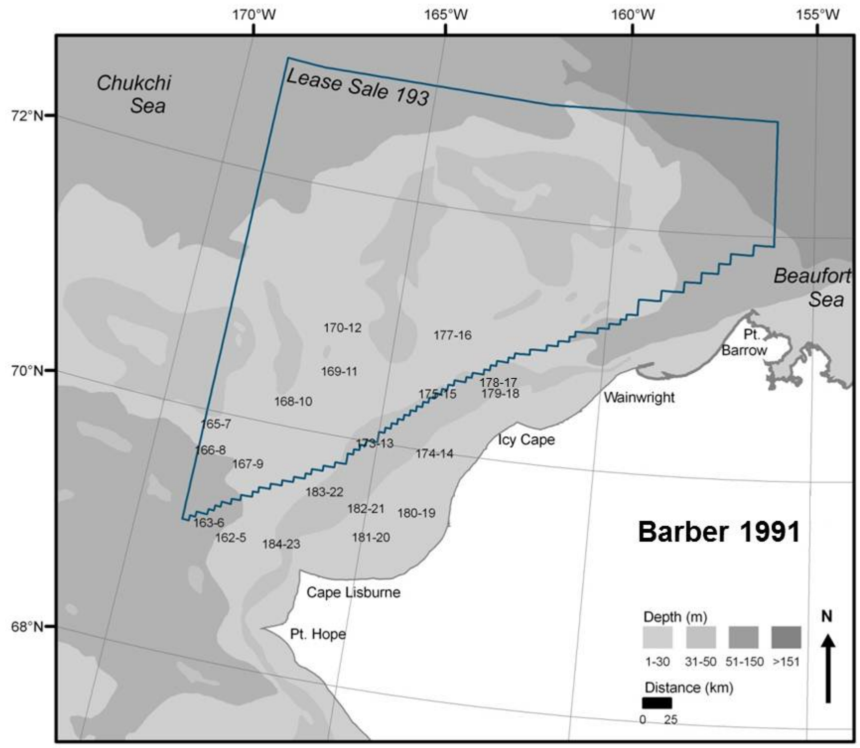

Figure A3.3. Map of fishing stations sampled during Barber 1991. Labels indicate station names and bottom trawl haul numbers.

A3.4 BARBER 1992

The cruise we refer to as Barber 1992 has been referred to elsewhere as OS44 and Hokkaido 1992. Data from the Barber 1992 cruise contributed to Appendix 4 of this report.

Vessel: T/S *Oshoro-Maru*.
N=17 stations.
Demersal fishing gear: 43-m otter trawl with 45-mm codend liner; coded 43mOT in this report.
Fish data: Counts of fish per haul.
Source of fish data:
Barber et al. (1994: Appendix 4) –*Cruise report with collection methods and counts of fish*.

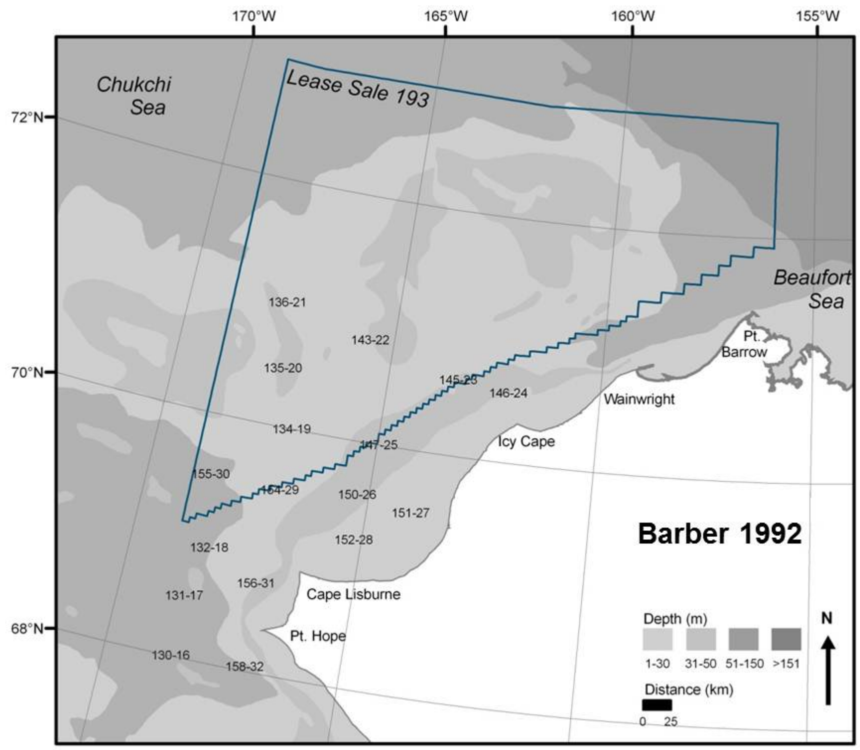

Figure A3.4. Map of fishing stations sampled during Barber 1992. Labels indicate station names and bottom trawl haul numbers.

A3.5 COMIDA 2009

Data from the COMIDA 2009 cruise contributed to all chapters and Appendices 1–3 of this report.

Vessel: R/V *Alpha Helix*.
N=30 stations examined by bottom trawl.
Demersal fishing gear: Plumb staff beam trawl with 4-mm codend liner mesh, 7-mm mesh, 3.1-m beam; 2.26-m swath; coded 3mPSBT in this report.
Midwater fishing gear: Isaacs-Kidd midwater trawl with 3 mm mesh; opening = 1.5 m wide, 1.8 m high.
Fish data: Count and biomass of fish per area fished; length and weight of fish specimens; age of fish based on otoliths analysis; fish stomach contents; stable isotope analyses of fish muscle and of fish prey taxa ($^{15}N/^{14}N$ and $^{13}C/^{12}C$).
Source of fish data:
Norcross and Holladay (2010) –*Abundance*.
Norcross BL, Holladay BA (unpublished data) –*Length, weight, age, and stomach contents of fish; stable isotopes of fish and prey*.

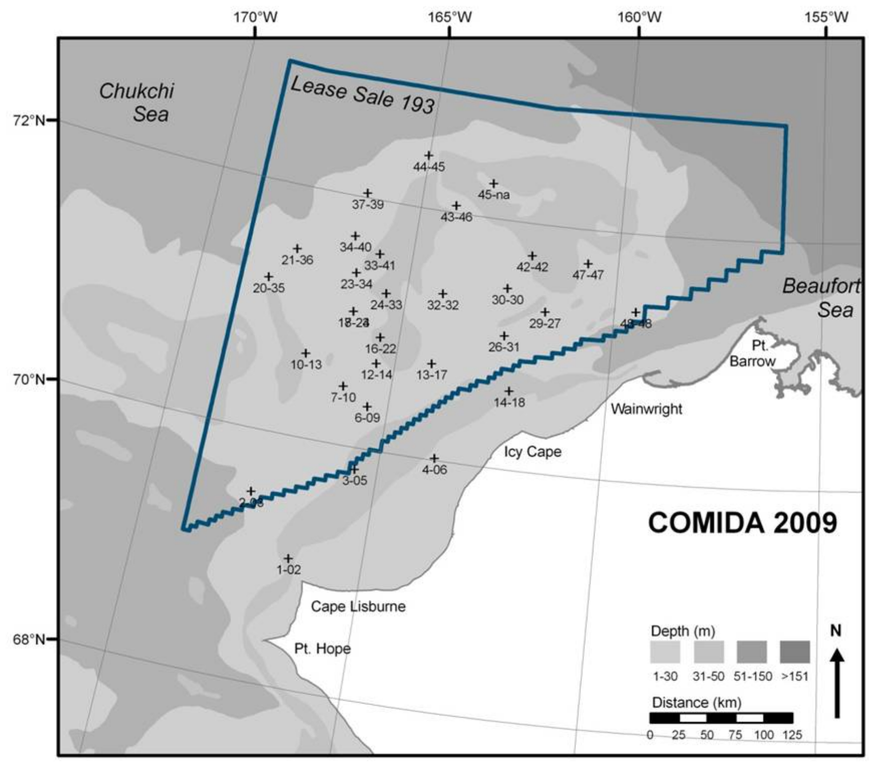

Figure A3.5. Map of fishing stations sampled by plumb staff beam trawl during COMIDA 2009. Labels indicate station names and haul numbers.

A3.6 WWW0902

Data from the CSESP cruise WWW0902 contributed to all chapters and Appendices 1–3 of this report.

Vessel: M/V *Westward Wind*.
N=26 stations.
Demersal fishing gear: Plumb staff beam trawl with 4-mm codend liner mesh, 7-mm mesh, 3.1-m beam; 2.26-m swath; coded 3mPSBT in this report.
Midwater fishing gear: Isaacs-Kidd midwater trawl with 3-mm mesh; opening = 1.5 m wide, 1.8 m high.
Fish data: Count and biomass of fish per area fished; length and weight of fish specimens; age of fish based on otoliths analysis; fish stomach contents; stable isotope analyses of fish muscle and of fish prey taxa ($^{15}N/^{14}N$ and $^{13}C/^{12}C$).
Sources of fish data:
Norcross et al. (2011) –*Abundance and biomass*.
Data have been provided to Olgoonik-Fairweather, Inc. and industry sponsors of this research – *Electronic files of all fish data*.

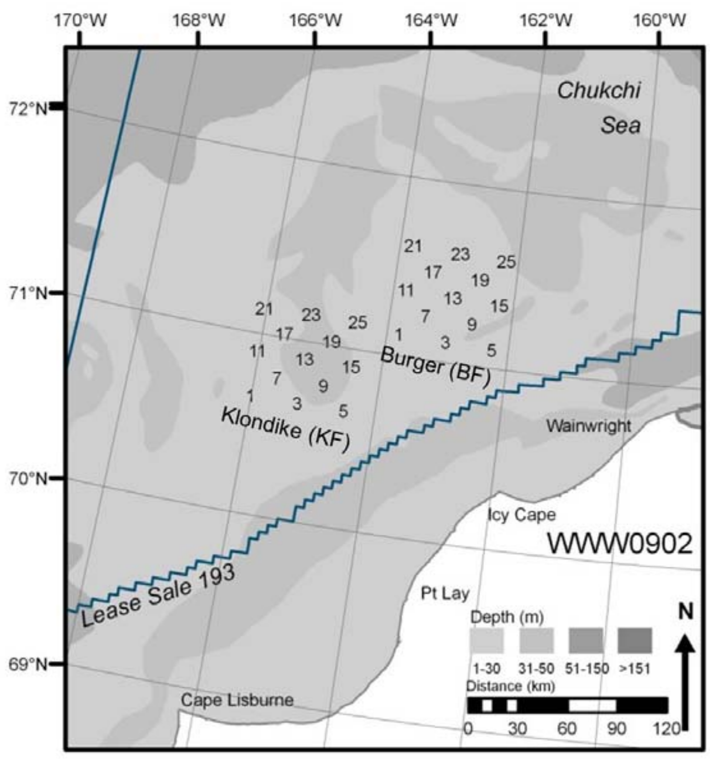

Figure A3.6. Map of fishing stations sampled during CSESP cruise WWW0902. Labels indicate station names within the study area, e.g., KF001 and KF003 in Klondike, BF001 and BF003 in Burger. Stations were examined by both demersal and midwater fishing gears.

A3.7 WWW0904

Data from the CSESP cruise WWW0904 contributed to all chapters and Appendices 1–3 of this report.

Vessel: M/V *Westward Wind*.
N=26 stations.
Demersal fishing gear: Plumb staff beam trawl with 4-mm codend liner mesh, 7-mm mesh, 3.1-m beam; 2.26-m swath; coded 3mPSBT in this report.
Midwater fishing gear: Isaacs-Kidd midwater trawl with 3-mm mesh; opening = 1.5 m wide, 1.8 m high.
Fish data: Count and biomass of fish per area fished; length and weight of fish specimens; age of fish based on otoliths analysis; fish stomach contents; stable isotope analyses of fish muscle and of fish prey taxa ($^{15}N/^{14}N$ and $^{13}C/^{12}C$).
Source of fish data:
Norcross et al. (2011) –*Abundance and biomass*.
Data have been provided to Olgoonik-Fairweather, Inc. and industry sponsors of this research – *Electronic files of all fish data*.

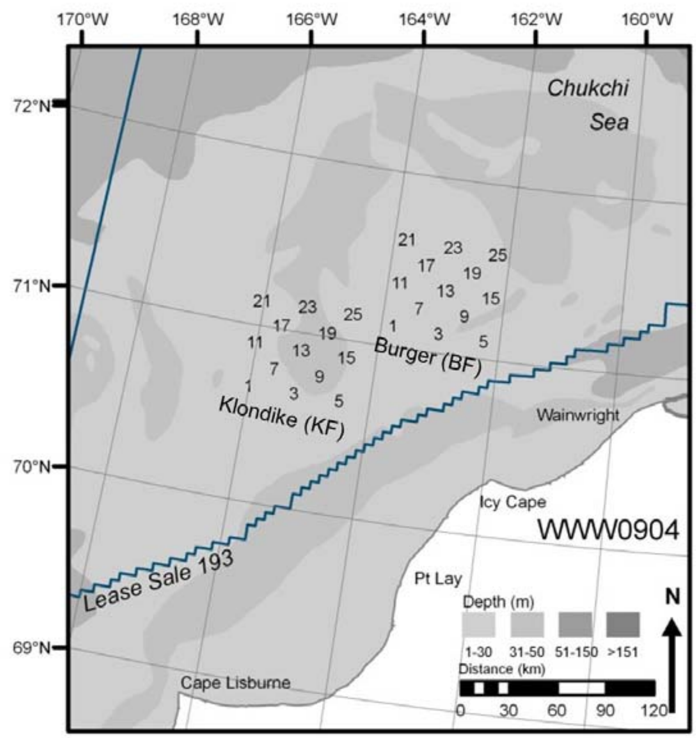

Figure A3.7. Map of fishing stations sampled during CSESP cruise WWW0904. Labels indicate station names within the study area, e.g., KF001 and KF003 in Klondike, BF001 and BF003 in Burger. Stations were examined by both demersal and midwater fishing gears.

