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Beaufort Sea Marine Fish Monitoring 2008: Pilot Survey and Test of Hypotheses

Final Report

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Further analysis and interpretation of the ecological data collected in this study will be published in a future BOEMRE report.

REPORT AVAILABILITY

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Abstract

The Minerals Management Service (MMS), Alaska OCS Region funded a pilot survey in 2008 of the offshore marine fishes of the Beaufort Sea. This was the first offshore marine fish survey to have taken place since an opportunistic survey in 1977 (Frost and Lowry 1983). This pilot survey provided recommendations for future monitoring methods in addition to baseline data against which to compare future anthropogenic and climate impacts. Because it was a pilot survey, different techniques were employed to assess fish abundance. It is important to note that density, abundance, and biomass estimates from the bottom trawl and acoustic/midwater trawl surveys targeted different sections of the water column, used different sampling gears, and followed disparate sampling strategies and analytic paths. Demersal fish and benthic invertebrates were assessed using standardized bottom trawl gear and methods. Pelagic fish abundance was assessed using hydroacoustics and midwater net tows. The distribution of zooplankton was sampled with small-meshed bongo nets and physical oceanographic data were collected with conductivity-temperature-depth instruments. Demersal fish made up 6% of the bottom trawl catch by weight, and invertebrates made up the remaining 94% of the catch. A total of 32 fish were identified to species, two were identified to genus and 1 to family, and 174 species of invertebrates were identified. The four most abundant benthic fish taxa were Arctic cod (*Boreogadus saida*), eelpouts (*Lycodes* spp.), Bering flounder (*Hippoglossoides robustus*), and walleye pollock (*Theragra chalcogramma*). The most abundant invertebrates were notched brittle stars (*Ophiura sarsi*), opilio crab (*Chionoecetes opilio*), mollusks (*Musculus* spp.) and a seastar (*Ctenodiscus crispatus*). Comparison of our results with historic data suggests that climate change may have resulted in northward expansion of some species' ranges, including commercially valuable species such as pollock and Pacific cod (*Gadus macrocephalus*). This survey was also the first to document commercial-sized opilio crab (*Chionoecetes opilio*) in the North American Arctic. Acoustics and midwater trawling were used to quantify density distributions of pelagic and semi-demersal fish in the survey area (20-500 m bottom depths) and to evaluate relationships between fish distribution and habitat descriptors. Year-plus Arctic cod were the dominant pelagic/semi-demersal fish species, with peak densities of 150,000 fish/ha at bottom depths of 100-350 m. Oceanographically, year-plus Arctic cod were associated with cold, saline waters. The density distribution of year-plus Arctic cod closely mirrored published foraging distributions for beluga whales (*Delphinapterus leucas*). Young of the year fish (Arctic cod, unidentified sculpin (Cottidae), and undentified eelblenny (*Lumpenus* sp.)), dominated the pelagic biomass at bottom depths of 20-75 m, with peak densities up to 160,000 fish/ha, but were also found in surface waters at bottom depths greater than 75 m. The age-0 fish were associated with warm, fresher water throughout the study area. Physical oceanographic data indicated the presence of Pacific Ocean-derived waters (modified on the Bering and Chukchi shelves) that likely exited the Chukchi shelf through Barrow Canyon and into the Beaufort Sea. In addition, evidence of recent ice melt was found in cold, low salinity waters in the upper few meters of the water column in the western portion of the study area. River outflow water influenced water column properties in the eastern portion of our study area, as evidenced by a lens of very low salinity, warm water near the surface.

Introduction

In August 2008 researchers from NOAA-NMFS Alaska Fisheries Science Center (AFSC), University of Washington (UW) and University of Alaska Fairbanks (UAF) conducted a survey of offshore marine fish, invertebrates, and physical and biological oceanography of the western Beaufort Sea in the vicinity of Cape Simpson to Cape Halkett. The most recent previous survey of Beaufort Sea offshore marine fish was conducted opportunistically from a US Coast Guard cutter during 1976-1977 (Frost and Lowry 1983). The majority of previous fish studies have focused on anadromous fish in estuaries, inlets, river deltas, or lagoons (Bond and Erickson 1997, Gallaway et al. 1997, Jarvela and Thorsteinson 1997, Moulton et al. 1997, Underwood et al. 1997). A few studies have examined the occurrence of marine fish in nearshore waters (<20 m deep), often in the transition zone between marine and brackish waters (Craig 1984, Craig et al. 1982, Jarvela and Thorsteinson 1999, Moulton and Tarbox 1987). The distribution and abundance of benthic invertebrates in the Beaufort Sea have only been documented in two previous publications, and the most recent was published over 20 years ago (Carey et al. 1984, Frost and Lowry 1983). The physical and biological oceanography of the Beaufort Sea shelf have been investigated more thoroughly and more recently (Aagaard 1984, Ashjian et al. 2009, Ashjian et al. 2006, Matthews 1981, Okkonen 2008, Pickart 2004, Pickart et al. 2005, Weingartner et al. 2005b), although no synchronous measures of marine fish distribution and the oceanographic characteristics of their habitat have been made prior to the survey reported here.

Minerals Management Service (MMS) requires information on the species presence, distribution and abundance of marine fishes to assess and manage the potential environmental effects of offshore development. This information is used in National Environmental Protection Act (NEPA) analyses of lease sales, exploration plans, and development and production plans. The primary potential effects on fish that MMS analysts commonly evaluate in these NEPA documents are the effects 1) within the water column (e.g. from an unlikely but potentially wide spread oilspill or from seismic exploration), and 2) in benthic (e.g. from building and operating subsea pipelines) habitats.

The overarching goal of the survey presented here is to generate a baseline against which to assess the effects of offshore development on marine fish and to provide information for designing mitigation measures. A related goal is to provide a baseline against which to assess the impact of climate change, the manifestation of which is particularly severe in the Arctic as evidenced by recent dramatic declines in sea ice cover (Maslanik et al. 2007, Stroeve et al. 2007, Stroeve et al. 2008)

The specific objectives of the study are:

1. Quantify the distribution of benthic and pelagic fish in a subset of the Beaufort Sea Outer Continental Shelf (OCS) Planning Area
2. Quantify the characteristics of marine habitats occupied by fish
3. Recommend methods for future monitoring

A suite of field methods was employed to accomplish these objectives. A standardized bottom-trawl survey was conducted to quantify the distribution and density of benthic fish and invertebrates. The distribution and density of pelagic fish was assessed with an acoustic-midwater trawl survey. Marine habitats were characterized with data on water temperature and salinity. Data on the species distribution of zooplankton prey will be incorporated in the future. The diets of benthic and pelagic fish, a measure of habitat use, will be determined from stomach specimens. In addition, data on the density of seabirds was collected with standardized strip-transects and opportunistic observations of marine mammals were recorded. Recommendations for future monitoring methods are based on these results and on the collective experience of the investigators during the survey. The results document the distribution and abundance of key ecological species that could be vulnerable to offshore development, such as Arctic cod (*Boreogadus saida*). Arctic cod are important prey for seabirds and marine mammals and are in turn important consumers of secondary production (Bradstreet et al. 1986, Frost and Lowry 1981 and 1983, Jarvela and Thorsteinson 1999). The results also document potential northerly expansions in the known ranges of some species, a potential indicator of the impact of climate change. A brief literature review of past studies in the US and Canadian Beaufort Sea can be found in Appendix II of this report.

Methods

The survey was conducted on board the chartered fishing vessel F/V *Ocean Explorer*, a 155-foot (47.2 m) trawler, equipped with two net reels. The vessel departed from Dutch Harbor, Alaska on July 30, 2008 arriving on the survey grounds on August 6. The survey was completed on August 22, and the vessel returned to Dutch Harbor on August 27. Sunrise on August 5 (the day we arrived on the survey grounds) was at 03:45 and sunset was at 00:13. Sunrise on August 22 (the day we finished the survey) was 05:22 and sunset was at 22:30. There was one full moon during the survey on August 16th.

Oil and gas industry vessels conducted seismic surveys during August-September 2008 in the Beaufort Sea in both state (nearshore) and federal waters. Quantitative data on the distribution, timing and amount of seismic activity are proprietary and confidential. However, it is known that the seismic surveys that took place in state waters were over 50 nmi from our marine fish survey area. The seismic surveys that were conducted in federal waters were 93 nmi from the eastern boundary of the fish survey area and 140 nmi from the western boundary. These distances are greater than the spatial extent of fish response to seismic survey activity that has been documented in the literature (Engås, et al. 1996; Slotte et al. 2004).

Survey area

The survey area started at approximately 155°W and extended to 152°W (Figure 1); the south end of the transects started at approximately 71°N and continued north to 72°N, crossing the shelf break.

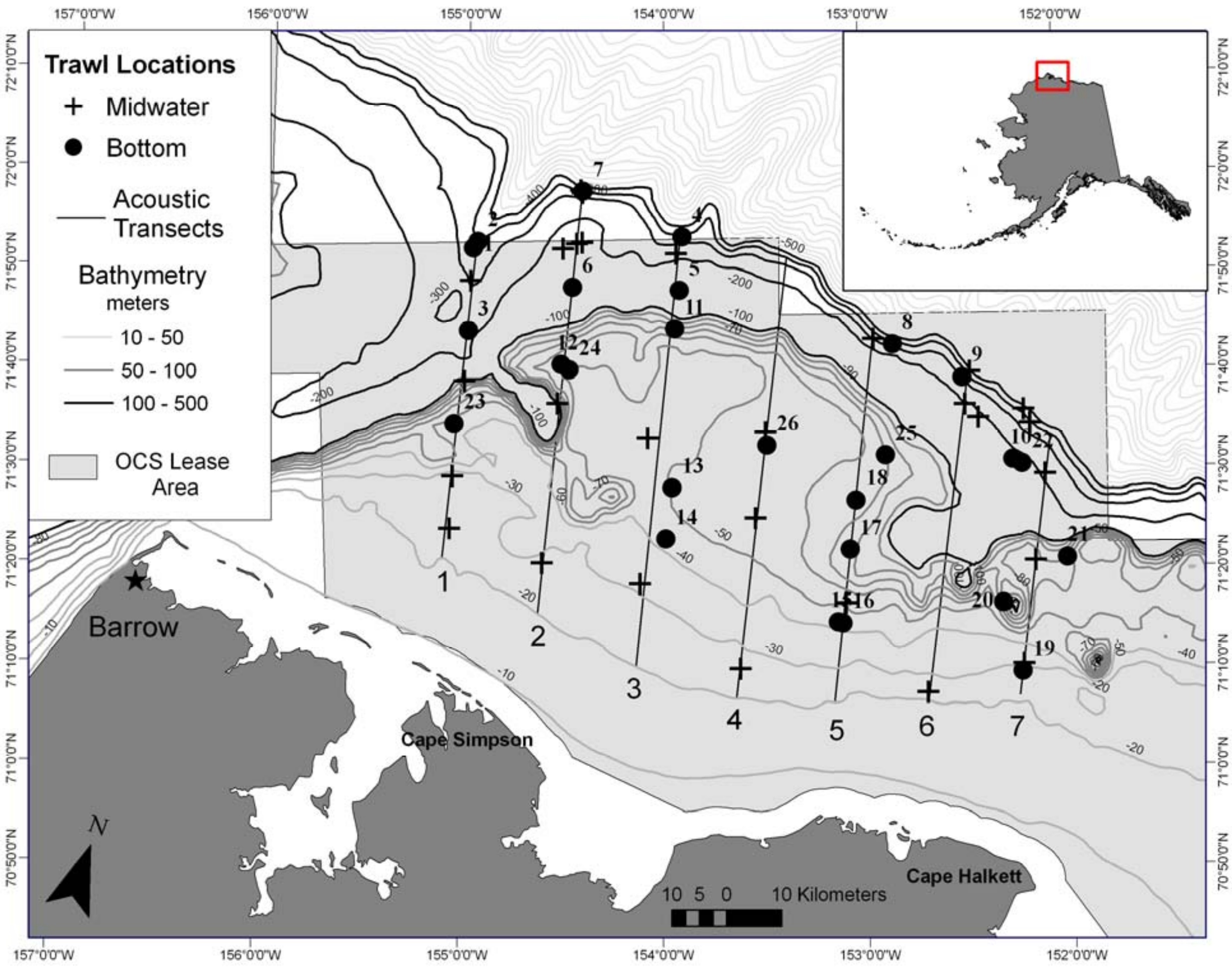


Figure 1. Bottom and midwater trawl locations and acoustic transects, Beaufort Sea, August 2008. Bottom trawl numbers (only) are also shown. North-south lines (1-7) are systematic acoustic transect lines. The Outer Continental Shelf (OCS) Lease Area is shown in gray shading (Bathymetry data from IBCAO, http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/arctic.html).

Bottom trawl stations were occupied first, using a stratified sampling plan with a random start location. The survey design called for bottom trawl locations to be distributed evenly among three depth strata, 20-40 m, 40-100 m, and 100-500 m (Figure 1). However, due to the presence of sea ice during the first 6 days of the survey and untrawlable habitat for setting bottom gear (e.g. boulders, high relief), trawling was limited to areas that would minimize potential gear loss or damage. If a predetermined station was found to be unsuitable for trawling, the trawlable site closest to the station was used. If no suitable trawling site was located near the predetermined station, the site was eliminated and we moved to the next station. In addition, we were not able to do bottom trawls in the 20-40 m strata, due to untrawlable habitat. Table 1 summarizes all the bottom trawl locations, depth, distance fished and total catch weight (all species combined).

After all the bottom trawl stations were sampled, a total of seven acoustic transects were surveyed spaced 18.42 km (10 nautical miles) apart with a random start location (Figure 1). Midwater tows were conducted opportunistically to identify the species composition and to collect other biological samples of the backscatter (Figure 1).

Conductivity-temperature-depth (CTD) casts and zooplankton net (bongo) tows were conducted at nearly all bottom and midwater trawl locations, generally immediately after the trawl was brought on board (Figure 2). Additional CTD stations spaced 3-4 km apart were sampled on the westernmost transect 1, and eastern transect 5 to capture small-scale cross-shelf variability in water properties.

Table 1. Bottom trawl locations (Lat/Long) in decimal degrees, bottom depth, qualitative bottom type, distance fished, bottom temperature and total catch weight for all bottom trawls conducted. “No catch” in the “Total Catch Weight” column, indicates the gear was lost or damaged resulting in no catch sample.

Trawl No.	Start Latitude (DD)	Start Longitude (DD)	Avg Bottom Depth (m)	Qualitative Bottom Type	Depth Classification	Distance fished (km)	Bottom temp °C	Tow Time (minutes)	Lined or Unlined net	Total Catch Weight (kg)	Comments
1	71.88	-154.97	428	mud	Slope	3.6	0.5	30	lined	No catch	lost codend
2	71.89	-154.95	470	mud	Slope	1.127	0.5	10	lined	694.93	
3	71.74	-154.99	198	rocks	Slope	1.355	-0.1	15	lined	751.34	net tore, replaced
4	71.90	-153.91	347		Slope	1.288	0.6	15	lined	1881.89	
5	71.81	-153.92	143	rocks	Slope	1.26	-1.2	15	lined	1846.51	
6	71.81	-154.46	158	mud	Slope	1.454	-1.4	15	lined	9502.65	
7	71.98	-154.41	322		Slope	1.64	0.5	15	lined	2028.50	
8	71.72	-152.84	318	mud	Slope	1.393	0.5	15	lined	1382.47	
9	71.66	-152.49	302	mud	Slope	1.513	0.6	15	lined	1984.08	
10	71.52	-152.25	175	mud	Slope	1.52	-0.8	15	lined	2359.84	paired with 22
11	71.75	-153.94	66	rocks	Shelf	1.397	-0.7	15	lined	419.10	
12	71.69	-154.52	50	rocks	Shelf	1.51	1.8	15	lined	251.08	paired with 24
13	71.48	-153.96	49	mud	Shelf	1.346	1.5	15	lined	339.30	
14	71.39	-153.99	41	mud	Shelf	1.363	1.8	15	unlined	No catch	lost whole net
15	71.25	-153.13	41	rocks	Shelf	1.425	1.0	15	unlined	No catch	lost codend
16	71.25	-153.11	41	rocks	Shelf	0.395	1.0	5	unlined	19.45	
17	71.37	-153.07	75	rocks	Shelf	0.459	0.3	5	unlined	256.35	
18	71.46	-153.04	64	hard	Shelf	0.561	0.7	5	unlined	87.81	
19	71.16	-152.23	30	mud	Shelf	0.423	1.3	5	unlined	No catch	large net tear
20	71.28	-152.31	50	rocks	Shelf	0.572	-0.4	5	unlined	38.74	
21	71.35	-151.99	83	rocks	Shelf	0.624	-1.4	5	unlined	27.45	
22	71.51	-152.20	178		Slope	0.708	-0.4	5	unlined	77.74	paired with 10
23	71.58	-155.05	44	rocks	Shelf	0.62	-0.1	5	unlined	43.05	
24	71.68	-154.48	50	rocks	Shelf	0.579	-0.9	5	unlined	52.78	paired with 12
25	71.53	-152.89	59	hard	Shelf	0.613	-0.9	5	unlined	35.52	
26	71.55	-153.48	52	hard	Shelf	0.482	1.2	5	unlined	10.59	

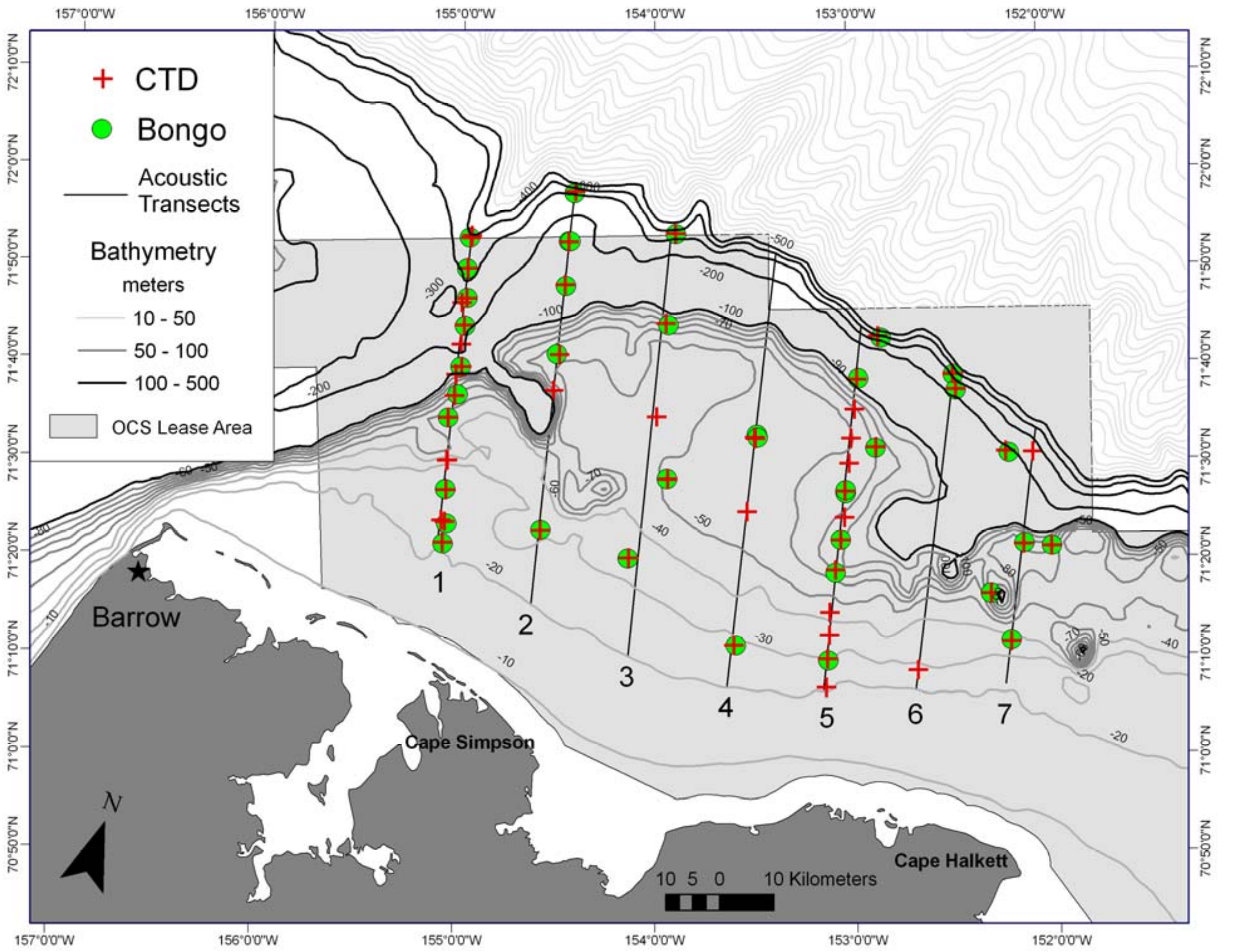


Figure 2. Bongo tow and CTD cast stations, Beaufort Sea, August 2008. The Outer Continental Shelf (OCS) Lease Area is shown in gray shading.

Fish, invertebrate, and habitat data collection

Refer to "Recommendations for Future Monitoring" for a discussion of how sampling gears were selected, how they addressed the characteristics of Arctic benthic and pelagic fish and potential sources of bias.

Demersal fish and invertebrate data collection

All bottom trawls were conducted in concordance with standards set by the Alaska Fisheries Science Center's Resource Assessment and Conservation Engineering (RACE) Division (Stauffer 2004). The net used for the bottom trawls was a standard 83-112 Eastern otter trawl (built at AFSC), which has a 25.3-m (83 ft) headrope and a 34.1-m (112 ft) footrope. The Eastern trawl has a 10.16 cm (4") mesh in wings and body and 8.89 cm (3.5") mesh in intermediate and codend. Bottom trawls 1 through 13 were conducted with a standard 83-112

Eastern otter trawl net modified with a small-mesh liner in order to catch relatively small Arctic fish. The mesh liner was 3.8 cm (1.5”) and covered the entire bottom body of the net, both bottom wings and completely covered the top and bottom of the intermediate and cod end. The original field plan was to conduct the entire bottom trawl survey with the lined 83-112, but unfortunately, all three lined nets were irreparably damaged during the first half of the cruise. Trawls 14 through 26 were conducted with the backup nets, standard 83-112 nets with no liner. The result of this gear change was that with the exception of one station, all the rise stations (bottom depths 101-500 m) were sampled with the lined net and tows were 15 minutes long. Nearly all the shelf/slope stations (9 out of 12 stations in bottom depths 40-100 m) were sampled with the unlined net and were 5 minutes long. This confounding was not intentional but was the result of the fact that only the rise stations were free of ice early in the survey and so we sampled them first with the lined net. When the ice cleared out of the shelf/slope area we had damaged all the lined nets and were forced to complete the survey with the unlined net. Tow time was reduced to 5 minutes when we switched to the unlined net to minimize the chance of damaging our last remaining bottom trawl net. In summary, the sample collection order imposed by practical constraints during the cruise (ice cover and availability of nets) prevented collection of the data as originally planned. All trawls were towed behind 1.83 x 2.75-m (6x9 ft), 816 kg steel V-doors paired with 54.9-m dandylines (Appendix IV for net schematic, trawl door details, the footrope plan and frame lines).

Due to the unexpected change in gear type half way through the bottom trawl survey, near the end of the survey we returned to two locations that had previously been trawled with the lined net and trawled again with the unlined 83-112 net. We refer to these two pair of trawls as “paired trawls”, because they occurred at the same location, with both gear types, however, they occurred at different times. Trawl 10 (lined net, 100-500 m depth) was paired with trawl 22 (unlined net, 100-500 m depth) and they occurred four days apart; trawl 12 (lined net, 40-100 m depth) was paired with trawl 24 (unlined net, 40-100 m depth), also occurring four days apart.

The trawl warps onboard the F/V *Ocean Explorer* were measured and calibrated at the start of the survey using Olympic 750-N in-line wire counters. To standardize trawl performance, a table of trawl wire out for optimal trawl performance at a particular depth was used for all bottom trawls (Stauffer 2004). After the wires were marked, a test tow was done to make sure the survey trawl was performing to standardized specifications found in Stauffer 2004.

Net height and width were measured with Netmind net mensuration equipment during trawling operations (Northstar Technical Inc., St. John’s, Newfoundland). A hydrophone was lowered into the water and data were recorded from the net sensors during trawl operations. A sensor was placed on the headrope of the net that measured the distance to the bottom. This was monitored during trawl operations to insure the net opening remained consistent during the towing. A pair of spread sensors were connected to each of the dandylines and provided net width data. Net width was averaged over the duration of the trawl, based on the data recorded by the net mensuration sensors. The net width sensors failed during three trawls (6, 18 and 23). For these trawls, net width was estimated based on a regression equation that predicts net width from scope (amount of wire out). No regression has been developed specifically for the F/V *Ocean Explorer* so a regression developed for a similar-sized trawler (the F/V *Northwest Explorer*) was employed (Lauth and Acuna 2007). Trawl footrope contact with the seafloor was monitored at 1 second intervals using a calibrated bottom contact sensor (BCS). The BCS consists of a tilt sensor and other electronics inside a stainless steel pipe and is attached at the center of the footrope. Bottom contact data were used to estimate distance fished. Net width and distance fished were then used to calculate area swept which was then used to determine catch-per-unit-effort (CPUE) (Appendix IV, Table IV.1).

A bathythermograph (SBE-39 from Seabird Electronics Inc., Bellevue, Washington) was attached to the headrope of the trawl net. Temperature and depth were recorded at 3-second intervals from the time of net deployment from the vessel to net retrieval and instrument removal.

Trawls were deployed at a constant vessel speed of approximately three knots. The first tow was deployed for 30 minutes of bottom time (the AFSC survey standard), but it was immediately obvious that tows of that duration would result in catch volumes that were too large to effectively sort and quantify. So tow times were reduced to 15 minutes. Even at these shorter tow times, several trawl nets were damaged due to large catches. When only one undamaged trawl net remained, tow times were further reduced to five minutes. Tow times and distances trawled are summarized in Table 1. Tows were conducted in whatever direction was optimal, based on wind and current conditions.

Demersal fish and invertebrate sampling

The entire catch for each bottom trawl (with the exception of trawl 6; see below) was weighed on a marine Marel scale (www.marel.com). The scale was calibrated daily. The preferred method for quantifying the bottom trawl catch was to sort, identify, count and weigh all individual fish and invertebrates. However, due to large catch sizes, and high species diversity, the most common method of sampling the bottom trawl catch was sub-sampling. A random sample of the catch was weighed and sorted for fish to the lowest taxonomic level possible. A sub-subsample (i.e. a sample of the subsample) was taken of the invertebrates due to the high species diversity and quantity of invertebrates caught. Within the sub-subsample of invertebrates, all species were sorted, counted and weighed to the lowest taxonomic level. As the survey progressed and bottom trawl times were reduced, we were able to count and weigh all species in the catch. When the total catch weight was <200 kg, the entire catch (fish and invertebrates) was sorted to the lowest possible taxonomic level, counted, and weighed. Trawls 2-13 and 17 were subsampled; subsample sizes ranged from 31 kg to 200 kg with the average at 79 kg. Trawls 16, 18 and 20-26 were sampled entirely.

We had one bottom trawl that was estimated to be between 9 and 10 metric tons (trawl 6), too large to weigh in baskets on the Marel scale. Several measurements were taken of the codend (length, height, and width in meters). Catch density was estimated by recording the weight, height and width of a square basket filled with unsorted catch. Using the mean codend measurements, and estimated unsorted catch density, a volumetric formula was used to estimate the entire weight of the unsorted codend. The volumetric formula, Frustum of a Cone, was used where h is the height of the cone, R is the radius at the lower base of the cone and r is the radius at the upper base of the cone:

$$V = \frac{\pi h}{3}\left(R^2 + Rr + r^2\right)$$

The catch was then sub-sampled as described above.

Pelagic fish data collection

Acoustic data were collected using a Simrad ES60 split beam 38 kHz echosounder (model ES-380) mounted on the vessel's hull at a depth of 4.75 m. The transducer had an 8º, 3 dB beam width, an equivalent beam angle of 19.5 dB, and a power output of 2000 W. A ping rate of 1 ping/second and a pulse duration of 0.512 msec were used.

A preliminary calibration of the system was performed prior to the survey, but final calibration values were based on a full calibration after the survey. The calibration took place in Broad Bay, near Dutch Harbor, Alaska following standard sphere methods detailed in Foote et al. (1987). Transducer gain (S_v gain, 21.28 dB re 1 m^{-1}, herein referred to as "dB") and S_a correction (0.63 dB re 1 m^2/m^2, herein referred to as "dB") were determined using calibration data. The S_v gain and S_a correction are input values to quantitatively align the acoustic output with the standard calibration sphere. A CTD was deployed to provide estimates of temperature and salinity for the calculation of sound speed and absorption coefficient for the calibration conditions.

Acoustic data were collected during three operations; during the acoustic-midwater trawling along transect lines, during the bottom trawl survey, and opportunistically after daytime survey operations had ended (e.g. while drifting). As opportunistic stationary data were not needed for our analysis, only the data collected during the acoustic-midwater trawling survey and during the bottom trawl survey are used in this report.

Survey operations were conducted during daytime hours from approximately 07:00 to 19:00 Alaska Daylight Time (ADT). Sunrise on August 5 (the day we arrived on the survey grounds) was at 03:45 and sunset was at 00:13. Sunrise on August 22 (the day we finished the survey) was 05:22 and sunset was at 22:30. Acoustic data was collected continuously along a series of parallel transects (Figure 1, Acoustic Transects). Data collection along transects was interrupted to conduct midwater trawling to verify the identity and obtain measurements from the species contained in aggregations observed on the acoustics. At each midwater trawl location a CTD was deployed to measure temperature and salinity to determine a mean sound speed (1452.3 m/sec) and absorption coefficient (0.009397 dB/m) for the study area.

When trawling was complete, acoustic data collection resumed at the transect break point. During acoustic operations, the vessel maintained a speed of approximately 3.6-4.6 m/s (7-9 knots), depending on weather conditions in the survey area. Data were logged using the ES60 software.

A Marinovich net was used for midwater trawling operations. The designed opening dimensions of the net are 6.10 m horizontal and 6.10 m vertical, but average fishing dimensions during the survey were 3-4 m vertical and 6 m horizontal based on third wire measurements (see below). The net was fished with the same doors used for bottom trawling. The vessel's third wire net monitoring system (Simrad Mesotech FS903) was used to monitor net headrope depth and net dimensions during deployment. A bathythermograph was attached to the headrope to collect temperature and depth data. Vessel speed was maintained at 1.0-2.1 m/s (2-4 kt) during midwater trawling and the tows lasted 10-60 minutes depending on acoustic target density observed on the ES60 and third wire display.

Pelagic fish sampling

All midwater trawl catches were generally <50 kg and were sampled in one of two ways. For catches dominated by large (>60 mm fork length) Arctic cod, all fish were sorted to species, each species was weighed, and up to 50 fish from each species were measured for fork length. For catches dominated by fish <60 mm fork length, the entire catch was weighed and a subsample was selected and weighed. This subsample was then sorted to the lowest possible taxonomic level and up to 50 fish from each taxonomic group were measured.

Demersal and pelagic trawl data entry

All bottom and midwater trawl data were entered using the AFSC's RACE Division data entry program in MS Access. For each trawl, the subsample was entered as a fraction of the trawl's total catch weight. The subsample was considered to be a representative proportion of the entire catch, thus the counts and weights were used to obtain average weights for each species, and then each species was extrapolated to the total catch level. When there was no subsample, such as in the case of bottom trawls <200 kg and most midwater trawls, the entire catch was counted and weighed, requiring no extrapolation. When a sub-subsample was taken, species were extrapolated up to the subsample level (using counts and weights), and then to the total catch level.

A database from the 2008 Beaufort Sea Survey is available through MMS. A metadata report associated with the database is located in Appendix I. All descriptions and limitations of the data are summarized in the metadata report.

Zooplankton data collection

Zooplankton tows typically occurred before or after a CTD cast (Figure 2) and were launched using the same winch system. The zooplankton net consisted of two bongo net frames. The top frame had two 20-cm aluminum hoops with 153-µm mesh nets. The bottom frame, one meter away, had two 60-cm aluminum hoops with 333-µm mesh nets. Flow meters were mounted in the center of the net mouth openings. The flow meters provided data used to estimate the volume of water sampled by the zooplankton nets.

The nets were towed between 1.0 and 2.5 knots depending on weather conditions. This was done to insure the wire angle was as close as possible to 45 degrees, the angle which maximizes the fishing capacity of the gear, not necessarily to keep the speed of the net constant relative to the bottom. The wire out rate was 30-m per minute and the wire in rate was 20-m per minute. The wire out rate was determined by the deployment speed required for the CTD because both the CTD and the zooplankton nets were deployed from the same winch. The few tows not meeting specifications (i.e. hit bottom, poor wire angles, nets tangled, etc.) were repeated.

When the nets were brought to the surface, the total tow time was recorded along with flow meter revolutions. The nets were rinsed with seawater starting at the mouth and working down towards the codend. All zooplankton samples from both mesh sizes were preserved in 5% formaldehyde (in seawater), buffered with a saturated sodium borate buffered solution and seawater. Numerical composition of plankton samples will be determined in Szczecin, Poland, by the Plankton Sorting and Identification Center following established AFSC protocols, pending availability of additional funds.

Habitat characteristic data collection (physical oceanography)

Conductivity-temperature-depth (CTD) data were collected at the stations shown in Figure 2. CTDs were deployed at all bottom trawl locations and most of the midwater trawl locations immediately following the trawl. Additional intensive sampling along transects 1 and 5 was conducted on 16-17 August and 19 August, respectively. The instrument was a calibrated SBE 19*plus* CTD profiler (Seabird Electronics Inc., Bellevue, Washington) deployed with a portable winch installed on the vessel for this survey. The CTD was deployed at depths of 1 to 2 m off bottom and at a rate of no more than 30 meters/minute.

A series of cross-sections were constructed from the CTD data collected along the various sampling transects that begin inshore at about the 20 m isobath and extend to the offshore end of the transect (500 m depth). The geostrophic velocity relative to the bottom was computed from the thermal wind shear. The spatial distribution of water masses were summarized in separate potential temperature-salinity (θ-S) plots composited for each line.

Fish lengths and biological collections

Several species of fish from both bottom and midwater trawls were sexed when feasible and the fork length (FL) was recorded (termed “sexed-length”). Small or juvenile fish were not sexed. Lengths were recorded on deck using an Allegro polycorder (www.junipersys.com) in conjunction with a barcode wand and barcoded length strips. All lengths for fish in the bottom trawls were recorded in centimeters. For small or juvenile fish (<7 cm) in the midwater trawls, lengths were recorded manually in millimeters.

Lengths were collected for Arctic cod (*Boreogadus saida*), walleye pollock (*Theragra chalcogramma*), Greenland turbot (*Reinhardtius hippoglossoides*), Bering flounder (*Hippoglossoides robustus*) and from two Pacific cod (*Gadus macrocephalus*) caught in the bottom trawls. From the midwater trawls, lengths were recorded for Arctic cod, an unidentified sculpin (family Cottidae), and an unidentified eelblenny (family Lumpenus).

Samples of fish for sexed-lengths were randomly collected if the number of fish in the trawl catch was greater than approximately 150 fish. This was the case only for Arctic cod. The number of pollock, turbot, flounder and Pacific cod was low, so we were able to measure all individuals in the catch or subsample.

Biological collections included sex, length, weight, otoliths (age structures), stomachs, and ovaries. All specimens were weighed on a motion compensated Marel specimen scale (smaller than Marel scale mentioned above) to the nearest hundredth gram. The collections varied by species and depended on information necessary for future analysis (e.g. otoliths for stock assessment). Otoliths were preserved in a 70% solution of ethyl alcohol and seawater. Stomachs were preserved in a 10% solution of formaldehyde and seawater buffered with sodium bicarbonate. Due to the small sizes of fish encountered on the survey, it was not possible to excise stomachs or ovaries without significant damage to the specimen. Instead, the other data and samples were collected (otoliths, length, weight) and the remainder of the fish specimen was preserved. The same method applied to the collection of ovaries. The method of collection for each species is described below:

Arctic cod. Within each bottom trawl, a subsample of approximately 25 fish was collected from the 150 sexed lengths. The fish's length, weight, and age structures were collected. Ten females were selected for the ovary collection. In addition, 10-15 fish were randomly collected from sexed lengths for the stomach collection. Approximately fish fish from five trawls were frozen for stable isotope analysis; each of the five fish were frozen whole, in one bag per trawl. Stable isotope analysis does not require freezing of individual fish per trawl. Stomachs and ovaries were not collected at every trawl but collections were distributed so that they were made across the survey area. A summary table of total samples sizes and final destinations of the samples is located in Appendix V.