A3.8 COMIDA 2010

Data from the COMIDA 2010 cruise contributed to Chapters 2–4 and all appendices of this report.

Vessel: R/V *Moana Wave*.
N=24 stations.
Demersal fishing gears:

- 5-m plumb staff beam trawl composed of a model 38 Skate Trawl with 38-mm mesh and 12-mm liner fitted to a 5-m long tubular steel beam (5.1 cm schedule 40 iron pipe); each wing of the net was attached to a 75-cm long wooden 4.5 x 9-cm plumb staff, which in turn was attached to each end of the beam; effective mouth opening of the net was approximately 4.9 m wide by 1 m high; coded 5mPSBT in this report.
- Plumb staff beam trawl with 4-mm codend liner mesh, 7-mm mesh, 3.1-m beam and 2.26- m swath was used by COMIDA investigators to sample invertebrates (Dr. Brenda Konar, IMS/UAF, not reported here); gear is identical to that coded 3mPSBT in this report.

Fish data: Counts of fish per haul, length of fish.
Source of fish data:
Crawford SC, et al. (unpublished data) –*Abundance and length*.

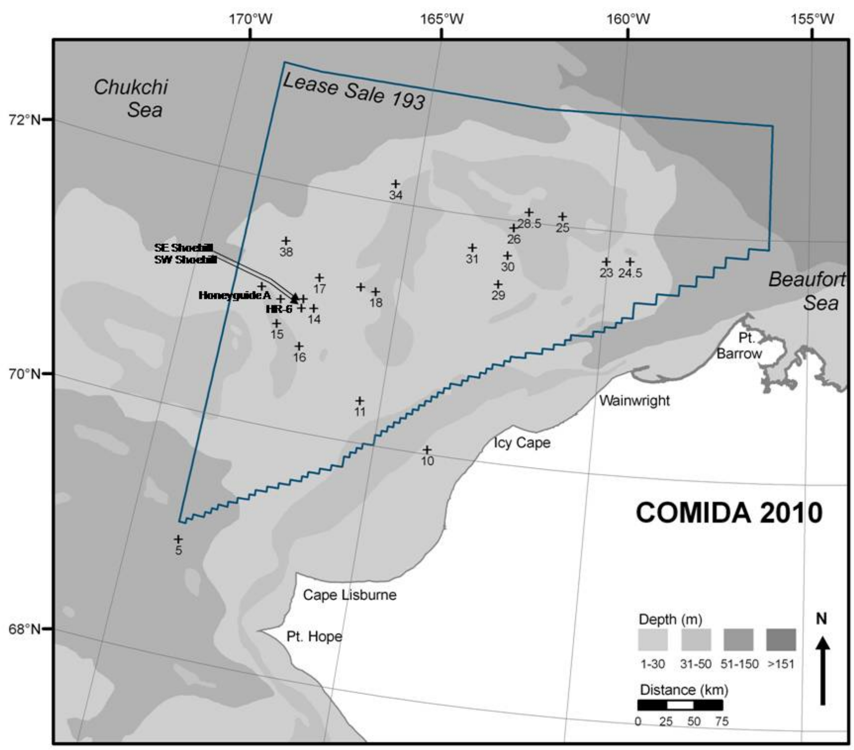

Figure A3.8. Map of fishing stations sampled during COMIDA 2010 by 5-m plumb staff beam trawl. Labels indicate station names.

A3.9 WWW1003

Data from the CSESP cruise WWW1003 contributed to all chapters and appendices of this report.

Vessel: M/V *Westward Wind*.
N=40 stations.
Demersal fishing gears:

- Model 38 Skate Trawl attached directly to a 3.1-m beam and trawl shoes; effective opening 2.9 m wide by 1.5 m high; coded 3mBT in this report.
- Model 38 Skate Trawl with 38-mm mesh and 12-mm liner fitted to a 5-m Misago beam; coded 5mBT in this report.
- Plumb staff beam trawl with 4-mm codend liner mesh, 7-mm mesh, 3.1-m beam; 2.26-m swath; coded 3mPSBT in this report.
- Modified 3-m plumb staff beam trawl, i.e., 3mPSBT modified with additional floats and less tickler; coded MPSBT in this report.

Midwater fishing gears:

- Isaacs-Kidd midwater trawl with 3-mm mesh; opening = 1.5 m wide, 1.8 m high.
- 10-m Meyer-Aluette Pelagic Trawl with estimated effective opening 4.5 m x 4.5 m.

Fish data: Count and biomass of fish per area fished; length and weight of fish specimens; age of fish based on otoliths analysis; fish stomach contents; stable isotope analyses of fish muscle and of fish prey taxa ($^{15}N/^{14}N$ and $^{13}C/^{12}C$).
Source of fish data:
Data have been provided to Olgoonik-Fairweather, Inc. and industry sponsors of this research – *Electronic files of all fish data*.

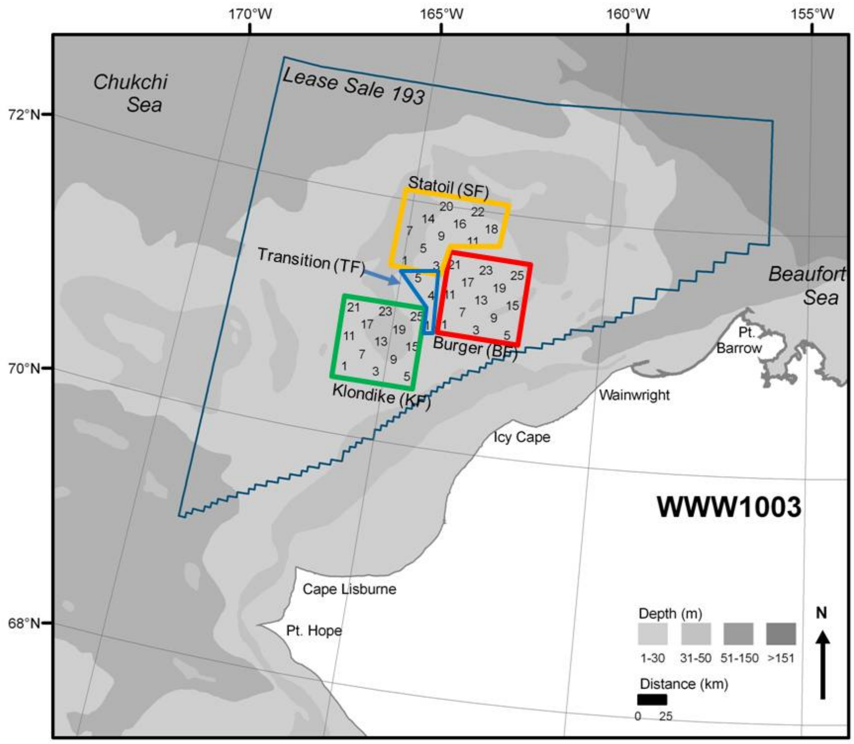

Figure A3.9. Map of fishing stations sampled during CSESP cruise WWW1003. Labels indicate station names within the particular study area, e.g., KF001 and KF003 in Klondike, BF001 and BF003 in Burger, SF001 and SF003 in Statoil, and TF004 in Transition.

A3.10 REFERENCES

Barber WE, Smith RL, Vallarino M, Meyer RM (1997) Demersal fish assemblages of the northeastern Chukchi Sea, Alaska. Fishery Bulletin 95:195–209.

Barber WR, Smith TJ, Weingartner TJ (1994) Fisheries Oceanography of the Northeastern Chukchi Sea: Final Report. Anchorage, AK: OCS Study MMS-93-0051.

Norcross BL, Holladay BA (2010) COMIDA-2009: Fish distribution, ecology and feeding in the Chukchi Sea. Final Report to the University of Texas at Austin, December 2010.

Norcross BL, Holladay BA, Edenfield LE (2011) 2009 Environmental Studies Program in the Northeastern Chukchi Sea: Fisheries Ecology of the Burger and Klondike Survey Areas. Final Report to ConocoPhilips Alaska Inc., Shell Exploration & Production Company, and Statoil USA E&P, Inc. Anchorage, Alaska.

APPENDIX 4 - AN EVALUATION OF BENTHIC TRAWLS THAT HAVE BEEN USED TO SAMPLE DEMERSAL FISHES IN THE NORTHEASTERN CHUKCHI SEA, ALASKA

[1]R.M. Meyer, [2]B.A. Holladay

Historical trawl surveys in the eastern Chukchi Sea and western Beaufort Sea have demonstrated that the few fishes that grow to a sufficient size for commercial harvest are present in a quantity far below what would be commercially feasible (Norcross et al. 2011a; Barber et al. 1994; Logerwell et al. 2010). Further, these surveys have indicated that, except for the warmer coastal waters, the demersal fish community is composed primarily of a few species that are generally small, aquarium-sized fish (<15 cm in length). Occasionally, a few larger strays or “waifs” (fishes occurring outside their normal range) are taken. These include species such as Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*), Greenland halibut (*Reinhardtius hippoglossoides*) and Pacific halibut (*Hippoglossus stenolepis*).

Fish communities in the Alaskan Arctic are dominated, in terms of numbers and biomass, by cods (Gadidae) with Arctic cod (*Boreogadus saida*) being the most prevalent species. Arctic cod have comprised 34–76% of the total catch in past studies (Barber et al. 1997; Norcross et al. 2011a). However, the majority of the fish species found in Arctic waters are demersal fishes such as sculpins (Cottidae), eelpouts (Zoarcidae), pricklebacks (Stichaeidae) and flatfishes (Pleuronectidae). Barber et al. (1994), sampling over four years in the eastern Chukchi Sea using several types of plankton nets, midwater nets and bottom trawls, reported capturing 66 fish species. More recent studies (e.g., RUSALCA 2004 in Mecklenburg et al. 2007; Norcross et al. 2010, 2011a) have examined a broader geographic region yet captured fewer species. FishBase (Froese and Pauly 2010) currently lists 82 species as inhabiting the Chukchi Sea, though many of these species are anadromous, nearshore forms or occur in the southern Chukchi Sea.

Epibenthic invertebrate communities in the northeastern Chukchi Sea are characterized by dense patches of tubeworms, brittle stars and crabs occurring arm-to-arm or leg-to-leg (Figure A4.1). These invertebrate communities present a challenge when conducting benthic trawl surveys. Trawls designed to catch the small fish characteristic of the region also harvest epibenthic invertebrates that weigh down the nets and cause them to fill with mud. With some benthic trawls, the bycatch mortality is large and the impact of studies has been cause for concern (J. Grebmeier, personal communication, 2010).

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[1] LGL Ecological Research Associates, Inc., Bryan, Texas
[2] University of Alaska Fairbanks, Fairbanks, Alaska

In offshore areas of the northern Chukchi Sea where sampling for our study occurred, the sea bottom shows little relief and ranges in depth from 30 to about 50 meters (Figure A4.2). The bottom is generally hard with a veneer of soft mud, interspersed with sand, gravel, cobble-sized rocks and boulders. In addition, ice keels produce steep-sided trenches (ice gouges) as deep as five meters, tens of meters wide and up to kilometers in length (Toimil 1978). Those features cause problems for benthic trawl operations.

In this chapter we evaluate the effectiveness of different types of benthic trawls used in Chukchi Sea studies. Historically, large trawls like the NMFS 83-112 Eastern otter trawl are used by the National Marine Fisheries Service (NMFS) as a standard fisheries survey trawl. However, the NMFS 83-112 is plagued by bycatch problems and requires large trawlers to safely operate. Given that the fish communities in the offshore, northeastern Chukchi Sea consist mainly of small fish, the authors have placed emphasis on developing sampling gears that would effectively sample the resident fishes without requiring a large trawler per se. The 3-m plumb staff beam trawl proved effective but was still plagued by bycatch problems. Various other beam trawls, equipped with 3 to 5-m beams and skids, were designed to reduce bycatch as described below.

A major consideration in making impact assessments concerns the ability to define differences attributable to differences in sampling gears, rather than other factors. This chapter focuses on comparing the effectiveness of the five beam trawl configurations used by the authors in 2010, and compares these results with a historic trawl survey that used larger trawls (Barber et al. 1994, 1997). It constitutes the observational basis for the quantitative evaluation of gear types included in later chapters.

A4.1 OVERVIEW OF BENTHIC TRAWL SAMPLING GEARS

In anticipation of oil and gas activities in the northeastern Chukchi Sea in the 1980's and 90's, two comprehensive trawl surveys were conducted in the area by Fechhelm et al. (1984) and Barber et al. (1994). Fechhelm et al. (1984) focused primarily on nearshore fishes, and Barber et al. (1994) targeted offshore fishes. Data from Barber's stations that corresponded generally with our study area are compared with the results from our 2010 surveys.

Barber et al. (1994), over four years, deployed some eight types of nets to sample plankton, ichthyoplankton and juvenile and adult fishes. Of these, only a 6.1-m otter trawl (deployed from the R/V *Alpha Helix* in 1989), a NMFS 83-112 (~25-meter) otter trawl (deployed from the F/V *Ocean Hope* III in 1990 and 1991) and a 43.3-m otter trawl (deployed from the T/S *Oshoro Maru* in 1991 and 1992) were used to sample demersal fishes (Table A4.1). Catches by these three types of otter trawls are summarized and discussed below.

In 1989, Barber et al. (1994) conducted a preliminary trawl survey that extended north from the Bering Strait into the northeastern Chukchi Sea. Only results from the northernmost 14 stations are included in this analysis. The 6-m otter trawl (6mOT) used in that survey had a 6.l-m headrope with a 35-mm mesh codend and was towed for 30 minutes at a speed of approximately 2.5 knots. Two tows were made at each station.

In 1990 and 1991 (Barber et al. 1994) conducted otter trawling operations from a 40-m chartered fishing vessel (the F/V *Ocean Hope III*) using a standard fisheries survey trawl, i.e., NMFS 83-112 Eastern otter trawl (83-112OT). This net had a 25.2-m head rope and a 34.1-m footrope set back 7.1 cm from a tickler chain. The codend consisted of 8.9-cm stretched mesh webbing with a 3.2-cm stretched mesh codend liner. Net mensuration equipment measured the effective width and height during the 1990 tows; the average effective opening was 15.3 m wide and 2.7 m high. Each station consisted of two 30-minute tows. Due to heavy weather in 1991, sampling was restricted to the nearshore southern portion of the study area and therefore results from that year's sampling are not included in this analysis.