Walleye pollock. All walleye pollock present in the bottom trawls were sexed, lengthed, weighed and the entire fish was frozen for processing at the AFSC. Freezing the fish allowed for future genetic analysis.

Bering flounder. All Bering flounder were sexed, lengthed, weighed and the entire specimen was preserved for the stomach collection (no ovaries collected).

Greenland turbot. All Greenland turbot were sexed, lengthed, weighed and the entire specimen was preserved for the stomach collection (no ovaries collected).

Pacific cod. Only two specimens were caught in the bottom trawls. Both were sexed, lengthed, weighed and frozen for verifying species identification and future analysis at the AFSC.

Collections from the micro- and macro- zooplankton Bongo tows (~20 samples) were also frozen for stable isotope analysis, to coincide with the fish stable isotope analysis.

All species of fish were collected for species identification in the AFSC taxonomic laboratory. All specimens were photographed with the trawl number for proper assignment when species ID was verified or changed. Specimens were counted, weighed and preserved in a 10% formaldehyde and seawater solution buffered with sodium bicarbonate. Most specimens collected are stored at the University of Washington's (UW) Fish Collection (http://www.washington.edu/burkemuseum/collections/ichthyology/). The UW Fish Collection laboratory will also work to provide specimens from several fish species to the University of Alaska's Museum of the North (www.uaf.edu/museum/collections/aqua/). See Appendix V for more details.

All invertebrate species were photographed, collected and preserved in 95% ethyl alcohol or 10% formaldehyde and seawater solution buffered with hexamethylenetetramine. All invertebrates collected on the survey are currently stored at the University of Alaska Fairbanks, pending funding for species identification. See Appendix V for details.

Special projects

We were able to accommodate four special projects on the survey. A special project requested by the AFSC RACE Division entailed collecting two taxa of crab; *Chionoecetes opilio* and *Hyas* sp. The crabs were examined for the presence of Bitter Crab Syndrome. The carapace length/width was recorded to the nearest 0.1 mm, the weight (g), sex, shell condition, and clutch size were recorded. Approximately 20-30 crabs were randomly selected from the catch, when large numbers of crab were caught (greater than 100 kg). See Appendix VI, *Auxillary studies,* for preliminary results of the Bitter Crab Syndrome study.

Arctic cod were collected for the Marine Gene Probe Lab at Dalhousie University as part of a genetic analysis examining transarctic exchange between marine fish species in the Pacific and Atlantic oceans. Fish species (1-10 individuals per species) also were collected for genetic bar coding at the Point Stephens Research Lab in Auke Bay, Alaska. Finally, a small collection of juvenile Arctic cod was requested by Minerals Management Service, Anchorage, Alaska. See Appendix V for information on the destination of all the genetic specimens.

Auxiliary studies

Marine mammals

Opportunistic marine mammal sightings were recorded in collaboration with the Platforms of Opportunity Program (POP) at the National Marine Mammal Laboratory. The date, time, location, species and number of animals observed were recorded whenever possible. Taxonomic guides assisted in the proper identification of a marine mammal or it was recorded as "unidentified" if the observer was unsure or distance too far. See Appendix VI for a report summarizing the results.

Seabirds

Data on the distribution and abundance of seabirds were collected during the transit to and from Dutch Harbor and during the acoustic transects, when conditions allowed. This project was a collaboration with US Fish and Wildlife Service. Continuous strip transects up to 300 meters wide (depending on visibility) were conducted by a single observer, looking on one side of the vessel. Birds were identified to species, when possible, and counted. Observations were entered into a laptop computer using a program (Dlog2) that assigned time and position to each observation using a GPS receiver. See Appendix VI for a report summarizing the results.

Demersal fish data analysis

Abundance

Mean catch-per-unit effort (CPUE) was estimated for all fish species and the top 24 invertebrate taxa. CPUE was calculated as both kilograms (kg/ha) and numbers per hectare (#/ha) from the weight or number of each species or taxon divided by the area swept for each trawl. Area swept was calculated as the distance fished multiplied by the mean net width. The CPUE (kg/ha or #/ha) for each trawl was averaged by depth and also by net type (lined vs. unlined). Zero catches were included in these calculations.

Depth-specific estimates of fish and invertebrate biomass and abundance were calculated from mean CPUE in each depth and depth area (derived from GIS). Strata were defined by bottom depth (as opposed to vertical position in the water column). The estimated area for the 40-100 m depth is 370,399 ha and for the 100-500 m depth, it is 257,593 ha (Figure 1). All the bottom trawls that occurred in the 100-500 m depth range were conducted with the lined net (except one), by coincidence. The majority of trawls that occurred in the 40-100 m depth range were conducted with the unlined net, also by coincidence. However, three trawls were conducted with a lined net in the 40-100 m depth range (trawls 11, 12 and 13). These trawls were not used in calculating CPUE, biomass or abundance by depth, but were used in estimating mean CPUE and abundance for comparing catch of the lined vs.unlined nets. Trawl 22 was conducted in the 100-500 m depth range with an unlined net and so was not included in calculations of CPUE, biomass or abundance by depth.

Cluster analysis

Cluster analysis was employed to identify co-occurring groups of fish species and their distribution within the study area. To reduce the potential bias in CPUE due to different gear types (lined vs. unlined nets), the analysis was conducted on species presence/absence data. A matrix of species presence/absence by trawl was constructed from the bottom trawl data. An agglomerative hierarchical clustering analysis was then conducted on a dissimilarity matrix calculated from the presence/absence matrix using the S-Plus group average method (Insightful Corporation, 2005), following methods detailed in Kaufman and Rousseeuw (1990). A euclidean metric was used for calculating dissimilarities and the measurements were not standardized beforehand.

Coefficient of variation

Coefficients of variation (CV) among trawl CPUE (#/ha) were calculated for each fish species, for lined and unlined net samples separately and both net types combined. In order to make recommendations for future monitoring, sample size approximations were calculated based on observed CV, $z_\alpha=1.96$, $z_\beta=1.64$ and a range of delta (% difference between estimated and true mean, Ott 1993).

Demersal fish-habitat associations

We examined the associations between demersal fish distribution and several environmental variables using linear regression, generalized linear models (GLM) and generalized additive models (GAM). Due to low sample sizes we chose a *P*-value of 0.10 as our significance threshold for all statistical analyses, this reduces the risk of making a Type II error (failing to observe a relationship when in truth there is one). Data collected with lined and unlined nets were analyzed separately. For all analyses, the data were log transformed.

Linear regression

As part of the exploratory data analysis, we examined the relationships between several environmental variables and fish distributions using simple linear regression. This allowed us to determine what, if any, relationships may exist between fish catch per unit effort (CPUE) distribution and the environment. We examined the distributions of several species and groups of species:

1. All fish species; lined and unlined net trawl data analyzed separately
2. All invertebrates; lined and unlined nets separately
3. Arctic cod; lined and unlined nets separately
4. Walleye pollock; lined and unlined nets separately
5. All eelpouts; lined nets only (generalized linear model, GLM was used to examine correlations with unlined net catches)
6. All sculpins; unlined nets only (GLM was used to examine correlations with lined net catches)
7. Opilio crab; lined and unlined nets separately

All regressions were done with a single independent variable, and stations were separated by gear type, as indicated above (lined and unlined net). Due to the low sample size and increasing variance with increasing means CPUE #/ha and CPUE kg/ha were log transformed for all seven species groups and both lined and unlined net gear types. In cases where there was a zero observation, 0.5 was added to all data observation points in that group, and then the values were log transformed. Due to the high number of zero catches for “All sculpins”, lined net, and “All eelpouts”, unlined net, it was not appropriate to do a linear regression; instead a generalized linear model (GLM) was formulated. In a GLM, the outcome of the dependent variable (e.g. CPUE) is assumed to be from a particular distribution (e.g. poisson) (see below). Alternatively, a GAM is a non parametric model that can incorporate both linear and nonlinear relationships.

In many cases, it appeared that there was one observation that had significant leverage on the relationship. Therefore Cook’s Distance (Cook 1977) was calculated to determine if any of the data point(s) had a value greater than 1.0. A Cook’s Distance greater than 1.0 generally warrants further analysis (e.g., regression without the outlier). Cook’s Distance was calculated using transformed data. In many cases the transformation reduced the variance enough to result in a Cook’s Distance value less than 1.0.

The dependent variables were CPUE #/ha and CPUE kg/ha (with the exception of invertebrates for which CPUE #/ha was not feasible to calculate). The independent variables were:

1. Longitude of haul catch (in decimal degrees)
2. Bottom temperature (°C)
3. Temperature difference (°C) (difference between temperature at the seafloor bottom and temperature 1 m below the surface)
4. Bottom depth (m)
5. Bottom salinity (psu)
6. Salinity difference (psu) (difference between salinity at the seafloor bottom and salinity 1 m below the surface)
7. Bottom density (sigma-t)
8. Density difference (sigma-t) (difference between density at the seafloor bottom and density 1 m below the surface)

Bottom temperature and bottom depth were obtained from the MBT attached to the survey net. Salinity and density data were obtained from the CTD casts. The differences between bottom and near surface temperature, salinity, and density are an indicator of the amount of water column stratification (a lesser difference indicates greater mixing due to upwelling or other processes). We examined percent ice cover as a potential variable, (http://www.natice.noaa.gov/index.htm); however, it was not included in any of the analyses because it was categorical with only two categories for each of the gear types. Because bottom temperature and temperature difference were correlated we only used bottom temperature in the GAM models.

The variables that were chosen for generalized additive model (GAM) analysis and the order in which they were added to the model were based on the significance of the linear regressions. Variables with the most significant relationships were added first. Several of the independent variables were correlated. Because it is not appropriate to include correlated independent variables in a multivariate statistical analysis, one independent variable was selected from the correlated variables, as a representative in the GAM models. For stations sampled with the unlined net gear type, bottom depth was not included in the regression analysis due to the limited range of depths (i.e. there was only one observation in the 100-500 m depth range).

GLM Analysis

Due to the high frequency of zero catches for the group "All sculpins", lined net, and "All eelpouts", unlined net, it was more appropriate to examine the presence/absence of the species rather than CPUE. Possible relationships were examined with the same independent variables used in the linear regression. However, a generalized linear model (GLM), poisson distribution with a log link was used instead of linear regression. If the model showed a significant decrease from the null to residual deviance, that independent variable was considered significant in explaining the variance in the data.

GAM Analysis

The two to three independent variables that suggested a relationship with demersal fish CPUE (i.e. relatively low *P*-value) were initially selected for building a GAM model for each of the seven groups of fish and invertebrates (and each net type). To determine the best smoothing term (linear or non-linear) for each variable in the GAM analysis, scatterplots of each variable and CPUE were examined, linear and non-linear regressions were estimated, and the smoothing term with the lowest residual deviance was selected. In most cases, the relationship was linear and when not the case, a nonparametric b-spline linear smoothing term was used. The null deviance compared to the residual sum of squares (i.e. residual deviance) is reported. If the residual sum of squares is lower than the null deviance, this can support the use of the second or third variable in the model as an improvement in explaining the variance in the data. Mallow's Cp value is also reported, which rescales the estimated mean square error, however, it adds a penalty for additional model parameters. Models with the smallest Cp have the smallest estimated mean square error and would be considered the better model for the data.

Pelagic fish data analysis

Acoustic data processing

Vessel noise (S_v = -140 dB @ 1 m) was removed from backscatter (S_v) and target strength (TS) data using linear subtraction (Watkins and Brierley 1996, Korneliussen 2000). In addition, samples that did not meet a minimum 6 dB signal-to-noise (SNR) minimum threshold were removed from the analysis.

Data from within 9.0 m of the surface were excluded to account for transducer depth (4.75 m) and twice the nearfield range (the zone where valid data cannot be obtained) for the 38 kHz transducer (2*2.04 m). The bottom was detected using the Echoview line pick function (-50 dB discrimination level) and manually corrected as needed. Data from within 0.5 m of the bottom (the acoustic deadzone) were excluded from analysis.

Backscatter estimates

Acoustic data files were scrutinized in Echoview 4.70 (Myriax Pty Ltd, 2009) and off-systematic acoustic transect regions were removed from the analysis (e.g. when the vessel left the systematic survey track during trawling). A minimum S_v threshold of -75 dB was applied to all data. This value represents the upper 95% confidence level for vessel noise estimates (-81 dB) for the S_v data along acoustic transects plus a 6 dB SNR threshold.

Based on trawl results and visual inspection of echograms, a young-of-the-year fish (YOY) region was defined between the surface exclusion line (9.0 m from the surface) to 75 m depth. The YOY fish included Arctic cod, an unidentified sculpin (Family Cottidae) and an unidentified prickleback (*Lumpenus* sp.). In regions with bottom depths less than 75 m, the YOY region was defined down to the 0.5 m bottom exclusion line. All transects were inspected in the determination of the lower depth limit for the YOY region. A yearling-and-older Arctic cod (year-plus) region was between the 75 m line and the 0.5 m bottom exclusion line. As needed, the 75 m line was adjusted up or down to account for vertical fluctuations in YOY or year-plus distribution.

Backscatter (Area Backscattering Coefficient, m^2/m^2) data for YOY fish and year-plus Arctic cod regions were exported in 1 km horizontal bins. No additional vertical binning was used as we were interested in areal estimates of and year-plus backscatter. Young-of-the-year and year-plus data were separated into the 20-40, 40-100, and 100-500 m depth strata based on the mean bottom depth of the 1 km analytic bin.

Target strength

In situ target strengths of YOY and year-plus Arctic cod were examined using acoustic data collected during midwater trawl deployment. The data were chosen to horizontally span the region that was sampled by the trawl, which included a horizontal offset to account for trawl wire out, wire angle, and vessel speed.

To minimize the probability of mistakenly detecting multiple fish as a single fish (and erroneously increasing estimated target strength), we applied the N_v index (fish per reverberation volume, Sawada et al. 1993). The N_v index used the noise-cleaned S_v data (see *Acoustic data processing* above) that were binned into 20 m horizontal by 2 m vertical bins. As target strength for Arctic cod in the U.S. portion of the Beaufort Sea is not known, we used an estimated mean target strength of -60 dB re 1 m^2 (herein referred to as dB) for young-of-the-year and -55 dB for yearling-and-older in N_v calculations. S_v bins with N_v values greater than 0.10 fish per reverberation volume were excluded from single echo detection.

In each trawl region, single *in situ* target echoes were detected using criteria recommended by Rudstam et al. (2009) and Parker-Stetter et al. (2009). As the target strength, and variability in target strength, of YOY Arctic cod were not known, we used a minimum target strength of -90 dB for single echo detections. This value accounts for both potential off-axis location (-6 dB) and high directional variability in the swimbladder (c.f. Rudstam et al. 2009) that can reduce target strength. *In situ* targets were not detected above the 9.0 m surface exclusion line or below the 0.5 m bottom exclusion line. Schools within the 40-100 m depth and demersal and pelagic layers in the 100-500 m depth were not eligible for the detection of single targets due to estimated year-plus densities that exceeded our N_v cut-off. Our single target detections, for the development of the target strength to length relationship, were limited to regions around schools or in the top and bottom of layers. Mean target strength values for year-plus Arctic cod and YOY fish were used to convert backscatter values to areal density estimates.

Preliminary analysis suggested that *in situ* target strength did not change with depth in water greather than 100 m deep (See **Results**). This observation, coupled with the fact that the non-closing trawl likely fished during deployment and retrieval, lead us to set fixed vertical limits for data export regions rather than follow the exact trawl track. This approach also accounted for tow-yo net deployments, where the net was fished up and down through a layer, to sample the layer constituents. For trawls that were fished at depths 100 m in the water column, target strength data were restricted to between 100 m and the 0.5 m bottom exclusion line. For shallow trawls, or those in at depths <100 m, data were restricted to between the 9.0 m surface exclusion line and 50 m. The 50-100 m depth zone, from which no *in situ* target strength data were used, appeared to be a transition zone between YOY and year-plus Arctic cod and did not appear to represent the target strength of either group exclusively.

For each trawl a mean *in situ* target strength, weighted by the number of single echo detections within 1.5 dB target strength bins, was calculated. Each mean target strength value from the trawls was paired with a mean fish length calculated from the midwater trawl data to generate a target strength to length relationship. For YOY fish, only trawls which contained greater than 90% Arctic cod YOY were included in the *in situ* target strength to length relationship.

The limited length range of year-plus Arctic cod captured in midwater trawls and the shallow slope of the target strength to length regression equation reduced variability in target strength estimates over the length range present in the midwater trawl catches. Expected mean target strengths of year-plus captured in the midwater trawl ranged from -54.3 dB (65 mm) to -50.5 dB (190 mm). Within the 40-100 m depth, the weighted mean target strength (n=2, 116.2 mm weighted mean length) was -52.2 dB. Comparatively, the weighted mean target strength (n=13, 102.5 mm weighted mean length) was -52.7 dB in the 100-500 m depth. For YOY fish (assumed to be dominated by Arctic cod), the weighted mean target strengths were -55.8 dB (n=7, 42.2 mm weighted mean Arctic cod length, 20-40 m depth), -55.7 dB (n=4, 42.8 mm weighted mean Arctic cod length, 40-100 m depth), and -55.8 dB (n=1, 42.3 mm Arctic cod length, 100-500 m depth). As stated, only those trawls with greater than 90% Arctic cod YOY were used to develop the target strength to length relationship. The weighted mean target strength for all YOY catches combined (n=12, 39.7 mm weighted mean length for all YOY species) was -56.0 dB.

A target strength (dB) to length (fork length, cm) relationship was developed for Arctic cod using samples from 23 trawl collections that contained year-plus Arctic cod (n=15 trawls) and greater than 90% YOY Arctic cod (n=8 trawls). Two outlying points (121 mm and -59.3 dB; 111 mm and -58.3 dB) resulted when large year-plus schools were sampled with the midwater trawl, to provide length frequency estimates for year-plus Arctic cod, but the surrounding low-density acoustic targets, from which the target strength values were derived, were from YOY. In the resulting target strength to fork length regression equations, the equation that excluded the two outlying year-plus Arctic cod points and used a flexible intercept (Target Strength=$8.03\times\log_{10}$(Length)-60.78) is considered the most appropriate equation for this study.

Density distribution, mean density, and abundance

Densities of YOY fish and year-plus Arctic cod were calculated for each 1 km analytic bin by scaling the exported backscatter values (Area Backscattering Coefficient, m^2/m^2) with estimates of and 1+ Arctic cod target strengths (σ_{bs}, m^2/m^2). When scaling to density, mean target strengths for YOY and year-plus Arctic cod within the 20-40, 40-100, and 100-500 m depth strata were calculated by converting the mean fork length (within the depth) to target strength using the target strength to length relationship. Density estimates were made for analytic bins along the north-south transects and the connecting east-west cross-transects.

Cluster sampling (Schaeffer et al. 1996) was used to generate a mean density (#/ha) for YOY and year-plus within depth strata. To meet the statistical assumptions of cluster sampling (and to prevent oversampling of some depth regions), only those 1 km bins along the parallel north-south transects were used in this analysis. Transects were treated as clusters and 1 km bins along the transects represented elements within the cluster. For each depth, a mean density and standard deviation of the mean were calculated. Zero values (i.e. 1 km bins in which YOY or year-plus density estimates were zero) were included in the analysis.

Estimates of YOY and year-plus Arctic cod abundance and biomass were made for each depth using mean densities from cluster sampling. For each age-group and depth, the mean density (#/ha) was scaled to abundance (fish within the study area) using depth strata areas derived from ESRI's ArcMap GIS software (20-40 m depth: 205,372 ha, 40-100 m depth: 370,399 ha, 100-500 m depth: 257,593 ha). The standard deviations of the means were also scaled using the same area scalars. Finally, to estimate Arctic cod biomass (metric tons, t) within the study area, abundance was multiplied by the mean weight (g) of a YOY or year-plus (based on midwater trawl catches) within each depth and converted to metric tons (t).

We used a Pearson's Chi-Squared test to statistically evaluate differences in mean YOY fish densities among depth strata (<40, 40-100, 100-500 m). We used a Pearson's Chi-Squared test to statistically examine whether there were differences in mean year-plus Arctic cod densities between depth strata (40-100, 100-500 m).

Comparing acoustic and bottom trawl surveys

We compared year-plus Arctic cod densities (#/ha) from the acoustic and bottom trawl surveys. The acoustic data covered from 9.0 m below the surface to 0.5 m above the bottom, while the bottom trawl covered from 2.0 m above the bottom to the bottom. Our analysis evaluated the relationship between the bottom trawl catch and several acoustic estimates that are described below. As no acoustic estimates of year-plus density were made for the 20-40 m depth, no bottom trawls from the 20-40 m depth were used in this analysis.

Two acoustic data sets were used in the analysis: coincident (collected during the bottom trawl survey) and non-coincident (collected during the systematic acoustic survey ~1 week later). In both acoustic data sets, we selected the 1 km horizontal bin that was the nearest neighbor to the midpoint (latitude, longitude) of the bottom trawl path. Due to high vessel noise, which interfered with the acoustics during bottom trawling, we used the pre-trawl scouting pass that was closest to final trawl location.

Within each acoustic bin (paired with individual bottom trawls), we utilized several indices of year-plus Arctic cod density (#/ha):

1. Acoustic survey depths (9.0 m below surface to 0.5 m from bottom)
2. Acoustic survey depths above bottom trawl region (9.0 m below surface to 2.0 m above bottom)
3. Overlapped survey depths (2.0 m above bottom to 0.5 m above bottom)

4. Corrected overlapped region - proportional correction (2.0 m above bottom to the bottom, with the 0.5 m above bottom to bottom region corrected proportional to density in the 2.0 to 0.5 m above the bottom region)
5. Corrected overlapped region - adjacent correction (2.0 m above bottom to the bottom, with the 0.5 m above bottom to bottom region corrected using the adjacent amount of density in the 2.0 to 0.5 m above the bottom region)
6. Water column using the proportional correction (9.0 m below surface to bottom)
7. Water column using the adjacent correction (9.0 m below surface to bottom)

The deadzone corrections used in indices 4-7 (proportional and adjacent) are commonly used assumptions in acoustic studies of fish distribution.

There were three components to this analysis: (1) Evaluating distribution of Arctic cod from acoustic and bottom trawl surveys; (2) Comparison of acoustic (coincident and noncoincident) density estimates and bottom trawl CPUE, and; (3) Evaluating systematic bias in acoustic or bottom trawl estimates with depth.

Evaluating distribution of Arctic cod – As a simple visual comparison between acoustic and bottom trawl survey year-plus Arctic cod densities, we used the coincident data to calculate the density ratio:

$$Density\ ratio = \frac{Bottom\ CPUE\ (\#/ha)}{Acoustic\ density\ (\#/ha)}$$

where Acoustic density (#/ha) is the density calculated between 9.0 m from the surface and 0.5 m from the bottom (index #1 above). Density ratio values were plotted at the station location.

Comparison of acoustic density estimates and bottom trawl CPUE – Error structure in the data (bottom trawl, coincident acoustics, noncoincident acoustics) was evaluated using Shapiro-Wilk, Komogorov-Smirnov, QQ-Plots, and by examining histograms. The bottom trawl data were normalized using a log transformation (log(bottom trawl CPUE)) and the acoustic data (coincident and noncoincident) was normalized using either a fourth-root ((acoustic density)$^{0.25}$) transformation to normalize the residuals or the data were left untransformed. In some cases, data points were identified as outliers by a Cook's distance test (Cook's distance greater than 0.5). These points were removed from the analysis.

Simple linear regression models were used in this analysis. Both generalized linear models (GLM) and generalized additive models (GAMs) were also tested but provided similar, linear results. Two model groups were run:

Model group 1 contained the variables:
Acoustic density indices (1-7 above) as response (continuous)
Bottom trawl CPUE as predictor (continuous)
Lined versus unlined net as predictor (categorical)
Bottom depth (categorical)
+ interaction terms

Model group 1 was performed using coincident data and noncoincident data that included all lined and unlined bottom trawl results. The global model for this analysis was:

Acoustic index ~ Bottom trawl CPUE + net (lined/unlined) + depth (below/layer) + interactions

Model group 2 contained the variables:
Acoustic density indices (1-7 above) as response (continuous)
Bottom trawl CPUE as predictor (continuous)
Bottom depth (categorical)
+interaction terms

Model group 2 was performed using lined net only data from coincident and noncoincident datasets. This removed the potential dual-influence of the categorical bottom depth variable and the lined/unlined net variable. The global model for this analysis was:

Acoustic index ~ Bottom trawl CPUE + depth (below/layer) + interaction

In early model runs, depth was treated as a continuous variable, but this was deemed inappropriate as it did not represent the observed relationship between year-plus Arctic cod and bottom depth. Instead, we classified the bottom depth at each location relative to the year-plus Arctic cod layer. If the year-plus layer was in contact with the bottom, the depth was classified as "layer". If the year-plus layer was above the bollow, the depth was classified as "below"..

Optimal models were selected using AIC criteria. This procedure produces a global model that includes all possible combinations of variables as a starting point, but variable deletions are used to find the model with the lowest AIC score. This form of model selection, which uses a model with the lowest AIC, may result in predictors which are present in the model but are not significant.

Acoustic and bottom trawl potential bias with depth – Coincident acoustic and bottom trawl (lined and unlined) data were used in this analysis. Due to the possible nonlinear relationship with depth, generalized additive models (GAMs) were chosen. Acoustic indices of density (1-7 above) were log transformed to help with heteroscedasticity. A plot of residuals and tests of normality suggested that the error structure for the acoustic data were normal. Transformations of the bottom trawl data did not make the residuals normal, so a quasipoisson error structure was used. GAMs were used to test the relationship between the acoustic indices or bottom trawl density (response variables) and depth (continuous predictor variable). The global models for this analysis were:

Acoustic index ~ depth
Bottom trawl density ~ depth

Pelagic fish-habitat associations

This analysis evaluated relationships between YOY fish or year-plus Arctic cod densities with oceanographic characterizations of the habitat. Due to spatial correlation in both the acoustic and oceanographic data, this analysis used individual CTD casts paired with collocated acoustic data. A 3 km radius around each CTD location was considered a "point" observation.

To calculate mean YOY fish or year-plus Arctic cod densities (#/ha), we identified any 1 km horizontal bins from the systematic survey whose midpoint (median latitude, median longitude) fell within the 3 km radius around the CTD cast location. If more than one acoustic bin was identified within the 3 km radius, a mean YOY fish or year-plus Arctic cod density (#/ha) was calculated.

To characterize the habitat, CTD data were processed by applying the manufacturer's calibration curves to the raw data then binning to 1-dB pressure levels, using the Sea-Bird Electronics Inc. SBE Data Processing algorithms and all recommended processing steps. We used custom scripts developed on the MATLAB platform, all binned Temperature/Salinity profiles were visually inspected for egregious outliers, spikes, and density inversions, which were removed via interpolation (midwater column) or extrapolation (at surface). The threshold level for removal was at the ~0.01 ºC (temperature) and ~0.02 PSU (for salinity).

The following physical and oceanographic variables were available at each CTD deployment:
Latitude (decimal degrees)
Longitude (decimal degrees)
Bottom depth (meters)
Surface Temperature (ºC)
Surface Salinity (PSU)
Surface Density (Sigma-T, kg/m^3-1000)
Surface Turbidity (FTU)
Bottom Temperature (ºC)
Bottom Salinity (PSU)
Bottom Density (kg/m^3-1000)
Bottom Turbidity (FTU)
Surface-Bottom Temperature Difference (ºC)
Surface-Bottom Salinity Difference (PSU)
Surface-Bottom Density Difference (kg/m^3-1000)
Surface-Bottom Turbidity Difference (FTU)
Mixed Layer Depth (MLD) via change of 0.1 kg/m^3 from surface (m)
Depth of N^2 maximum (m; a.k.a. the Brunt-Vaisala frequency squared, a measure of vertical stratification)
Mean Temperature above the mixed layer depth (MLD, ºC)
Mean Salinity above MLD (PSU)
Mean Density above MLD (kg/m^3-1000)
Mean Turbidity above MLD (FTU)
Mean Temperature below MLD (ºC)
Mean Salinity below MLD (PSU)
Mean Density below MLD (kg/m^3-1000)
Mean Turbidity below MLD (FTU)

Spearman rank correlation tests suggested that many of the variables were significantly correlated ($P<0.05$). Variables that were highly correlated with other variables were sequentially removed and re-tested, resulting in a list of twelve variables. We then considered which variables were potentially biologically-relevant given the distribution of YOY fish and year-plus Arctic cod and came up with our list of "biological predictors":

Longitude (decimal degrees)
Bottom depth (meters)
Mixed Layer Depth (MLD) via change of 0.1 kg/m^3 from surface (m)
Depth of N^2 maximum (m)
Mean Temperature above MLD (ºC)
Mean Salinity above MLD (PSU)
Mean Temperature below MLD (ºC)
Mean Salinity below MLD (PSU)

In order to compare pelagic fish results with the demersal fish-habitat models, we also used a set of "standard predictors" that were comparable to bottom trawl model predictors:

Longitude (decimal degrees)
Bottom depth (meters)
Bottom Temperature (ºC)
Bottom Salinity (PSU)
Bottom Density (kg/m^3-1000)
Surface-Bottom Temperature Difference (ºC)
Surface-Bottom Salinity Difference (PSU)
Surface-Bottom Density Difference (kg/m^3-1000)

The response variables, YOY fish density and year-plus Arctic cod densities, were log transformed to reduce issues of heteroscedasticity in the regression models. Some variables (Bottom depth and Depth of the N^2 max) were also log transformed to help stabilize model variance.

The YOY fish models (comparing density to biological and standard predictors) were run using a simple linear model (with normal error structure) and a GAM. The two model types were run for comparison. Model assumptions were checked using residual plots, QQ-plots, and a Shapiro-Wilk test of the residuals. For the linear model, the optimal model was selected using AIC criteria. This procedure produces a global model that includes all possible combinations of variables as a starting point, but variable deletions are used to find the model with the lowest AIC score. This form of model selection, which uses a model with the lowest AIC, may result in predictors which are present in the model but are not significant. The GAM was run on the same dataset, but the number of knots in the smoother was limited due to the small sample size.

Year-plus Arctic cod densities were not estimated from the acoustic data in the nearshore because it was not possible to analytically separate them from the YOY layer in shallow depths. So for year-plus Arctic cod density models, the presence of these zero values in the nearshore complicated the analysis. When zero values were included in the model run, general linear models were used but when zero values were excluded from the model run, linear models were chosen. Model assumptions were checked using residual plots, QQ-plots, and a Shapiro-Wilk test of the residuals and, in one case a quasipoisson error structure was selected. Models comparing year-plus density to biological and standard predictors were performed using linear models (simple or general) and GAMs (for comparison) both including and excluding the nearshore zero values. We consider the models with zero values excluded to be the most appropriate given that zero values are artificial (i.e., analytic not biological), however we performed both model sets to compare results.

Results

As detailed in the "Methods" section, the distribution and abundance of fish were assessed using two different techniques: standardized bottom trawls for the benthic fish and acoustics (verified with midwater trawls) for the pelagic fish. The data from these two surveys should not be combined into a comprehensive benthic-pelagic estimate because the bottom trawls assess fish from the bottom to 2-3 m off bottom, and the acoustics assess fish from 9.0 m below the surface to 0.5 m off bottom. Given this overlap in the vertical zones surveyed with each method, and potential differences in gear selectivity, it is not valid to simply add the two data sets to obtain a full water-column abundance or biomass estimate of fish. Also, seismic surveys witin 100 nm overlapped with the survey time period (see "Methods").

Demersal fish

Demersal fish abundance

There were a total of 26 bottom trawls of which 22 were successful (Table 1). The first bottom trawl was on August 6, 2008 and the last bottom trawl was completed on August 21, 2008. Bottom depths ranged from 40 to 478 m. Twelve successful trawls were made in the 40-100 m bottom depth (only nine were used in CPUE estimates with the unlined net), and ten in the 100-500 m bottom depth. Bottom trawl durations ranged from approximately 7 to 19 minutes of bottom time. Distance fished for each bottom trawl ranged from 0.4 km to 3.6 km (Table 1).

Fish comprised 6% of the total weight captured in the bottom trawls and 34 species of fish were identified (Table 2). Several taxa could only be identified to the genus or family level in the field. However, all specimens were verified and/or identified in the AFSC taxonomy lab after the survey (James Orr and Duane Stevenson, AFSC, pers. com.). In this survey, Arctic cod made up 92% of the total numbers of fish captured and eelpouts made up 3.5% of the total numbers of fish captured. Together Bering flounder and Greenland turbot made up only 0.3% of the total numbers of fish captured in the bottom trawls. Arctic cod occurred at all bottom trawl stations.

Two species were identified in the AFSC taxonomic laboratory but not in the field, *Lycodes marmoratus* (festive snailfish), and *Nautichthys pribilovius* (eyeshade sculpin) and were subsequently reassigned to the appropriate trawl. However, because they were not identified in the field, no catch information was associated with either species (i.e. counts or weights).

Three trawls occurred at bottom depths 40-50 m (Tables 3a and 3b). Tables 3a and 3b show CPUE #/ha and kg/ha for each of the three trawls. Trawl 13 was with a lined net and trawls 16 and 23 were with an unlined net, thus we could not combine the three catch estimates. In Table 3c, mean CPUE (± 1 SD) in numbers (#/ha) and weight (kg/ha) were calculated by depth (40-100 m and 100-500 m). Trawl 13 was not included in Table 3c, the 40-100 m bottom depth, as it was with a lined net (all other hauls in this statum were with an unlined net). Trawls 16 and 23 were included in the table, as they were with an unlined net.

Table 2. Fish taxa from the bottom trawl caught during the 2008 Beaufort Sea survey, total numbers and weights were extrapolated from subsampling.

Scientific Name	Common Name	Total numbers	Total weight (kg)
Boreogadus saida	Arctic cod	66,278	1241.95
Lycodes raridens	marbled eelpout	1,642	141.65
Lycodes polaris	Canadian eelpout	772	38.48
Hippoglossoides robustus	Bering flounder	231	34.62
Theragra chalcogramma	walleye pollock	1,082	34.00
Reinhardtius hippoglossoides	Greenland turbot	221	11.55
Lycodes mucosus	saddled eelpout	18	8.38
Lycodes sp.	unid. eelpout	72	8.03
Liparis gibbus	variegated snailfish	132	10.17
Lycodes rossi	threespot eelpout	66	7.75
Liparis fabricii	gelatinous seasnail	165	4.97
Myoxocephalus verrucosus	warty sculpin	67	1.39
Triglops pingeli	ribbed sculpin	219	1.29
Gadus macrocephalus	Pacific cod	5	1.02
Careproctus sp. cf. rastrinus (Orr et al.)	salmon snailfish	59	1.10
Mallotus villosus	capelin	9	0.86
Gymnocanthus tricuspis	Arctic staghorn sculpin	77	0.84
Artediellus scaber	hamecon	154	0.94
Lumpenus medius	stout eelblenny	136	0.49
Liparis sp.	unid. snailfish	36	0.34
Aspidophoroides olriki	Arctic alligatorfish	134	0.33
Cottidae	sculpin family	79	0.32
Lumpenus maculatus	daubed shanny	40	0.31
Triglops nybelini	bigeye sculpin	71	0.21
Lumpenus fabricii	slender eelblenny	41	0.18
Lumpenus sp.	unid. eelblenny	21	0.16
Enophrys diceraus	antlered sculpin	1	0.10
Icelus spatula	spatulate sculpin	20	0.14
Eumesogrammus praecisus	fourline snakeblenny	3	0.10
Eleginus gracilis	saffron cod	4	0.06
Liparis marmoratus	festive snailfish	2	0.01
Nautichthys pribilovius	eyeshade sculpin	1	0.01
Eumicrotremus derjugini	leatherfin lumpsucker	6	0.16
Gymnelus viridis	fish doctor	3	0.05

Table 3a. CPUE in numbers (#/ha) of fish caught in 40-50 m bottom depths during the 2008 Beaufort Sea survey, bottom trawl. The haul depth is in parenthesis. Note: haul 13 was with a lined net and hauls 16 and 23 were with an unlined net, thus we were not able to combine them.