In 1991 and 1992 Barber et al. also assisted with trawl surveys aboard the Hokkaido University research and training vessel, the T/S *Oshoro Maru* (Hokkaido University 1992, 1993; Barber et al. 1994). The 43mOT trawl used aboard this vessel had a 43.3-m headrope, 48.6-m footrope fitted with rollers, and a 90-mm mesh codend (information on the size of the otter boards and lengths of bridles were not provided by Barber et al. 1994). In 1992, the net was outfitted with a 45-mm codend liner. At each station, the net was towed for an hour. The majority of the stations sampled with the 43mOT were inshore and south of the 2010 study area.

During the summer and fall of 2010, the authors participated in two benthic trawl surveys in the Chukchi and Beaufort Seas. The Chukchi Offshore Monitoring in the Drilling Area (COMIDA) survey, July 27–August 15, 2010, was conducted from the 64-m ABS Class R/V *Moana Wave* owned and operated by Stabbert Maritime of Seattle, Washington. This was a house-forward vessel with an open working deck aft. The trawls were deployed over the stern with the aid of a deck-mounted crane and stern-mounted "A" frame. The net was towed with a single 1.2 cm diameter tow cable. The Chukchi Sea Environmental Studies Program (CSESP) survey occurred during September 2010 and was conducted from the 57.7-m long M/V *Westward Wind*, a converted king crab fishing and processing vessel. This vessel had a well deck with the house aft and the working deck forward between the house and forecastle. All sampling gear was deployed from the starboard side, aft of the forecastle, using a ship-mounted deck crane. Sampling nets were towed from a davit mounted to the forecastle bulkhead using Rochester .323 inch standard Hydro wire.

Previous trawls surveys in the area had demonstrated that the northeastern Chukchi Sea fish community consists of sparsely-distributed small (<150 mm) aquarium-sized fish (e.g., Barber et al. 1994, 1997). Therefore, the authors selected sampling gear that was designed to capture small (<150 mm) fish. In addition, because the R/V *Moana Wave* and the M/V *Westward*

Wind were not designed or equipped for otter trawling, sampling was restricted to the use of beam trawls. A summary of the five different configurations of beam trawls used by the authors and the otter trawls used by Barber et al. (1994) are provided in Table A4.1.

Based on their demonstrated ability to sample small fish, the authors opted to use a Model 38 Skate Trawl fitted to a 5-m Masago beam to target demersal fish and a modified 3-m plumb staff beam trawl (3mPSBT) described by Gunderson and Ellis (1986) to collect epibenthic invertebrates and fish. However, due to several complicating factors, we ended up employing five beam trawl configurations during the 2010 season. The 3mBT was used only aboard the M/V *Westward Wind*. The 3mPSBT is a proven tool for sampling epibenthic communities and small fish (Norcross et al. 2010, 2011b), and was selected for use in 2010 to be consistent with a similar survey conducted in 2009 also conducted aboard the M/V *Westward Wind* (Norcross et al. 2011a).

The model 38 Skate Trawl used in this project had a 5-m headrope and a 6-m footrope and 9 m of 1.9-mm galvanized drop chain was attached to the footrope. The net was constructed using 38-mm Sapphire netting with 9-thread twine on the back and 15 thread twine on the belly and codend. The net was outfitted with a 12-mm mesh codend liner. To help keep the footrope from digging into the bottom, it was equipped with 10-cm “mud raisins” (foam rollers). Further, the bridle consisted of 13-m of 20-mm Dyneema line. The vertical opening of the net was 1.0 to 1.5 m. When fitted to the 3-m beam, the net’s wing ends were attached directly to the beam. When the 5-m beam was used, the wings were set back one meter from the beam.

The 3mPSBT used in this study was modified from that described by Gunderson and Ellis (1986). Modifications included shortening the beam from 3.66 to 3.05-m, attaching a lead-filled line (leadline) to the footrope, attaching 15-cm lengths of chain at 15-cm intervals along the footrope and lengthening the codend from 1 to 4-m. The trawl was constructed using 7-mm woven nylon netting and outfitted with a 4-mm mesh codend liner. The effective mouth opening of the net was 2.26 m wide x 1.20 m high (Figure A4.3). The 3mPSBT was also used during two CSESP cruises in 2009 (WWW0902 and WWW0904), but this gear comparison used only the CSESP 2010 cruise (WWW1003) to allow comparison between different benthic trawls in the same time frame and at the same station.

To help reduce the proportional bycatch of invertebrates and collection of mud, a 3mPSBT was further modified (MPSBT) by removing the tickler and drop chains, adding two additional 10.2-cm floats to the head rope, removing 0.5 m of leadline from the footrope, and adding a 22.9-cm trawl float to each end of the beam. These changes were made in an attempt to float the footrope off the bottom and reduce the amount of brittle stars and invertebrates captured during each tow. These modifications are similar to those described by Abookire and Rose (2005).

The five-meter beam trawl (5mBT) had a heavy-duty Masago beam (Figure A4.4) that could be dismantled for air shipment, which made it easy to ship to remote locations. However the Masago beam weighed 450 kg, which proved too heavy for safe deployment and recovery aboard the M/V *Westward Wind* and was therefore replaced with a three-meter tubular beam (3mBT).

The 3mBT beam was constructed using 5.1-cm diameter, schedule 80 (wall thickness of 5.54 mm) steel pipe with 1-m skids (shoes) bolted onto each end (Figure A4.5). The net was attached directly to the shoes. The top of the wing was attached near the top of the shoe and the bottom of the wing was attached 15 cm above the bottom of the shoe to allow the corners of the net to glide over rather than digging into the bottom. The tow bridle was attached to the middle of the leading edge of each shoe. The effective mouth opening of the net was approximately 2.9 m wide by 1.5 m high.

Aboard the R/V *Moana Wave*, the model 38 Skate Trawl was rigged as a 5-meter plumb staff beam trawl (5mPSBT) with a 5-m long tubular steel beam (5.1 cm schedule 40 iron pipe) (Figure A4.6). Each wing of the net was attached to a 75-cm long wooden 4.5 x 9 cm plumb staff, which in turn was attached to each end of the beam. The effective mouth opening of the net was approximately 4.9 m wide by 1.5 m high.

Sampling protocol aboard the both the M/V *Westward Wind* and the R/V *Moana Wave* was essentially the same. The trawl was set overboard while the vessel was moving ahead at a speed of at least 2 kt. Once the trawl was in the water, the vessel was slowed to trawling speed of 1.5–2 kts and a predetermined amount was paid out. The 3mPSBT was towed on the bottom for 2 to 3 minutes whereas the other nets were towed for 10 to 30 minutes. The short 3mPSBT tow time was used to reduce bycatch of epibenthic invertebrates.

The length of wire deployed was usually twice the water depth (scope = 2.0). In heavy seas a scope of 2.3 was used to ensure bottom contact. Abookire and Rose (2005) reported difficulty keeping a modified plumb staff beam trawl in contact with the bottom when using a scope ratio of 4:1. In this study, to ensure that the trawls were on the bottom, the authors painted the bottom of the wingtip weights of the 3mPSBT and MPSBT and the shoe bottoms of the 3mBT and 5mBT between tows. The weights and shoes were inspected after each tow for wear (proof of bottom contact). Throughout the study, the forward quarter of the wingtip weights showed little wear but paint wore off the aft three quarters during each tow. With the beam trawls, the paint was worn off the full length of the shoes.

Tow time for the beam trawls was determined to start when the predetermined amount of tow wire had been paid out and ended at a predetermined time when haul back commenced. This tow time is considered conservative because the nets reached the bottom before the all the cable was paid out and stayed on the bottom during the early part of haul back. Since the vessel continued moving ahead during the entire deployment, the net would likely have been dragged on the bottom for a longer duration than the recorded tow time.

A4.2 CATCH BY GEAR COMPARISONS

Catches obtained from the five beam trawl configurations employed in 2010 and catches made using the historical trawls described in Barber et al. (1994) were compared using species diversity (number of species); relative abundance, and where reported, the mean total length of fish taken by each gear type. The seven most abundant species were considered, including Arctic cod, Arctic staghorn sculpin (*Gymnocanthus tricuspis*), shorthorn sculpin (*Myoxocephalus scorpius*), Arctic alligatorfish (*Ulcina olrikii*), polar eelpout (*Lycodes polaris*), stout eelblenny (*Anisarchus medius*) and Bering flounder (*Hippoglossoides robustus*). An overview of the gear types evaluated, the number of stations sampled and the number of species taken is provided in Table A4.1. The 5mBT, MPSBT and 3mPSBT were deployed at four common stations, and the paired results for these four stations constitute Trial 1. The 3mBT (10 stations), MPSBT (15 stations and 3mPSBT (16 stations) were deployed in the same region; results from these stations constitute Trial 2. The 3mBT, 5mPSBT and 3mPSBT were deployed at 34, 39 and 24 stations, respectively; all located in the same general area. The results from these stations constitute Trial 3.

Trial 4 consists of comparing the 3mBT collections made in 2010 at 36 stations in the Lease Sale 193 area to collections made in the same area in 1) 1990 using the 83-112OT at 21 stations (Barber et al. 1994) and 2) 1989 using the 6mOT at 14 stations (Barber et al. 1994). The last trial, Trial 5, compares the 2010 3mBT catches at 36 stations in the Lease Sale 193 area to two other trawls used in this region by Barber et al. (1994): a 43mOT having a 90-mm mesh codend deployed at 19 stations in 1990, and the same trawl but with a 45-mm mesh codend deployed at 17 stations in 1991.

Due to the low numbers of fish typically captured per station by each gear type (1–2 individuals per species, per tow), trawl efficacy was assessed using relative species abundance rather than catch-per-unit-effort (CPUE), as CPUE is not considered an acceptable measure of trawl efficacy. The authors concluded that extrapolating the difference of a few fish per sample could lead to erroneous conclusion. In addition, the general sampling error within each trawl type would confound a comparison between trawls using CPUE. For example, during the 1989 trawl survey, results of paired (two 30 minute tows) tows at a station yielded abundance estimates varying by up to 300%, even when comparatively large numbers of Arctic cod were captured (Barber et al. 1994). However, because CPUE are the only data available for the Barber 1991 trawl survey, it is used as a basis for comparison with the 2010 3mBT catches. After examining trawl catch data from the 2010 trawl surveys, we determined that catch results using the 3-meter

Beam Trawl (3mBT) would be used as our standard against which other trawls would be compared.

A4.2.1 Trial 1

Three gear types (5mBT, MPSBT, 3mPSBT) were fished at the same four stations in 2010 (Table A4.2). The plumb staff beam trawls collected more specimens and species than the 5mBT. Arctic cod dominated the catches in each gear constituting about 25% of the total catch in each of the 5mBT and the MPSBT collections and nearly 54% of the catch in the 3mPSBT. The mean length of Arctic cod in the 3mPSBT was 55.5 mm as compared to mean lengths of 85.0 mm and 109.0 mm in the 5mBT and MPSBT collections, respectively. The relative abundance of the selected dominant species appeared similar across these three gear types.

A4.2.2 Trial 2

In Trial 2, 10 stations were sampled using a 3mBT, 15 with the MPSBT and 16 with the 3mPSBT (Table A4.3). Each gear caught a similar number of species (17 to 21) but the 3mBT caught 628 specimens as compared to 281 specimens caught in the MPSBT and 147 specimens taken by the 3mPSBT (Table A4.3). Arctic cod dominated the MPSBT collections (32.7%) and was also the most abundant species, in the 3mBT catches (18.8%). Arctic staghorn sculpin was the most abundant species (19.0%) in 3mPSBT collections, and Arctic cod comprised 14.3% of the catch.

A4.2.3 Trial 3

The 3mBT was deployed at 36 stations, the 3mPSBT was deployed at 39 stations and the 5mPSBT was deployed at 24 stations, with all collections occurring within the Lease Sale 193 area in 2010 (Table A4.4). The 3mBT captured 1,223 fish representing 23 species with Arctic cod being the most common fish caught, representing 38.1% of the total 3mBT catch. Stout eelblenny (10.0%) was ranked second in the catches made using this gear type followed by Arctic staghorn sculpin (7.0%) and polar eelpout (5.4%).

The 3mPSBT captured 859 fish representing 24 species. Arctic cod made up the largest portion of the catch (47.5%), followed by stout eelblenny (7.3%), Arctic staghorn sculpin (6.5%) and polar eelpout (6.4%). The 5mPSBT captured 853 fish representing 21 species. Arctic cod made up the largest portion of the catch (36.2%), followed by polar eelpout (13.5%), stout eelblenny (10.2%), shorthorn sculpin (7.2%) and Bering flounder (6.4%).

Subtle size differences were observed across the three gear types. Arctic cod captured by the 5mPSBT were slightly larger (88.1 mm) than those captured by the 3mBT (65.5 mm) and the

3mPSBT (64.4 mm). Similarly, Arctic staghorn sculpin captured by the 5mPSBT were larger (71.4 mm) and those captured by the 3mBT (42.5 mm) and by the 3mPSBT (37.3 mm). Shorthorn sculpin, Arctic alligatorfish and stout eelblenny captured by the three gear types were similar in size, but polar eelpout captured by the 5mPSBT were slightly larger (89.9 mm) than those captured by the 3mBT (85.3 mm), and the latter were larger than those taken with 3mPSBT (77.8 mm). Bering flounder captured by the 3mPSBT (75.0 mm) and the 5mPSBT (73.0 mm) were similar in size, but fish taken by the 3mBT were larger (76.4 mm).

A4.2.4 Trial 4

The 3mBT was deployed at 36 stations in 2010, the 83-112OT was deployed at 21 stations in 1990 and the 6mOT was deployed at 14 stations in 1989 (Table A4.5). Results for the latter two trawls were reported by Barber et al. (1994, 1997).