Scientific Nam	Common Name	CPUE (#/ha) Haul 13 (49 m) (lined net)	CPUE (#/ha) Haul 16 (41 m) (unlined net)	CPUE (k#/ha) Haul 23 (44 m) (unlined net)
Boreogadus saida	Arctic cod	1,294	22	32
Lycodes raridens	marbled eelpout	0	0	0
Lycodes polaris	Canadian eelpout	8	3	0
Hippoglossoides robustus	Bering flounder	3	0	2
Theragra chalcogramma	walleye pollock	6	3	7
Reinhardtius hippoglossoides	Greenland turbot	0	0	0
Lycodes mucosus	saddled eelpout	0	0	0
Lycodes sp.	unid. eelpout	0	0	0
Liparis gibbus	variegated snailfish	0	0	0
Lycodes rossi	threespot eelpout	0	0	0
Liparis fabricii	gelatinous seasnail	0	0	0
Myoxocephalus verrucosus	warty sculpin	13	0	< 1
Triglops pingeli	ribbed sculpin	15	0	0
Gadus macrocephalus	Pacific cod	0	0	0
Careproctus sp. cf. rastrinus (Orr et al.)	salmon snailfish	0	0	0
Mallotus villosus	capelin	4	0	0
Gymnocanthus tricuspis	Arctic staghorn sculpin	23	0	0
Artediellus scaber	hamecon	6	3	3
Lumpenus medius	stout eelblenny	2	0	0
Liparis sp.	unid. snailfish	6	0	0
Aspidophoroides olriki	Arctic alligatorfish	0	0	0
Cottidae	sculpin family	0	0	0
Lumpenus maculatus	daubed shanny	0	0	0
Triglops nybelini	bigeye sculpin	0	0	0
Lumpenus fabricii	slender eelblenny	8	0	0
Lumpenus sp.	unid. eelblenny	0	0	0
Enophrys diceraus	antlered sculpin	0	0	0
Icelus spatula	spatulate sculpin	2	0	0
Eumesogrammus praecisus	fourline snakeblenny	0	0	< 1
Eleginus gracilis	saffron cod	2	0	0
Liparis marmoratus	festive snailfish	0	0	0
Nautichthys pribilovius	eyeshade sculpin	0	0	0
Eumicrotremus derjugini	leatherfin lumpsucker	0	1	0
Gymnelus viridis	fish doctor	0	4	0

Table 3b. CPUE in fish weight (kg/ha) caught in 40-50 m bottom depths during the 2008 Beaufort Sea survey, bottom trawl. The haul depth is in parenthesis. Note: haul 13 was with a lined net and hauls 16 and 23 were with an unlined net, thus we were not able to combine them.

Scientific Name	Common Name	CPUE (kg/ha) Haul 13 (49 m) (lined net)	CPUE (kg/ha) Haul 16 (41 m) (unlined net)	CPUE (kg/ha) Haul 23 (44 m) (unlined net)
Boreogadus saida	Arctic cod	7.82	0.19	0.24
Lycodes raridens	marbled eelpout	0	0	0
Lycodes polaris	Canadian eelpout	0.29	0.03	0
Hippoglossoides robustus	Bering flounder	0.15	0	0.19
Theragra chalcogramma	walleye pollock	0.11	0.13	0.16
Reinhardtius hippoglossoides	Greenland turbot	0	0	0
Lycodes mucosus	saddled eelpout	0	0	0
Lycodes sp.	unid. eelpout	0	0	0
Liparis gibbus	variegated snailfish	0	0	0
Lycodes rossi	threespot eelpout	0	0	0
Liparis fabricii	gelatinous seasnail	0	0	0
Myoxocephalus verrucosus	warty sculpin	0.06	0	< 0.01
Triglops pingeli	ribbed sculpin	0.05	0	0
Gadus macrocephalus	Pacific cod	0	0	0
Careproctus sp. cf. rastrinus (Orr et al.)	salmon snailfish	0	0	0
Mallotus villosus	capelin	0.42	0	0
Gymnocanthus tricuspis	Arctic staghorn sculpin	0.13	0	0
Artediellus scaber	hamecon	0.04	0.02	0.02
Lumpenus medius	stout eelblenny	< 0.01	0	0
Liparis sp.	unid. snailfish	0.05	0	0
Aspidophoroides olriki	Arctic alligatorfish	0	0	0
Cottidae	sculpin family	0	0	0
Lumpenus maculatus	daubed shanny	0	0	0
Triglops nybelini	bigeye sculpin	0	0	0
Lumpenus fabricii	slender eelblenny	0.03	0	0
Lumpenus sp.	unid. eelblenny	0	0	0
Enophrys diceraus	antlered sculpin	0	0	0
Icelus spatula	spatulate sculpin	0.01	0	0
Eumesogrammus praecisus	fourline snakeblenny	0	0	0.02
Eleginus gracilis	saffron cod	0.03	0	0
Liparis marmoratus	festive snailfish	0	0	0
Nautichthys pribilovius	eyeshade sculpin	0	0	0
Eumicrotremus derjugini	leatherfin lumpsucker	0	0.02	0
Gymnelus viridis	fish doctor	0	0.07	0

Table 3c. Mean CPUE (± 1 SD) in numbers and weight of fish caught by bottom depth strata during the 2008 Beaufort Sea survey, bottom trawl. Note: does not include hauls 11, 12 and 13 (lined net) for the 40-100 m depth and haul 22 in the 100-500 m depth (unlined net), BUT hauls 16 and 23 are included in the 40-100 m statum from Tables 3a and 3b.

Scientific Name	Common Name	Mean CPUE (#/ha) 40-100 m depth (unlined net)	Mean CPUE (#/ha) 100-500 m depth (lined net)	Mean CPUE (kg/ha) 40-100 m depth (unlined net)	Mean CPUE (kg/ha) 100-500 m depth (lined net)
Boreogadus saida	Arctic cod	917 (± 2,532)	2,341 (± 3,472)	6.48 (± 17.60)	49.75 (± 77.89)
Lycodes raridens	marbled eelpout	0	72 (± 145)	0	6.14 (± 12.33)
Lycodes polaris	Canadian eelpout	< 1 (± 1)	33 (± 55)	0.01 (± 0.02)	1.85 (± 3.45)
Hippoglossoides robustus	Bering flounder	< 1 (± 1)	10 (± 11)	0.09 (± 0.09)	1.67 (± 1.74)
Theragra chalcogramma	walleye pollock	8 (± 7.56)	35 (± 46)	0.14 (± 0.2)	1.28 (± 2.03)
Reinhardtius hippoglossoides	Greenland turbot	0	10 (± 15)	0	0.55 (± 0.60)
Lycodes mucosus	saddled eelpout	0	1 (± 3)	0	0.46 (± 1.39)
Lycodes sp.	unid. eelpout	0	4 (± 8)	0	0.45 (± 1.10)
Liparis gibbus	variegated snailfish	0	6 (± 13)	0	0.42 (± 1.26)
Lycodes rossi	threespot eelpout	< 1 (± 1)	3 (± 4)	0.01 (± 0.02)	0.38 (± 0.66)
Liparis fabricii	gelatinous seasnail	0	7 (± 12)	0	0.23 (± 0.39)
Myoxocephalus verrucosus	warty sculpin	< 1 (± 1)	2 (± 5)	< 0.01 (± 0.002)	0.05 (± 0.15)
Triglops pingeli	ribbed sculpin	< 1 (± 1))	0	0.01 (± 0.01)	0
Gadus macrocephalus	Pacific cod	0	< 1 (± 1)	0	0.05 (± 0.15)
Careproctus sp. cf. rastrinus (Orr et al.)	salmon snailfish	0	3 (± 4)	0	0.05 (± 0.07)
Mallotus villosus	capelin	0	0	0	0
Gymnocanthus tricuspis	Arctic staghorn sculpin	< 1 (± 1)	0	< 0.01 (± 0.006)	0
Artediellus scaber	hamecon	3	0	0.02 (± 0.03)	0
Lumpenus medius	stout eelblenny	0	6 (± 13)	0	0.02 (± 0.06)
Liparis sp.	unid. snailfish	< 1 (± 1)	0	< 0.01 (± 0.0006)	0
Aspidophoroides olriki	Arctic alligatorfish	< 1 (± 1)	6 (± 11)	< 0.01 (± 0.0003)	0.02 (± 0.03)
Cottidae	sculpin family	0	0	0	0
Lumpenus maculatus	daubed shanny	0	2 (± 5)	0	0.01 (± 0.04)
Triglops nybelini	bigeye sculpin	0	3 (± 9)	0	0.01 (± 0.03)
Lumpenus fabricii	slender eelblenny	0	1 (± 3)	0	0.01 (± 0.02)
Lumpenus sp.	unid. eelblenny	0	0	0	0
Enophrys diceraus	antlered sculpin	0	0	0	0
Icelus spatula	spatulate sculpin	< 1 (± 1)	0	0.01 (± 0.02)	0
Eumesogrammus praecisus	fourline snakeblenny	< 1 (± 1)	0	< 0.01 (± 0.007)	0
Eleginus gracilis	saffron cod	0	0	0	0
Liparis marmoratus	festive snailfish	0	0	0	0
Nautichthys pribilovius	eyeshade sculpin	0	0	0	0
Eumicrotremus derjugini	leatherfin lumpsucker	< 1 (± 1)	0	0.01 (± 0.02)	0
Gymnelus viridis	fish doctor	< 1 (± 1)	0	< 0.01 (± 0.02)	0

Mean CPUE (± 1 SD) in numbers (#/ha) and weight (kg/ha) for all lined compared to all unlined trawls is summarized in Table 4. The CPUE (#/ha) for fish species found in the paired trawls are summarized in Table 5. For all species of fish, the CPUE is larger for the lined net catches than the unlined net catches. Species diversity also was lower in the unlined net catches (Table 6). For example, 11 of the 15 species that were captured in trawl 12 with a lined net, did not appear in trawl 24 using an unlined net.

Table 4. Mean CPUE (± 1 SD) in numbers and weight of fish caught in lined vs. unlined nets (includes all depths) during the 2008 Beaufort Sea survey, bottom trawl.

Scientific Name	Common Name	Mean CPUE (#/ha) lined net	Mean CPUE (#/ha) unlined net	Mean CPUE (kg/ha) lined net	Mean CPUE (kg/ha) unlined net
Boreogadus saida	Arctic cod	1,953 (± 3,324)	849 (± 2,397)	39.64 (± 68.96)	6.11 (± 16.63)
Lycodes raridens	marbled eelpout	54 (± 135)	0	4.60 (± 10.88)	0
Lycodes polaris	Canadian eelpout	26 (± 52)	< 1 (± 1)	1.41 (± 3.05)	0.01 (± 0.02)
Hippoglossoides robustus	Bering flounder	8 (± 11)	1 (± 1)	1.26 (± 1.66)	0.10 (± 0.10)
Theragra chalcogramma	walleye pollock	36 (± 45)	7 (± 12)	1.18 (± 1.77)	0.12 (± 0.19)
Reinhardtius hippoglossoides	Greenland turbot	8 (± 14)	0	0.41 (± 0.57)	0
Lycodes mucosus	saddled eelpout	< 1 (± 2)	0	0.34 (± 1.2)	0
Lycodes sp.	unid. eelpout	3 (± 7)	0	0.34 (± 0.96)	0
Liparis gibbus	variegated snailfish	4 (± 12)	0	0.31 (± 1.09)	0
Lycodes rossi	threespot eelpout	2 (± 4)	< 1 (± 1)	0.28 (± 0.59)	< 0.01 (± 0.02)
Liparis fabricii	gelatinous seasnail	5 (± 4)	0	0.16 (± 0.35)	0
Myoxocephalus verrucosus	warty sculpin	2 (± 5)	< 1 (± 1)	0.04 (± 0.13)	< 0.01 (± 0.002)
Triglops pingeli	ribbed sculpin	8 (± 22)	< 1 (± 1)	0.04 (± 0.14)	< 0.01 (± 0.01)
Gadus macrocephalus	Pacific cod	< 1 (± 1)	0	0.03 (± 0.13)	0
Careproctus sp. cf. rastrinus (Orr et al.)	salmon snailfish	2 (± 4)	< 1 (± 1)	0.03 (± 0.07)	0.01 (± 0.04)
Mallotus villosus	capelin	< 1 (± 1)	0	0.03 (± 0.12)	0
Gymnocanthus tricuspis	Arctic staghorn sculpin	3 (± 7)	< 1 (± 1)	0.03 (± 0.08)	< 0.01 (± 0.006)
Artediellus scaber	hamecon	5 (± 13)	3 (± 4)	0.02 (± 0.07)	0.01 (± 0.03)
Lumpenus medius	stout eelblenny	4 (± 12)	0	0.01 (± 0.05)	0
Liparis sp.	unid. snailfish	1 (± 3)	< 1 (± 1)	0.01 (± 0.03)	< 0.01 (± 0.0005)
Aspidophoroides olriki	Arctic alligatorfish	5 (± 11)	< 1 (± 1)	0.01 (± 0.03)	< 0.01 (± 0.0002)
Cottidae	sculpin family	3 (± 10)	0	0.01 (± 0.04)	0
Lumpenus maculatus	daubed shanny	1 (± 4)	0	0.01 (± 0.03)	0
Triglops nybelini	bigeye sculpin	2 (± 8)	0	< 0.01 (± 0.03)	0
Lumpenus fabricii	slender eelblenny	2 (± 4)	0	< 0.01 (± 0.02)	0
Lumpenus sp.	unid. eelblenny	< 1 (± 3)	0	< 0.01 (± 0.02)	0
Icelus spatula	spatulate sculpin	< 1 (± 2)	< 1 (± 1)	< 0.01 (± 0.01)	< 0.01 (± 0.02)
Eumesogrammus praecisus	fourline snakeblenny	< 1 (± 1)	< 1 (± 1)	< 0.01 (± 0.01)	< 0.01 (± 0.006)
Eleginus gracilis	saffron cod	< 1 (± 1)	0	< 0.01 (± 0.01)	0
Liparis marmoratus	festive snailfish	< 1 (± 1)	0	< 0.01 (± 0.001)	0
Nautichthys pribilovius	eyeshade sculpin	< 1 (± 1)	0	< 0.01 (± 0.001)	0
Eumicrotremus derjugini	leatherfin lumpsucker	0	< 1 (± 1)	0	0.01 (± 0.02)
Gymnelus viridis	fish doctor	0	< 1 (± 1)	0	< 0.01 (± 0.02)
Enophrys diceraus	antlered sculpin	< 1 (± 1)	0	< 0.01 (± 0.001)	0

Table 5. CPUE (#/ha) of fish caught in the paired lined and unlined comparison trawls during the 2008 Beaufort Sea survey, bottom trawl. The two pairs were trawls 10 and 22; and trawls 12 and 24. The trawl number is listed after net type.

Scientific Name	Common Name	CPUE (#/ha) lined net, 10 (100-500 m)	CPUE (#/ha) unlined net, 22 (100-500 m)	CPUE (#/ha) lined net, 12 (40-100 m)	CPUE (#/ha) unlined net, 24 (40-100 m)
Boreogadus saida	Arctic cod	825	234	556	8
Lycodes raridens	marbled eelpout	0	0	0	0
Lycodes polaris	Canadian eelpout	58	1	4	0
Hippoglossoides robustus	Bering flounder	14	3	1	0
Theragra chalcogramma	walleye pollock	0	0	84	41
Reinhardtius hippoglossoides	Greenland turbot	43	0	0	0
Lycodes mucosus	saddled eelpout	0	0	1	0
Lycodes sp.	unid. eelpout	0	0	0	0
Liparis gibbus	variegated snailfish	0	0	0	0
Lycodes rossi	threespot eelpout	0	0	0	0
Liparis fabricii	gelatinous seasnail	0	0	0	0
Myoxocephalus verrucosus	warty sculpin	14	0	1	0
Triglops pingeli	ribbed sculpin	0	0	78	0
Gadus macrocephalus	Pacific cod	0	0	1	0
Careproctus sp. cf. rastrinus (Orr et al.)	salmon snailfish	0	3	0	0
Mallotus villosus	capelin	0	0	1	0
Gymnocanthus tricuspis	Arctic staghorn sculpin	0	0	13	1
Artediellus scaber	hamecon	0	0	44	1
Lumpenus medius	stout eelblenny	0	0	0	0
Liparis sp.	unid. snailfish	0	0	0.04	0
Aspidophoroides olriki	Arctic alligatorfish	29	0	1	0
Cottidae	sculpin family	0	0	36	0
Lumpenus maculatus	daubed shanny	14	0	0	0
Triglops nybelini	bigeye sculpin	29	0	0	0
Lumpenus fabricii	slender eelblenny	0	0	0	0
Lumpenus sp.	unid. eelblenny	0	0	9	0
Enophrys diceraus	antlered sculpin	0	0	0	0
Icelus spatula	spatulate sculpin	0	0	0	0
Eumesogrammus praecisus	fourline snakeblenny	0	0	0	0
Eleginus gracilis	saffron cod	0	0	0	0
Liparis marmoratus	festive snailfish	0	0	0	0
Nautichthys pribilovius	eyeshade sculpin	0	0	0	0
Eumicrotremus derjugini	leatherfin lumpsucker	0	1	0	0
Gymnelus viridis	fish doctor	0	0	0	0

Table 6. A summary table of the paired tows: tow time, if net was lined or unlined and trawl number are column headings. The number of species caught, total catch weight (kg), CPUE (kg/ha) and the total number of individuals caught for both fish and invertebrates make up the row headings.

		15 min	5 min	15 min	5 min
		lined	unlined	lined	unlined
		10	22	12	24
	No. species	8	5	15	4
Fish	Total catch weight	32.4	4.4	13.1	0.7
	CPUE (kg/ha)	13.3	3.3	5.9	0.8
	Total no. fish	2,506	315	1,846	52
	No. species	54	51	46	39
Invertebrates	Total catch weight	2327.4	73.3	238.0	52.0
	CPUE (kg/ha)	954.8	56.2	107.2	50.7
	Total no. invertebrates	1,777,752	1,889	20,347	1,250

Total numbers and biomass of all fish species were calculated from mean CPUE and area, by depth (Table 7). Arctic cod was the most abundant fish followed by several species of eelpouts, Bering flounder, walleye pollock, Greenland turbot, snailfish, and sculpins. The total dermersal fish number estimate for both strata combined was 1.0×10^9 (18,841 t) of which 65% was in the 100-500 m depth. Approximately 60% of the estimated total numbers of Arctic cod was in the 100-500 m depth (84% of the biomass). The second most abundant fish (by numbers and weight) was *Lycodes raridens*. This species was only caught in the 100-500 m depth. Eelpouts (genus *Lycodes* and *Gymnelus*) had a density estimate of 2.90×10^7 in the 100-500 m depth and 3.17×10^5 in the 40-100 m depth (biomass was estimated at 2,390 t in the 100-500 m depth and 6 t in the 40-100 m depth). Bering flounder and walleye pollock were the second and third most abundant species in the 40-100 m depth.

Table 7. Biomass and total number estimates of fish taxa from the 2008 Beaufort Sea survey, bottom trawls, extrapolated to whole bottom depth strata area. Note: trawls 11, 12, and 13 are not included in these results as they were with a lined net in the 40-100 m depth and trawl 22 was not included in the 100-500 m depth, it was with an unlined net.

Scientific Name	Common Name	Total no. 40-100 m depth (unlined net)	Total no. 100-500 m depth (lined net)	Biomass (t) 40-100 m depth (unlined net)	Biomass (t) 100-500 m depth (lined net)
Boreogadus saida	Arctic cod	3.39×10^8	6.03×10^8	2,402	12,815
Lycodes raridens	marbled eelpout	0	1.84×10^7	0	1,582
Lycodes polaris	Canadian eelpout	227,904	8.54×10^6	3	475
Hippoglossoides robustus	Bering flounder	328,419	2.61×10^6	32	430
Theragra chalcogramma	walleye pollock	2.80×10^6	9.08×10^6	53	330
Reinhardtius hippoglossoides	Greenland turbot	0	2.61×10^6	0	142
Lycodes mucosus	saddled eelpout	0	242,356	0	119
Lycodes sp.	unid. eelpout	0	938,202	0	116
Liparis gibbus	variegated snailfish	0	1.46×10^6	0	108
Lycodes rossi	threespot eelpout	89,814	809,043	3	97
Liparis fabricii	gelatinous seasnail	0	1.88×10^6	0	58
Myoxocephalus verrucosus	warty sculpin	36,306	410,960	0.3	13
Triglops pingeli	ribbed sculpin	246,462	833,661	2	0
Gadus macrocephalus	Pacific cod	0	50,698	0	13
Careproctus sp. cf. rastrinus (Orr et al.)	salmon snailfish	0	693,827	0	12
Mallotus villosus	capelin	0	0	0	0
Gymnocanthus tricuspis	Arctic staghorn sculpin	40,119	0	1	0
Artediellus scaber	hamecon	1.05×10^6	0	7	0
Lumpenus medius	stout eelblenny	0	1.46×10^6	0	5
Liparis sp.	unid. snailfish	0	0	0	0
Aspidophoroides olriki	Arctic alligatorfish	35,781	1.57×10^6	0.04	4
Cottidae	sculpin family	0	0	0	0
Lumpenus maculatus	daubed shanny	0	410,960	0	3
Triglops nybelini	bigeye sculpin	0	833,661	0	2
Lumpenus fabricii	slender eelblenny	0	316,659	0	2
Lumpenus sp.	unid. eelblenny	0	0	0	0
Enophrys diceraus	antlered sculpin	0	0	0	0
Icelus spatula	spatulate sculpin	223,509	0	3	0
Eumesogrammus praecisus	fourline snakeblenny	36,306	0	1	0
Eleginus gracilis	saffron cod	0	0	0	0
Liparis marmoratus	festive snailfish	0	0	0	0
Nautichthys pribilovius	eyeshade sculpin	0	0	0	0
Eumicrotremus derjugini	leatherfin lumpsucker	204,740	0	4	0
Gymnelus viridis	fish doctor	142,818	0	0.13	0

Demersal fish cluster analysis

Agglomerative hierarchical clustering identified five clusters of trawl stations based on species presence/absence (Figure 3). Arctic cod were present in all trawls, so were not included in the clustering analysis.

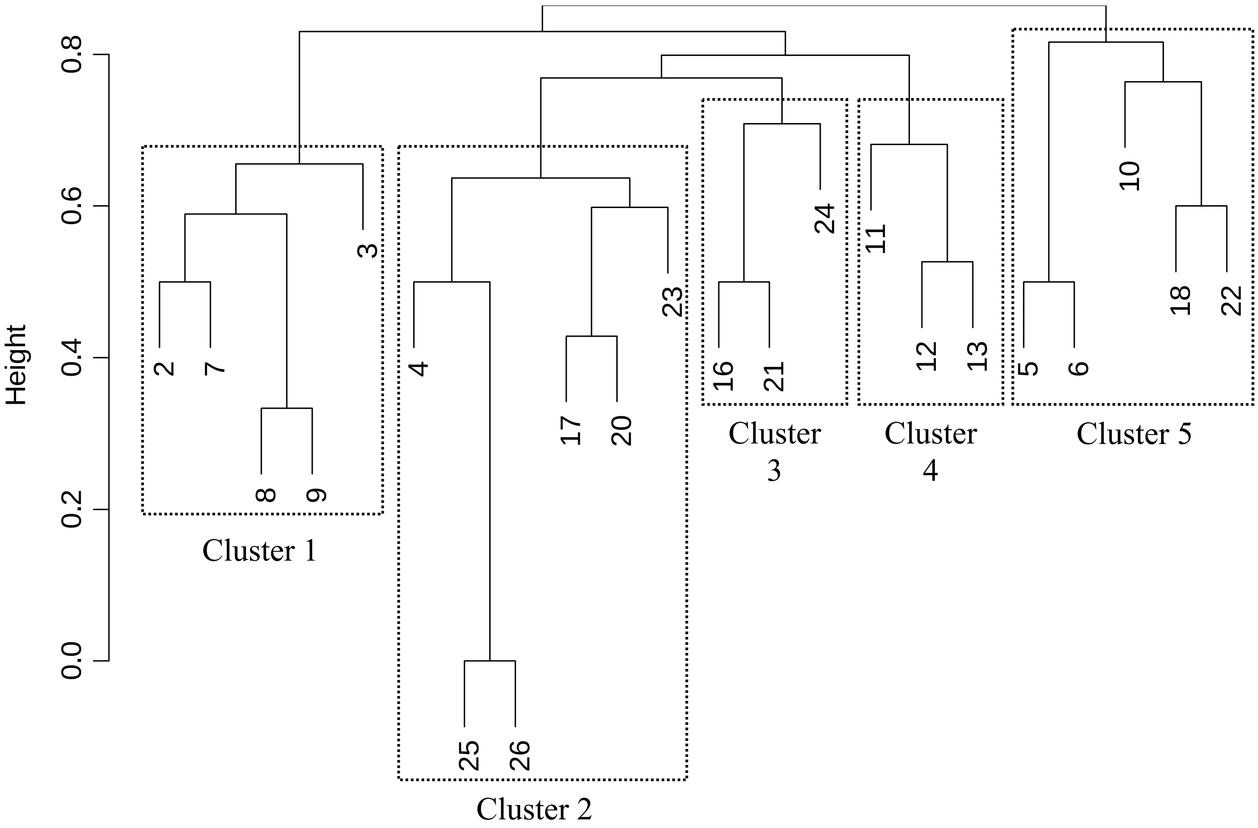


Figure 3. Clustering tree based on species presence/absence in the bottom trawl data. The vertical coordinate ("height") of the place where two branches join equals the dissimiliarity between the corresponding cluster. Bottom trawls only shown.

Table 8 shows the predominant species in each cluster, and Figure 4 shows the distribution of trawls belonging to each cluster. Species are grouped for the purposes of summarizing the results in Table 8, but the cluster analysis was conducted on a species-basis. Walleye pollock were present in at least half the trawls for nearly all clusters. Clusters 1 and 5 were made up of trawls in the most offshore depth (100-500 m). Bering flounder, snailfish, eelpouts and Greenland turbot characterized Cluster 1. The species composition of Cluster 5 was similar except Greenland turbot was not present and eelblennies were found in more than half the trawls. The trawls in Clusters 2 and 3 were distributed primarily in the shallower (40-100 m) depth. Species distinguishing Cluster 2 were Bering flounder and sculpins. Sculpins were common in

Cluster 3, but Bering flounder were not present. In addition, leatherfin lumpsucker and eelpouts were a presence in Cluster 3. The trawls making up Cluster 4 were found in the shallower depth and only in the western half of the survey area. This was a diverse cluster with several species occurring in all of the trawls. The presence of capelin and alligatorfish in more than half the trawls was a unique characteristic of this cluster.

The clustering analysis was conducted with species presence/absence data in the hopes of avoiding the bias towards higher CPUE in the lined net catches, compared to the unlined net catches. Net type neverthelss may have influenced the trawl composition of some of the clusters. Clusters 1 and 4 were comprised exclusively of trawls conducted with the lined net, and Cluster 3 was made of only un-lined trawls. The other clusters were comprised of a mix of lined and un-lined trawls.

Table 8. Proportion of trawls (both net types included) in which the species shown was present for each of five clusters identified with agglomerative hierarchical clustering. Only species that were present in at least 50% of the trawls in at least one cluster are shown. Arctic cod were present in all trawls and thus not included in the clustering analysis. Species are grouped for the purposes of summarizing results in this table, but the clustering analysis was conducted on a species-basis. Numbers in bold are proportions that are 0.50 or greater. Bottom trawls only shown.

Cluster	leatherfin lump-sucker	Bering flounder	snailfish spp.	eel-blenny	eelpout spp.	capelin	Greenland turbot	walleye pollock	alligator-fish	sculpin spp.
1	0	**0.60**	**1**	0.20	**1**	0	**0.80**	**0.80**	0	0
2	0.17	**1**	0.17	0	0	0	0	**1**	0	**0.50**
3	**0.67**	0	0.33	0	**0.67**	0	0	**1**	0.33	**1**
4	0	**1**	**1**	**1**	**1**	**0.67**	0	**1**	**0.67**	**1**
5	0.20	**0.80**	**0.60**	**0.60**	**1**	0	0.20	0.20	0.40	0.40

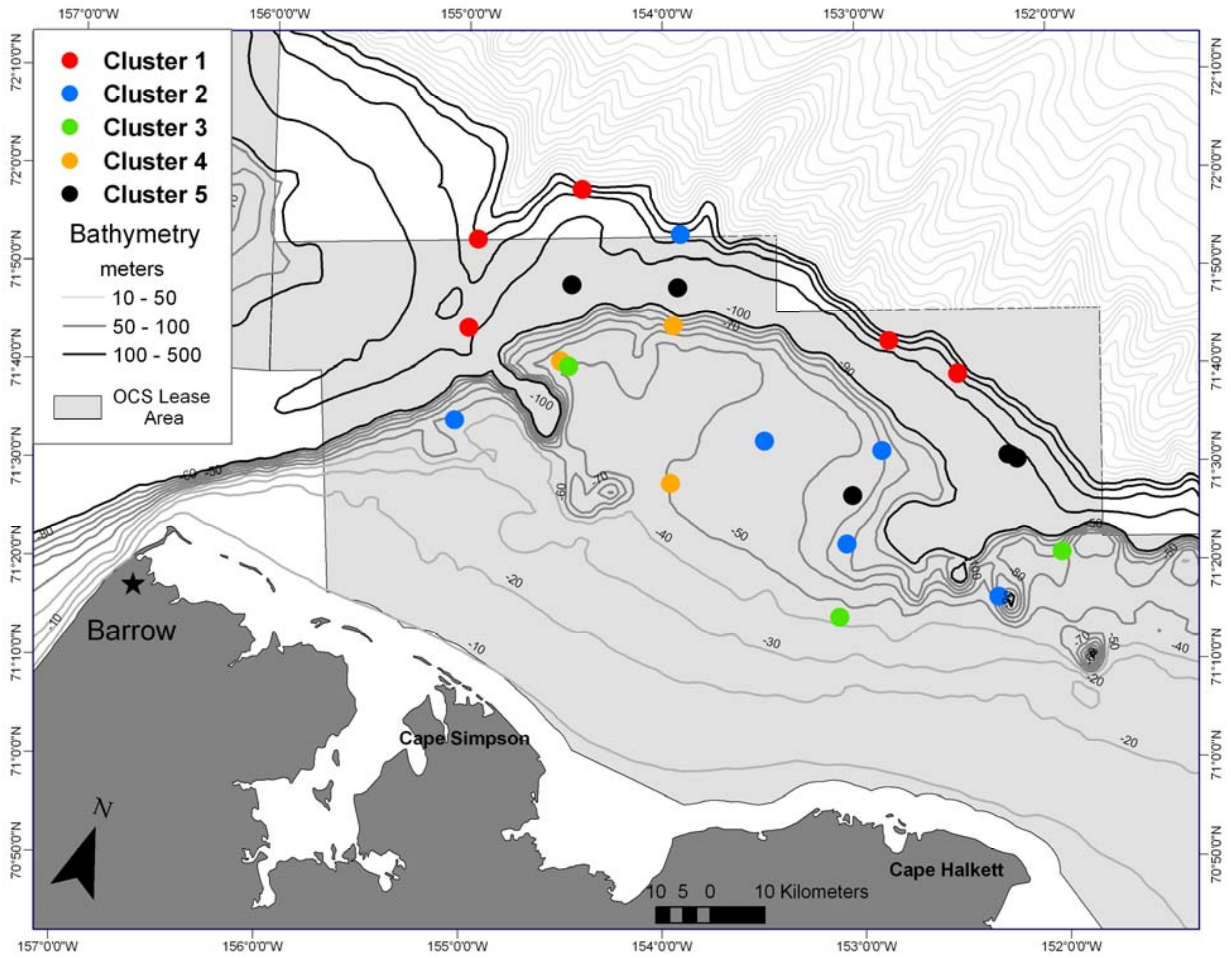


Figure 4. Distribution of trawls making up the five clusters identified with agglomerative hierarchical clustering based on species presence/absence in the bottom trawl data (see Table 5, Figure 3). The Outer Continental Shelf (OCS) Lease Area is shown in gray shading.

Demersal fish coefficient of variation

CVs among trawls of a single type (lined or unlined) were fairly high, ranging from 0.88 to 3.00, mostly likely due to small sample size: less than 10 for each net type (Table 9). CVs among all trawls, lined and unlined combined, were similarly high with a maximum value of 4.69, likely due to the substantial decrease in CPUE in unlined compared to lined nets. Sample size approximations for the highest and lowest CVs over a range of deltas (% difference between estimated and true mean, (Ott 1993) are shown in Table 10.

Table 9. Coefficients of variation (CV) among bottom trawl CPUE (#/ha) for all fish species caught. CVs are shown for lined net trawls in the 100-500 m bottom depth (all towed for 15 minutes) and unlined net trawls in 40-100 m bottom depth (all towed for 5 minutes), and for all trawl nets combined.

Scientific name	Common name	CV lined net, 100-500 m (n=9)	CV unlined net, 40-100 m (n=9)	CV all trawls (n=22)
Artediellus scaber	hamecon		1.59	2.51
Aspidophoroides olriki	Arctic alligatorfish	1.99	3.00	2.92
Boreogadus saida	Arctic cod	1.57	2.76	1.98
Careproctus sp. cf. rastrinus (Orr, et al.)	salmon snailfish	1.56		2.33
Cottidae	sculpin unident.			4.69
Eleginus gracilis	saffron cod			4.69
Enophrys diceraus	antlered sculpin			4.69
Eumesogrammus praecisus	fourline snakeblenny		3.00	3.24
Eumicrotremus derjugini	leatherfin lumpsucker		1.68	2.47
Gadus macrocephalus	Pacific cod	3.00		3.81
Gymnelus viridis	fish doctor		2.28	3.65
Gymnocanthus tricuspis	Arctic staghorn sculpin		3.00	3.27
Hippoglossoides robustus	Bering flounder	1.14	0.88	1.76
Icelus spatula	spatulate sculpin		2.41	2.54
Liparis fabricii	gelatinous seasnail	1.73	3.00	2.85
Liparis gibbus	variegated snailfish	2.49		3.95
Liparis marmoratus	festive snailfish			4.69
Liparis sp.	unid. snailfish			2.66
Lumpenus fabricii	slender eelblenny	3.00		3.29
Lumpenus maculatus	daubed shanny	3.00		4.03
Lumpenus medius	stout eelblenny	2.49		3.80
Lumpenus sp.	unid. eelblenny			4.69
Lycodes mucosus	saddled eelpout	3.00		4.45
Lycodes polaris	Canadian eelpout	1.77	1.99	2.76
Lycodes raridens	marbled eelpout	2.15		3.46
Lycodes rossi	threespot eelpout	1.51	3.00	2.40
Lycodes sp.	unid. eelpout	2.30		3.33
Mallotus villosus	capelin			4.21
Myoxocephalus verrucosus	warty sculpin	3.00	3.00	2.92
Nautichthys pribilovius	eyeshade sculpin			4.69
Reinhardtius hippoglossoides	Greenland turbot	1.58		2.69
Theragra chalcogramma	walleye pollock	1.39	1.68	1.64
Triglops nybelini	bigeye sculpin	3.00		4.69
Triglops pingeli	ribbed sculpin		2.33	3.63

Table 10. Sample size (n) approximations based on lowest and highest CVs of bottom trawl CPUE (#/ha) observed during the 2008 Beaufort Sea survey, for a range of delta values (% difference between estimated and true mean, Ott 1993).

0.25	1.96	1.64	0.88	321
0.3	1.96	1.64	0.88	223
0.4	1.96	1.64	0.88	125
0.5	1.96	1.64	0.88	80
0.6	1.96	1.64	0.88	55
0.2	1.96	1.64	4.69	14253
0.25	1.96	1.64	4.69	9122
0.3	1.96	1.64	4.69	6334
0.4	1.96	1.64	4.69	3563
0.5	1.96	1.64	4.69	2280
0.6	1.96	1.64	4.69	1583

Demersal fish distribution maps

Arctic cod

The distribution of Arctic cod CPUE by kg/ha is illustrated in Figure 5. The highest CPUE (kg/ha) for Arctic cod was found in the 100-500 m depth, in the westernmost half of the survey area. Arctic cod CPUE was consistent from west to east (25.83-58.64 kg/ha) along the deepest part of the survey area, 300-500 meters. Figure 6 illustrates the distribution of Arctic cod CPUE by #/ha and shows similar patterns as CPUE by kg/ha.

Walleye pollock

Walleye pollock CPUE distribution by kg/ha (Figure 7) was similar to that of Arctic cod, however CPUE (kg/ha) values were an order of magnitude smaller (0-6.47 kg/ha). The highest CPUE was found in the western part of the survey area, in the 100-500 m depth, with zero catches occurring in the 100-500 m depth in the eastern half of the survey area. Walleye pollock CPUE distribution by #/ha is shown in Figure 8, again the distribution is similar to CPUE by kg/ha.

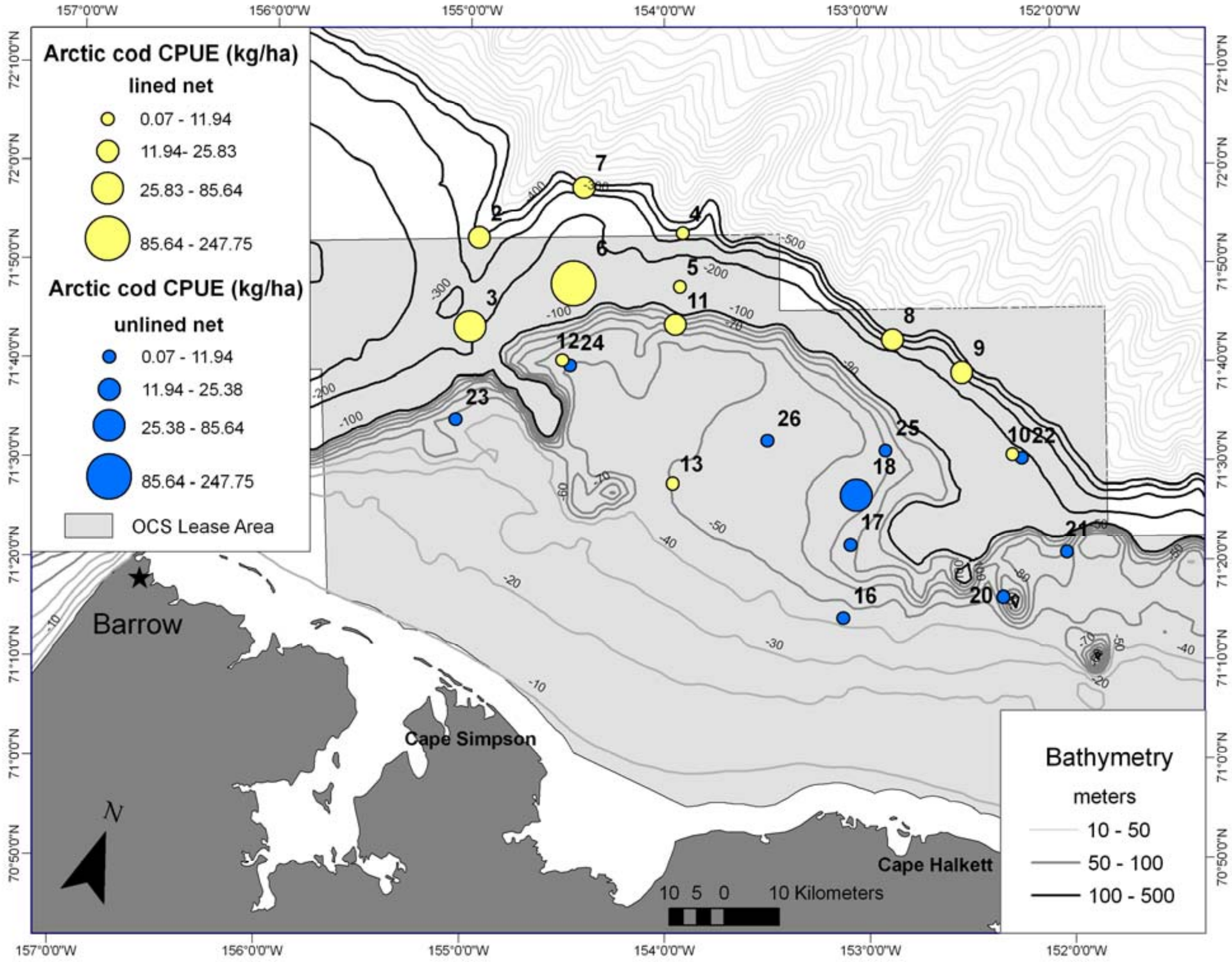


Figure 5. Arctic cod CPUE (kg/ha) distribution from the Beaufort Sea survey, 2008, bottom trawls only. The Outer Continental Shelf (OCS) Lease Area is shown in gray shading.

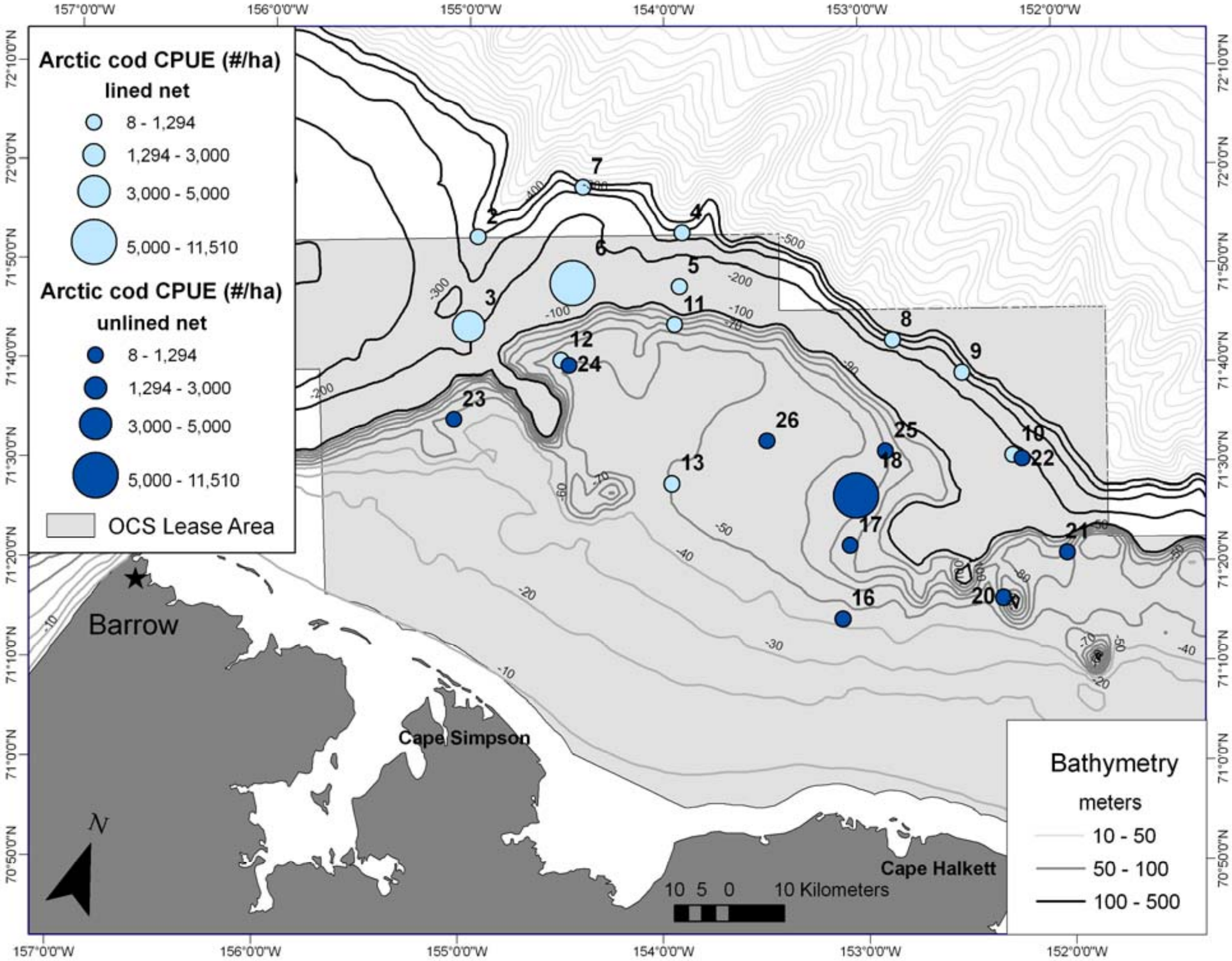


Figure 6. Arctic cod CPUE (#/ha) distribution from the Beaufort Sea survey, 2008, bottom trawls only. The Outer Continental Shelf (OCS) Lease Area is shown in gray shading.

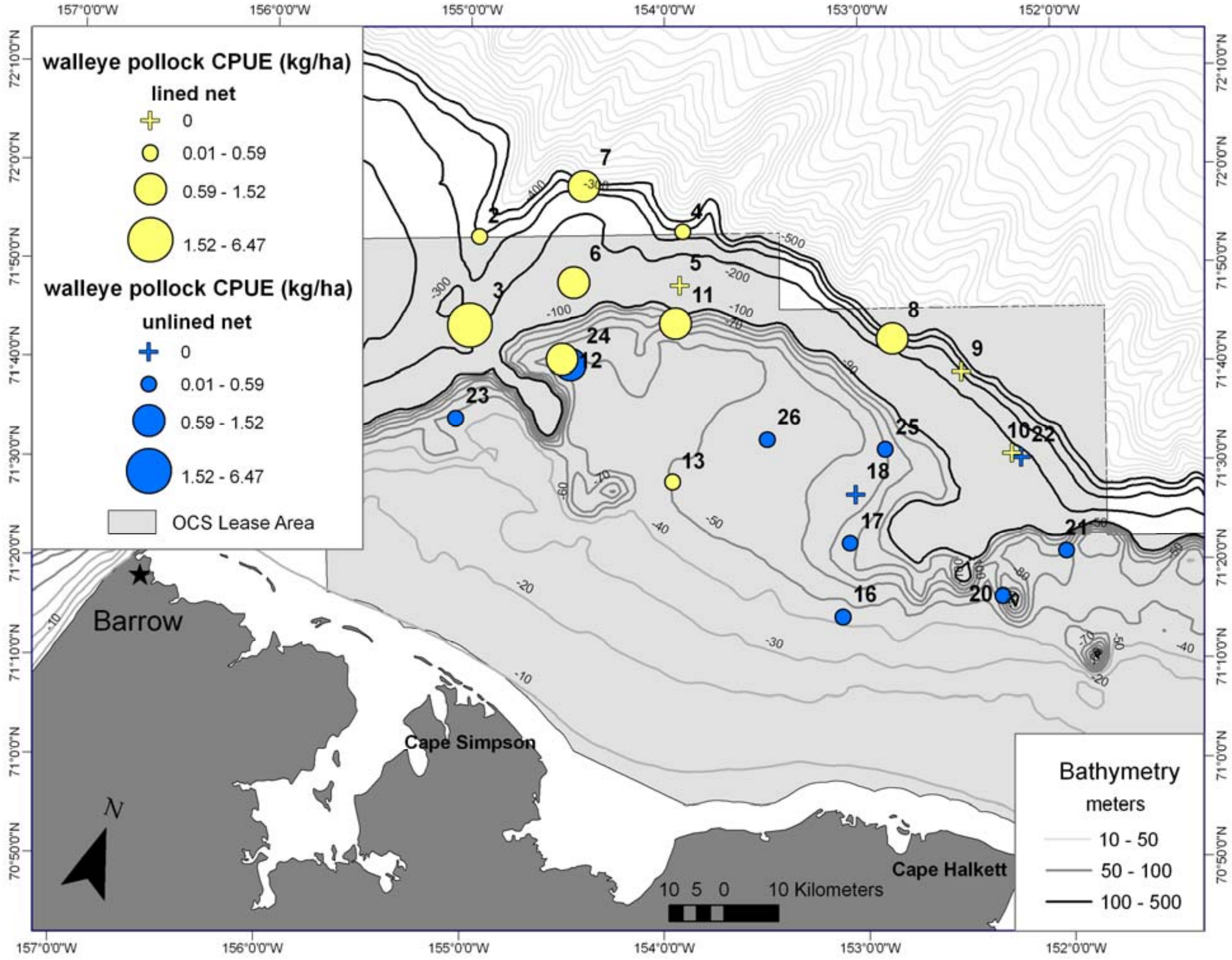


Figure 7. Walleye pollock CPUE (kg/ha) distribution from the Beaufort Sea survey, 2008, bottom trawls only. The Outer Continental Shelf (OCS) Lease Area is shown in gray shading.

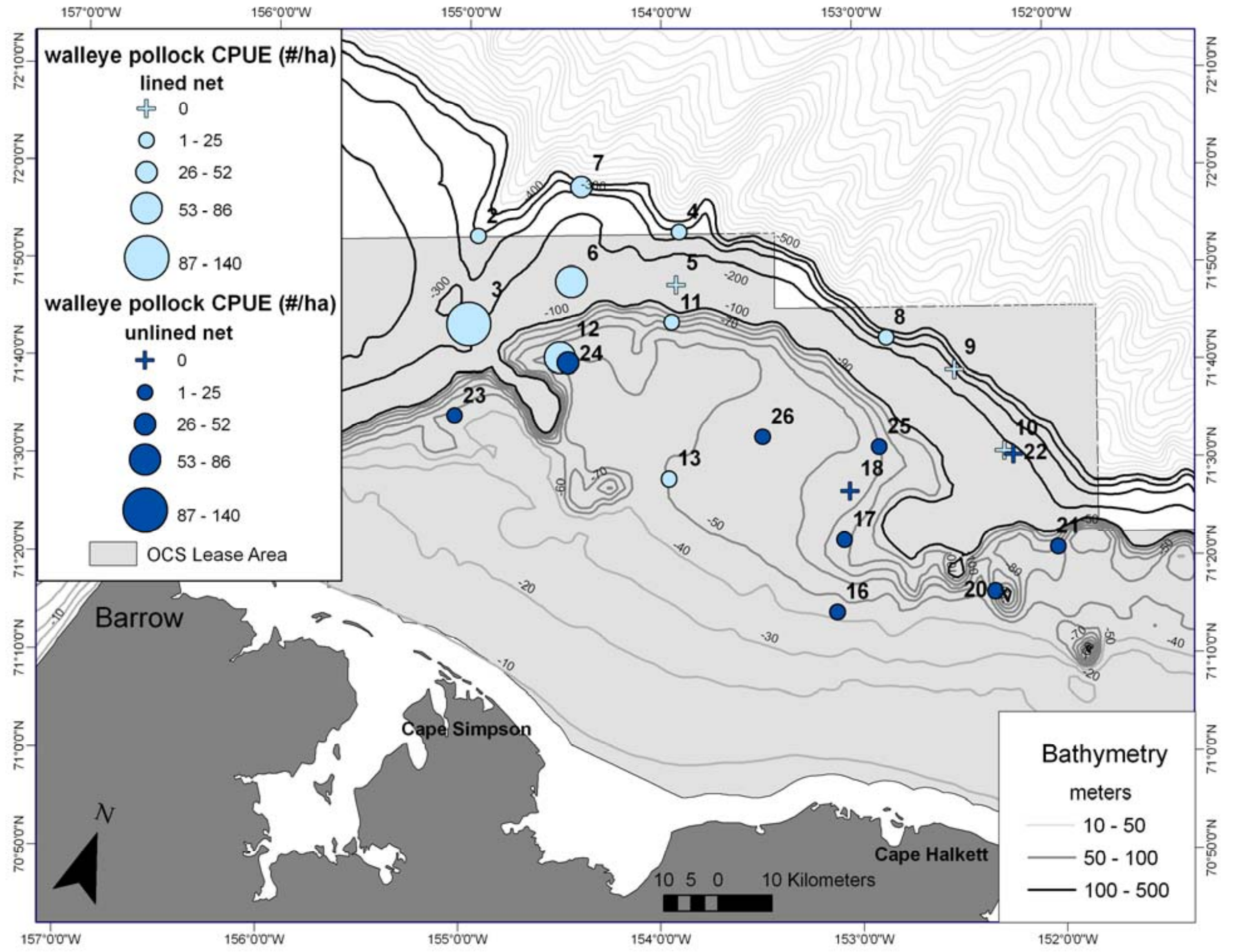


Figure 8. Walleye pollock CPUE (#/ha) distribution from the Beaufort Sea survey, 2008, bottom trawls only. The Outer Continental Shelf (OCS) Lease Area is shown in gray shading.

Eelpouts (all species combined*)*

Eelpouts were the second most abundant species of fish captured in the 2008 Beaufort Sea survey. All species of eelpouts were combined and the CPUE (kg/ha) distribution is illustrated in Figure 9 and CPUE (#/ha) in Figure 10. Similar to Arctic cod and walleye pollock, the highest CPUE both both kg/ha and #/ha occurred in the 100-500 m depth and primarily in the western half of the survey area. Zero and low CPUE trawls (0.04-1.89 kg/ha) dominated the 40-100 m depth.

Sculpins (all species combined)

Sculpin species were combined and the CPUE (kg/ha) distribution over the survey area is shown in Figure 11 and CPUE (#/ha) in Figure 12. The trawls with the highest CPUE for sculpins (0.50-2.06 kg/ha), were primarily located in the 40-100 m depth. Several zero catches occurred in the 100-500 m depth, particularly in the western half of the survey area. Sculpins were found across the entire survey area, from west to east.

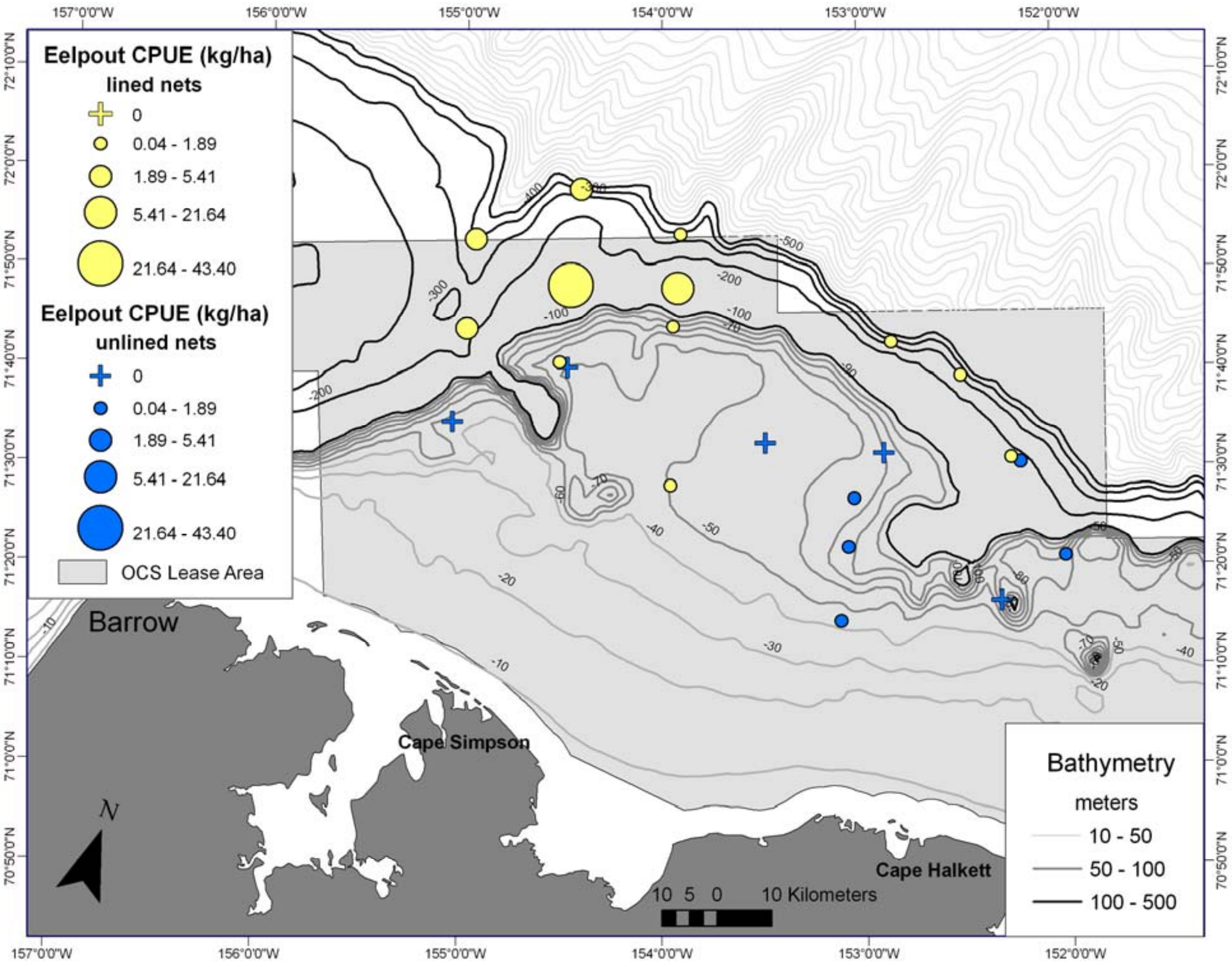


Figure 9. Eelpouts (all species combined) CPUE (kg/ha) distribution from the Beaufort Sea survey, 2008, bottom trawls only. The Outer Continental Shelf (OCS) Lease Area is shown in gray shading.

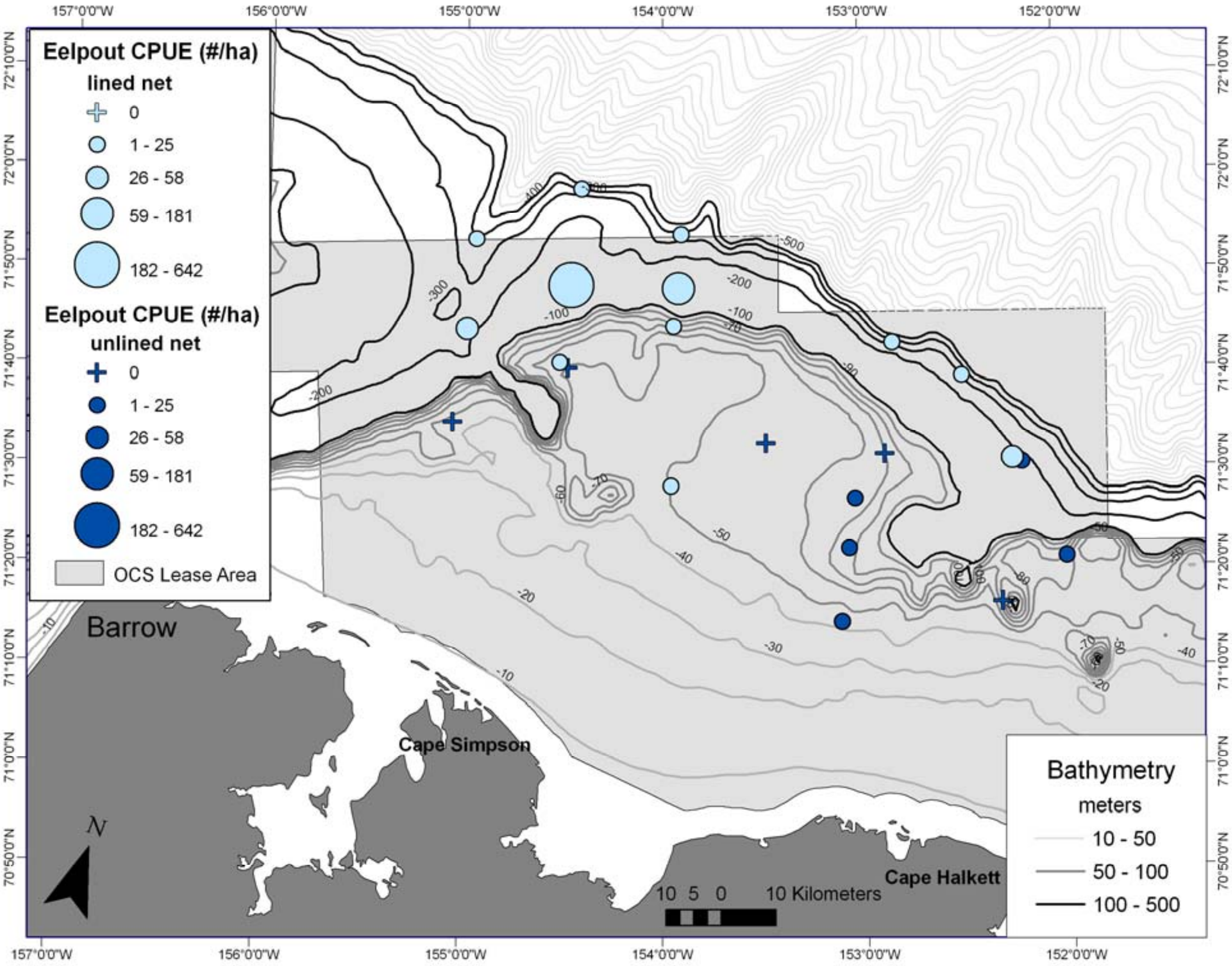


Figure 10. Eelpouts (all species combined) CPUE (#/ha) distribution from the Beaufort Sea survey, 2008, bottom trawls only. The Outer Continental Shelf (OCS) Lease Area is shown in gray shading.

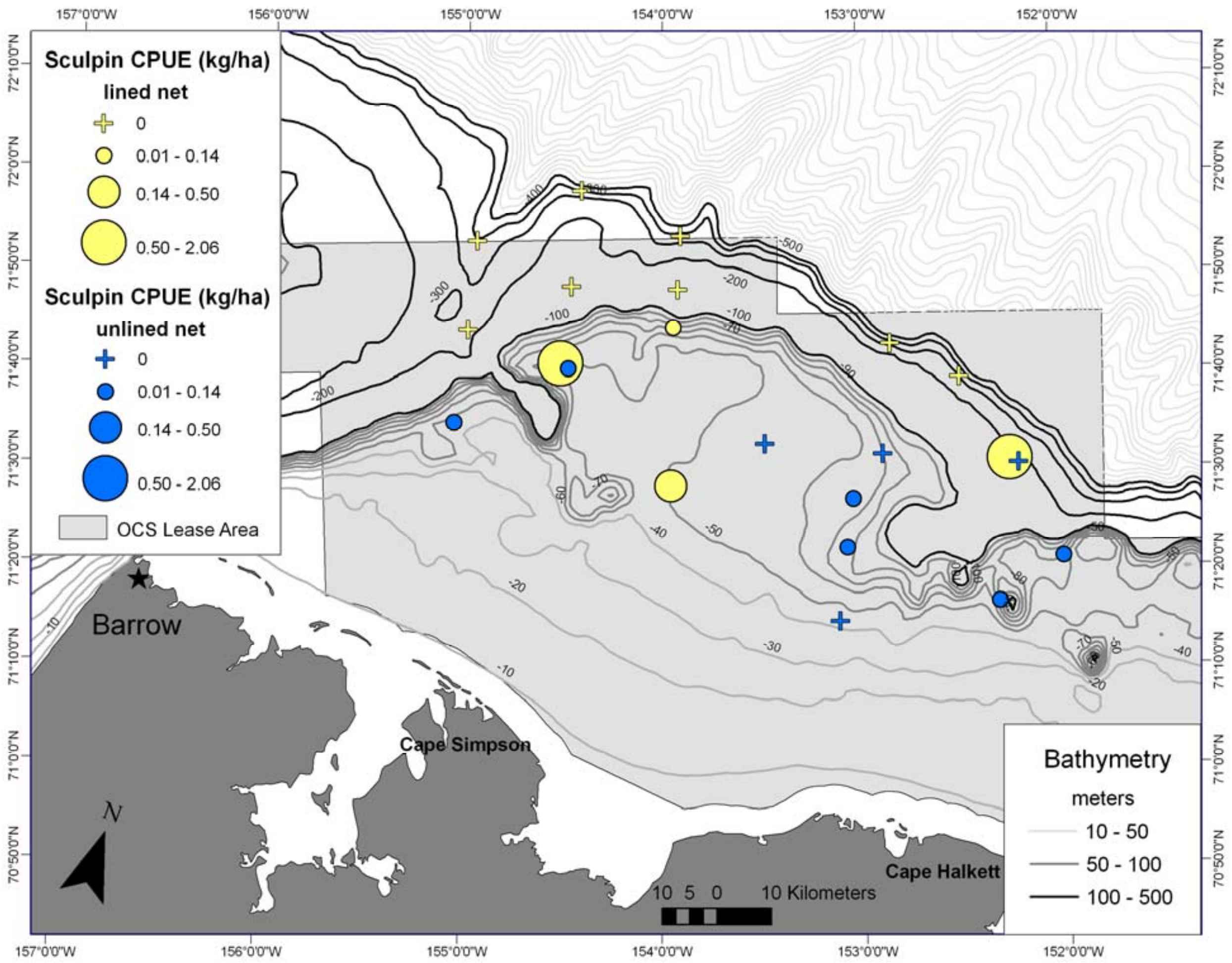


Figure 11. Sculpins (all species combined) CPUE (kg/ha) distribution from the Beaufort Sea survey, 2008, bottom trawls only. The Outer Continental Shelf (OCS) Lease Area is shown in gray shading.

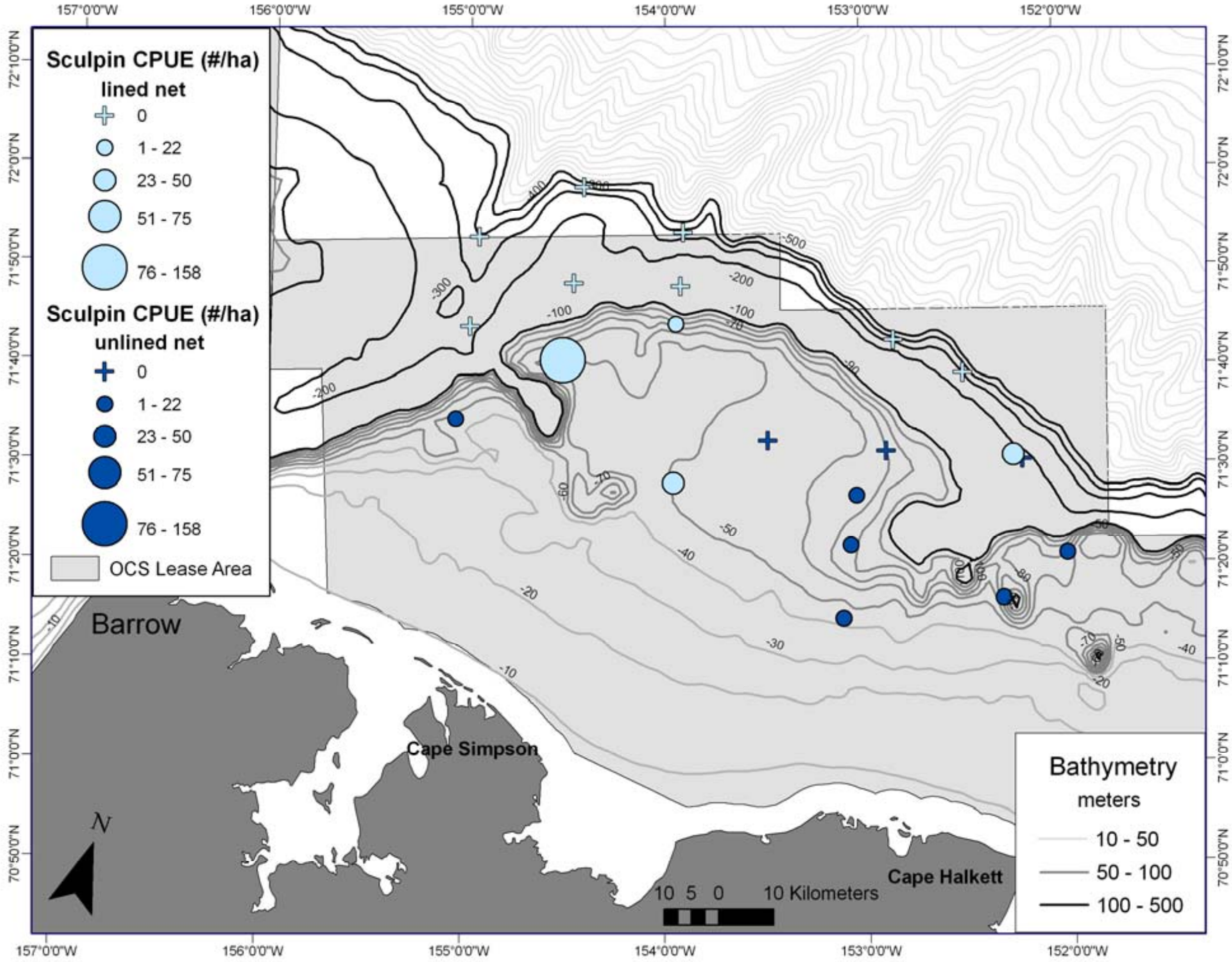


Figure 12. Sculpins (all species combined) CPUE (#/ha) distribution from the Beaufort Sea survey, 2008, bottom trawls only. The Outer Continental Shelf (OCS) Lease Area is shown in gray shading.

Demersal fish biological collections

Approximately 1,493 Arctic cod from bottom trawls were sexed and lengthed (701 males and 792 females). In addition, 753 Arctic cod were sexed, lengthed and individually weighed (331 males, 399 females, 30 unsexed).

The mean length for both sexes and all trawls combined was 113 mm with both a median and mode at 110 mm. The mean length for males was 108 mm and 120 mm for females, for all trawls. The median for males was 110 mm and for females it was 120 mm, for all trawls. For the lined nets (trawls 1-13), the mean length for males was 112 mm and 128 mm for females. The mode for males in the lined trawls was 110 mm and for females, there were 2 modes at 80 and 150 mm (Figure 13). For the unlined nets (trawls 16-26), the distribution of males and females size is similar with a mean of 102 mm for males and 107 mm for females. The mode for both males and females in the unlined trawls was 100 mm (Figure 14). Larger sized cod, along with the smaller sizes (~100 mm) appear to be distributed primarily in the 100-500 strata (lined net, Figure 13) whereas there were very few larger size cod found in the 40-100 mm strata (unlined net, Figure 14).

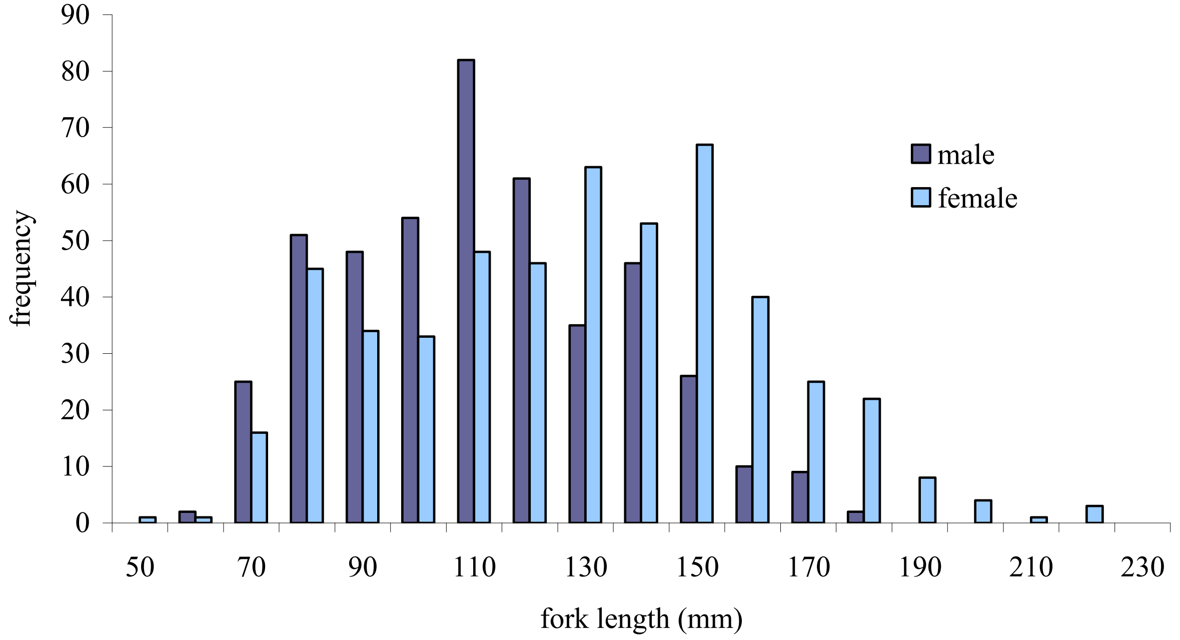


Figure 13. Length frequencies for male and female Arctic cod captured in the lined net during the 2008 Beaufort Sea survey, bottom trawls.