Barber et al. (1994, 1997) reported summaries of length for some, but not all, fish species. Fish data records for the 6mOT and 43mOT were limited to only the number of fish captured by species. Table A4.5 reflects CPUE and actual catches where available. Length frequencies were reported only for Arctic cod, Arctic staghorn sculpin and Bering flounder. These species were selected for length/frequency analysis because they were of sufficiently large size range that diet could be assessed relative to predator size (Coyle et al. 1997). Therefore the lengths of these species reflect a bias for larger fish and are not representative of the overall catch.

Catches by the 3mBT were dominated by Arctic cod (38.1%). Stout eelblenny was the second most abundant species (10.0%) taken in this gear, followed by Arctic staghorn sculpin (7.5%), Arctic alligatorfish (6.5%) and polar eelpout (5.4%). In terms of catch per 1,000 m^2, the 3mBT had a higher catch rate than the two otter trawls for all species except for Bering flounder (0.5 versus 0.3 per 1,000 m^2). By species, the catch rates were: Arctic cod 21.1/1,000 m^2 versus 19.5/1,000 m^2 in the 83-112OT; Arctic staghorn sculpin 4.4/1,000 m^2 versus 0.8/1,000 m^2; shorthorn sculpin 1.4/1,000 m^2 versus 0/1,000 m^2; Arctic alligatorfish 2.3/1,000 m^2 versus 0.002/1,000 m^2; polar eelpout 3.4/1,000 m^2 versus 0.3/1,000 m^2 and stout eelblenny 10/1,000 m^2 versus 0.1/1,000 m^2. Catch rates were not reported for the 6mOT (Barber et al. 1994).

The 83-112OT captured some 21 species from 21 stations sampled in 1990 (Barber et al. 1997). Most of these stations were located in or near the 2010 study area. Catches were dominated by Arctic cod (76.1%) followed by Arctic staghorn sculpin (3.1%), Bering flounder (1.3%) and small amounts of shorthorn sculpin, polar eelpout, stout eelblenny and Arctic alligatorfish. Fishes captured by the 83-112OT were larger than fishes taken by the 3mBT. For example, Arctic cod averaged 124.1 mm in length and weighed 15.9 g. This compares to 65.5 mm average length and 1.9 g for the 3mBT.

The 6mOT captured 773 fish representing 19 species from 14 stations sampled in 1989 (Barber et al. 1994). Catches were dominated by Arctic cod (61.4%) followed by Arctic staghorn sculpin (10.1%), Bering flounder (4.9%), Arctic alligatorfish (4.1%) and polar eelpout (0.3%). Fish size was not reported from the 6mOT catches (Barber et al. 1994).

A4.2.5 Trial 5

The 3mBT was deployed at 36 stations in 2010, the 43mOT without a codend liner was deployed at 19 stations in 1991 (Hokkaido University 1992; Barber et al. 1994), and it was deployed at 17 stations in 1992 with a codend liner (Hokkaido University 1993; Barber et al. 1994; Table A4.6). Catches by the 43mOT without a codend liner were the lowest of the three trawl configurations in terms of number and species captured. However, the relative abundances of Arctic cod from both the lined and unlined trawls were similar: 65.6% versus 64.5%. Bering flounder (11.0%) was the second most dominant species taken in the 43mOT without a codend liner followed by Arctic staghorn sculpin (1.8%). The lined 43mOT caught 7,563 fish representing 30 species. Catches were dominated by Arctic cod (65.6%) followed by Bering flounder (19.6%), Arctic staghorn sculpin (7.8%), polar eelpout (0.6%) and Arctic alligatorfish (0.1%).

The 3mBT captured 1,223 fish representing 23 species with Arctic cod being the most common fish caught comprising 38.1% of the total catch. Stout eelblenny (10.0%) was ranked second followed by Arctic staghorn sculpin (7.0%), and polar eelpout (5.4%).

A4.3 DISCUSSION

Conducting demersal trawl surveys to assess fishes in the northeastern Chukchi Sea requires some considerations unique to the Arctic. These include the lack of harbor for resupply, the lack of protection during periods of heavy weather, that operations will be conducted in an ice-dominated environment requiring an ice-strengthened vessel, that trawl catches will be dominated by epibenthic invertebrates, that the density of fish is very low and that the fish are generally small (<150 mm).

As previously noted, the dense patches of tubeworms, brittle stars and crabs that characterize the epibenthic community of the northeastern Chukchi Sea are an important consideration when conducting trawl surveys. Barber et al. (1994) reported that epibenthic invertebrates dominated every trawl catch. The 3mPSBT was selected for the CSESP WWW1003 cruise to be consistent with previous trawl surveys (Norcross et al. 2010, 2011a), but the relative proportion of invertebrate bycatch to fishes was quite high. The quantity of invertebrate bycatch in 3mPSBT hauls is less than in standard survey gear such as the NMFS 83-112 (Figure A4.7) due in part to smaller gear size and shorter tows, but bycatch remains problematic (Figure A4.7). The model 38 skate trawl was used because of its known ability to sample the size of fishes that dominate the northeastern Chukchi Sea fish community. This net was rigged on a beam trawl frame with shoes to minimize the habitat disruption that occurs when employing standard otter trawls and plumb staff beam trawls. The footropes of the 5mBT and 3mBT nets were fitted with mud raisins to help reduce the bycatch of invertebrates.

All the data collected to date confirm that the marine fish community in the Chukchi Sea is comprised mainly of small (<150 mm) fishes. The community is dominated by cod (Arctic and saffron cod) with smaller numbers of demersal fishes (sculpins, poachers, snailfishes, eelpouts and pricklebacks). Larger fishes are occasionally taken, including Pacific cod, walleye pollock and Greenland halibut. These are considered to be waifs as opposed to being resident fish.

The 3mBT and 3mPSBT were designed to capture small demersal fishes. The 3mPSBT was designed to dig into the soft mud on the bottom to catch flatfishes that are buried in the substrate (Gunderson and Ellis 1986) in addition to other small demersal fishes. However, in the northeastern Chukchi Sea, the net could be towed for only a short time because it quickly filled with invertebrates and mud. The large proportion of invertebrates increased significantly the time required to handle gear and sort the catches.

The 3mBT was designed to skim over the bottom to minimize the catch of epibenthic invertebrates. This feature permitted the net to be towed longer, which probably resulted in sampling more microhabitats. However, even this net when left on the bottom too long, would eventually fill with invertebrates and mud. Therefore, tow time was reduced to between 10 and 15 minutes.

Both 3mPSBT and 3mBT nets proved effective at capturing small fish and the species composition and species size distributions were similar across these gears. However, our assessment shows the 3mBT was a more efficient gear for surveying fishes because it could be deployed longer and, generally the resulting catches could be sorted within a shorter time. However, tows of both short and long duration captured approximately the same number of species.

The 3mBT had a higher catch rate (number/1,000 m^2) than the large 83-112OT for all species except for Bering flounder. Although the biomass estimates from Barber et al. (1997) appear high, the data suggest that fish taken by the 83-112 are indeed larger than those captured during this study. The observed differences in catch rates and size of fish might be explained by several factors, including a potential increase in fish size since the early 1990's, differences in the size of codend mesh and the mesh size of codend liners (1.2 cm, 3.2 cm, 3.5 cm, 4.5 cm and 9.0 cm; Table A4.1) and/or fishing efficacy.

Logerwell et al. (2010) conducted a trawl survey in the Beaufort Sea near Point Barrow using a lined and unlined 83-112 otter trawl similar to the one employed by Barber et al. (1997). Their catches of Arctic cod, Arctic staghorn sculpin, stout eelblenny and Bering flounder were similar in size to those reported by Barber et al. (1997). Although not a definitive comparison, this evidence suggests that the sizes of the dominant fish species may not have changed significantly in the past 20 years.

Mesh size, particularly in the codend of the net, is important in determining the size of fish retained, i.e., the larger the mesh size, the larger the size of fish retained. Barber et al. (1994) reported a significant increase in the number of fish caught with the 43-meter otter trawl when a 45 mm codend liner was added to the net. Logerwell et al. (2010) reported similar findings when comparing catches with lined (38 mm mesh) and unlined trawls (89 mm mesh). The 6mOT and the 83-112OT each had larger mesh (32 mm and 35 mm, respectively) than the 3mBT (12 mm). Therefore, mesh size could explain part of the difference in the fishing efficiency of the nets.

How the nets were designed to fish may also explain the difference in catch rates. Otter trawls used by Barber et al. (1994, 1997) were designed to capture large fish and tended to fish further off bottom. The 43mOT was equipped with roller gear that allowed the net to ride up and over rocks and boulders by keeping the footrope off bottom. In similar fashion, the 7.6mOT and NMFS 83-112 were designed to keep the footrope about 5–10 cm off of the bottom (personal observations). Given the small size of the fish in the study area, even with tickler chains to help flush fish off bottom into the water column, these nets may simply float over most fishes. Munro and Somerton (2002) have reported fishes escaping under a trawl's footrope and demonstrated that yellowfin sole were less susceptible to capture by the NMFS 83-112 Eastern otter trawl than other species of fish. He also demonstrated that flatfish were not fully represented in trawl catches until they reached 30 to 35 cm in length. Few fish were caught in the size range common to fishes in the northeastern Chukchi Sea. This suggests that small fish are under-represented in trawl catches taken by larger trawls such as the NMFS 83-112 Eastern otter trawl.

The 2009 CSESP Study (Norcross et al. 2011a) and this study have demonstrated that the Chukchi Sea fish populations are sparsely distributed throughout the area. Trawl catches generally consisted of a few representatives of several dominant species, while other species were represented by only one or two specimens. Surveys that included stations nearshore or in the southern Chukchi Sea yielded more species regardless of the gear type utilized. For example, Barber et al. (1997) reported catching 23 species at a station south of the study area in Ledyard Bay, but only one or two species at some of the northern stations.

Similar to past studies, we found the fish community of the northeastern Chukchi Sea to be dominated by Arctic cod along with a number of benthic species. However, there were some noticeable differences between the past and present studies. Saffron cod (*Eleginus gracilis*) was the second most common species found by Barber et al. (1997); but we collected only two in 2009 and none in 2010. Bering flounder was the fifth-most common species reported by Barber et al. (1997) while we observed them only occasionally, and never in large numbers. Conversely, Barber caught only one stout eelblenny during two years of sampling whereas stout eelblenny were the second-most common fish in 2010 and made up almost 10% of the total catch. This difference could be explained by changes in the fish community over time, and/or by the differences in sampling gear (i.e., the use of beam trawls designed to capture small fish versus using an 83-112 Eastern type otter trawl that was designed and used for assessing commercial-sized fish populations).

Our finding of 25 species is lower than the number observed by Norcross et al. (2011b), and much lower than the 66 species count reported by Barber et al. (1994), or the 82 species FishBase lists as present in the Chukchi Sea. Much of this discrepancy is likely due to the timing of sampling efforts, the location of sampling and the type of sampling equipment employed. For example, Barber et al. (1994) sampled a much larger geographic area than our 2010 collections, including the area we examined and additional stations inshore and to the south. They also sampled for four years using eight different gear types. Likewise, the total species count from FishBase includes fish from the entire Chukchi Sea, of which many species are likely not available for capture in the northeast Chukchi Sea.

All benthic trawl configurations used in present and past surveys in the Alaskan arctic suffered from a problem that is common to fish surveys, i.e., over sampling of epibenthic invertebrates. This, in turn, led to large invertebrate catches and mud. In some cases, the large catches of mud and invertebrates led to the loss of the nets and samples. Our experience was not unique as other authors such as Barber et al. (1997) and Logerwell et al. (2010) reported losing nets to large catches of invertebrates, mud and boulders. Mud usually enters a net through bottom meshes when the codend becomes weighted down with catch (fish, invertebrates, rocks or mud balls; G. Faulkner, Innovative Net Systems, personal communication, 2010). In the Arctic, mud balls (chunks) may enter the net when it impacts the sidewall of an ice gauge and then sinks the net to the bottom allowing more mud to enter through the meshes. Rock chutes sown into the bottom of the net would permit cobbles and larger mud balls to exit the net without weighting down the codend. Our results indicate that fitting mud raisins to the footrope is an effective method to reduce the invertebrate bycatch, but in areas with high populations of benthic invertebrates, shortening the tow from 30 minutes down to 10–15 minutes was determined to be the most practical method to reduce oversampling and excess mud.

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Table A4.1. Summary of gear types compared in this report.

Sampling Gear Headrope Length / Mesh Size, Codend Principle Investigator – Year, Cruise	Code	Number of Stations	Number of Species
5-meter Beam Trawl 5-meter beam / 12 mm codend liner Gallaway 2010, WWW1003	5mBT	4	8
3-meter Beam Trawl 3.1-meter beam / 12 mm codend liner Gallaway 2010, WWW1003	3mBT	36	21
3-meter Plumb Staff Beam Trawl 3.1-meter beam / 12 mm codend liner Gallaway 2010, WWW1003	3mPSBT	39	24
Modified Plumb Staff Beam Trawl 3.1-meter beam / 12 mm codend liner Gallaway 2010, WWW1003	MPSBT	15	17
5-meter Plumb Staff Beam Trawl 5-meter beam / 12 mm codend liner Gallaway 2010, COMIDA 2010	5mPSBT	24	22
6.1-meter Otter trawl 35 mm codend Barber 1989	6mOT	14	19
83-112 Otter Trawl 32 mm codend liner Barber 1990	83-112OT	48	56
43-meter Otter Trawl 90 mm codend – No codend liner Barber 1991	43mOT	19	17
43-meter Otter Trawl 45 mm codend liner Barber 1992	43mOT	17	21

Table A4.2. Results of Trial 1 comparing catches of the 5mBT, MPSBT and 3mPSBT from the same four (4) stations where these gear types were deployed in 2010.