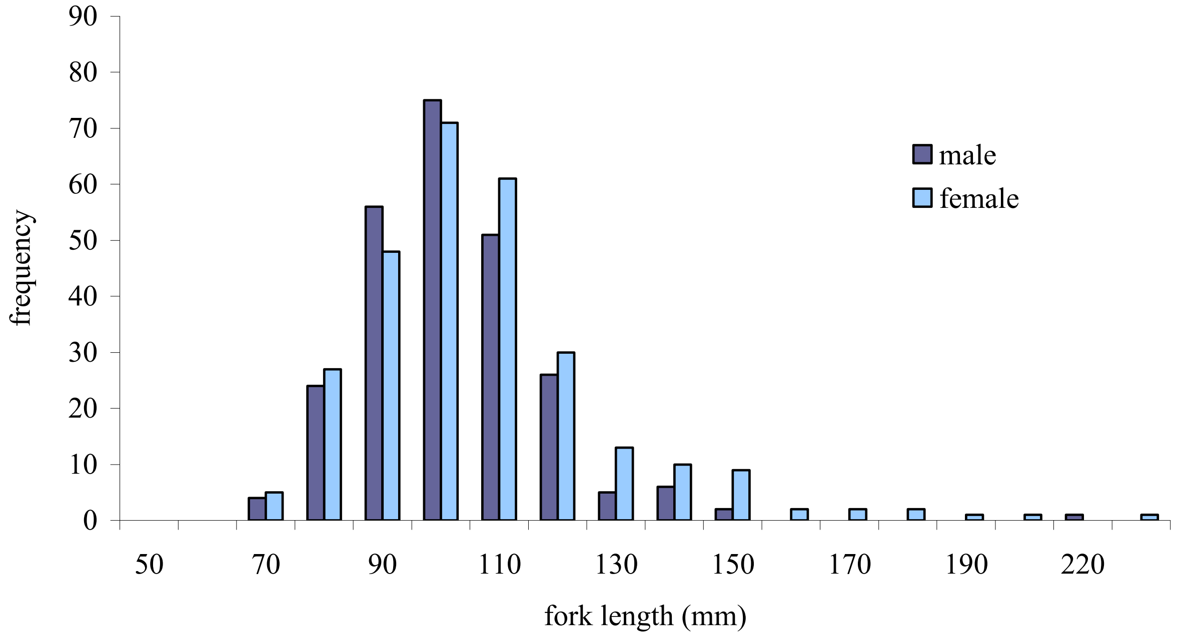


Figure 14. Length frequencies for male and female Arctic cod captured in the unlined net during the 2008 Beaufort Sea survey, bottom trawls.

The overall mean individual weight for Arctic cod in bottom trawls was 12 g (both sexes combined). The mean individual weight of males was 10 g and of females was 15 g. Some differences in the spatial distribution of individual weights for Arctic cod were observed: cod were somewhat larger in deeper water (Figure 15), similar to the larger lengths observed in the lined nets (Figure 13). The average length and weight for Arctic cod in the 100-500 m depth was 132 mm and 16 g, whereas the average length and weight for cod in the 40-100 m depth was 102 mm and 7 g (both sexes combined). In addition, trawls 8 and 9 had the highest individual average weights and lengths of cod and the sex ratio was greater than 75% females. Note that most of the catch in the 100-500 m depth was from the lined net, and most of the catch in the 40-100 m depth was from the unlined net.

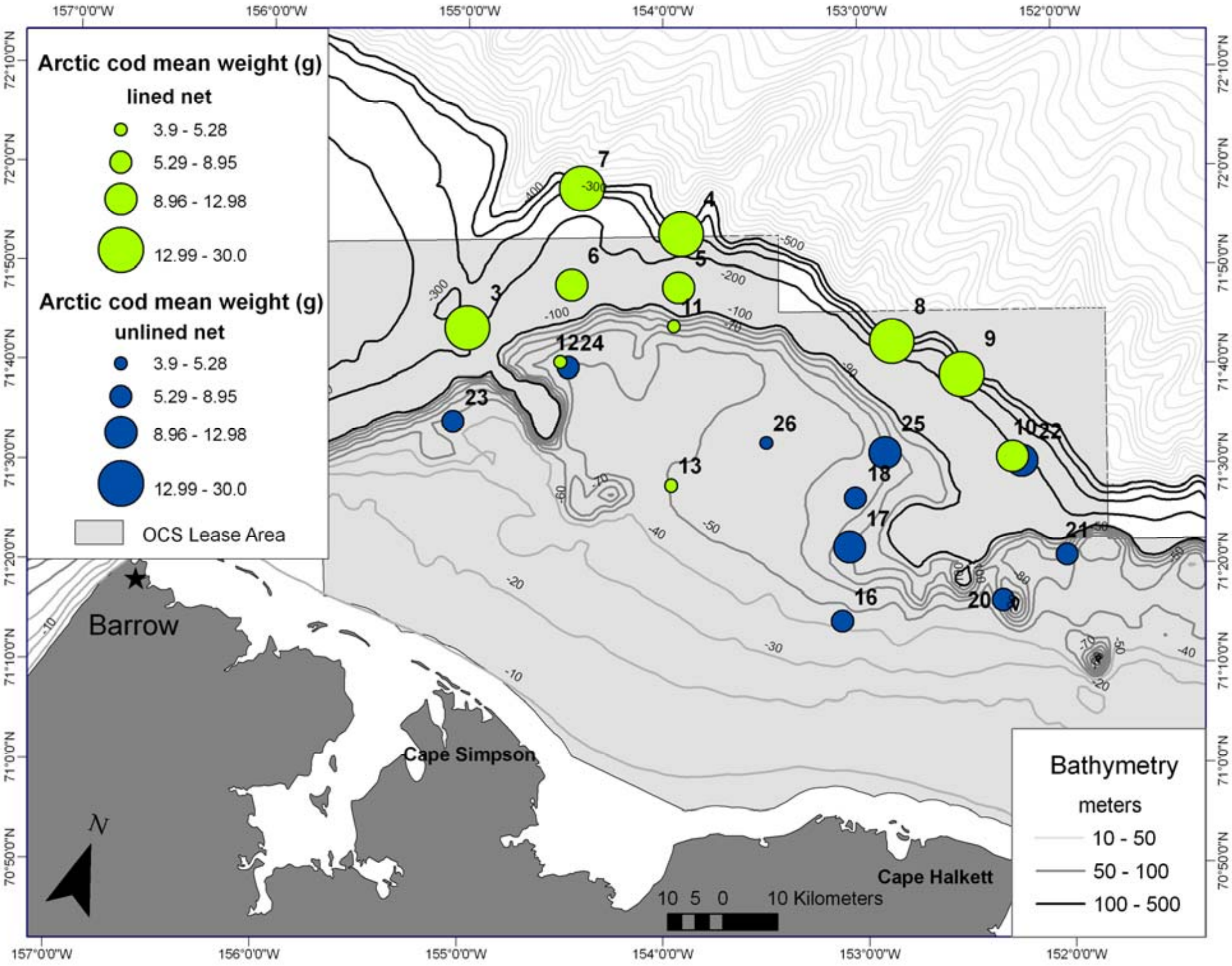


Figure 15. The average individual weight (g) of Arctic cod from each bottom trawl during the 2008 Beaufort Sea survey, bottom trawls. Trawl numbers are indicated for each point. The Outer Continental Shelf (OCS) Lease Area is shown in gray shading.

A length-weight relationship for Arctic cod was determined using Ricker's (1973) model: $weight\ (g) = 1.47x10^{-5} \times length\ (mm)^{2.8313}$. Males and females were examined separately, however, there was no difference between the estimated model parameters, and therefore sexes were combined. These results are illustrated in Figure 16.

In addition to Arctic cod lengths, lengths were collected from walleye pollock. There were 51 males, 44 females, and 4 unsexed (Figure 17). The mean fork length for all walleye pollock was 159 mm, with a median at 150 mm and mode at 130 mm. The mean for male pollock was 155 mm and 170 mm for females. Walleye pollock from the 2008 Beaufort Sea survey were aged at the AFSC and length-at-age is illustrated in Figure 18. For comparison, the lengths of Bering Sea walleye pollock collected in 2007 are included in Figure 18. In the Beaufort Sea 2008 survey, walleye pollock, age 2, occurred most frequently with a range of 110 to 203 mm in length. The Beaufort Sea pollock were similar in size to the Bering Sea pollock age 1 (2007 data), but at ages 2 and older the Beaufort Sea pollock were smaller than Bering Sea pollock.

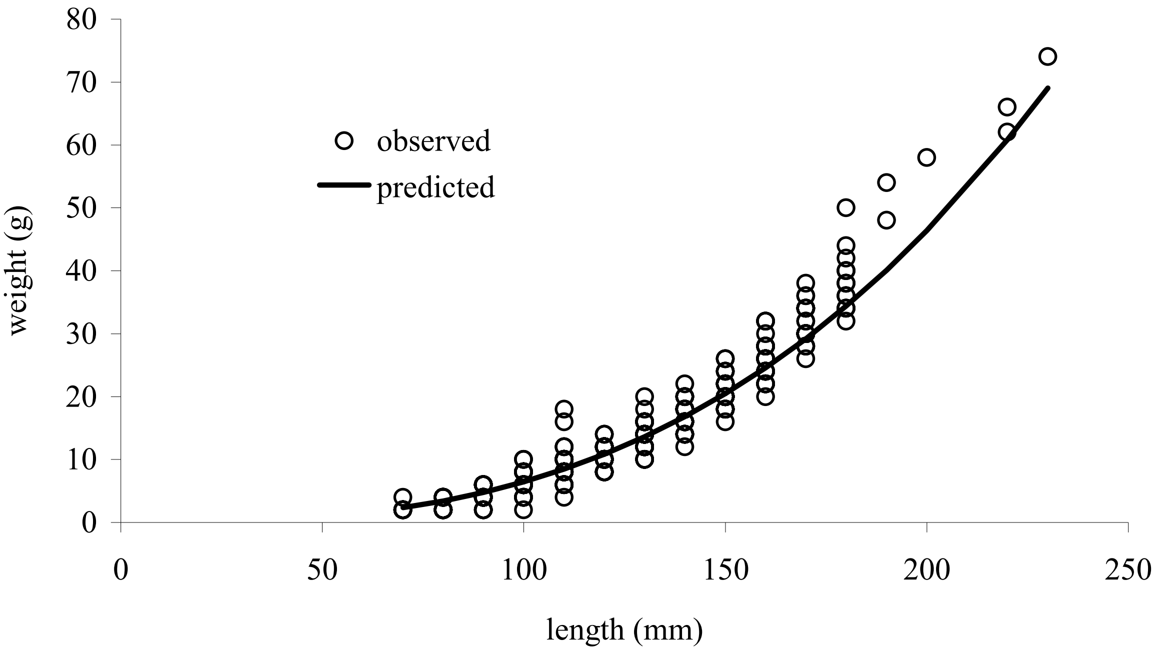


Figure 16. The length-weight relationship for Arctic cod from bottom trawls, both sexes combined.

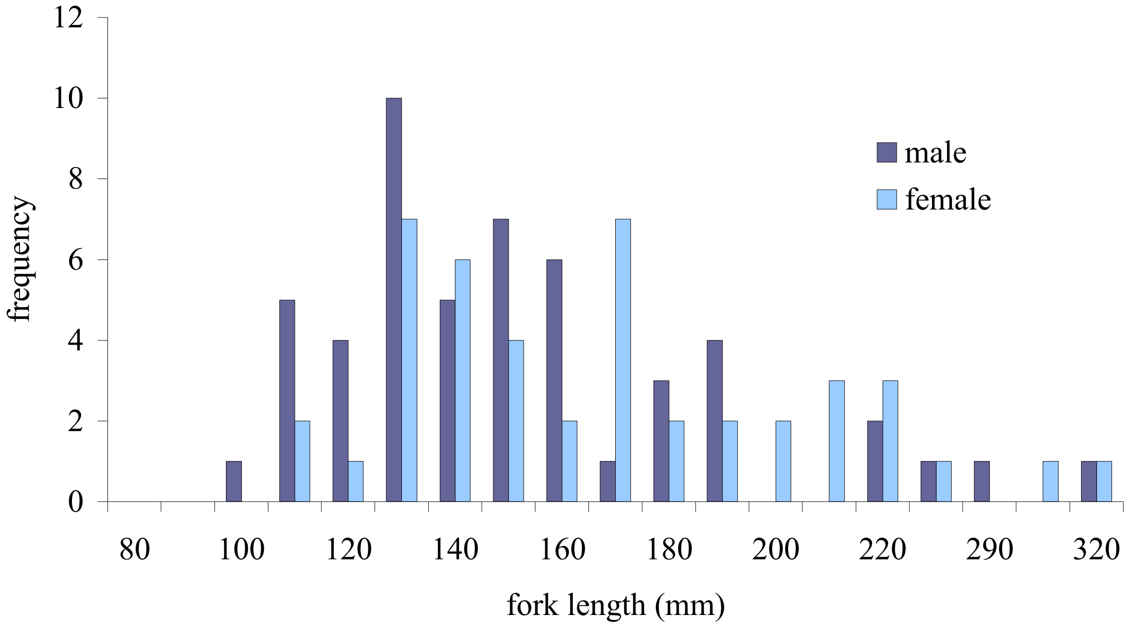


Figure 17. Length frequencies of male and female walleye pollock captured in the 2008 Beaufort Sea survey, bottom trawls.

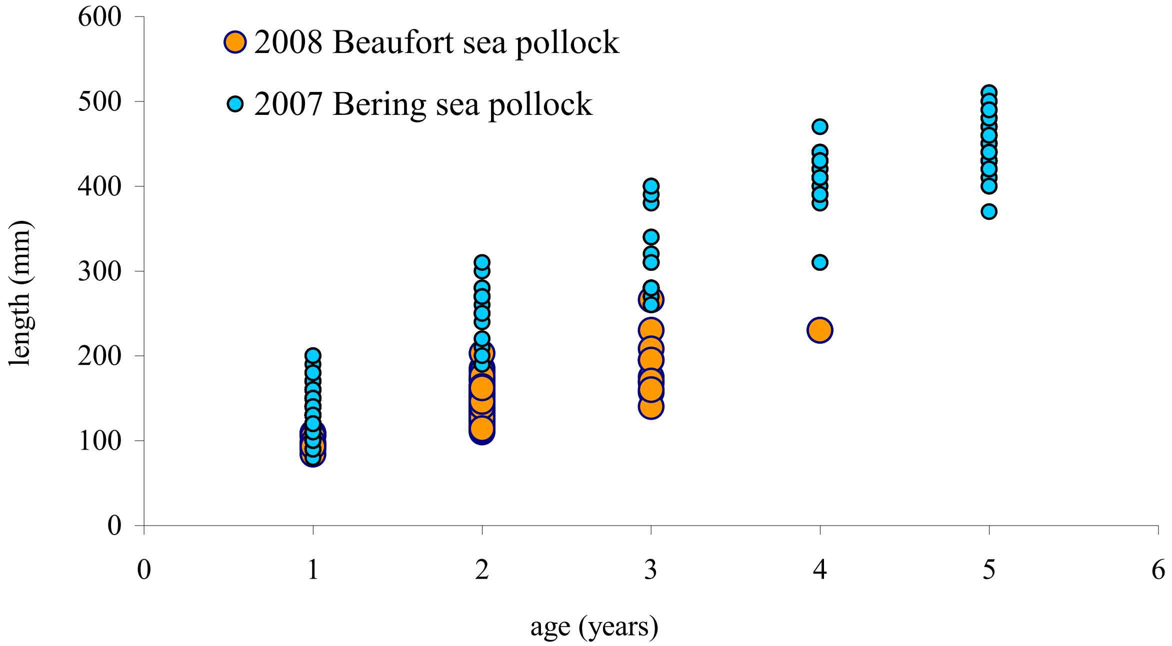


Figure 18. Length-at-age for walleye pollock captured in the 2008 Beaufort Sea survey (large, orange circles), and 2007 Bering Sea walleye pollock (small, blue circles), bottom trawls. Note the age 1 overlap.

Demersal fish geographic comparisons

The mean CPUE of species from current surveys of the Chukchi and Bering Seas is compared to CPUE of species from the Beaufort Sea survey (Table 11). All three surveys used the same standardized bottom trawl nets (unlined, 83-112 otter trawl). The Beaufort CPUE data shown are only from the unlined net stations. Arctic cod were the most prevalent fish species found in both the 2008 Beaufort, and the 1990 Chukchi Sea surveys (Barber et al. 1997). In the Bering Sea, walleye pollock was the most abundant fish species in terms of total CPUE, at 61.2 kg/ha compared to 0.13 kg/ha in the Beaufort Sea and 0.02 kg/ha in the Chukchi Sea. In addition, the flatfish species that were dominant in the Bering Sea (Arrowtooth/Kamchatka flounder, Bering flounder, flathead sole, Greenland turbot, northern rock sole, and yellowfin sole) were absent or found in low densities in the Chukchi and Beaufort Seas. Saffron cod was most abundant in the Chukchi Sea: it was absent from the Beaufort Sea 2008 survey and at very low densities in the Bering Sea.

All fish species captured during the 2008 Beaufort Sea survey are listed in Table 12, along with the presence or absence of those species caught during the 1990 Chukchi Sea survey (Barber et al. 1997). Presence/absence of fish in the Bering Sea is based on AFSC surveys conducted in 1984-2008 and taxonomy expertise (James Orr AFSC, pers. com.). Note: Species *Liparis tunicatus* and *Lycodes seminudus* occurred in the Beaufort Sea survey; however, there are no associated weights or numbers because they were not identified in the field, but in the laboratory from vouchers. They are listed in this table for ecosystem presences.

Table 11. Mean CPUE (kg/ha) of common species found in the Beaufort, Chukchi and Bering Seas. The CPUE reported for the Beaufort Sea is from the bottom trawl, **unlined nets only**. An asterisk indicates that there was no catch of that species.

Species Common Name	Beaufort Sea 2008[1] CPUE (kg/ha)	Chukchi Sea 1990[2] CPUE (kg/ha)	Bering Sea 2008[3] CPUE (kg/ha)
Arctic cod	6.12	3.02	1.04
Arrowtooth/Kamchatka flounder	*	*	11.87
Bering Flounder	0.11	0.18	0.45
Cottidae (sculpin family)	0.03	0.76	4.22
Flathead sole	*	*	10.81
Greenland turbot	*	<0.01	0.27
Northern rock sole	*	*	41
Pacific cod	*	0.12	8.65
Saffron cod	*	0.39	<0.01
Walleye pollock	0.13	0.02	61.2
Yellowfin sole	*	*	42.4
Zoarcidae (eelpout family)	0.03	0.21	0.5

[1] Beaufort Sea 2008 Survey
[2] Barber et al., 1997
[3] Eastern Bering Sea 2008 survey (Jason Conner, AFSC, pers. com.)

Table 12. Fish species presence/absence for the Beaufort, Chukchi and Bering Seas. An asterix represents species present and blank space represents species absent. Sources are: [1]Beaufort Sea 2008 survey, [2]Barber et al., 1997, and [3]Eastern Bering Sea 1984-2008 surveys (Jason Conner and Jay Orr, AFSC, pers. com.)

Scientific Name	Common Name	Beaufort Sea[1]	Chukchi Sea[2]	Bering Sea[3]
Artediellus scaber	hamecon	*	*	*
Aspidophoroides olriki	Arctic alligatorfish	*	*	*
Boreogadus saida	Arctic cod	*	*	*
Careproctus sp. cf. rastrinus (Orr et al.)	salmon snailfish	*		*
Cottidae	sculpin family	*	*	*
Eleginus gracilis	saffron cod	*	*	*
Enophrys diceraus	antlered sculpin	*	*	*
Eumesogrammus praecisus	fourline snakeblenny	*	*	*
Eumicrotremus derjugini	leatherfin lumpsucker	*		
Gadus macrocephalus	Pacific cod	*	*	*
Gymnelus viridis	fish doctor	*	*	*
Gymnocanthus tricuspis	Arctic staghorn sculpin	*	*	*
Hippoglossoides robustus	Bering flounder	*	*	*
Icelus spatula	spatulate sculpin	*	*	*
Liparis fabricii	gelatinous seasnail	*	*	
Liparis gibbus	variegated snailfish	*	*	*
Liparis marmoratus	festive snailfish	*		*
Liparis tunicatus	kelp snailfish	*	*	*
Liparis sp.	unid. snailfish	*	*	*
Lumpenus fabricii	slender eelblenny	*	*	*
Lumpenus maculatus	daubed shanny	*		*
Lumpenus medius	stout eelblenny	*	*	*
Lumpenus sp.	unid. eelblenny	*	*	*
Lycodes mucosus	saddled eelpout	*	*	*
Lycodes polaris	Canadian eelpout	*	*	*
Lycodes raridens	marbled eelpout	*	*	*
Lycodes rossi	threespot eelpout	*	*	
Lycodes seminudus	longear eelpout	*		
Lycodes sp.	unid. eelpout	*	*	*
Mallotus villosus	capelin	*	*	*
Myoxocephalus verrucosus	warty sculpin	*	*	*
Nautichthys pribilovius	eyeshade sculpin	*	*	*
Reinhardtius hippoglossoides	Greenland turbot	*	*	*
Theragra chalcogramma	walleye pollock	*	*	*
Triglops nybelini	bigeye sculpin	*		
Triglops pingeli	ribbed sculpin	*	*	*

Demersal fish historical comparisons

The most recent previous survey of Beaufort Sea *offshore* marine fish was conducted during 1976-1977 (Frost and Lowry 1983). The Frost and Lowry (1983) survey took place in 1977 from August 2nd until September 3rd. There was a nearshore (<10 m water depth) marine fish survey that took place in the central/eastern Beaufort Sea in 1988-1990 (Jarvela and Thorsteinson 1999), but because the survey was in habitat shallower than the current survey the data are not useful for a historical comparison of the occurrence of fish species in the offshore habitat. Of the 34 species captured and identified from the 2008 Beaufort Sea survey, 17 of those species had also been documented in the 1976-77 survey (Table 13). Although CPUE was not calculated during the earlier survey, the number of fish caught was recorded at each station. Arctic cod (*Boreogadus saida*) was the most numerous fish species found in both surveys. Bering flounder (*Hippoglossoides robustus*) and walleye pollock (*Theragra chalcogramma*) were fairly abundant relative to other species in the 2008 survey but were not observed during the 1977 survey. Pacific cod (*Gadus macrocephalus*), festive snailfish (*Liparis marmoratus*), eyeshade sculpin (*Nautichthys pribilovius*) and bigeye sculpin (*Triglops nybelini*) were caught in small numbers compared to other species during the 2008 survey and were absent from the 1977 survey.

Eelpouts were common during both surveys, but different species were dominant: marbled eelpouts (*Lycodes raridens*) were the most abundant eelpout in the 2008 survey, whereas Canadian eelpouts (*Lycodes polaris*) and fish doctors (*Gymnelus viridis*) were most abundant in the 1977 survey. Snailfish were a fairly common species during both surveys. Variegated (*Liparis gibbus*) and gelatinous seasnail (*Liparis fabricii*) were the most abundant snailfish species in the 2008 survey, but unfortunately the snailfish were not identified to species in the 1977 survey. Sculpins were caught during both surveys, but they appeared to be ranked higher in abundance during the 1977 survey. In addition, different species were apparantly caught: warty (*Myoxocephalus verrucosus*) and ribbed sculpin (*Triglops pingeli*) were most common during the 2008 survey and spatulate (*Icelus spatula*) and twohorn sculpin (*Icelus bicornis*) were the dominant species during the 1977 survey. In fact, the twohorn sculpin was the third most prevelant species in the 1977 survey and did not occur in the 2008 survey. *Arctogadus glacialis* (polar cod) was likewise caught during the 1977 survey but not the 2008 survey. Only 1 polar cod was recorded in the 1977 survey.

Table 13. Fish species from the 2008 Beaufort Sea survey, bottom trawls, (CPUE in #/ha from all nets combined) compared to the previous Beaufort Sea survey in 1977 by Frost and Lowry (1983).

Scientific Name	Common Name	2008 survey mean CPUE (#/ha)	2008 survey no. of stations	1977 survey No. individuals	1977 survey No. stations
Arctogadus glacialis	polar cod			1	1
Artediellus scaber	hamecon	6	9	30	5
Aspidophoroides olriki	Arctic alligatorfish	2	6	19	3
Boreogadus saida	Arctic cod	1,303	22	194	18
Careproctus sp. cf. rastrinus (Orr et al.)	salmon snailfish	1	6		
Cottidae	sculpin family	3	1		
Eleginus gracilis	saffron cod	1	1		
Enophrys diceraus	antlered sculpin	1	1		
Eumesogrammus praecisus	fourline snakeblenny	1	2	4	1
Eumicrotremus derjugini	leatherfin lumpsucker	1	4	29	11
Gadus macrocephalus	Pacific cod	1	2		
Gymnelus viridis	fish doctor	1	2	23	7
Gymnocanthus tricuspis	Arctic staghorn sculpin	3	3	2	2
Hippoglossoides robustus	Bering flounder	4	16		
Icelus bicornis	twohorn sculpin			74	13
Icelus spatula	spatulate sculpin	1	4	14	2
Liparis fabricii	gelatinous seasnail	2	5		
Liparis gibbus	variegated snailfish	2	1		
Liparis marmoratus	festive snailfish	1	1		
Liparis sp.	unid. snailfish	1	4	29	15
Lumpenus fabricii	slender eelblenny	1	2	11*	2*
Lumpenus maculatus	daubed shanny	1	2	1	1
Lumpenus medius	stout eelblenny	2	3	1	1
Lumpenus sp.	unid. eelblenny	1	1		
Lycodes mucosus	saddled eelpout	1	2	2	2
Lycodes polaris	Canadian eelpout	12	8	81	11
Lycodes raridens	marbled eelpout	24	5	7	1
Lycodes rossi	threespot eelpout	1	4	2*	1*
Lycodes sp.	unid. eelpout	2	3		
Mallotus villosus	capelin	1	2		
Myoxocephalus verrucosus	warty sculpin	2	5		
Nautichthys pribilovius	eyeshade sculpin	1	1		
Reinhardtius hippoglossoides	Greenland turbot	3	5		
Theragra chalcogramma	walleye pollock	23	17		
Triglops nybelini	bigeye sculpin	1	1		
Triglops pingeli	ribbed sculpin	8	6	2	2

* found in 1976 survey but not in 1977 survey

Benthic invertebrates

Benthic invertebrate abundance

Invertebrates made up 94% of the total weight in the bottom trawls and 174 taxa were identified. Similar to fish, all invertebrates were identified to the lowest taxonomic level possible in the field (family, genus or species). Species identifications are preliminary and will be confirmed in the laboratory pending further funding. Not all invertebrate species are typically enumerated (such as corals and ascidians) so the summary table only shows total catch weight and not number. Of the invertebrates, *Ophiura sarsi* (notched brittle star) made up 41% and *Chionoecetes opilio* (opilio crab) made up 10% of the total weight (kg). The catch of the 24 taxa that comprised 94% of the total invertebrate weight is shown in Table 14.

Table 14. The 24 most abundant invertebrate taxa captured in the bottom trawls during the 2008 Beaufort Sea survey, ranked by total weight (all trawls combined). Species identifications are preliminary.

Species Name	Common name	Total weight (kg)
Ophiura sarsi	notched brittle star	9775.93
Chionoecetes opilio	opilio crab	3916.96
Musculus spp.	mussels	1424.95
Ctenodiscus crispatus	mud star	940.07
Actiniaria	sea anenomes	488.22
Strongylocentrotus sp.	sea urchin	418.61
Psolus fabricii	sea cucumber	352.89
Buccinum polare	polar whelk	213.27
Pyrulofusus spp.	whelk	204.23
Gorgonocephalus arcticus	basket starfish	168.16
Neptunea spp.	whelk	154.28
Golfingia margaritacea	worm	149.47
Gersemia rubiformis	soft coral	125.35
Psolus phantapus	sea cucumber	123.21
Halocynthia aurantium	ascidian	114.99
Stomphia sp.	anemone	110.07
Pagurus rathbuni	hermit crab	83.03
Naticidae	moon snails	70.74
Buccinum glaciale	glacial whelk	67.68
Margarites spp.	snail	67.00
Hyas coarctatus	lyre crab	58.42
Buccinum spp.	whelk	56.62
Pagurus trigonocheirus	hermit crab	49.44
Brada spp.	polychaete	49.29

The CPUE for the 24 most abundant invertebrate taxa are shown in Table 15. The top three taxa by CPUE weight in the 40-100 m depth were *Halocynthia arurantium* (ascidian), *Psolus fabricii* (sea cucumber), and *Ctenodiscus crispatus* (mud star). In the 100-500 m depth, the top three species by CPUE weight were *Ophiura sarsi* (notched brittle star), *Chionoecetes opilio* (opilio crab), and *Musculus* spp. (mussels).

Mean CPUE in both numbers and weight (± 1 SD) was greater for catches made with the lined versus the unlined survey net (Table 16). The mean CPUE by weight for only a few taxa captured in the unlined net was higher or similar to the CPUE in the lined net: *Halocynthia aurantium* (ascidian), *Pagurus trigonocheirus* (hermit crab), and *Hyas coarctatus* (lyre crab). The CPUE by numbers of the two crab species was much lower in the unlined net, suggesting larger organisms were caught with the unlined net.

The CPUE of invertebrates for the paired trawls are summarized in Table 17. The difference in CPUE between the lined and unlined survey nets was even more dramatic for invertebrates than it was for fish catches. For virtually all species, the CPUE was higher at the same location fished with a lined net compared to an unlined net. For example, the CPUE for *Ophiura sarsi* (notched brittle star) sampled with a lined net was 696.47 kg/ha compared to using an unlined net at the same location, <0.01 kg/ha.

Total invertebrate biomass estimated for both depths combined was 247,639 t, with 23,660 t in the 40-100 m depth and 223,979 t in the 100-500 m depth. The invertebrate with the largest estimated biomass was *Ophiura sarsi* (notched brittle star) (Table 18). The most prevalent invertebrate in the 40-100 m depth was *Halocynthia aurantium* (ascidian) and this species did not occur in the 100-500 m depth. In the 100-500 m depth, *Chionoecetes opilio* (opilio crab) had the second highest biomass.

Table 15. Mean CPUE in numbers and weight of the top 24 invertebrate taxa that were caught during the 2008 Beaufort Sea survey, by bottom depth strata. Species identifications are preliminary. (Note: trawls 11, 12, and 13 are not included in these results as they were with a lined net in the 40-100 m stratum).

Species Name	Common name	Mean CPUE (#/ha) 40-100 m depth (unlined net)	Mean CPUE (#/ha) 100-500 m depth (lined net)	Mean CPUE (kg/ha) 40-100 m depth (unlined net)	Mean CPUE (kg/ha) 100-500 m depth (lined net)
Ophiura sarsi	notched brittle star	67	343,266	0.17	449.38
Chionoecetes opilio	opilio crab	6	1,127	0.31	114.98
Musculus spp.	mussels	0	10,461	0	66.82
Ctenodiscus crispatus	mud star	497	2,989	2.96	31.45
Actiniaria	sea anemones	0	135	0	21.02
Strongylocentrotus sp.	sea urchin	47	414	1.43	16.0
Buccinum polare	polar whelk	0	1,051	0	9.81
Pyrulofusus spp.	whelk	2	172	0.08	9.78
Gorgonocephalus arcticus	basket starfish	0	32	0	8.29
Golfingia margaritacea	worm	< 1	4,447	< 0.01	6.37
Neptunea spp.	whelk	9	156	0.42	5.40
Psolus phantapus	sea cucumber	0	81	0	5.12
Stomphia sp.	anemone	23	143	0.93	4.14
Psolus fabricii	sea cucumber	131	181	4.44	3.81
Pagurus rathbuni	hermit crab	5	889	0.06	3.42
Naticidae	moon snails	0	516	0	3.32
Buccinum glaciale	glacial whelk	1	139	0.03	2.90
Buccinum spp.	whelk	< 1	289	< 0.01	2.76
Margarites spp.	snail	< 1	1,350	< 0.01	2.70
Gersemia rubiformis.	soft coral	*	*	0.04	2.55
Brada spp.	polychaete	0	839	0	2.44
Hyas coarctatus	lyre crab	41	99	1.24	1.10
Pagurus trigonocheirus	hermit crab	90	6	1.73	0.04
Halocynthia aurantium	ascidian	*	*	11.85	0

* = species typically not counted

Table 16. Mean CPUE numbers and weight of the top 24 invertebrate taxa caught in lined vs. unlined nets during the 2008 Beaufort Sea survey. Species identifications are preliminary.

Species Name	Common name	Mean CPUE (#/ha) lined net	Mean CPUE (#/ha) unlined net	Mean CPUE (kg/ha) lined net	Mean CPUE (kg/ha) unlined net
Ophiura sarsi	notched brittle star	286,277	61	337.61	0.16
Chionoecetes opilio	opilio crab	996	8	86.54	0.47
Musculus spp.	mussel	8,718	< 1	50.12	< 0.01
Ctenodiscus crispatus	mud star	4,122	454	34.73	2.7
Actiniaria	sea anemones	112	0	15.76	0
Strongylocentrotus sp.	sea urchin	281	122	12.23	4.95
Psolus fabricii	sea cucumber	526	118	11.97	4.0
Buccinum polare	polar whelk	872	6	7.36	0.06
Pyrulofusus spp.	whelk	144	2	6.28	0.07
Neptunea spp.	whelk	178	9	5.32	0.40
Gorgonocephalus arcticus	basket starfish	26	< 1	5.28	< 0.01
Golfingia margaritacea	worm	3,706	< 1	4.78	< 0.01
Gersemia rubiformis	soft coral	*	*	4.66	0.04
Psolus phantapus	sea cucumber	69	0	3.88	0
Stomphia sp.	anemone	125	26	3.25	1.13
Pagurus rathbuni	hermit crab	800	8	2.92	0.07
Naticidae	moon snails	432	1	2.50	0.01
Margarites spp.	snail	1,254	< 1	2.36	< 0.01
Buccinum glaciale	glacial whelk	115	3	2.20	0.06
Buccinum spp.	whelk	241	< 1	2.08	< 0.01
Brada spp.	polychaete	699	< 1	1.83	< 0.01
Hyas coarctatus	lyre crab	155	37	1.69	1.52
Pagurus trigonocheirus	hermit crab	255	83	1.32	1.57
Halocynthia aurantium	ascidian	*	*	0.56	10.69

* = species typically not counted

Table 17. CPUE for the top 24 invertebrate taxa caught in the paired comparison trawls. The two pairs were trawls 10 and 22; and trawls 12 and 24. Species identifications are preliminary.

Species Name	Common name	CPUE (kg/ha) lined trawl 10 (100-500 m)	CPUE (kg/ha) unlined trawl 22 (100-500 m)	CPUE (kg/ha) lined trawl 12 (40-100 m)	CPUE (kg/ha) unlined trawl 24 (40-100 m)
Ophiura sarsi	notched brittle star	696.47	< 0.01	0.77	0
Strongylocentrotus sp.	sea urchin	142.97	36.68	1.81	0
Pyrulofusus spp.	whelk	21.78	0	0	0
Margarites spp.	snail	18.87	0.01	0.05	0
Ctenodiscus crispatus	mud star	15.29	0.38	0	0
Chionoecetes opilio	opilio crab	14.82	1.96	0.06	0.08
Stomphia sp.	anemone	9.41	2.89	1.49	3.24
Pagurus rathbuni	hermit crab	6.6	0.23	0.05	0.04
Buccinum polare	polar whelk	4.11	0.6	0	0
Buccinum glaciale	glacial whelk	3.01	0.33	0	0.02
Naticidae	moon snails	1.18	0.11	0	0
Brada spp.	polychaet	0.49	< 0.01	0	0
Gersemia rubiformis	soft coral	0.34	0.05	1.01	0.08
Hyas coarctatus	lyre crab	0.17	0	3.85	2.38
Neptunea spp.	whelk	0.14	0.15	9.29	0
Musculus spp.	black mussel	0.08	< 0.01	0	0
Pagurus trigonocheirus	hermit crab	0.08	0.19	7.46	2.73
Actiniaria	sea anemones	0	0	0	0
Psolus fabricii	sea cucumber	0	0.02	41.92	16.62
Gorgonocephalus arcticus	basket starfish	0	0	0	0
Golfingia margaritacea	worm	0	0	0	0
Psolus phantapus	sea cucumber	0	0	0.53	0
Buccinum spp.	whelk	0	0	0.06	0.02
Halocynthia aurantium	ascidian	0	0.31	6.42	9.66

* = species typically not counted

Table 18. Biomass of invertebrate taxa caught during the 2008 Beaufort Sea survey, extrapolated to bottom depth area. Species identifications are preliminary. (Note: trawls 11, 12, and 13 are not included in these results as they were with a lined net at the 40-100 m depth).