Stations and Catches	5mBT	MPSBT	3mPSBT
Number of Stations	4	4	4
Number of Species	8	14	12
Number of Fish	109	250	301
Arctic cod			
Relative Abundance (%)	24.8	24.8	53.5
Average Length (mm)	85.0	109.0	55.5
Arctic staghorn sculpin			
Relative Abundance (%)	2.8	2.8	2.3
Average Length (mm)	55.0	39.0	39.3
Shorthorn sculpin			
Relative Abundance (%)	3.7	3.7	1.3
Average Length (mm)	45.0	75.0	47.5
Arctic alligatorfish			
Relative Abundance (%)	1.8	-	0.7
Average Length (mm)	60.0	-	65.0
Polar eelpout			
Relative Abundance (%)	6.4	6.4	5.0
Average Length (mm)	122.1	82.1	93.0
Stout eelblenny			
Relative Abundance (%)	5.5	5.5	6.6
Average Length (mm)	118.3	109.7	103.5
Bering flounder			
Relative Abundance (%)	4.6	4.6	5.2
Average Length (mm)	85.0	65.0	59.3

Table A4.3. Results of Trial 2 comparing catches of the 3mBT, MPSBT and 3mPSBT from the same sixteen (16) stations where these gear types were deployed in 2010.

Stations and Catches	3mBT	MPSBT	3mPSBT
Number of Stations	10	15	16
Number of Species	21	17	20
Number of Fish	628	281	147
Arctic cod			
Relative Abundance (%)	18.8	32.7	14.3
Average Length (mm)	75.3	61.9	79.1
Arctic staghorn sculpin			
Relative Abundance (%)	12.7	3.6	19.0
Average Length (mm)	45.6	46.1	79.1
Shorthorn sculpin			
Relative Abundance (%)	3.2	7.8	4.1
Average Length (mm)	76.7	107.7	68.3
Arctic alligatorfish			
Relative Abundance (%)	5.9	9.6	5.4
Average Length (mm)	49.6	52.0	53.3
Polar eelpout			
Relative Abundance (%)	2.1	2.5	3.4
Average Length (mm)	115.8	75.0	155.0
Stout eelblenny			
Relative Abundance (%)	8.8	3.6	6.8
Average Length (mm)	114.2	106.0	103.9
Bering flounder			
Relative Abundance (%)	0.2	-	0.7
Average Length (mm)	-	-	75.0

Table A4.4. Results of Trial 3 comparing catches of the 3mBT, 5mPSBT and 3mPSBT gear types deployed in 2010. Most of the 3mBT and 3mPSBT catches came from the same stations.

Stations and Catches	3mBT	5mPSBT	3mPSBT
Number of Stations	36	24	39
Number of Species	23	21	24
Number of Fish	1223	853	859
Arctic cod			
Relative Abundance (%)	38.1	36.2	47.5
Average Length (mm)	65.5	88.1	64.4
Arctic staghorn sculpin			
Relative Abundance (%)	7.0	1.6	6.5
Average Length (mm)	42.5	71.4	37.3
Shorthorn sculpin			
Relative Abundance (%)	2.3	7.2	8.8
Average Length (mm)	69.4	69.9	66.1
Arctic alligatorfish			
Relative Abundance (%)	6.5	0.6	3.7
Average Length (mm)	47.0	47.0	46.5
Polar eelpout			
Relative Abundance (%)	5.4	13.5	6.4
Average Length (mm)	85.3	89.9	77.9
Stout eelblenny			
Relative Abundance (%)	10.0	10.2	7.3
Average Length (mm)	110.3	109.7	103.7
Bering flounder			
Relative Abundance (%)	0.6	6.4	1.2
Average Length (mm)	76.4	73.0	75.0

Table A4.5. Results of Trial 4 comparing catches of the 3mBT deployed in 2010, 83-112OT deployed in 1990 and 6mOT deployed in 1989.

Stations and Catches	3mBT	83-112OT	6mOT
Number of Stations	36	21	14
Number of Species	23	21	19
Number of Fish	1223	-	773
Arctic cod (/1,000 m^2)	21.1	19.5	-
Relative Abundance (%)	38.1	76.1	61.4
Average Length (mm)	65.5	124.1	-
Average Weight (g)	1.9	15.9	-
Arctic staghorn sculpin (/1,000 m^2)	4.4	0.8	-
Relative Abundance (%)	7.0	3.1	10.1
Average Length (mm)	42.5	96.9	-
Average Weight (g)	0.9	12.8	-
Shorthorn sculpin (/1,000 m^2)	1.4	0	-
Relative Abundance (%)	2.3	-	-
Average Length (mm)	69.4	-	-
Average Weight (g)	2.3	-	-
Arctic alligatorfish (/1,000 m^2)	2.3	0.002	-
Relative Abundance (%)	6.5	-	4.1
Average Length (mm)	47.0	-	-
Average Weight (g)	0.7	42.5	-
Polar eelpout (/1,000 m^2)	3.4	0.3	-
Relative Abundance (%)	5.4	-	0.3
Average Length (mm)	85.3	-	-
Average Weight (g)	4.6	93.7	-
Stout eelblenny (/1,000 m^2)	1.0	0.1	-
Relative Abundance (%)	10.0	-	-
Average Length (mm)	110.3	-	-
Average Weight (g)	3.3	38	-
Bering flounder (/1,000 m^2)	0.3	0.5	-
Relative Abundance (%)	0.6	1.3	4.9
Average Length (mm)	76.4	126	-
Average Weight (g)	3.9	26.9	-

Table A4.6. Results of Trial 5 comparing catches of the 3mBT deployed in 2010, and the 43mOT gears deployed in 1991 (90 mm codend) and 1992 (45 mm liner).

Stations and Catches	3mBT 12 mm codend	43mOT 90 mm codend	43mOT 45 mm liner
Number of Stations	36	19	17
Number of Species	23	17	30
Number of Fish	1223	228	7563
Arctic cod			
Relative Abundance (%)	38.1	64.5	65.6
Average Length (mm)	65.5		
Arctic staghorn sculpin			
Relative Abundance (%)	7.0	1.8	7.8
Average Length (mm)	42.5		
Shorthorn sculpin			
Relative Abundance (%)	2.3	-	-
Average Length (mm)	69.4	-	-
Arctic alligatorfish			
Relative Abundance (%)	6.5	-	0.1
Average Length (mm)	47.0		
Polar eelpout			
Relative Abundance (%)	5.4	0.9	0.6
Average Length (mm)	85.3		
Stout eelblenny			
Relative Abundance (%)	10.0	-	-
Average Length (mm)	110.5		
Bering flounder			
Relative Abundance (%)	0.6	11	19.6
Average Length (mm)	76.4	-	-


Figure A4.1. Photograph of invertebrate bycatch showing brittle stars and other epibenthic organisms that are common to the study area.

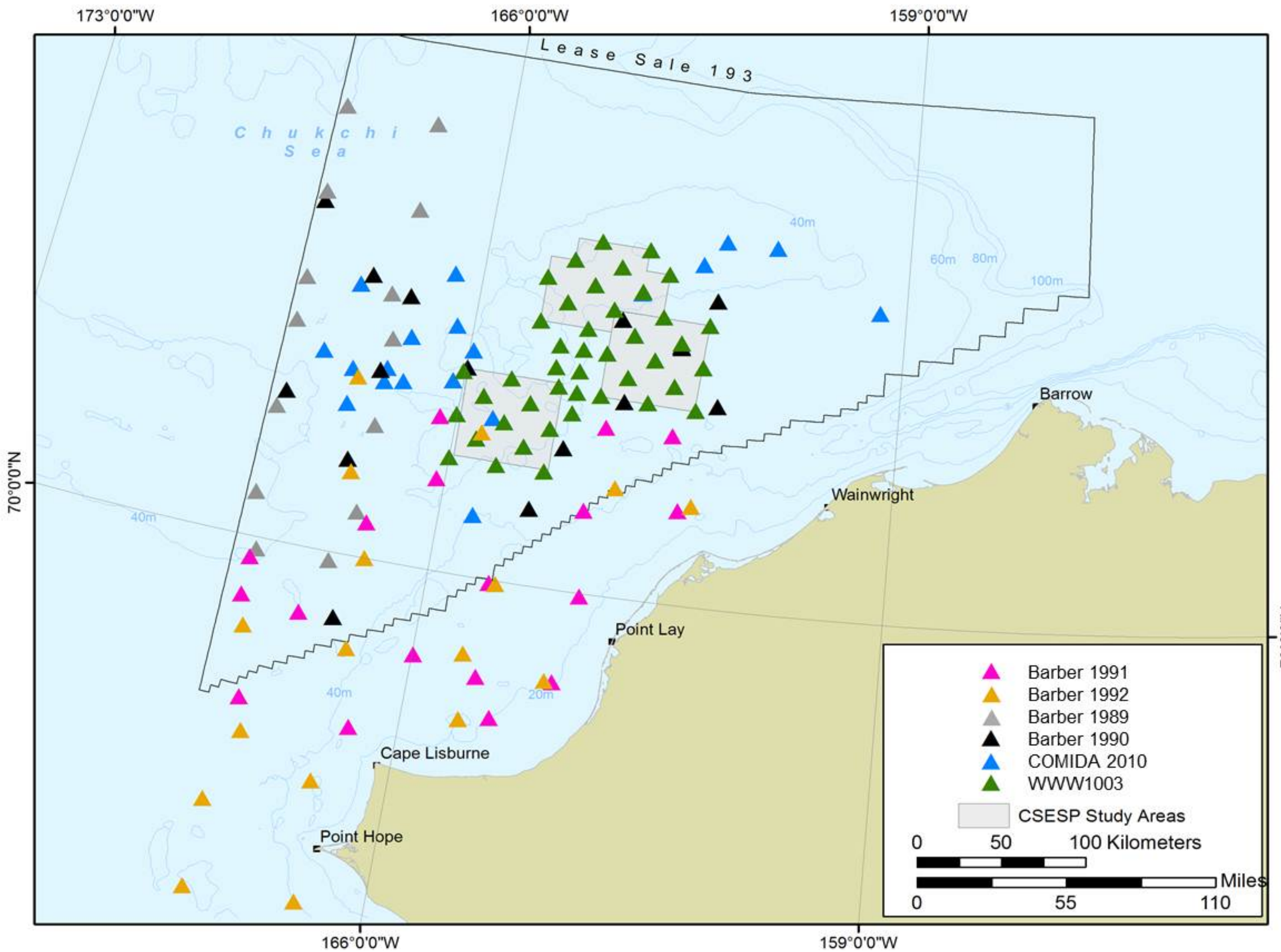

Figure A4.2. Map of the study area showing bathymetry and sampling stations described in the text; Barber 1989 (6mOT); Barber 1990 (83-112OT); Barber 1991 and 1992 (43mOT); COMIDA 2010 (5mPSBT) and the WWW1003 (3mBT) stations.

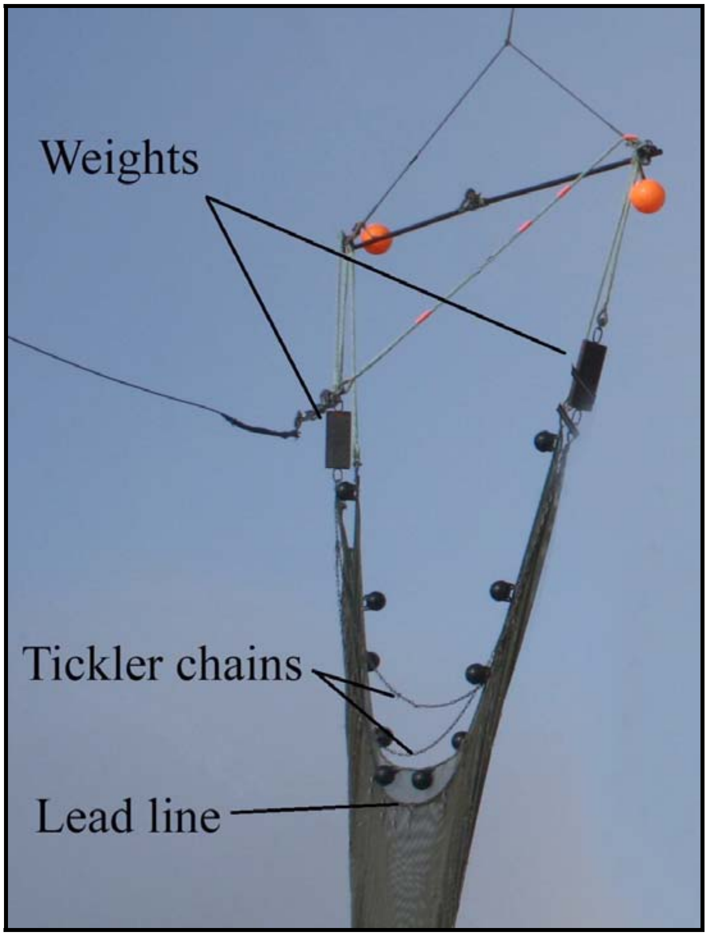

Figure A4.3. 3mPSBT being brought on board the M/V *Westward Wind* in the northeastern Chukchi Sea, 2010. Note that the trawl does not have “shoes,” but instead has weights at each end of the footrope.

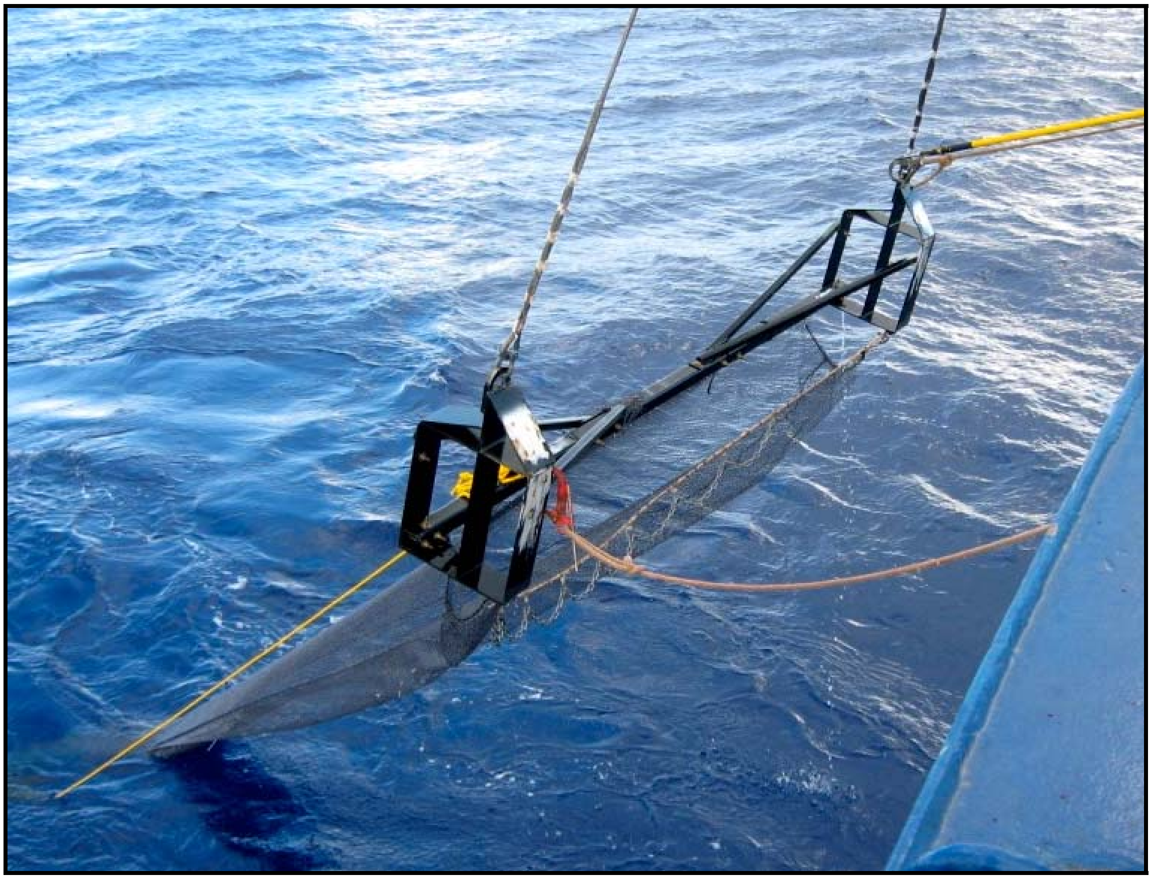

Figure A4.4. A typical 5mBT with heavy duty Masago-Beam similar to the one deployed during cruise WWW1003 in the northeastern Chukchi Sea, 2010.

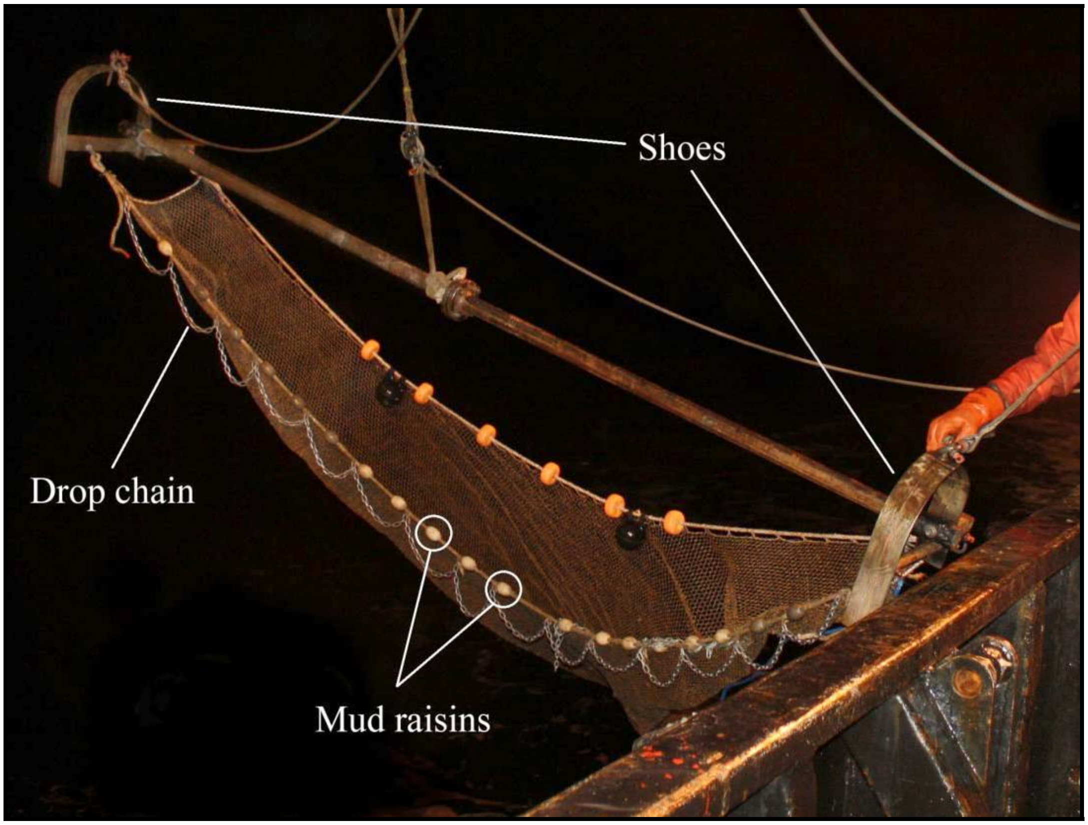

Figure A4.5. The 3mBT being deployed from the M/V *Westward Wind* in 2010.


Figure A4.6. The 5mPSBT being readied for deployment from the R/V *Moana Wave* in 2010.

Figure A4.7. Comparison of invertebrate bycatch associated with the 83-112OT (Logerwell et al. 2010) and the 3mPSBT.

APPENDIX 5 - AGE ESTIMATES OF FIVE SPECIES BY ADF&G

[1]B.L. Norcross, [1]B.A. Holladay, [1]C. Gleason

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[1] University of Alaska Fairbanks, Fairbanks, Alaska

STATE OF ALASKA
DEPARTMENT OF FISH AND GAME
AGE DETERMINATION UNIT

SEAN PARNELL, GOVERNOR

PO Box 115526
Juneau, AK 99811-5526
Phone: (907) 465-3054
FAX: (907) 465-6533

May 8, 2011

Dear Ms. Gleason and Dr. Norcross,

I have completed age pattern review of the 21 specimens of 5 species: *Anisarchus medius* (n=4), *Boreogadus saida* (n=8), *Gymnocanthus tricuspis* (n=3), *Hippoglosoides robustus* (n=3), and *Lycodes polaris* (n=3). I initially received from you the otoliths mounted on slides and sectioned in the sagittal or transverse planes, and later received the whole otoliths. You informed me that all of these specimens were collected in September 2009 from arctic waters. You did not provide fish length data (e.g. age estimates were produced without this bias). The age assignments and some general comments are indicated in Table 1.

I previously had not aged any of these species; however, I had previous experience in aging fish (>40spp) from these families or "otolith types", with the exception of "eelpouts" and "blennies". My biases (or, scientific understandings/experience and inclinations therein) may be important to consider in my results: *i)* cold-deepwater fishes are surprisingly old and their growth patterns sometimes are 'underaged'; *ii)* otoliths accrete as a function of somatic growth and time; *iii)* otolith growth (accretion) patterns can abruptly change ("transition zone") once the fish has reached sexual maturity; and *iv)* 'small otolith' does not always imply 'less old' (this point in relation to the very small otolith size for the species' you sent, all of which had 'small otoliths'). I additionally considered: *a)* that these species inhabit cold and relatively shallow waters, and *b)* that these species may demonstrate different life history strategies given their arctic environment (relative to which I am accustomed). But, I assumed no differences in otolith accretion mechanisms or "pattern interpretation problems".

The ideal scenario to originate an understanding of how to interpret otolith growth patterns for a species is best accomplished with numerous specimens representing the entire range of somatic size. To compensate for lack of data on fish size, and the low volume of specimens per species in your sample, I repeatedly examined all specimens within a species (using sectioned and whole otoliths) and in relation to the pattern in the largest otolith. From this I developed a general understanding of the pattern tendencies for the species, and then tested this understanding against other specimens. Following are my species-specific observations.

Anisarchus medius (n=4) Stout Eelblenny

Age determinations for this species are tentative but with some confidence in "age range". Assigned ages ranged from 5 to 7y. I can confidently say that specimens are older than 3y. For your sample #521, this specimen seemed to 'grow slow' following age-2y, and the increments became fine after this transition zone. This suggests that the potential for error in my ages may be slight underaging of very fine increments.

Boreogadus saida (n=8) Polar Cod (Arctic Cod)
Age determinations for this species are tentative, but with some confidence in the age range. Assigned ages ranged from 0 to 11y. I felt confident that some of these specimens were older than 6y (fishbase.org indicates t_{max}=7y). I believe that an abrupt transition zone was followed by numerous fine increments which are more challenging to enumerate; it is possible I underaged a few specimens slightly (e.g., max age may be ~13y for one specimen). The "September-captured age-0 specimens" and their otolith diameters (~0.5mm) were helpful in establishing an estimated size of the first year, in fish >1y. I applied 'break and burn method' to all larger otoliths. I also applied an understanding of 'gadid aging' that differs from convention: I recognize that 'unit-accretion' to encircle the gadid otolith core (in contrast to other marine species) can result in finer width otolith increments after the transition to slower growth, which generally results in older ages for gadids.

Gymnocanthus tricuspis (n=3) Staghorn Sculpin
Age determinations for this species are final and confidently assigned. Assigned ages ranged from 0 to 4y. Growth patterns were strong and clear and annuli were perceived to be widely spaced. The diameter of the first annulus ranged from ~0.8 to ~1.2mm.

Hippoglosoides robustus (n=3) Bering Flounder
Age determinations for this species are tentative. Assigned ages ranged from 1 to 9y. The 9y old specimen growth pattern transitioned after the first year, and subsequent enumerated annual increments were fine. This suggests that the potential for error in my ages may be slight underaging of very fine increments; although I cannot rule out range error. Increasing sample size across the entire range in size for this species should improve confidence in pattern interpretation.

Lycodes polaris (n=3) Canadian eelpout
Age determinations for this species are tentative, though with confidence in the age range. Assigned ages ranged from 0 to 11y. The 11y old specimen had 2 transition zones: >4y and >6y. After each of these transitions the growth pattern increments were more finely parsed. This suggests that the potential for error in my ages may be slight underaging of very fine increments after the transition zone.

I further note that the best sectioning method for all of these species is likely in the transverse plane; however the sagittal sections were sometimes helpful to discern the early years and transition zones. The gadids especially benefitted from the break and burn method. Crude measurement of the otolith diameter of age-0s or of a pronounced "first annulus" was helpful to relating interpretation amongst specimens within a species.

If you have any questions of my review of age of these fish, please do not hesitate to contact me.

Sincerely,

Kristen M. Munk
Fishery Biologist

Table 1. Ages of 5 marine species from Arctic waters.

Species	UAF Sample #	ADU Specimen #	Age	Comment
Anisarchus medius	523	1	6	>=5
Anisarchus medius	533	2	7	>=7
Anisarchus medius	521	3	6	
Hippoglosoides robustus	215	4	9	T>1; >6
Boreogadus saida	606	5	0	
Lycodes polaris	1506	6	0	0 to 1
Boreogadus saida	1333	7	6	>=6; Bb
Boreogadus saida	1350	8	11	slow>7; BB
Boreogadus saida	1360	9	6	>=6; slow>5; BB
Hippoglosoides robustus	220	10	2	
Hippoglosoides robustus	1593	11	1	
Boreogadus saida	289	12	0	0.5mm
Boreogadus saida	272	13	8	>=8 to 11
Boreogadus saida	261	14	9	>=8 to 13
Boreogadus saida	311	15	3	>=3 to 5
Gymnocanthus tricuspis	1105	16	0	1st = 1mm
Gymnocanthus tricuspis	1258	17	2	1st = 1.2mm
Gymnocanthus tricuspis	1260	18	4	1st = .8mm
Anisarchus medius	509	19	5	>=5
Lycodes polaris	1614	20	9	>7
Lycodes polaris	1648	21	11	>6; T1>4, T2>6

APPENDIX 6 - AGE ESTIMATES OF ARCTIC COD BY AFSC

[1]B.L. Norcross, [1]B.A. Holladay, [1]C. Gleason

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[1] University of Alaska Fairbanks, Fairbanks, Alaska

Fwd: Arctic Cod

Subject: Fwd: Arctic Cod
From: Thomas Helser <Thomas.Helser@noaa.gov>
Date: 5/27/2011 8:16 AM
To: Brenda Norcross <brenda.norcross@gmail.com>
CC: betty Goetz <Betty.Goetz@noaa.gov>

Brenda,
Attached are the age determination results for your Arctic cod sample from two readers in the program. There was quite good agreement between the two independent readers applying the same age determination criterion. I will send along an image showing how annual growth zones were determined from one or two specimens. We would be interested to see how these results compared to those from your reader. Let me know if you have any questions.
Thanks
Tom

-------- Original Message --------
Subject: Arctic Cod
Date: Thu, 26 May 2011 16:33:25 -0700
From: Christopher.Gburski <Christopher.Gburski@noaa.gov>
To: Thomas Helser <Thomas.Helser@noaa.gov>, Betty Goetz <Betty.Goetz@noaa.gov>, Charles Piston <Charlie.Piston@noaa.gov>

Here are the age data forms for Brenda's arctic cod. Charlie Piston was the reader and Chris Gburski was the tester. The agreement between the reader and tester was 20/23 = 87% for +/- 0. The 3 discrepancies have not been resolved. We will acquire a digital image form one of the clear thin sections.