Species Name	Common name	Biomass estimate (t) 40-100 m depth	Biomass estimate (t) 100-500 m depth
Ophiura sarsi	notched brittle star	70	127,332
Chionoecetes opilio	opilio crab	124	32,580
Musculus spp.	mussels	0	18,935
Ctenodiscus crispatus	mud star	1,207	8,911
Actiniaria	sea anemones	0	5,596
Strongylocentrotus sp.	sea urchin	581	4,533
Buccinum polare	polar whelk	0	2,781
Pyrulofusus spp.	whelk	34	2,772
Gorgonocephalus arcticus	basket starfish	0	2,348
Golfingia margaritacea	worm	2	1,806
Neptunea spp.	whelk	172	1,530
Psolus phantapus	sea cucumber	0	1,450
Stomphia sp.	anemone	380	1,174
Psolus fabricii	sea cucumber	1,808	1,080
Pagurus rathbuni	hermit crab	23	970
Naticidae	moon snails	0	939
Buccinum glaciale	glacial whelk	11	822
Buccinum spp.	whelk	1	783
Margarites spp.	snail	0	766
Gersemia rubiformis.	soft coral	15	722
Brada spp.	polychaete	0	692
Hyas coarctatus	lyre crab	505	311
Pagurus trigonocheirus	hermit crab	703	12
Halocynthia aurantium	ascidian	4,826	0

Benthic invertebrate distribution

Notched brittle star (*Ophiura sarsi*)

A distribution map of CPUE for *Ophiura sarsi* (notched brittle star), showed the highest CPUE in the 100-500 m depth range with a fairly similar CPUE from west to east across the study area (Figure 19).

Opilio crab

The highest CPUE for *Chionoecetes opilio* (opilio crab) was likewise found in the 100-500 m depth (Figure 20). However, the largest catches (kg/ha) occurred in the western portion of the study area. In contrast, CPUE varied little by longitude in the 40-100 m depth (0.01-14.82 kg/ha).

The legal size for opilio crab fished in the Bering Sea is 78 mm carapace width, and a map of the distribution of crab above this limit would be of interest. However, individual crab were not measured and weighed from all trawls. Eighty-six *Chionoecetes opilio* (both males and females with eggs) from three trawls and 50 *Hyas coarctatus* (both males and females) from two trawls were weighed, measured and collected as part of a special project on Bitter Crab Syndrome (BCS). Because individual opilio crab were not lengthed and weighed from every trawl, a length-weight relationship dervied from the BCS project data was used to deduce the expected weight of a crab above 78 mm carapace width. Female crab carapace width ranged from 58-78 mm (n=16), and male carapace width ranged from 55-119 mm (n=70). Average individual crab weight for all trawls was calculated from total crab catch weight and numbers. The carapace width vs. weight of *Chionoecetes opilio* (male and female combined) is shown in Figure 21.

Using this relationship, it was estimated that most crabs with a weight above 0.11 kg would have been greater than 78 mm. The distribution for average individual weight of crab is shown in Figure 22. The crabs with average weights greater than 0.11 kg were found only in the 100-500 m depth. In addition, the depth range can be narrowed to trawls that occurred between 306-478 m. In the 40-100 m depth, crab average weight varied little and ranged between 0.02-0.10 kg.

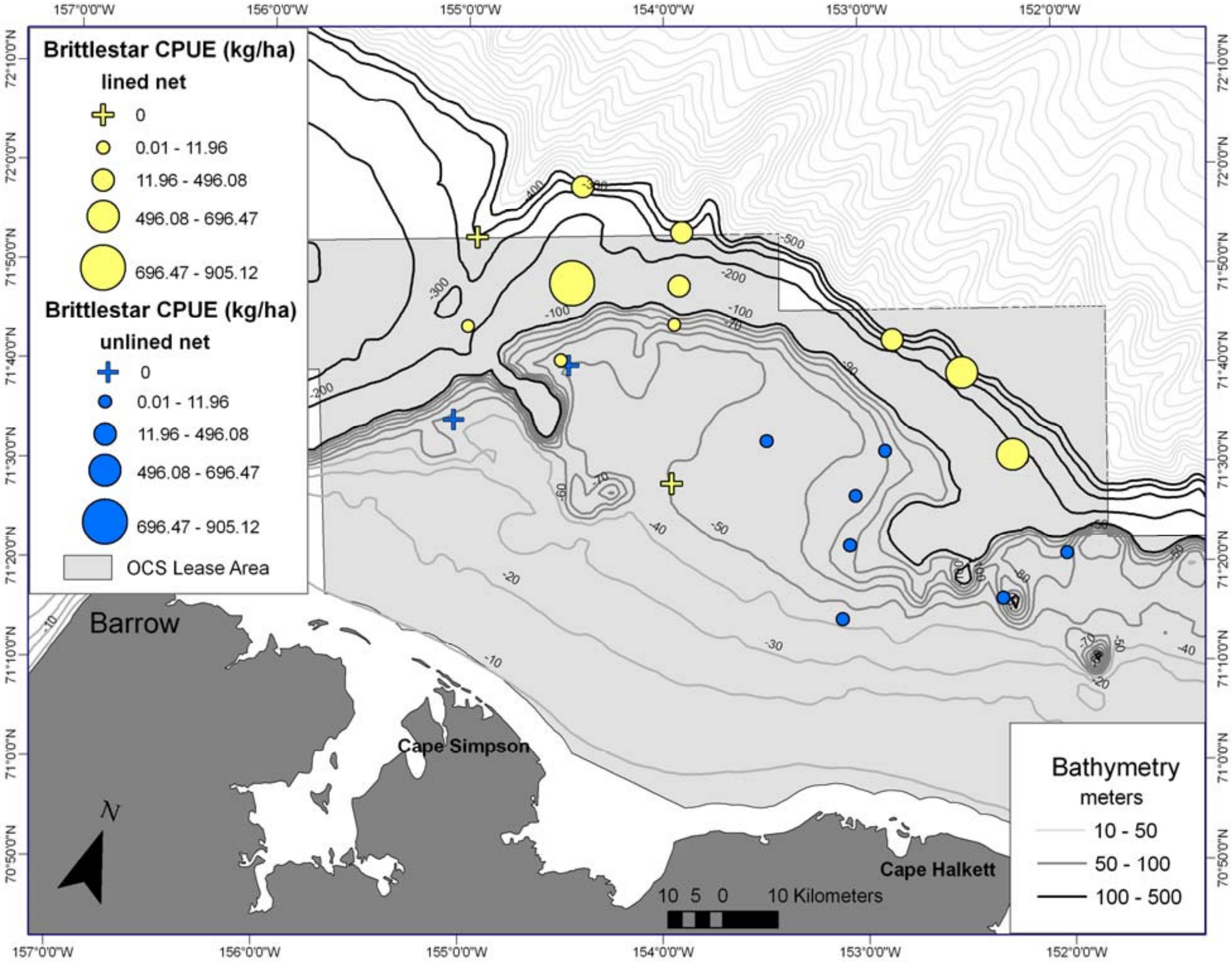


Figure 19. Distribution of *Ophiura sarsi* (notched brittle star) CPUE (kg/ha) from the Beaufort Sea survey, 2008, bottom trawls. The Outer Continental Shelf (OCS) Lease Area is shown in gray shading.

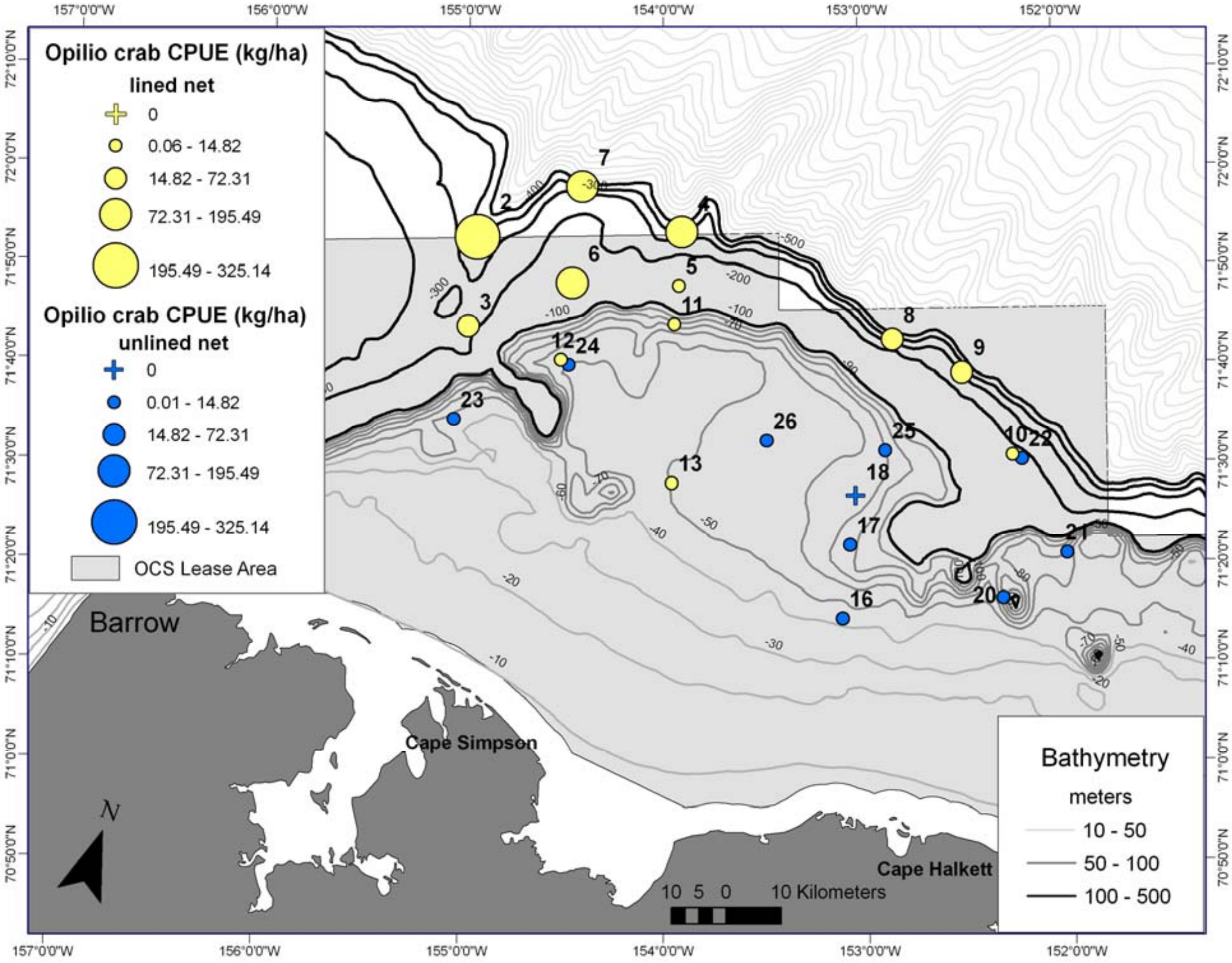


Figure 20. Distribution of *Chionoecetes opilio* (opilio crab) CPUE (kg/ha) from the Beaufort Sea survey, 2008, bottom trawls. The Outer Continental Shelf (OCS) Lease Area is shown in gray shading.

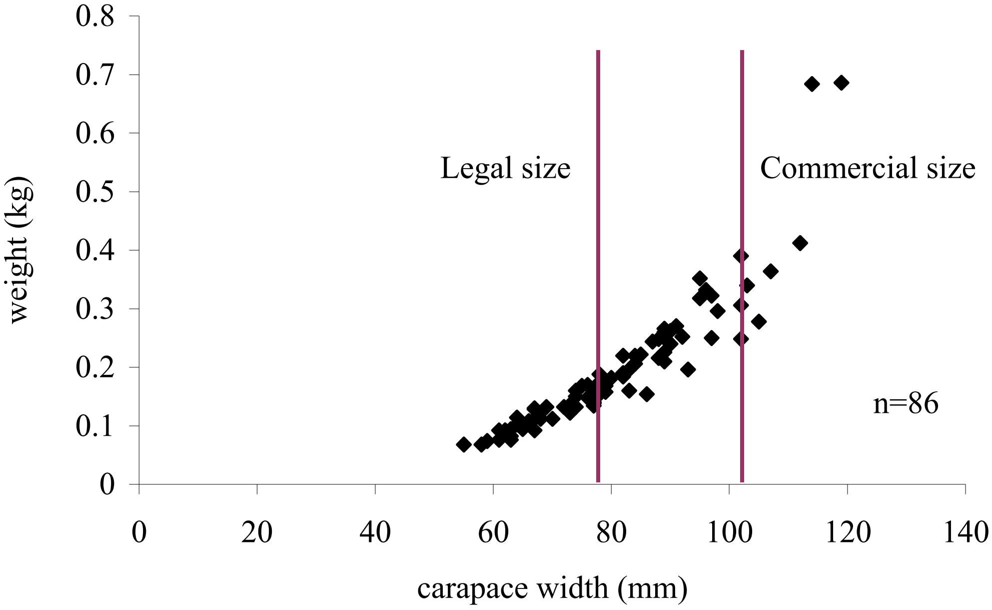


Figure 21. *Chionoecetes opilio* (opilio crab) weight (kg) vs. carapace width (mm). Legal crab size is 78 mm (red line) and commercial size starts at 101 mm (red line). This figure includes males and females. Female width ranged from 58-78 mm and male carapace width ranged from 55-119 mm.

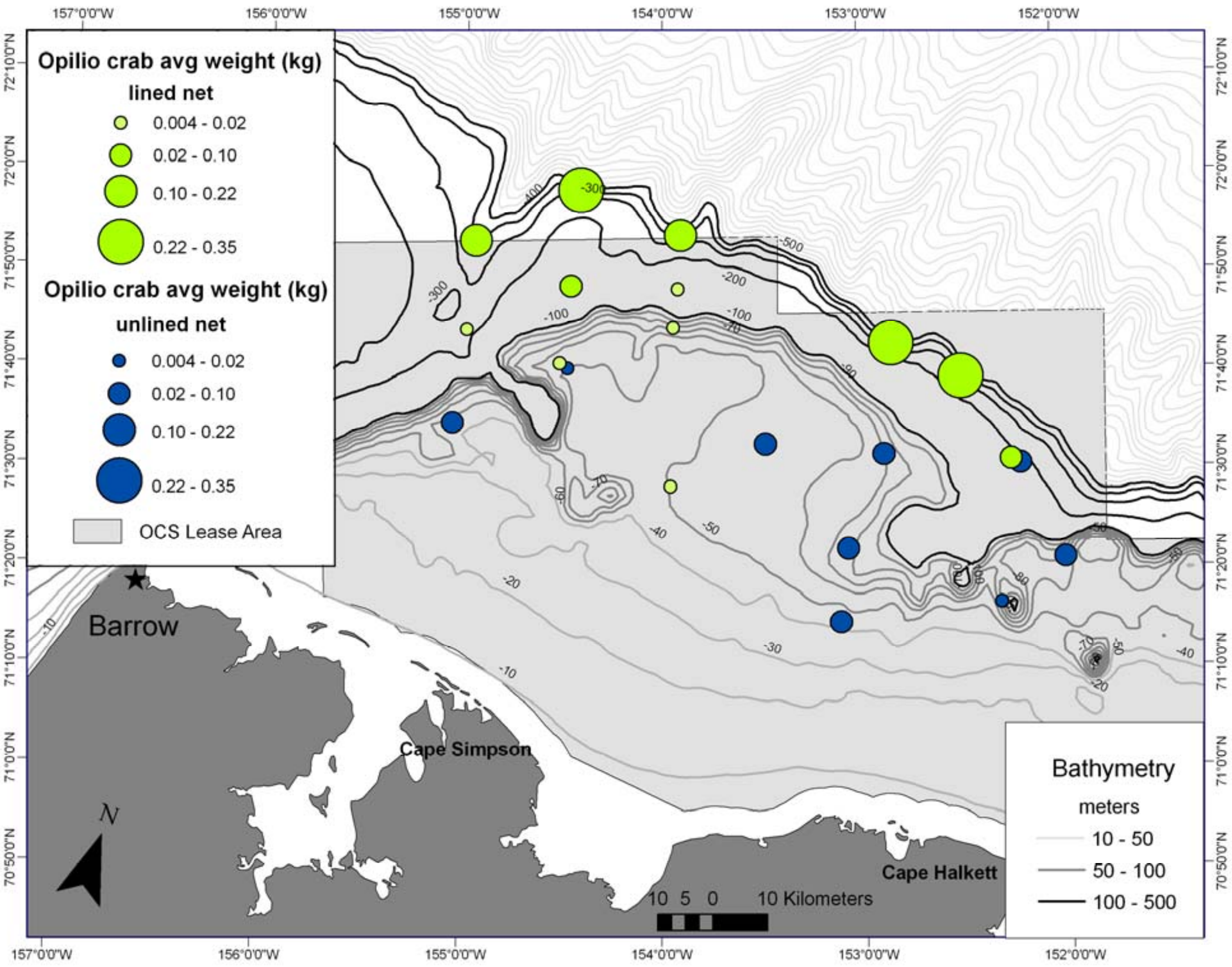


Figure 22. Distribution map of *Chionoecetes opilio* (opilio crab) average individual weight from the Beaufort Sea survey, 2008, bottom trawls. The Outer Continental Shelf (OCS) Lease Area is shown in gray shading.

Pelagic fish data analysis

Pelagic fish midwater trawls

Twenty-eight midwater trawls were completed during the acoustic survey (Figure 1 and Table 19). Depth terminology used in the pelagic fish data analysis is analogous to the bottom depth terminology used in the demersal trawl data analysis section. Of the twenty-eight trawls, seven were completed in the 20-40 m depth (referring to bottom depth), six in the 40-100 m depth (referring to bottom depth), and 15 in the 100-500 m depth (referring to bottom depth). All but two midwater trawl catches weighed <50 kg total. Midwater trawls were used to identify fish species within aggregations observed on echograms, to sample species-specific length frequencies, and to proportion the backscattered energy by species or age group for echo integration. Net catch composition was considered representative of the fish community but not quantitative. Midwater trawls were therefore not used as quantitative estimates of biomass and no measures of CPUE were calculated for midwater trawl catches.

Table 19. Midwater trawl number, latitude and longitude (decimal degrees), and headrope depth (m).

Midwater trawl no.	Latitude (DD)	Longitude (DD)	Bottom depth (m)	Headrope depth (m)
101	71.88	-154.97	263	232
102	71.89	-154.95	316	219
103	71.74	-154.99	193	178
104	71.90	-153.91	191	41
105	71.81	-153.92	190	35-55
106	71.81	-154.46	190	175
107	71.98	-154.41	45	20
108	71.72	-152.84	30	25
109	71.66	-152.49	25	15
110	71.52	-152.25	40	34
111	71.75	-153.94	210-300	180-230
112	71.69	-154.52	24	15
113	71.48	-153.96	56	35-55
114	71.39	-153.99	52	41
115	71.25	-153.13	230-310	198
116	71.25	-153.11	47	40
117	71.37	-153.07	25	17
118	71.46	-153.04	224-442	23
119	71.16	-152.23	200	185
120	71.28	-152.31	35	26
121	71.35	-151.99	62	15
122	71.51	-152.20	225	215
123	71.58	-155.05	400	271
124	71.68	-154.48	385	300
125	71.53	-152.89	25	17
126	71.55	-153.48	20	17
127	71.66	-155.00	100	47
128	71.82	-154.98	330	240-320

Arctic cod dominated midwater trawl catches in all depth strata (Figure 23). Yearling-and-older (year-plus) Arctic cod catches contained <1% “other” fish species which were identified snailfish, unidentified poacher, and capelin (*Mallotus villosus*). Arctic cod young-of-the-year (YOY) dominated midwater trawl catches in the 20-40 m depth, were a large (>20%) component of the catch within the 40-100 m depth, and were present (12%) in the single near-surface tow within the 100-500 m depth. Unidentified sculpin (Family Cottidae) constituted <20% of the catch in the 20-40 m depth, 10-70% of the catch in the 40-100 m depth, and dominated (77%) the single near-surface tow in the 100-500 m depth. Eelblenny (*Lumpenus* sp.) were <5% of the catch in all trawl catches except a single trawl within the 20-40 m depth and the single near-surface tow in the 100-500 m depth.

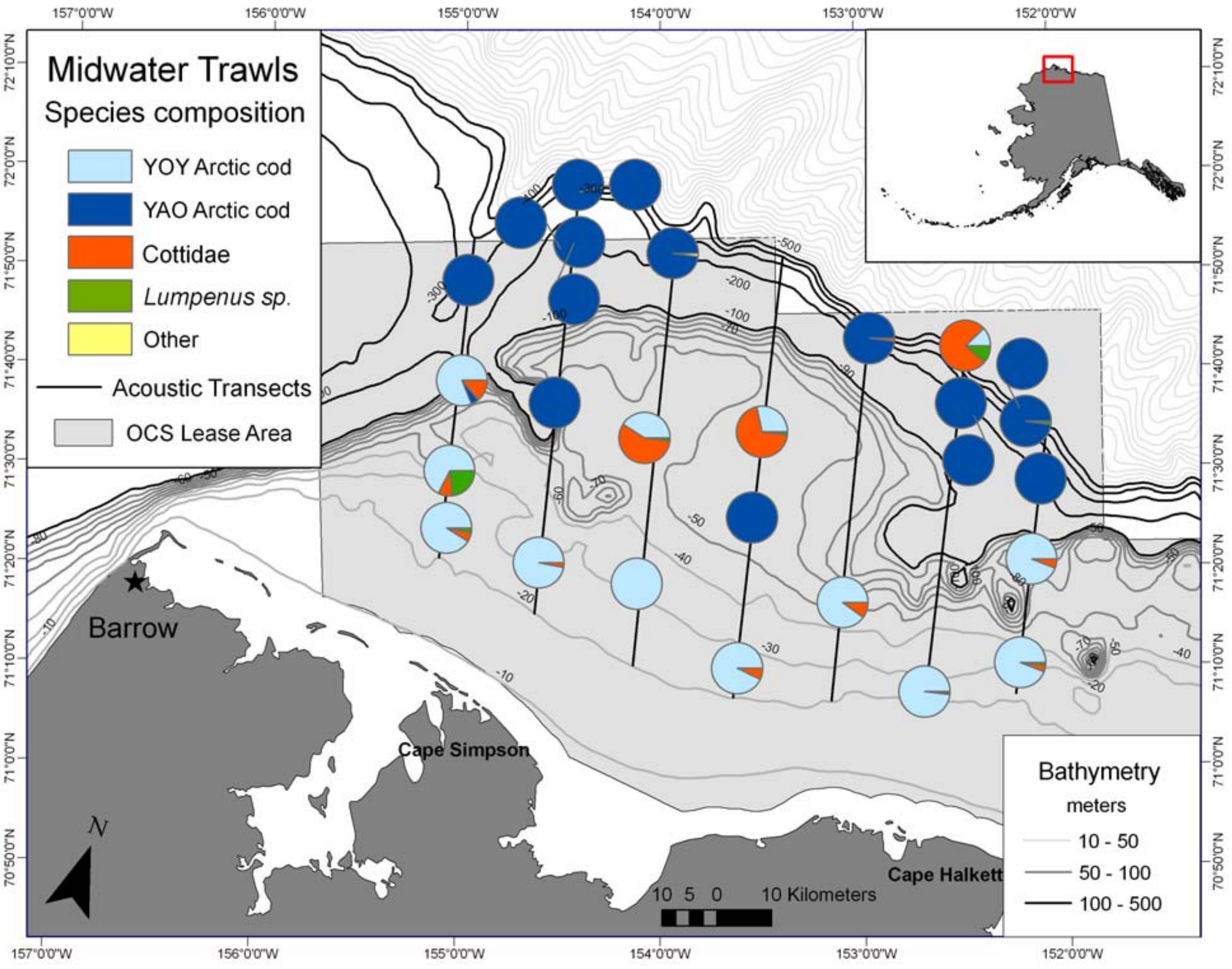


Figure 23. Midwater trawl location and catch composition for young-of-the-year (YOY) Arctic cod, yearling-and-older (YAO) Arctic cod, YOY Cottidae (sculpin family), YOY *Lumpenus* sp. (unidentified eelblenny), and other species. The Outer Continental Shelf (OCS) Lease Area is shown in gray shading.

Fork lengths of the three most abundant YOY species (Arctic cod, Cottidae, and *Lumpenus* sp.) ranged from 25 mm to 60 mm (n=671) with a weighted mean length of 39.7 mm. Of these, Arctic cod lengths ranged from 30-60 mm (n=316, Figure 24), Cottidae from 25-50 mm (n=286, Figure 25), and *Lumpenus* sp. from 30-60 mm (n=69, Figure 26). When YOY Arctic cod length samples were stratified by depth, mean lengths were 42.2 mm in the 20-40 m depth, 42.8 mm in the 40-100 m depth, and 42.3 mm in the 100-500 m depth. As the fork length-to-weight relationship for Arctic cod (developed in this study) did not include data from YOY fish, we calculated a mean weight of 0.37 g for YOY using midwater trawl subsamples.

Yearling-and-older Arctic cod fork lengths from midwater trawl catches ranged from 65 to 190 mm (n=1474, Figure 24). The overall weighted mean length for year-plus Arctic cod was 104.3 mm. Fish caught within the 40-100 m depth were larger (116.2 mm weighted mean fork length) compared to the 100-500 m depth (102.5 mm weighted mean fork length). Using the fork length to weight relationship, the mean weight for year-plus Arctic cod in the 40-100 m depth was 10.35 g and 7.27 g in the 100-500 m depth.

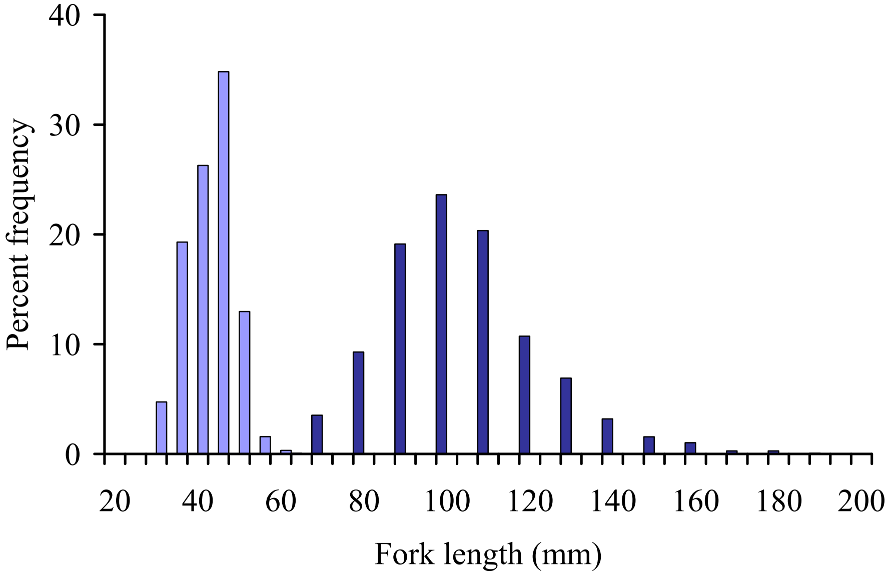


Figure 24. Young-of-the-year (YOY) Arctic cod length frequencies collected in midwater trawls (n=316), measured to a 1 mm resolution (light blue bars). Yearling-and-older (YAO) Arctic cod length frequencies collected in midwater trawls (n=1474). YAO were measured to a 1 cm resolution (dark blue bars).

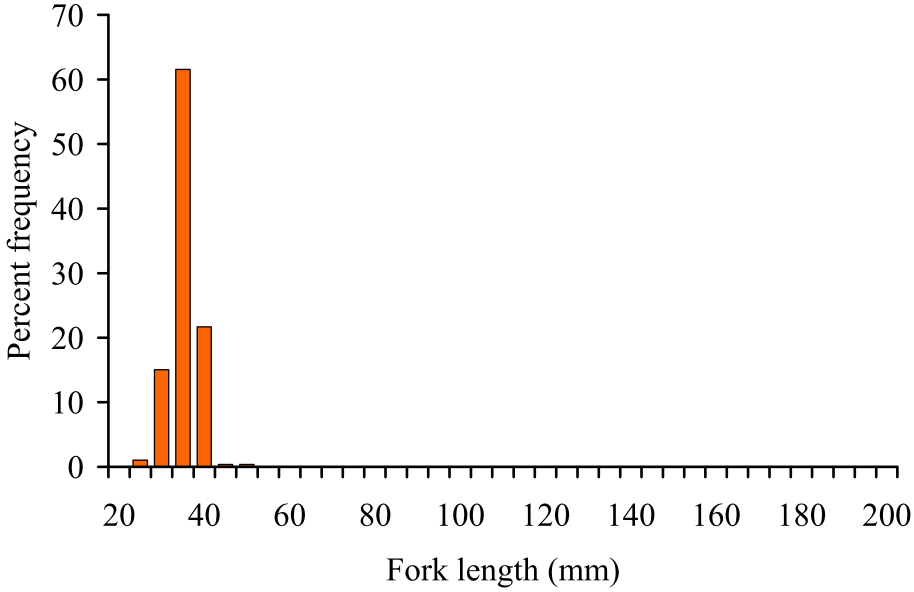


Figure 25. Young-of-the-year (YOY) sculpin (Cottidae) length frequencies collected in midwater trawls (n=286). YOY were measured to a 1 mm resolution.

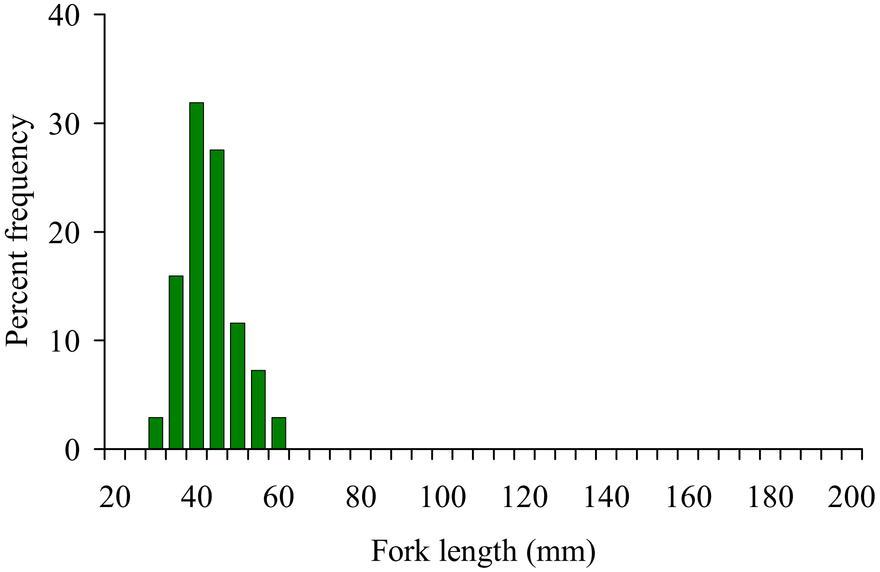
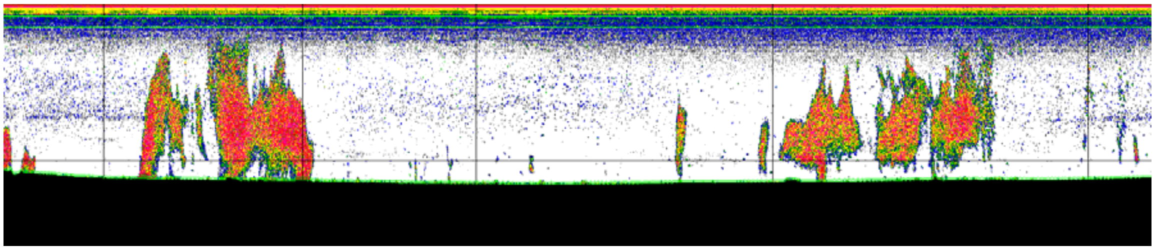


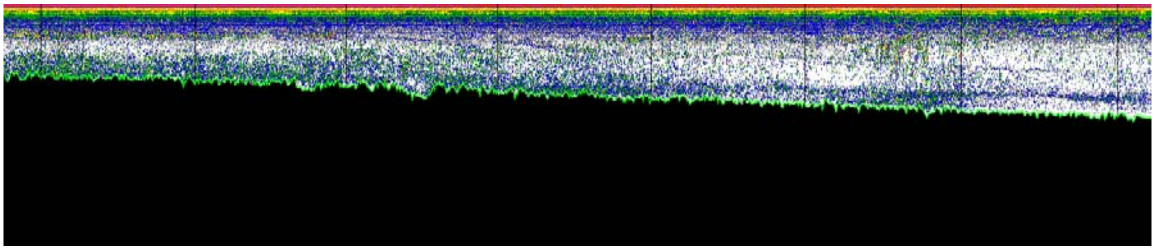
Figure 26. Young-of-the-year (YOY) eelblenny (*Lumpenus* sp.) length frequencies collected in midwater trawls (n=69). YOY were measured to a 1 mm resolution.

Backscatter

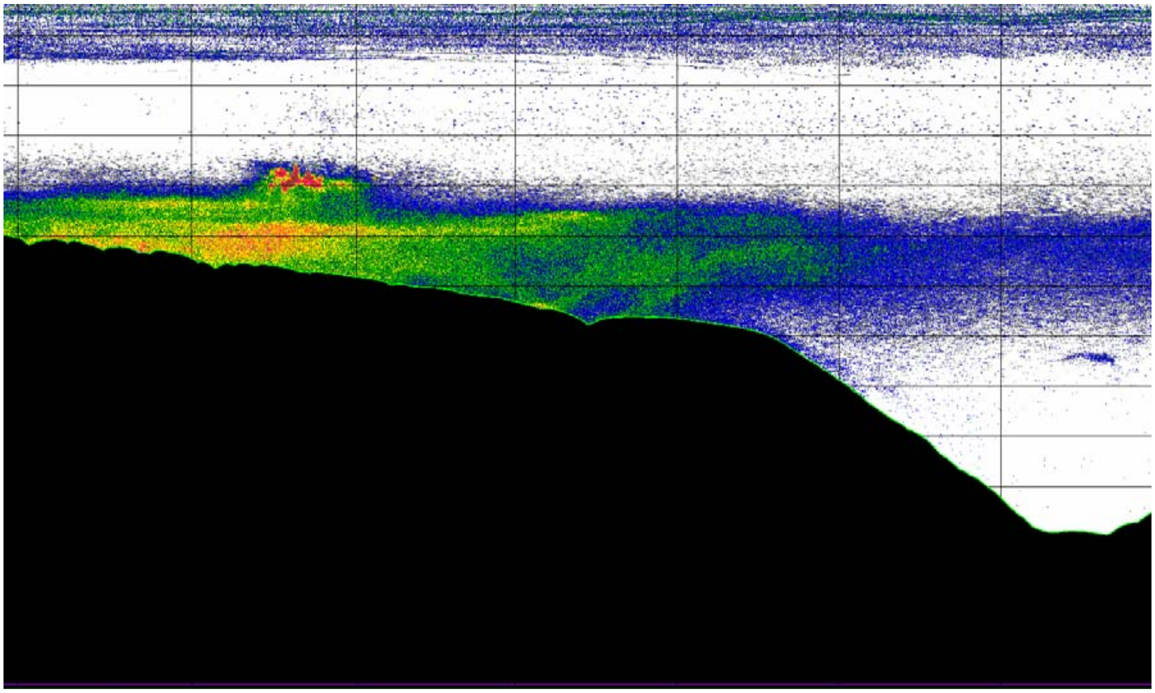
Young-of-the-year (YOY) fish (varying proportions of Arctic cod, Cottidae, and *Lumpenus* sp.) and year-plus Arctic cod were detected throughout the study area. Midwater trawl catches used for target identification confirmed that year-plus Arctic cod were found in large schools in water <75 m deep (Figure 27a) and in bottom-associated layers that extended as a pelagic layer into the midwater in water depths greater than 75 m (Figure 27c). Young-of-the-year (YOY) were observed throughout the water column in water depths <75 m (Figure 27b) and in surface-associated layers in water depths 75 m (Figure 27c).



a) YAO Arctic cod schools in shallow water (60 m)



b) YOY Arctic cod in shallow water (25 m) (likely with small numbers of Cottidae and *Lumpenus* sp.) in shallow water (25 m),



c) YOY Arctic cod in surface water (<75 m), and yearling-and-older Arctic cod extending off bottom into the pelagic zone in water >300 m.