Thanks, Chris

Attachments:

Rusalca09 Arctic cod special collection ages_Piston.docx 14.8 KB

NOAA, NMFS, AFSC, REFM, Age and Growth Program
Special Collection, Age Assessment

Species: Arctic Cod
Structure: otoliths
Catch Location: Chukchi Sea, Russia
Survey Name: Rusalca 09 cruise
Catch Date: summer 2009
For: Brenda Norcross, University of Alaska Fairbanks, (907) 474-7938
23 otolith specimens-- slide mounted thin-section and part of whole otolith
Date of Age Assignments: 5/26/2011

Age Reader: Charlie Piston-Reader (206) 526-6524

Specimen ID	otolith width	Age	
3125	~1.0 mm	0+	
3271	~0.7 mm	0+	
3137	~1.1 mm	1+	
3167	1.5 mm	1+	
3392	~1.4 mm	(1)?	
3164	~1.6 mm	1+	(or 2 w/no new growth)
3162	~1.8 mm	1+	
3236	~2.5 mm	2+	(2 or 3)
3272	~1.9 mm	1+	
3163	~1.8 mm	1+	
3240	~2.0 mm	1+	
3245	~2.0 mm	1+	
3242	~2.0 mm	1+	
3252	~2.0 mm	1+	
3253	~2.2 mm	1+	
3255	~2.2 mm	1+	
3251	~2.2 mm	1+	
3302	~2.4 mm	2+	check in 2^{nd} yr (or possible 3+)
3267	~2.0 mm	1+	
3248	~1.4 mm	1+	
3275	~2.7 mm	2+	
3273	~2.9 mm	2+	
3274	~2.9 mm	2+	check in 2 yr (or possible 3+)

NOAA, NMFS, AFSC, REFM, Age and Growth Program
Special Collection, Age Assessment

Species: Arctic Cod
Structure: otoliths
Catch Location: Chukchi Sea, Russia
Survey Name: Rusalca 09 cruise
Catch Date: summer? 2009
For: Brenda Norcross, University of Alaska Fairbanks, (907) 474-7938
23 otolith specimens-- slide mounted cross-section and part of whole otolith
Date of Age Assignments: 5/26/2011

Age Reader: Chris Gburski-Tester (206) 526-4268

Specimen ID	otolith width	Age	Notes
3125	~1.0 mm	0	0, transition zone on edge
3271	~0.7 mm	0	0, very difficult
3137	~1.1 mm	0	0, e ~ 3?
3167	~1.5 mm	1+	1+ with check on edge?, (2)?
3392	~1.4 mm	0	0?, very difficult, 1+?
3164	~1.6 mm	1+	1+ with check?
3162	~1.8 mm	1+	2+ or 1 with check?
3236	~2.5 mm	1+	1+ with checks?, (2)?
3272	~1.9 mm	1+	1+ with checks?
3163	~1.8 mm	1+	1+ with checks
3240	~2.0 mm	1+	Clear 1+ (PHOTO)
3245	~2.0 mm	1+	1+, e~4
3242	~2.0 mm	1+	1+, checky, e~4
3252	~2.0 mm	1+	1+ with check in firsy year or 2+, e~2
3253	~2.2 mm	1+	1+?
3255	~2.2 mm	1+	1+, e~3
3251	~2.2 mm	1+	1+, e~3 (PHOTO
3302	~2.4 mm	2+	2+, first year with check (3)
3267	~2.0 mm	1+	1+ with checks
3248	~1.4 mm	1+	1+, e~3
3275	~2.7 mm	2+	2+, e~3
3273	~2.9 mm	2+	2+, e~2
3274	~2.9 mm	2+	2+, faint(3), first year broad, checky

APPENDIX 7 - LENGTH-FREQUENCY PLOTS OF NON-KEY SPECIES

[1]B.L. Norcross, [1]B.A. Holladay, [1]C. Gleason

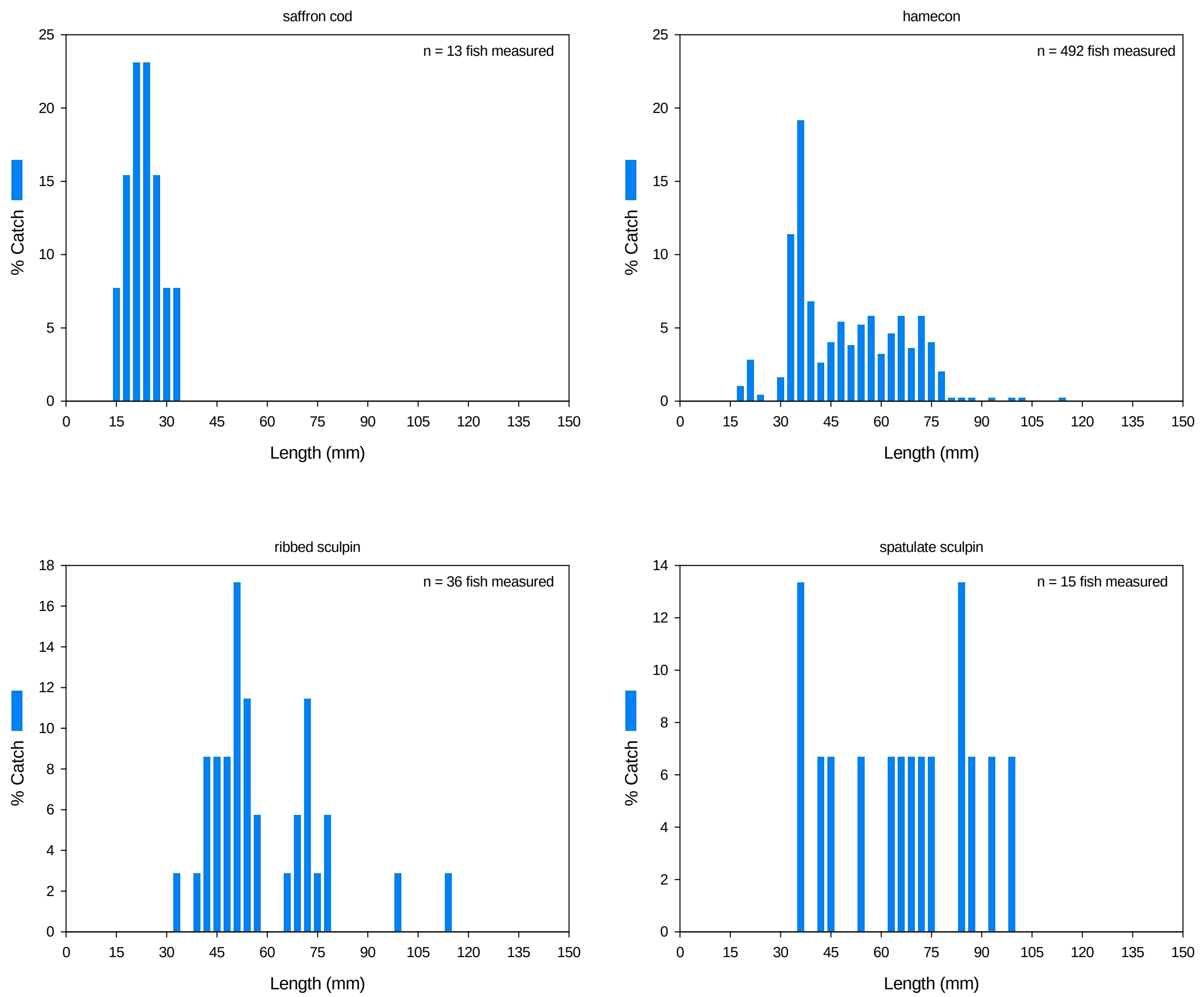

Figure A7.1. Length distribution of saffron cod, hamecon, ribbed sculpin, and spatulate sculpin combined over collections July/August 2009, September/October 2009, and September 2010.

[1] University of Alaska Fairbanks, Fairbanks, Alaska

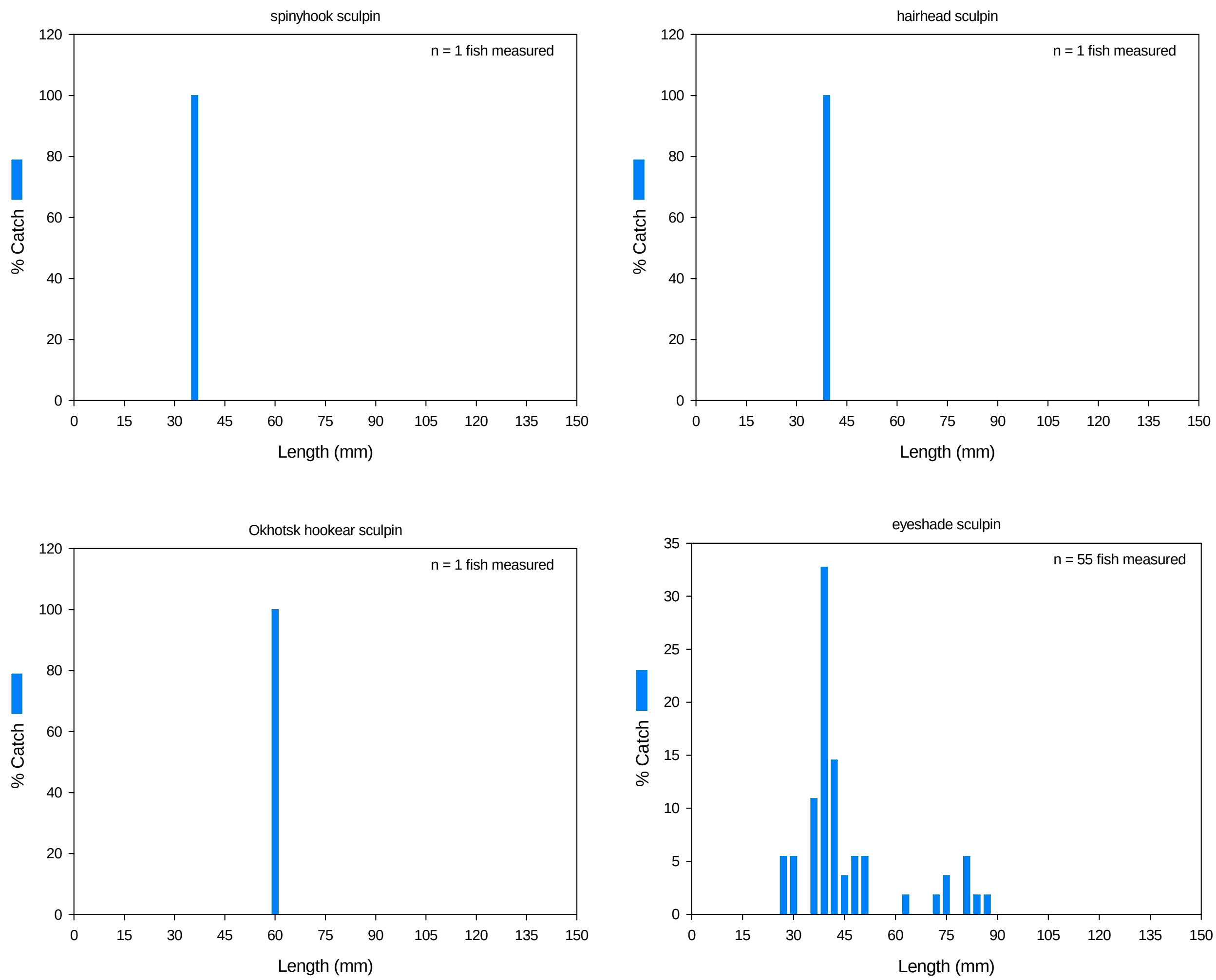

Figure A7.2. Length distribution of spinyhook sculpin, hairhead sculpin, Okhotsk hookear sculpin, and eyeshade sculpin combined over collections July/August 2009, September/October 2009, and September 2010.

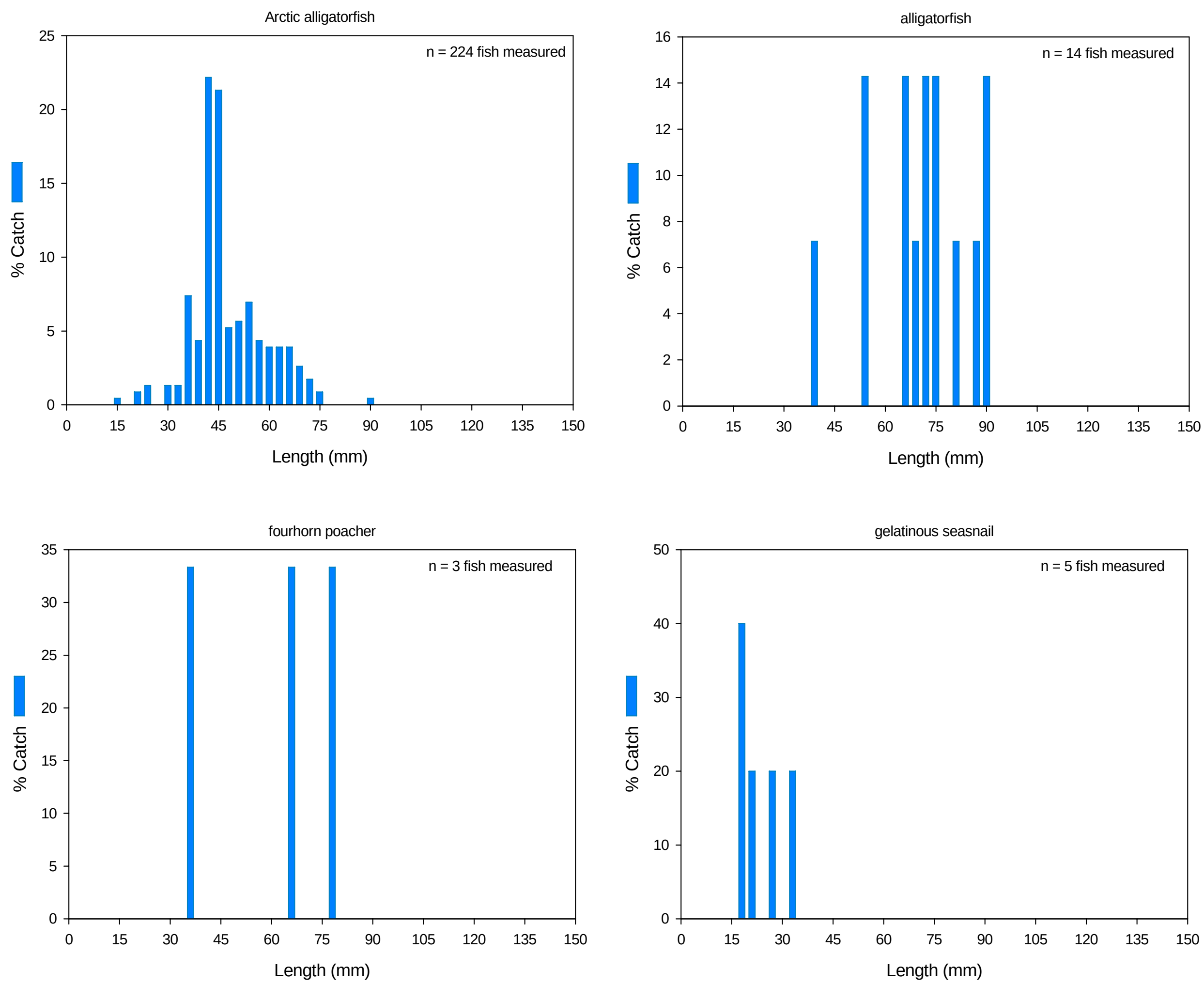

Figure A7.3. Length distribution of Arctic alligatorfish, alligatorfish, fourhorn poacher, and gelatinous seasnail combined over collections July/August 2009, September/October 2009, and September 2010.