Figures 27a-c. Example acoustic echograms (S_v threshold = -80 dB) for young-of-year. Backscatter is shown as high (red) to low (grey). Vertical lines occur at 1 km intervals and horizontal lines at 50 m intervals. The bottom and below is shown in black and includes 0.5 m “deadzone” that cannot be accurately used in the acoustic analysis.

Target strength

Target strength results suggested that year-plus Arctic cod are often found in dense aggregations (see “Methods” N_v index). . Single target detections for the 100-500 m depth depth suggested that target strength did not change with depth (Figure 28).

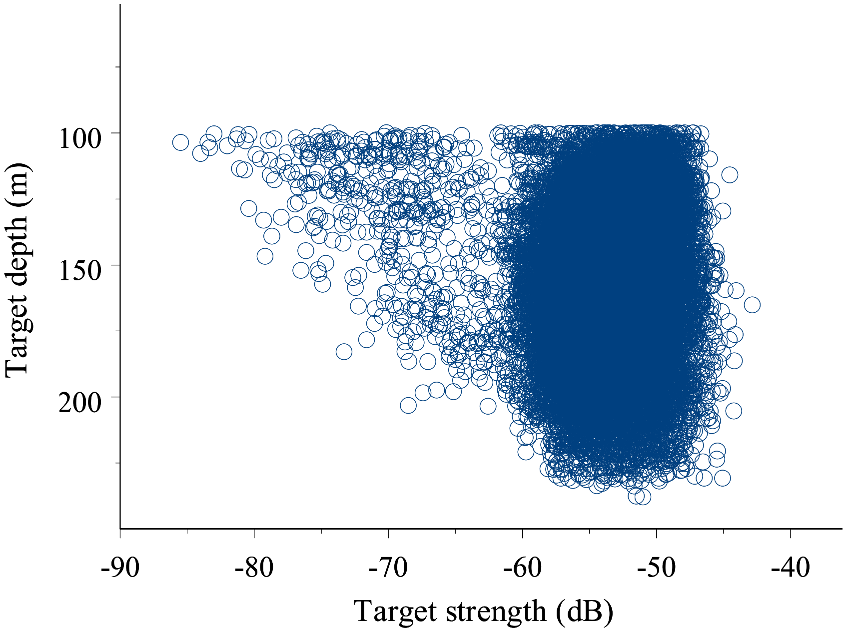


Figure 28. Depth distribution (m) and target strength (dB) of single targets detected between 100 m and the 0.5 m bottom exclusion line for midwater trawl no. 24. Target strength minimum threshold was -90 dB (see Methods).

In the target strength to fork length regression equations, the equation that excluded the two outlying year-plus Arctic cod points and used a flexible intercept (Target Strength=8.03×$\log_{10}$(Length)-60.78) is considered the most appropriate equation for this study (Figure 29). Figure 29 also illustrates how the relationship used in this study compares with other general and Arctic cod-specific target strength to length relationships. It is likely that regression equations in the literature were developed with year-plus -sized individuals only.

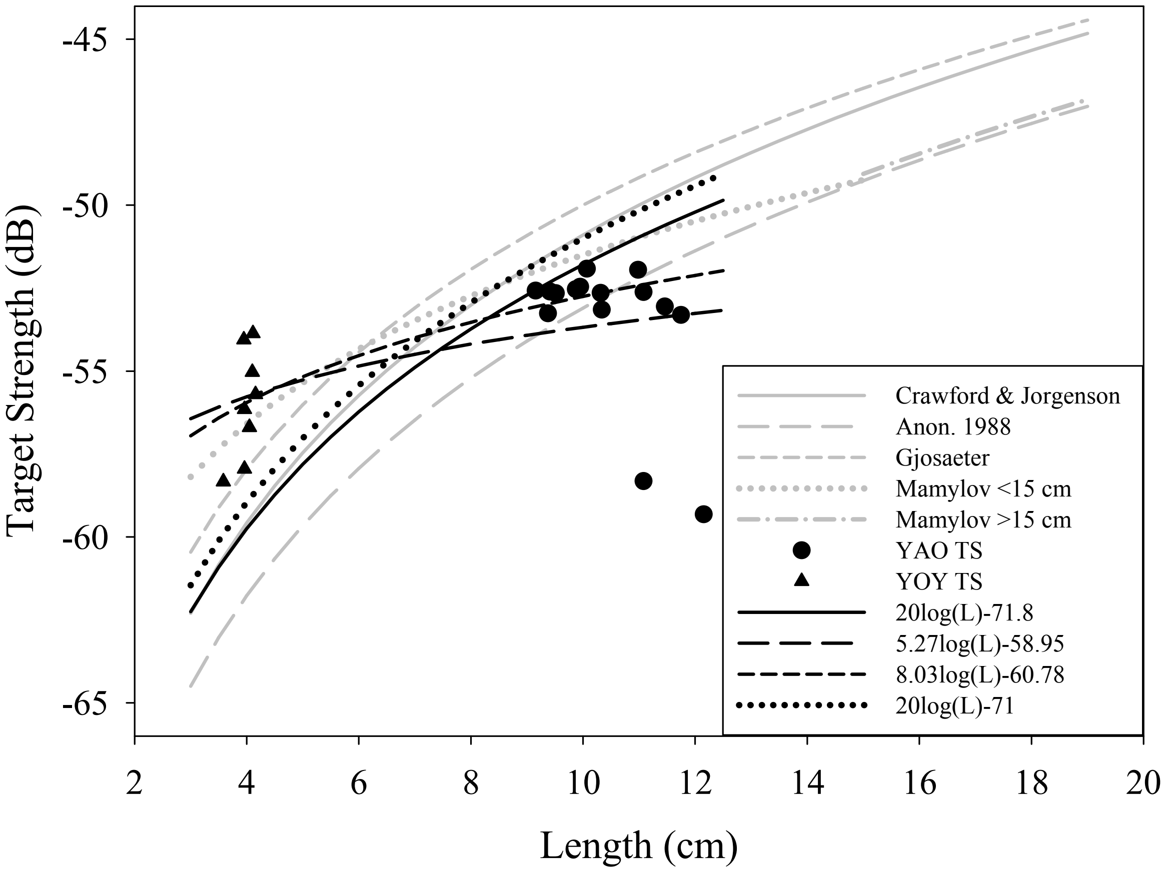


Figure 29. Target strength to length (cm) relationship for Arctic cod. Year-plus target strength (YAO TS) and YOY TS data are from this study. The equations for Crawford and Jorgenson, Anon (1988), and Gjosaeter are presented in Crawford and Jorgenson (1996). The Mamylov (for polar cod) equation is from Mamylov (2003). All points and equations derived from this study are shown in black.

Density distribution, mean density, and abundance

Densities of year-plus Arctic cod and YOY fish varied throughout the study area. Arctic cod year-plus densities ranged from 0 to 155,052 #/ha, with the highest densities found along the continental slope observed during the east-west cross-transects (Figure 30). Using only along-transect data from cluster sampling estimates, year-plus Arctic cod densities ranged from 0 to10,693 #/ha in the 40-100 m depth and 0 to 155,052 #/ha in the 100-500 m depth (Figure 30). No year-plus Arctic cod were estimated in the 20-40 m depth (Figure 30) as they were not visible on the acoustics and trawling confirmed little to no year-plus Arctic cod in this depth depth. Little to no year-plus Arctic cod were detected with either acoustics or trawls in 20-40m depths. Yearling-and-older Arctic cod densities were highest at depths greater than 100 m wi th the highest values in the 150-300 m depth range (Figure 31).

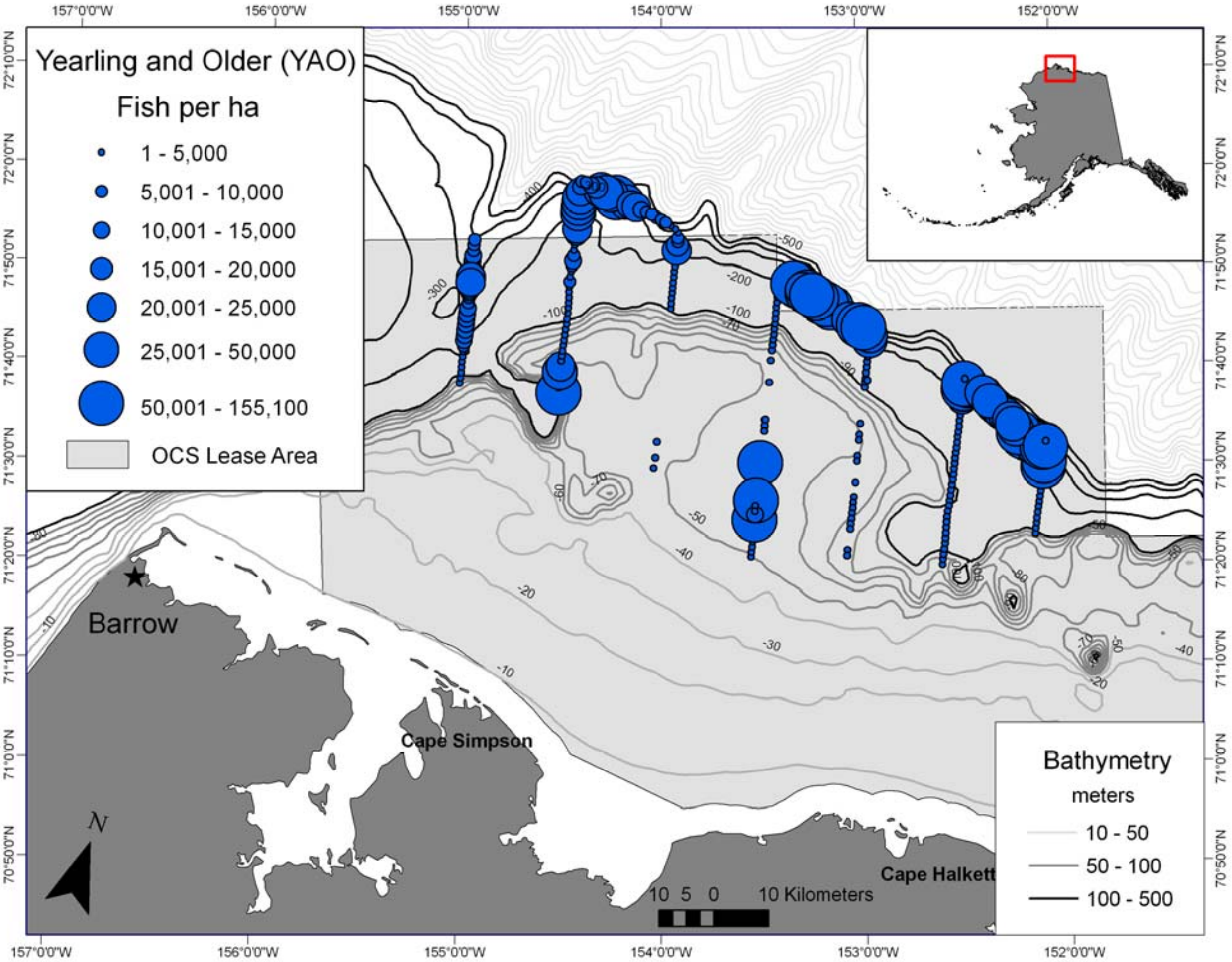


Figure 30. Density distribution of yearling-and-older (YAO) Arctic cod along acoustic transects and cross-transects. Density is shown as #/ha. The Outer Continental Shelf (OCS) Lease Area is shown in gray shading.

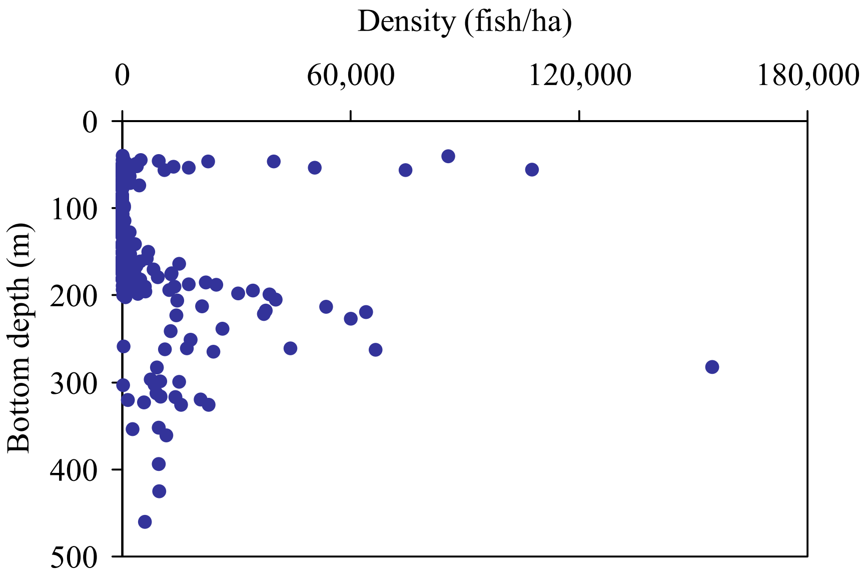


Figure 31. Yearling-and-older (YAO) Arctic cod density (#/ha) versus bottom depth (m) for 1 km analytic bins (n=209 analytic bins with non-zero values) used in cluster sampling and abundance estimates.

Young-of-the-year (YOY) fish densities ranged from 4 to 160,553 #/ha (Figure 32). The highest densities were detected inshore along the east-west cross-transects (Figure 32). Along-transect estimates of YOY densities used in cluster sampling estimates were 119 to 25,170 #/ha in the 20-40 m depth, 38 to 22,086 #/ha in the 40-100 m depth, and 4 to 21,830 in the 100-500 m depth (Figure 32). As mean lengths of Arctic cod YOY were larger than those of Cottidae or *Lumpenus* sp., expected mean target strengths of Arctic cod would also be larger, and therefore resulting density estimates of YOY using the YOY Arctic cod mean target strength are conservative estimates of Cottidae or *Lumpenus* sp. densities. Densities of YOY fish were highest in water depths <100 m, but some high density values were observed in surface layers in regions with bottom depths greater than 150 m (Figure 33).

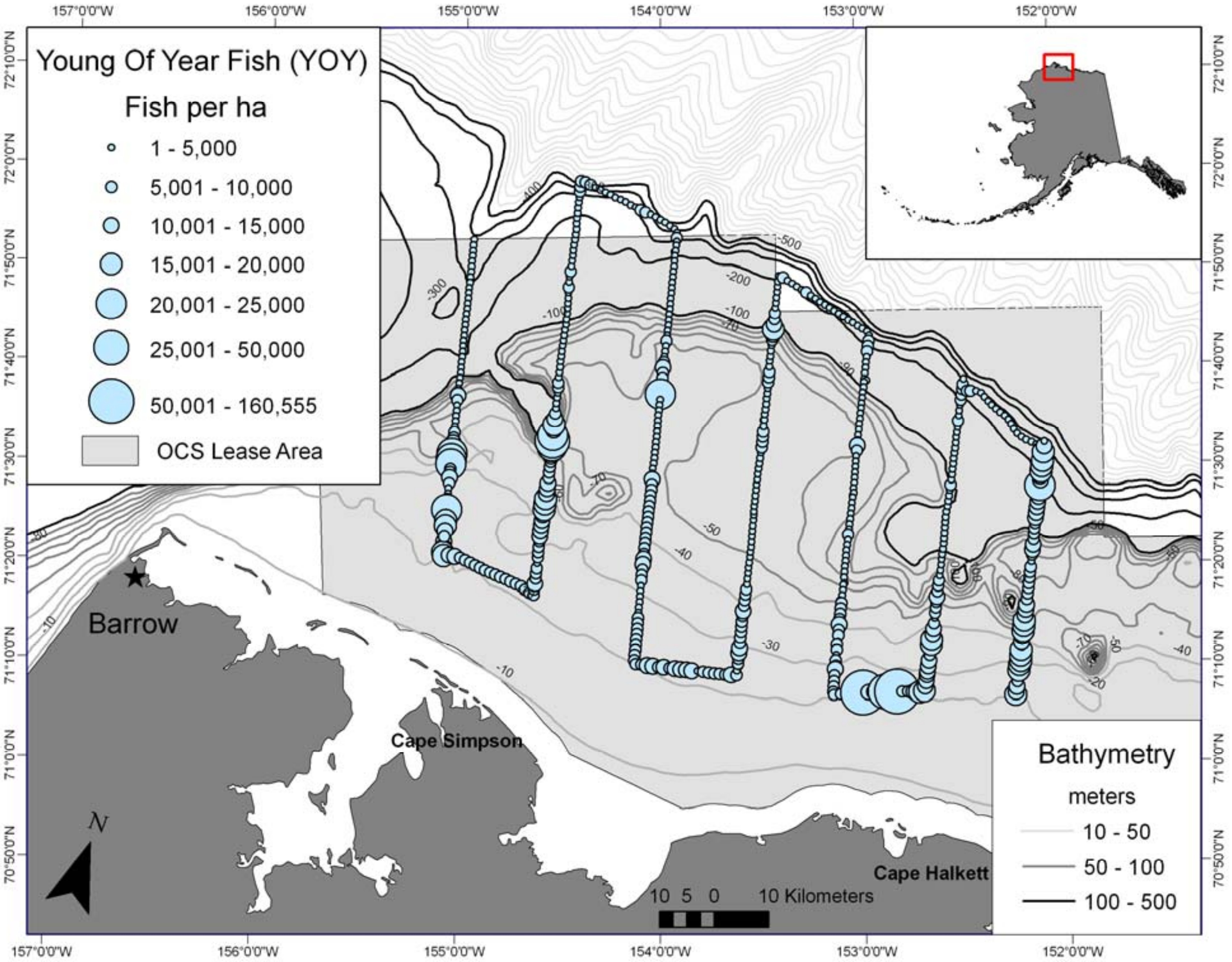


Figure 32. Density distribution of young-of-the-year (YOY) fish (assumed to be dominated by Arctic cod) along acoustic transects and cross-transects. Density is shown as #/ha. The Outer Continental Shelf (OCS) Lease Area is shown in gray shading.

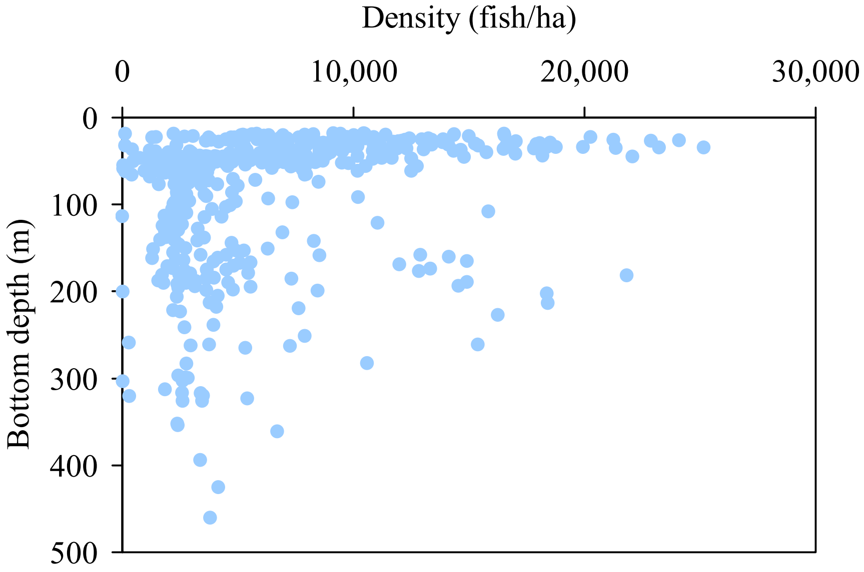


Figure 33. Young-of-the-year (YOY) fish density (#/ha), versus bottom depth (m) for for 1 km analytic bins (n=489 analytic bins with non-zero values) used in cluster sampling and abundance estimates.

Cluster sampling estimates of mean fish densities suggest that year-plus Arctic cod and YOY fish (assumed to be dominated by Arctic cod) had different distributions in the study area. The highest mean density (Table 20, 9580 ± 926 #/ha, mean ± 1 SD) for YOY fish was found within the 20-40 m depth depth. Mean YOY fish densities were similar between the 40-100 m depth (4342 ± 649 #/ha) and the 100-500 m depth (4706 ± 1296 #/ha), with the higher standard deviation in the 100-500 m depth attributed to patchiness in the near-surface distribution (Table 20). Yearling-and-older (year-plus) Arctic cod had the highest mean density (9387 ± 1768 #/ha) in the 100-500 m depth, with a lower and more variable density (2354 ± 1436 #/ha) within the 40-100 m depth depth (Table 20). The higher standard deviation can be explained by the fact that year-plus Arctic cod within the 40-100 m depth were generally found within patchily-distributed schools (Figures 27a-c) and therefore many zero (i.e. no year-plus fish detected) values were included in estimates of mean density for the 40-100 m depth. No estimate of year-plus Arctic cod was made for the 20-40 m depth as no year-plus were observed on the acoustic echograms. Midwater trawling confirmed that year-plus Arctic cod were present in low numbers in the 20-40 m depth depth. Six large year-plus Arctic cod schools were observed in the 40-100 m depth depth (Figure 32) during the systematic acoustic survey, but we can only speculate that this region is important for feeding and/or has desirable physical characteristics. Our survey and sampling effort was not sufficient to allow the fine-scale sampling needed to evaluate why year-plus Arctic cod were schooled in the 40-100 m depth.

Table 20. Cluster sampling (Scheaffer et al. 1996) results for acoustic estimates of young-of-the-year (YOY) fish and yearling-and-older (year-plus) Arctic cod in thre depth strata (20-40, 40-100, and 100-500 m). # Clusters is the number of clusters (i.e. transects) used in the analysis and Range elements is the range of elements (i.e. 1 km bins) included in the analysis. Mean density, standard deviation, and CV for each estimate are given. No estimate of year-plus density was made in the 20-40 depth stratum.

Age-class	Bottom Depth (m)	# Clusters	Range elements	Mean density (#/ha)	Standard deviation	CV
YOY	20-40	7	14-38	9580	926	0.10
	40-100	7	12-50	4342	648	0.15
	100-500	7	11-27	4706	1296	0.28
year-plus	20-40	n/a				
	40-100	7	12-50	2354	1436	0.61
	100-500	7	11-27	9387	1768	0.19

Scaling cluster sampling estimates of mean density to the entire survey area provides an abundance (fish within the study area) estimate for year-plus Arctic cod and YOY fish (assumed to be dominated by Arctic cod). Young-of-the-year abundance estimates were high in all strata, with the highest estimate occurring in the 20-40 m depth ($1.967 \times 10^9 \pm 0.190 \times 10^9$, abundance ± 1 SD). The two deeper strata within the study area had similar YOY fish abundance estimates, with an estimated $1.608 \times 10^9 \pm 0.240 \times 10^9$ fish (± 1 SD) present in the 40-100 m depth, and $1.212 \times 10^9 \pm 0.334 \times 10^9$ fish in the 100-500 m depth. These abundance estimates scale to biomass estimates of 734 ± 71 t (20-40 m strata), 600 ± 90 tonnes (40-100 m strata), and 452 ± 125 t (100-500 m strata) using an average YOY fish weight of 0.37 g.

Estimates of year-plus Arctic cod abundance from cluster sampling mean densities also illustrate a strong presence of year-plus Arctic cod in deeper water. Within the 40-100 m bottom depth, year-plus Arctic cod abundance is estimated to be $0.872 \times 10^9 \pm 0.532 \times 10^9$ fish (± 1 SD). This abundance corresponds to a biomass estimate of 9034 ± 5510 t (± 1 SD) using an average year-plus Arctic cod weight of 10.35 g. In the 100-500 m depth, abundance of year-plus Arctic cod is estimated to be $2.418 \times 10^9 \pm 0.455 \times 10^9$ fish (± 1 SD). Converting this number to biomass using an average year-plus Arctic cod weight of 7.26 g resulted in a biomass estimate of 17,559 ± 3308 t (± 1 SD) of year-plus Arctic cod in the 100-500 m depth depth.

Likely due to the low sample size (n=7 systematic acoustic transects) and high variability in the data, there was no statistically significant ($P > 0.10$) differences in mean YOY fish densities among the depth strata (<40, 40-100, 100-500 m).

There was no statistically significant (*P* > 0.10) difference in mean year-plus Arctic cod densities between the depth strata (40-100, 100-500 m). This is likely due to the low sample size (n=7 systematic acoustic transects) and high variability in the data.

Comparing acoustic and bottom trawl surveys

By examining the ratio of bottom trawl to acoustic density estimates for year-plus Arctic cod, we can draw inferences on the "picture" of distribution that the two approaches provide. Inshore of the 100 m depth contour bottom trawl estimates of year-plus Arctic cod were greater than acoustic estimates for 3 out of 4 stations (Figure 34). Deeper than the 100 m contour, only one out of nine bottom trawl estimates was higher than the concurrent acoustic estimate. .

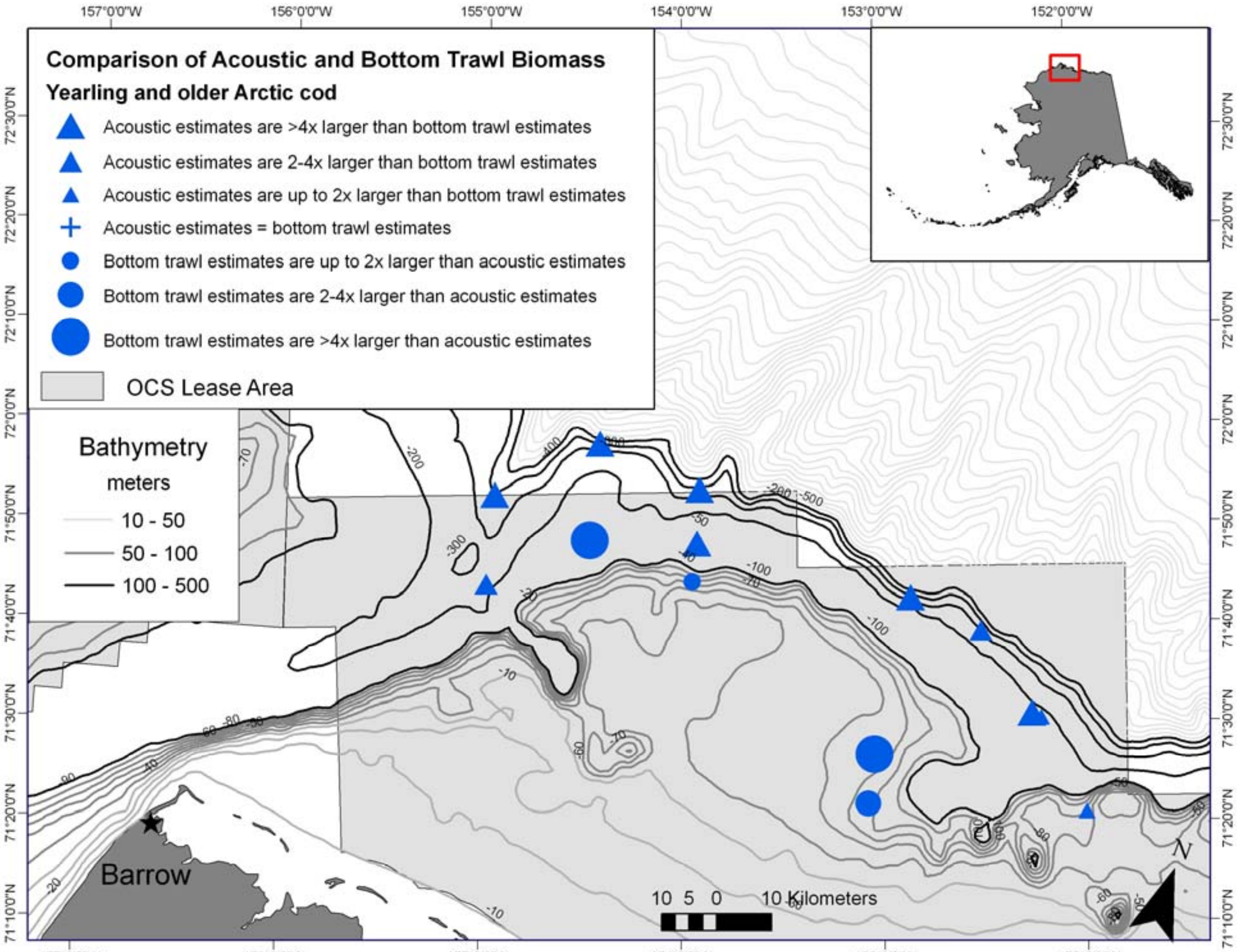


Figure 34. Density ratio for yearling-and-older (year-plus) Arctic cod, calculated as (bottom trawl density / acoustic density) where acoustic density is from 9.0 m from the surface to 0.5 m from the bottom. A value of 1 indicates that bottom trawl = acoustic estimates. The Outer Continental Shelf (OCS) Lease Area is shown in gray shading.

Model results are presented for coincident acoustic density estimates and bottom trawl CPUE with combined lined and unlined trawls (Table 21), coincident data using lined bottom trawls only (Table 22), and noncoincident data using lined bottom trawls only (Table 23).

When a predictor was found to be significant, the relationship between the acoustic response variable (A) and significant variables (i.e. logBT, dep, net, and interactions) are listed in the "Relationship" column (i.e. A = b0 + b1*logBT), and categorical variable conditions are listed in parentheses (Tables 21-23). When bottom trawl CPUE (BT) and depth (dep) or the interaction term (logBT:dep) were significant, the relationship was tested for bottom trawls in water depths both below (below) and within (layer). When depth (dep) was a significant predictor but bottom trawl CPUE (BT) was not, the model estimate of the mean ± 1 standard error is given (Tables 21-23).

In the comparison between coincident acoustic data and combined lined and unlined bottom trawl data, several patterns emerge (Table 21). Depth (dep), the categorical predictor of whether the year-plus Arctic cod aggregations were in contact with the bottom at the site, was a significant predictor of acoustic density for all comparisons (Table 21). Within models that used the acoustic density only within overlap regions (indices 3-5), depth was the only significant predictor of year-plus Arctic cod density ($P = 0.03$, Table 21). In the overlap regions (variable 3-5), there was no relationship between bottom trawl CPUE and acoustic densities (Table 21). In the four water column models (variable 1, 2, 6, 7), bottom trawl CPUE (logBT), depth (dep), and the interactions between bottom trawl CPUE and depth (logBT:dep) were significant in all models and the overall models were also significant ($P = 0.03$-0.05, Table 21). Figure 35 is shown as an example of this relationship – within year-plus Arctic cod aggregation layer, there is a positive relationship between acoustic density and bottom trawl catch but below the layer there is a negative (or no) relationship between the acoustics and bottom trawl (Table 21).

Table 21. Model results for coincident acoustic and bottom trawl (lined and unlined nets) data. A=acoustics, BT=bottom trawl, net=lined or unlined categorical predictor, dep=depth categorical predictor (below or within the layer), and ":" denotes an interaction term. **Acoustic density response variable** and numbers in parentheses ( ) refer to the list of acoustic predictors found in the text, ^{a} denotes a fourth root transformation of the response variable, ***n*** is the number of data points, **Predictor** is the list of predictors in the model with the lowest AIC value (* denotes a significant predictor), **F** is the F statistic for the model, **df** are the number of degrees of freedom for the F distribution (# parameters, remaining degrees of freedom for test), ***P*** is the p-value for the model fit, ${}_{Adj.}\boldsymbol{R}^2$ is the fit to the model accounting for the number of predictors in the model, and **Relationship** is the model output. e# is an abbreviation for •10$^{\#}$.

Acoustic density response variable	*n*	Predictor	F	df	*P*	${}_{Adj.}R^2$	Relationship i.e. A = b0 + b1*logBT
A survey depth (**1**) *9.0 m from surface to 0.5 m from bottom*	14	logBT* dep* net logBT:dep*	3.803	4,9	0.04	0.46	10e4 - 14e3•logBT (below) 10e2 + 600.5•logBT (layer)
A above BT (**2**) *9 m from surface to 2.0 m from bottom*	14	logBT* dep* net logBT:dep*	4.395	4,9	0.03	0.51	10e4 - 14e3•logBT (below) -2900 + 630•logBT (layer)
A & BT overlap region (**3**) ^{a} *2.0 m from bottom to 0.5 m from bottom*	13	logBT dep* net	4.306	3,10	0.03	0.43	1.7 ± 0.8 (layer)
A & BT overlap region A corrected (**4**) ^{a} *2.0 m from bottom to bottom*	14	logBT dep* net	4.305	3,10	0.03	0.43	1.9 ± 0.8 (layer)
A & BT overlap region A corrected (**5**) ^{a} *2.0 m from bottom to bottom*	14	logBT dep* net	4.305	3,10	0.03	0.43	1.8 ± 0.8 (layer)
A to bottom corrected (**6**) *9.0 m from surface to bottom*	14	logBT dep* net logBT:dep*	3.639	4,9	0.05	0.45	10e4 ± 41e3 (below) 1037.0 + 636.7•logBT (layer)
A to bottom corrected (**7**) *9.0 m from surface to bottom*	14	logBT* dep* net logBT:dep*	3.692	4,9	0.05	0.45	10e4 - 14e3•logBT (below) 991.7 + 655.5•logBT (layer)

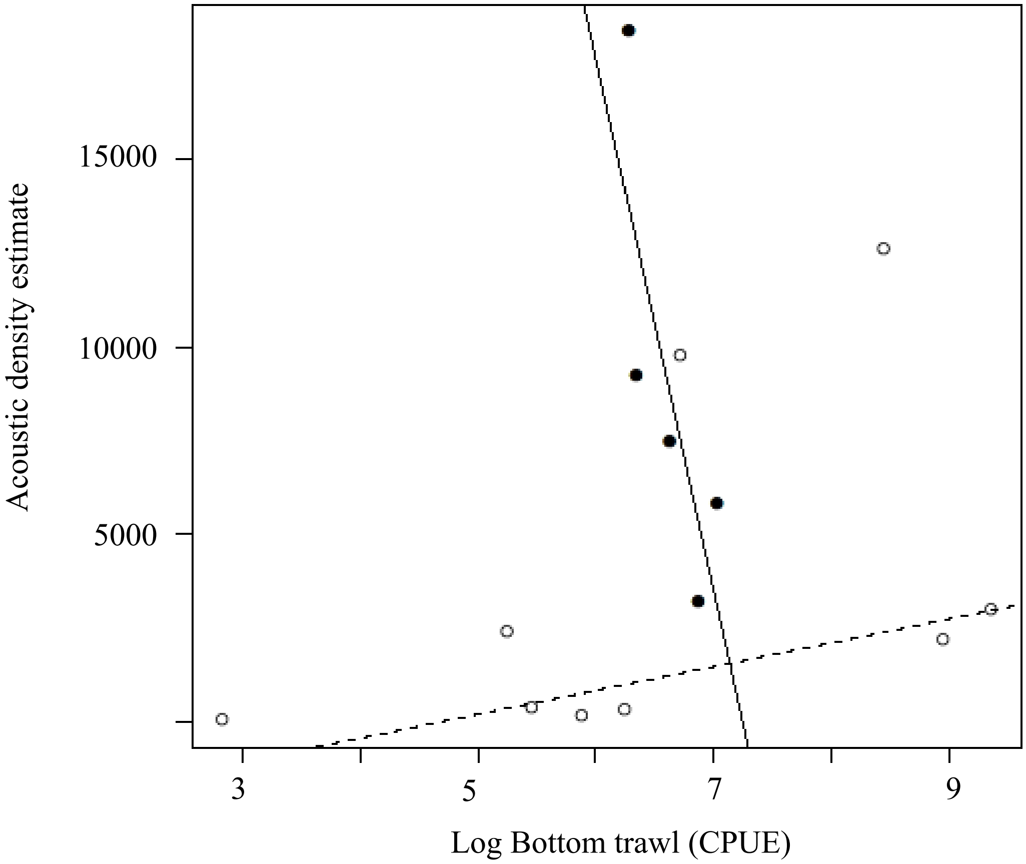


Figure 35. Model results for coincident data comparing acoustic density estimates for YAO Arctic cod (9.0 m from the surface to 0.5 m from the bottom) to bottom trawl density estimates below (solid circles, solid line) and within (hollow circles, broken line) the YAO Arctic cod layer.

Depth was a strong predictor ($P < 0.01$) of acoustic density within the overlap region for acoustic data and lined bottom trawl only data (variables 3-5, Table 22), as was found in the previous comparison (using combined lined and unlined bottom trawl data). For the water column models (variables 1, 2, 6, 7), depth and the interaction between bottom trawl CPUE and depth (logBT:dep) were significant predictors in variables 1, 6, and 7 but variable 2 had no significant predictors (Table 22). No water column model results were significant (P = 0.10-0.18).