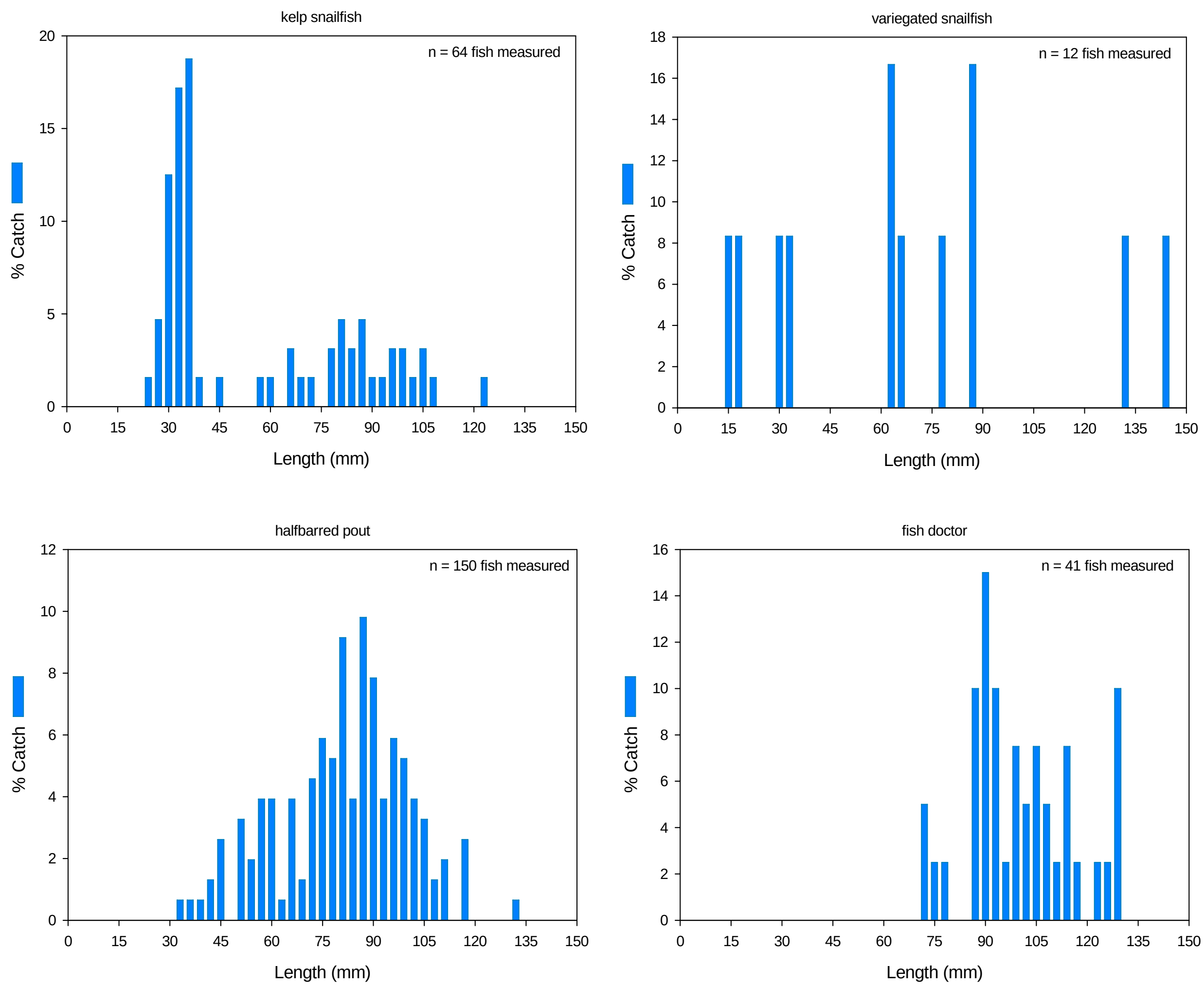

Figure A7.4. Length distribution of kelp snailfish, variegated snailfish, halfbarred pout, and fish doctor combined over collections July/August 2009, September/October 2009, and September 2010.

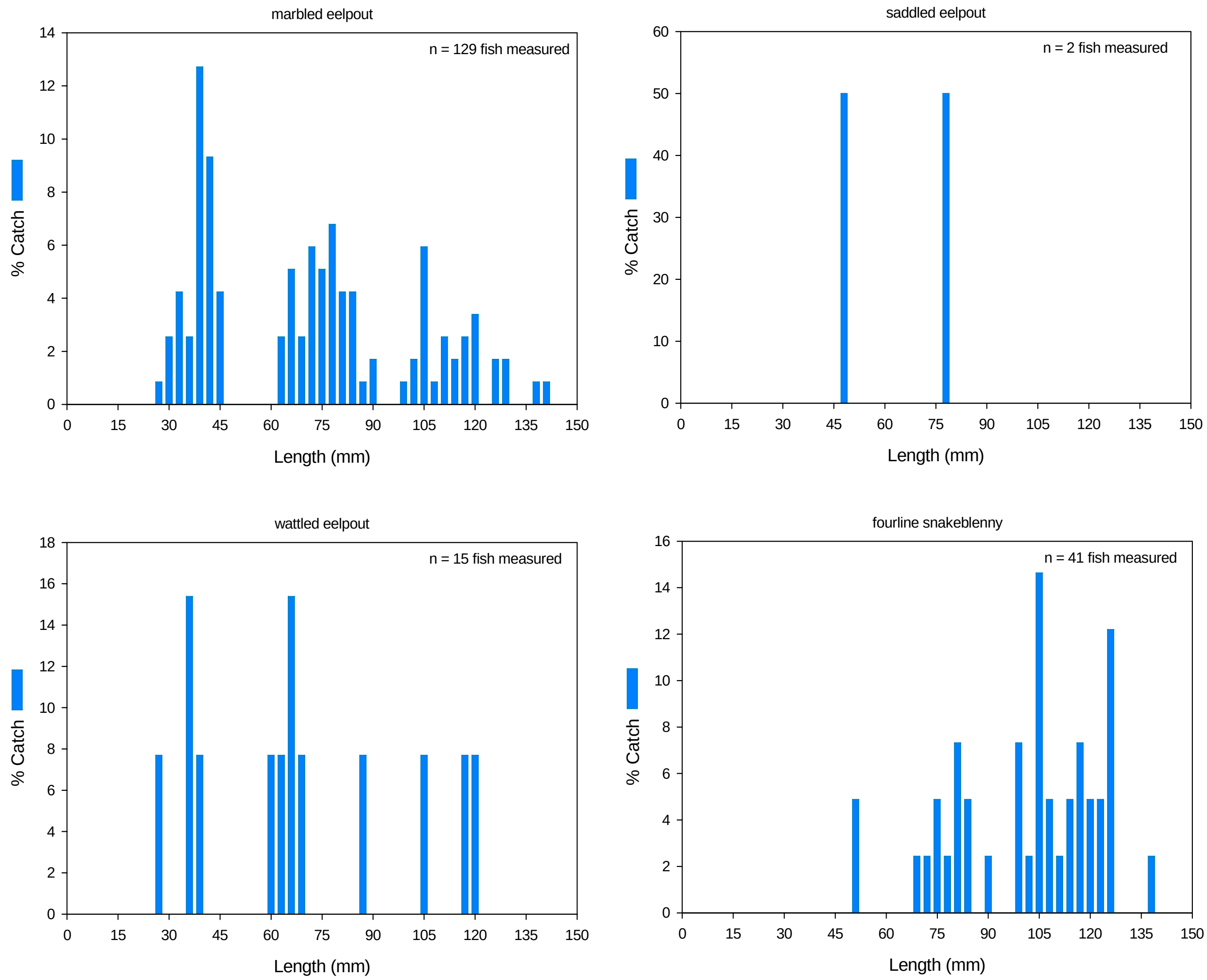

Figure A7.5. Length distribution of marbled eelpout, saddled eelpout, wattled eelpout, and fourline snakeblenny combined over collections July/August 2009, September/October 2009, and September 2010.

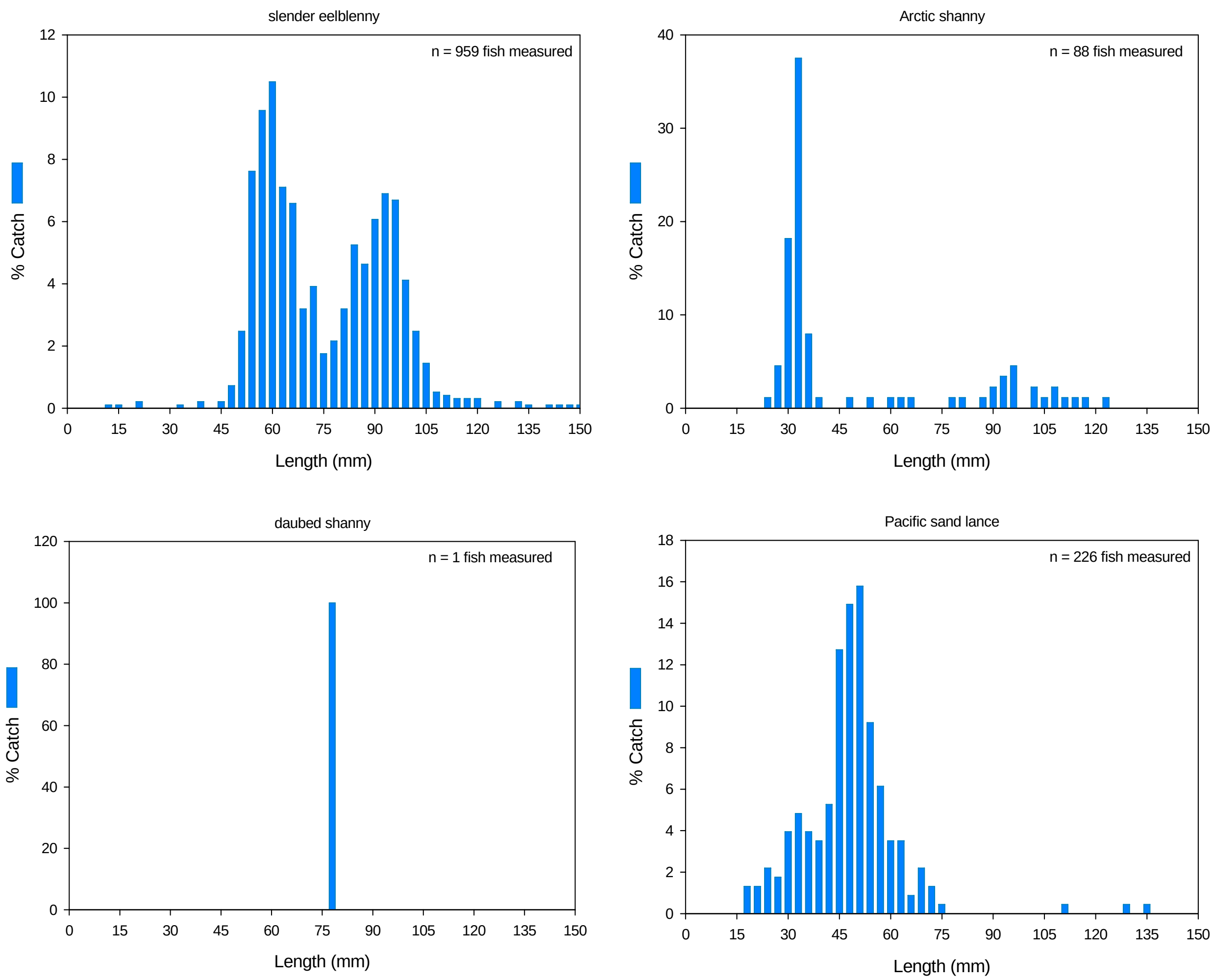

Figure A7.6. Length distribution of slender eelblenny, Arctic shanny, daubed shanny, and Pacific sand lance combined over collections July/August 2009, September/October 2009, and September 2010.

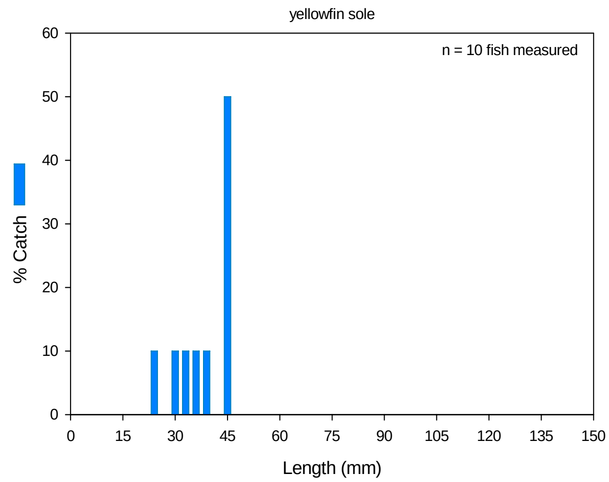

Figure A7.7. Length distribution of yellowfin sole combined over collections July/August 2009, September/October 2009, and September 2010.