Finally, Table 23 presents model results for the noncoincident acoustic data using only lined bottom trawl data. Within overlap regions (variables 3-5), there were no significant predictors (P = 0.35-0.45, Table 23) of acoustic density. In the water column models (variables 1, 2, 6, 7), depth (dep) was the only significant predictor but overall water column model results were not significant (P = 0.6-0.10).

Acoustic and bottom trawl potential bias with depth – For the acoustic variables of year-plus Arctic cod density, only water column predictors (1, 2, 6, 7) were significantly positively related to depth (P = 0.01-0.02, Table 24). An example of this relationship is shown in Figure 36 for acoustic index #1 which shows that Arctic cod acoustic density is positively related to bottom depth. General additive models for bottom trawl densities were run using all data (lined and unlined combined), lined only, and unlined only. No significant relationships were found between bottom trawl densities and depth (Table 24). Figure 37 presents the bottom trawl results, showing lined and unlined nets, with the model fit for the combined dataset.

Table 22. Model results for coincident acoustic and bottom trawl (lined nets only) data. A=acoustics, BT=bottom trawl, dep=depth categorical predictor (below or within the layer), and ":" denotes an interaction term. **Acoustic density response variable** and numbers in parentheses ( ) refer to the list of acoustic predictors found in the text, [a] denotes a fourth root transformation of the response variable, ***n*** is the number of data points, **Predictor** is the list of predictors in the model with the lowest AIC value (* denotes a significant predictor), **F** is the F statistic for the model, **df** are the number of degrees of freedom for the F distribution (# parameters, remaining degrees of freedom for test), ***P*** is the p-value for the model fit, $_{Adj.}R^2$ is the fit to the model accounting for the number of predictors in the model, and **Relationship** is the model output. e# is an abbreviation for $\bullet 10^{\#}$.

Acoustic density response variable	*n*	Predictor	F	df	*P*	$_{Adj.}R^2$	Relationship i.e. A = b0 + b1*logBT
A survey depth (1) *9.0 m from surface to 0.5 m from bottom*	9	logBT dep* logBT:dep*	3.661	3,5	0.10	0.50	-18e3 + 35e2•logBT (layer)
A above BT (2) *9 m from surface to 0.5 m from bottom*	10	logBT dep logBT:dep	2.301	3,6	0.18	0.30	
A & BT overlap region (3) [a] *2.0 m from bottom to 0.5 m from bottom*	9	dep*	40.560	1,7	<0.01	0.83	2.7 ± 0.3 (below) 5.7 ± 0.5 (layer)
A & BT overlap region A corrected (4) [a] *2.0 m from bottom to bottom*	9	dep*	40.560	1,7	<0.01	0.83	2.9 ± 0.3 (below) 6.1 ± 0.5 (layer)
A & BT overlap region A corrected (5) [a] *2.0 m from bottom to bottom*	9	dep*	45.810	1,7	<0.01	0.85	2.9 ± 0.3 (below) 6.2 ± 0.5 (layer)
A to bottom corrected (6) *9.0 m from surface to bottom*	9	logBT dep* logBT:dep*	3.512	3,5	0.11	0.49	-18e3 + 36e2•logBT (layer)
A to bottom corrected (7) *9.0 m from surface to bottom*	9	logBT dep* logBT:dep*	3.520	3,5	0.10	0.49	-18e3 + 37e2•logBT (layer)

Table 23. Model results for noncoincident acoustic and bottom trawl (lined nets only) data. A=acoustics, BT=bottom trawl, dep=depth categorical predictor (below or within the layer), and ":" denotes an interaction term. **Acoustic density index** and numbers in parentheses ( ) refer to the list of acoustic predictors found in the text, [a] denotes a fourth root transformation of the response variable, ***n*** is the number of data points, **Predictor** is the list of predictors in the model with the lowest AIC value (* denotes a significant predictor), **F** is the F statistic for the model, **df** are the number of degrees of freedom for the F distribution (# parameters, remaining degrees of freedom for test), ***P*** is the p-value for the model fit, $_{Adj.}R^2$ is the fit to the model accounting for the number of predictors in the model, and **Relationship** is the model output.

Acoustic density response variable	*n*	Predictor	F	df	*P*	$_{Adj.}R^2$	Relationship i.e. A = b0 + b1*logBT
A survey depth (1) [a] *9.0 m from surface to 0.5 m from bottom*	11	logBT dep*	3.18	2,8	0.10	0.30	-5.8 ± 2.1 (layer)
A above BT (2) [a] *9 m from surface to 0.5 m from bottom*	11	logBT dep*	3.966	2,8	0.06	0.37	-6.3 ± 2.0 (layer)
A & BT overlap region (3) [a] *2.0 m from bottom – 0.5 m from bottom*	11	logBT dep logBT:dep	1.283	3,7	0.40	0.08	
A & BT overlap region A corrected (4) [a] *2.0 m from bottom to bottom*	11	logBT dep logBT:dep	0.989	3,7	0.45	0.00	
A & BT overlap region A corrected (5) [a] *2.0 m from bottom to bottom*	11	logBT dep logBT:dep	1.004	3,7	0.45	0.00	
A to bottom corrected (6) [a] *9.0 m from surface to bottom*	11	logBT dep*	3.598	2,8	0.08	0.34	-6.6 ± 2.1 (layer)
A to bottom corrected (7) [a] *9.0 m from surface to bottom*	11	logBT dep*	3.16	2,8	0.10	0.30	-5.8 ± 2.1 (layer)

Table 24. Relationship of acoustic (indices 1-7) and bottom trawl yearling-and-older (YAO) Arctic cod densities and depth for coincident data. A=acoustics, BT=bottom trawl, Depth=depth continuous predictor. **Response variable** and numbers in parentheses ( ) refer to the list of acoustic predictors found in the text except for the bottom trawl data., ***n*** is the number of data points, **F** is the F statistic for the model, ***P*** is the p-value for the model fit (* denotes a significant relationship), $_{Adj.}\boldsymbol{R^2}$ is the fit to the model accounting for the number of predictors in the model, and **Relationship** is the model that was used.

Response variable	*n*	Predictor	F	*P*	$_{Adj.}R^2$		Relationship
A survey depth (1)	14	Depth	5.598	0.02*	0.46	positive	GAM
9.0 m from surface to 0.5 m from bottom							
A above BT (2)	14	Depth	6.311	0.01*	0.49	positive	GAM
9 m from surface to 0.5 m from bottom							
A & BT overlap region (3)	14	Depth	3.127	0.07	0.40		GAM
2.0 m from bottom to 0.5 m from bottom							
A & BT overlap region A corrected (4)	14	Depth	3.127	0.07	0.40		GAM
2.0 m from bottom to bottom							
A & BT overlap region A corrected (5)	14	Depth	3.314	0.06	0.42		GAM
2.0 m from bottom to bottom							
A to bottom corrected (6)	14	Depth	5.391	0.02*	0.46	positive	GAM
9.0 m from surface to bottom							
A to bottom corrected (7)	14	Depth	5.389	0.02*	0.46	positive	GAM
9.0 m from surface to bottom							
Bottom trawl density (2.0 m to bottom)	22	Depth	0.887	0.56	0.15	flat	GAM, quasipoisson
Combined lined and unlined nets							
Bottom trawl density (2.0 m to bottom)	10	Depth	3.783	0.07		flat	GAM
Unlined nets only							
Bottom trawl density (2.0 m to bottom)	12	Depth	1.354	0.32		flat	GAM
Lined nets only							

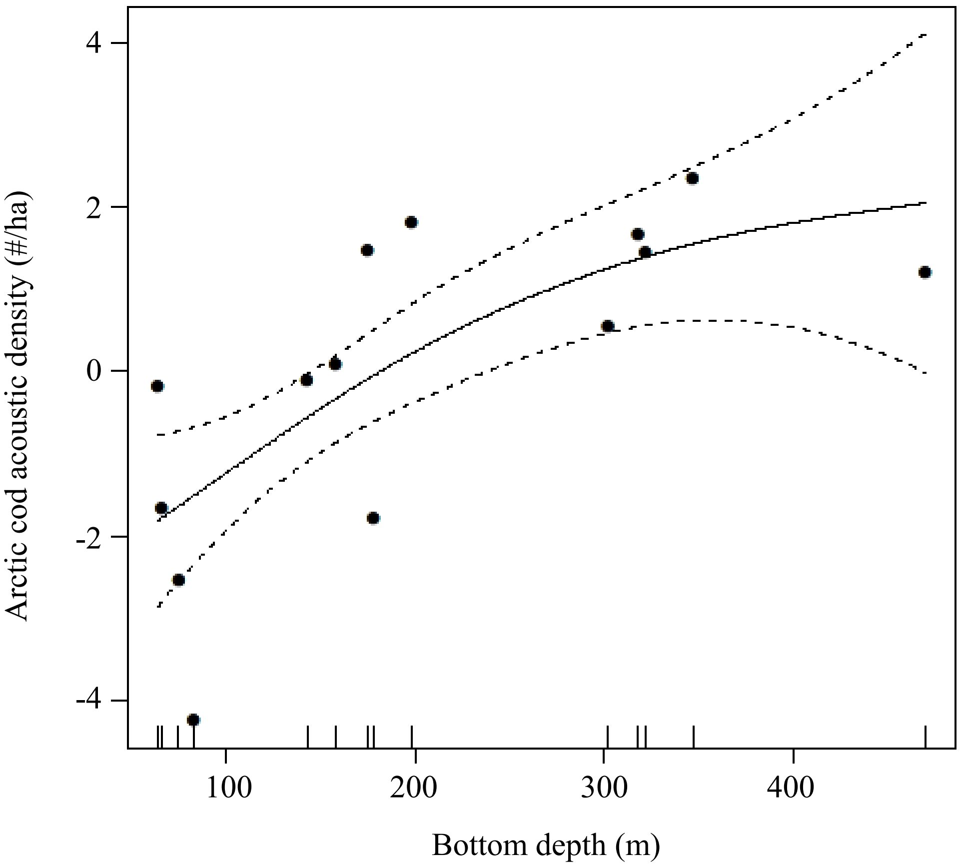


Figure 36. GAM model showing what bottom depth (m) is contributing to the model of yearling-and-older (YAO) Arctic cod density (#/ha, 9.0 m below the surface to 0.5 m above the bottom). Dashed lines indicate the 95% confidence interval.

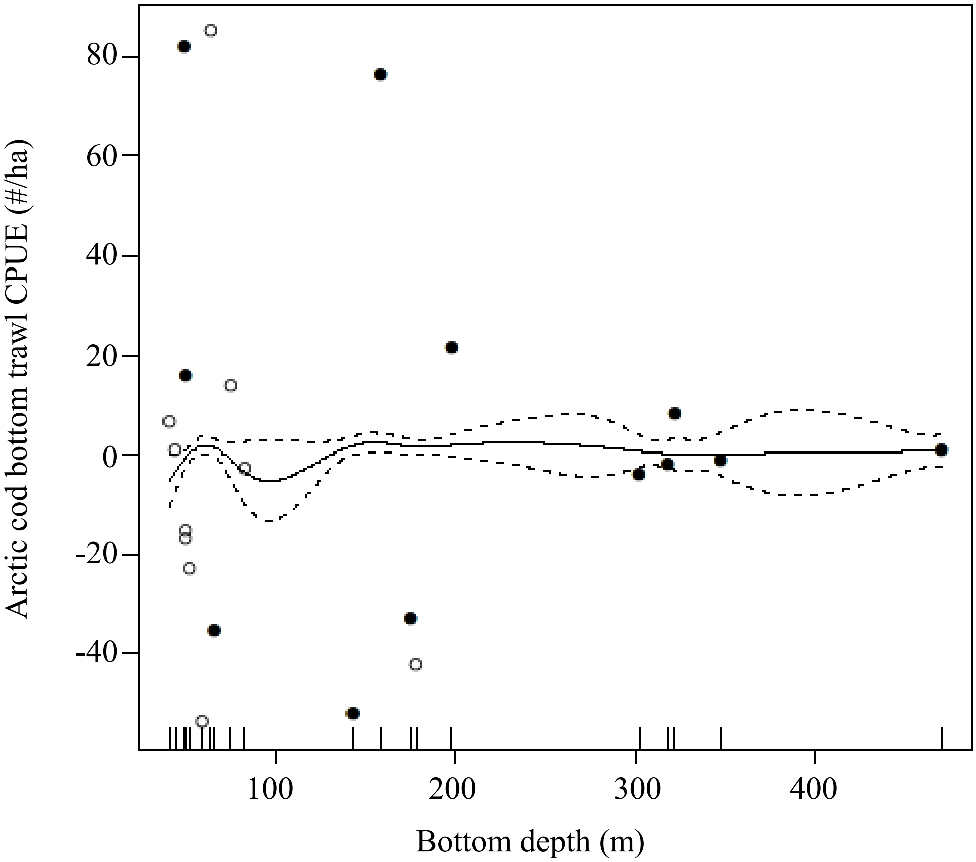


Figure 37. General additive model showing what bottom depth (m) is contributing to the model of yearling-and-older (YAO) Arctic cod density (CPUE, #/ha) from the bottom trawl. Hollow circles are unlined nets, solid circles are lined nets. Dashed lines indicate the 95% confidence interval.

Fish habitat (physical oceanography)

A total of fifty-six CTD casts and thirty-eight bongo tows were successfully completed during the survey (Appendix II, Table II.1).

Winds and sea ice

Figures 38a-c show the regional wind fields obtained from evening passes of the QuikSCAT satellite for the period of August 2-19, 2008. The satellite resolves wind vectors on a 25 km grid. Data contamination, due to the presence of land or sea ice within a grid, is indicated by black in the figures.

Moderate concentrations of sea ice persisted over the Northeast Chukchi Sea and the shelfbreak of the western Beaufort Sea in early August and then gradually melted or receded from the sampling area. By the end of the field season only small patches of ice remained over the Northeast Chukchi shelf.

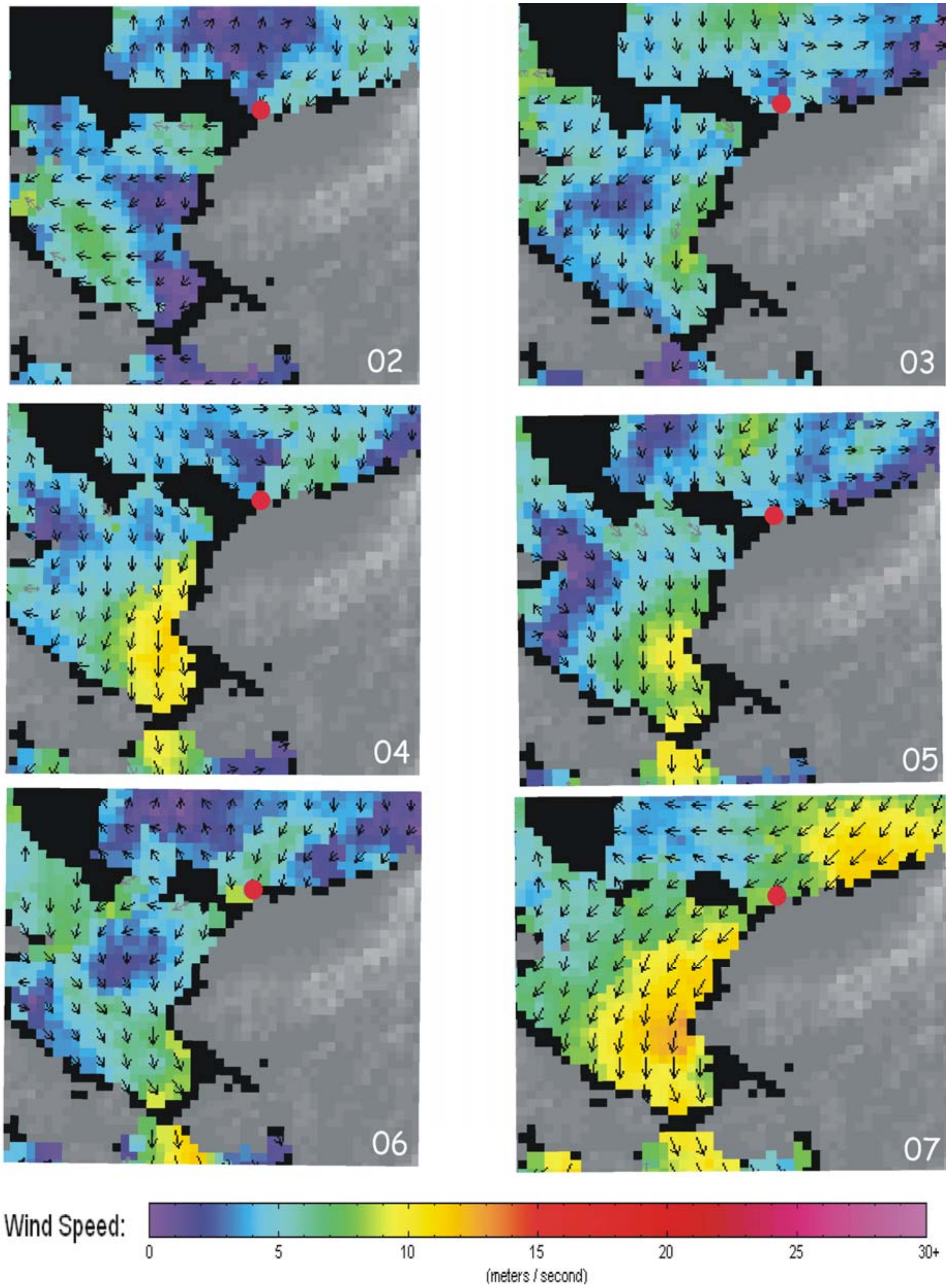


Figure 38a. Beaufort/Chukchi regional wind fields from August 2-7, 2008. The date is given in the lower right corner of each panel. The red dot indicates Pt. Barrow. Black areas indicate sea ice or contaminated data. North is toward the top of each panel.

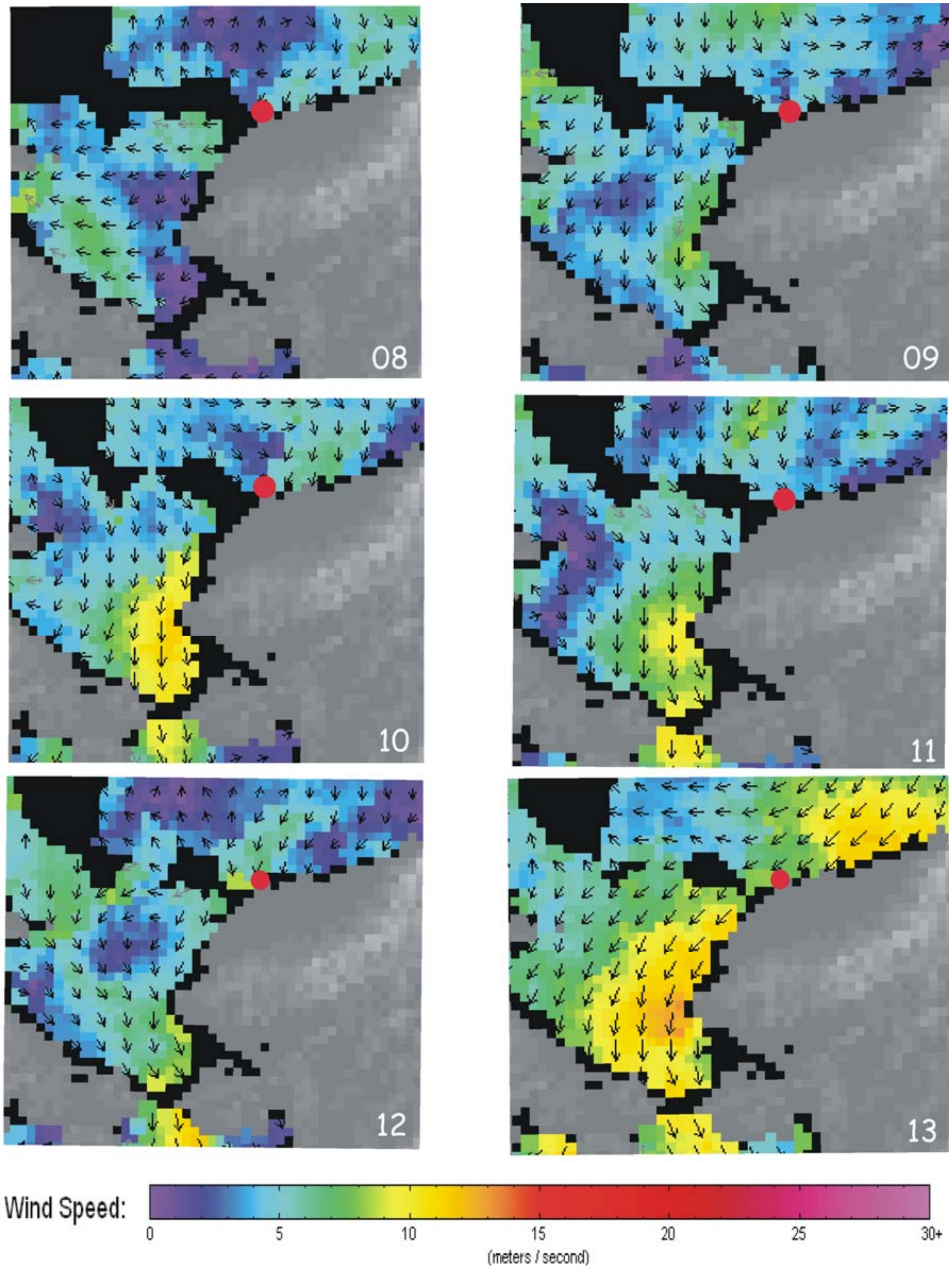


Figure 38b. Beaufort/Chukchi regional wind fields from August 8-13, 2008. The date is given in the lower right corner of each panel. The red dot indicates Pt. Barrow. Black areas indicate sea ice or contaminated data. North is toward the top of each panel.

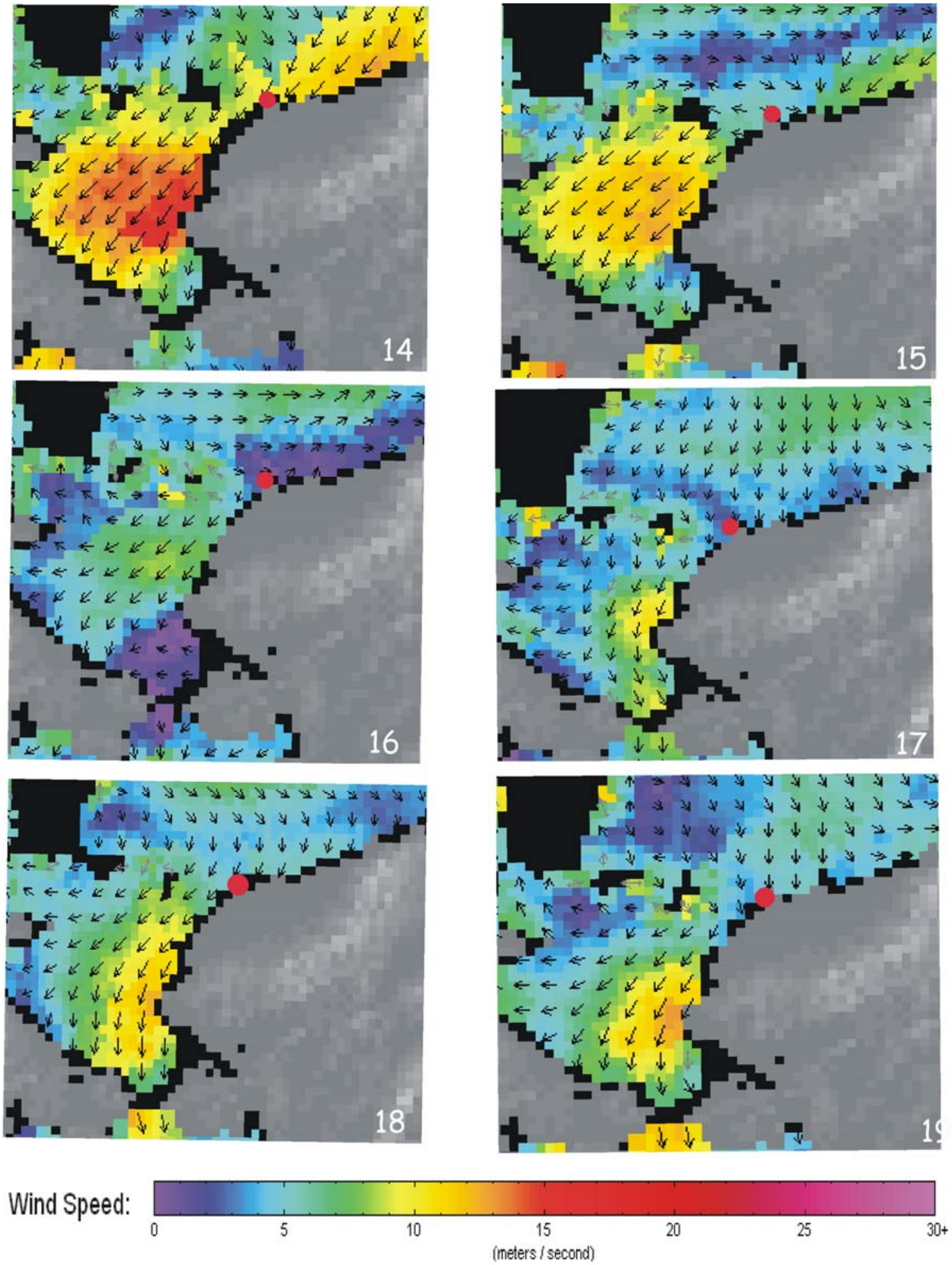


Figure 38c. Beaufort/Chukchi regional wind fields from August 14-19, 2008. The date is given in the upper left hand corner of each panel. The red dot indicates Pt. Barrow. Black areas indicate sea ice or contaminated data. North is toward the top of each panel.

Temperature and salinity

Before presenting the spatial distribution of temperature and salinity along the CTD transects we first describe the various water masses that occur in the region with the aid of Figure 39, which shows

The temperature and salinity characteristics at each one-meter averaged CTD sample from all casts. These data are plotted as a scatter plot in potential temperature-salinity (θ/S) space and color-coded according to depth range (figure 39). Potential temperature is the temperature that a parcel of water would acquire if brought to a standard reference pressure, usually 1000 millibars. Less scatter among points of a similar color indicates less variability in water mass characteristics at that depth. The plot includes isopleths (gray) of sigma-θ (density based on potential temperature) and the freezing point curve.

The temperature and salinity data distribution indicates considerable variability amongst the warmer and fresher water types, while colder and saltier waters show less scatter.

Upper ocean waters are considerably more variable than deeper waters. For example, temperatures and salinities in the upper 15 m of the water column range between 1 and 5^{o}C and 26-30. The sources of low-salinity water in the study area include: ice melt, Alaskan Coastal Water (ACW), and local runoff modified by mixing with ambient shelf waters.
Our analyses cannot unequivocally discriminate easily amongst the three, but ACW and runoff-modified waters are generally warmer (due to solar heating) than ice melt water. However, shallow ice melt lenses can easily warm rapidly under relatively calm and sunny conditions. Below, in discussion we will indicate areas which we believe are likely due to ice melt, based on their distance offshore.

The bulk of the remaining waters (where ice melt waters are not found), between 16 and 80 m depth, have temperatures between 2 and -1^{o}C and salinities between 30 and 32. The colder and saltier fractions are waters formed in winter on the Bering, Chukchi and Beaufort Sea shelves whereas the warmer and fresher water types are likely mixtures consisting of deeper winter water and surface waters (Mountain et al. 1976, Weingartner et al. 2005).

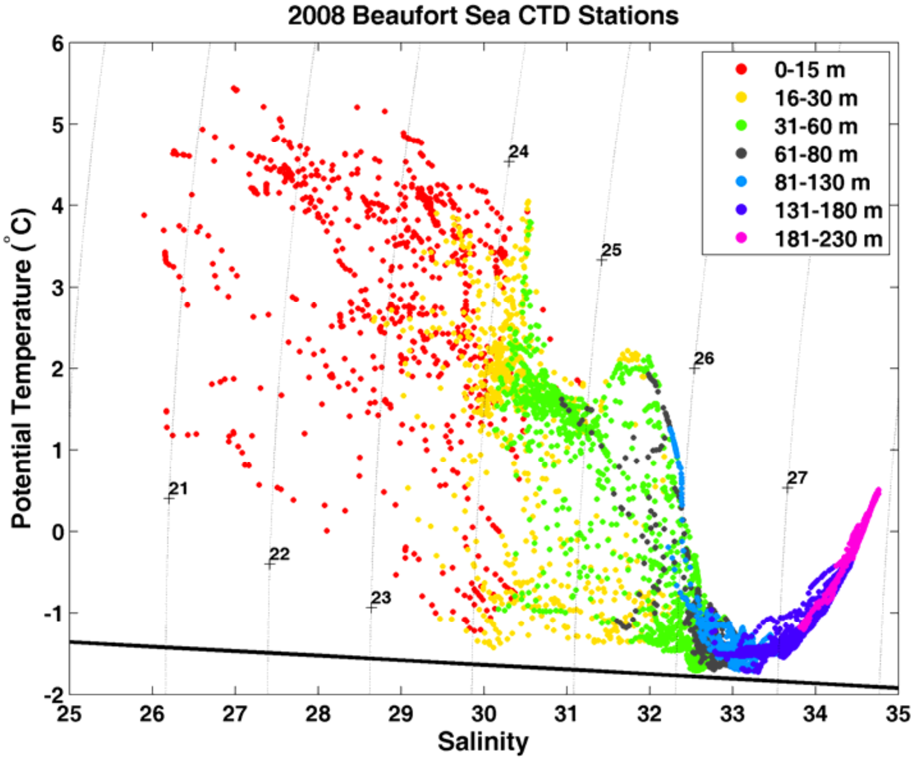


Figure 39. Potential temperature-salinity scatter plot composed of all data collected during the survey. The grey lines are isopleths of potential density and the straight black line denotes the freezing point curve.

The spatial distribution of temperature and salinity

Transect 1 (Figure 2) extends ~60 km northward from about the 20 m isobath inshore, across the eastern wall of Barrow Canyon and terminates at the mouth of the canyon in about 400 m water depth.

Properties along transect 1 are shown in Figures 40-xxx. The geostrophic velocity in these figures is relative to the unknown velocity at the reference depth, which could not be measured. Hence the velocity contours represent the velocity field relative to the (unknown) velocity at the reference depth. The velocity at the reference depth is assumed to be0 cm s^{-1}. Geostrophy refers to the force balance the Coriolis and horizontal pressure gradient forces and it assumes that these are the only two forces affecting the fluid motion. The pressure gradient is estimated from horizontal density gradients. Salinities in the upper 20 meters are relatively fresh (<30) over the entire line with the freshest (<29) water at the four outermost stations over the mouth of the canyon.

Transect 1 near-surface temperatures range between 3.5 and 4.5°C offshore to about the 140 m isobath (~35 km offshore), but relatively cold (<2°C) surface waters occur farther offshore, with the coldest temperatures coincident with the freshest surface waters. Seaward of the 30 m isobath the surface waters are separated from cold (<2°C) sub-surface waters by a strong seasonal halocline in which salinities increase rapidly from 30-32 from ~20-30 m depth. Below 30 m, salinities increase more gradually and reach a maximum of ~33.5 at 140 m. Temperatures at depths below 30 m are colder than 0°C, and temperatures at depths greater than 40 m are all below -1°C. There are three prominent fronts in the section. The first is relatively shallow surface haline front associated with fresh, ice melt water that lies approximately at the 40 km point along the transect, from the surface to 20 m depth in the water column. The second front is primarily a thermal front that is inshore of, but abuts, the salinity front associated with the ice melt, also found from the surface to approximately 20 m depth. The third front is trapped to the bottom between the 30 and 40 m isobaths. This is a thermohaline front, in which salinity (temperature) increases (decreases) seaward. Although this front includes strong salinity and temperature gradients, the density contrast is primarily associated with the salinity change.

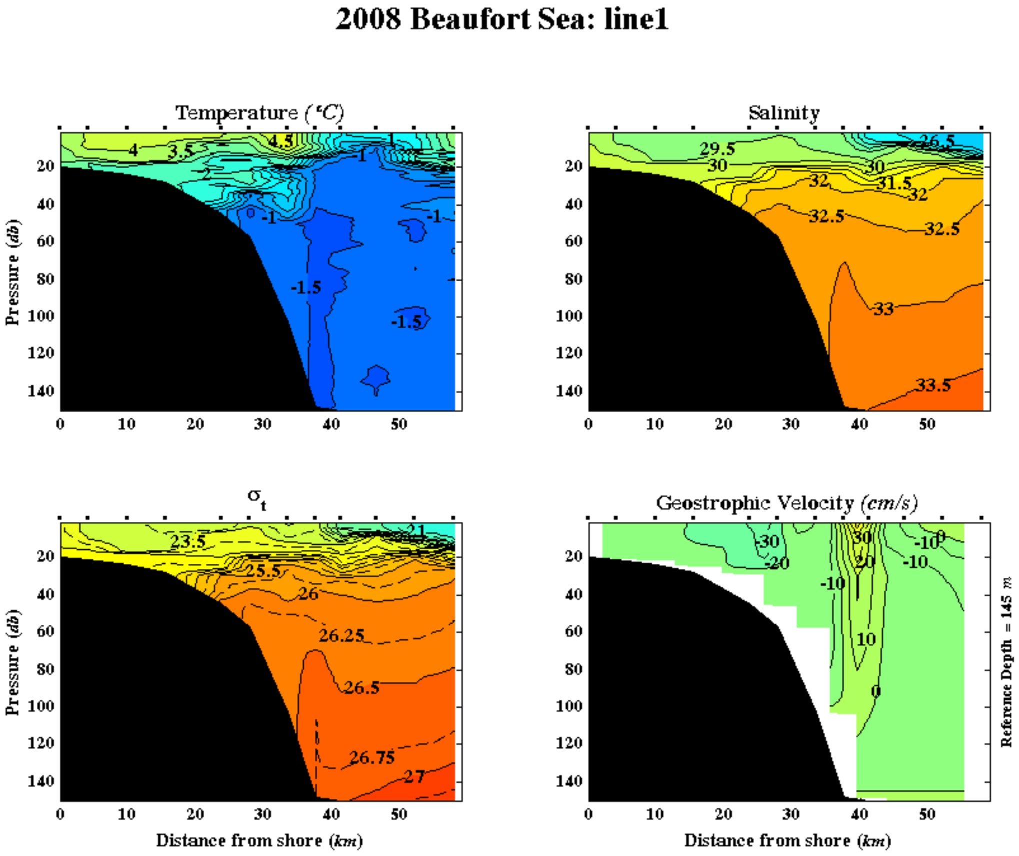


Figure 40. Transect 1 (labeled "line1"). The distribution of temperature (upper left), salinity (upper right), sigma-t (density; lower left), and the relative geostrophic velocity (lower right) along the transect. Black dots at the top of each plot indicate station locations used in the contouring.

The geostrophic velocity relative to the bottom as computed from the thermal wind shear, indicates a strong eastward jet over the eastern side of the canyon, at 10 to 20 m water depth, with weaker westward flow to either side of the jet. The jet is most likely part of the northeasterly outflow from Barrow Canyon that extends eastward along the shelfbreak of the Beaufort Sea shelfbreak (Pickart 2004, Pickart et al. 2005). The bulk of this outflow consists of cold (-1.5°C), salty (~32.5) water formed in winter on the Chukchi shelf (Itoh et al., in press; Pickart et al. 2005; Weingartner et al. 2005).

Although the stations along Transects 2 and 3 have coarser horizontal station spacing (Figure 2), he water property distributions along transects 2 and 3both (Figures 41 and 42) have several features in common with those along Transect 1. Relatively warm (~ 4.5 °C) , fresh (<30) water occupies the upper 20 m inshore, while ice melt waters occupy the upper 20 m seaward of the 50 m isobath. Ice melt fronts overlie the 40 and 50 m isobaths and cold, salty water occupies the outermost stations below 50 m depth along both transects. On Transect 2 warm (~4.5°C) surface waters are found inshore of a strong surface thermal that lies adjacent to and inshore of the ice melt front. The front is at 20 m water depth to the surface is located about 30 km from shore. Inshore surface waters are cooler (<2°C) along Transect 3 and the inshore surface thermal front is weaker. Bottom-trapped thermohaline fronts spanning the 30.5-32 isohalines are also evident on both transects but these are more diffuse than the subsurface front on Transect 1.

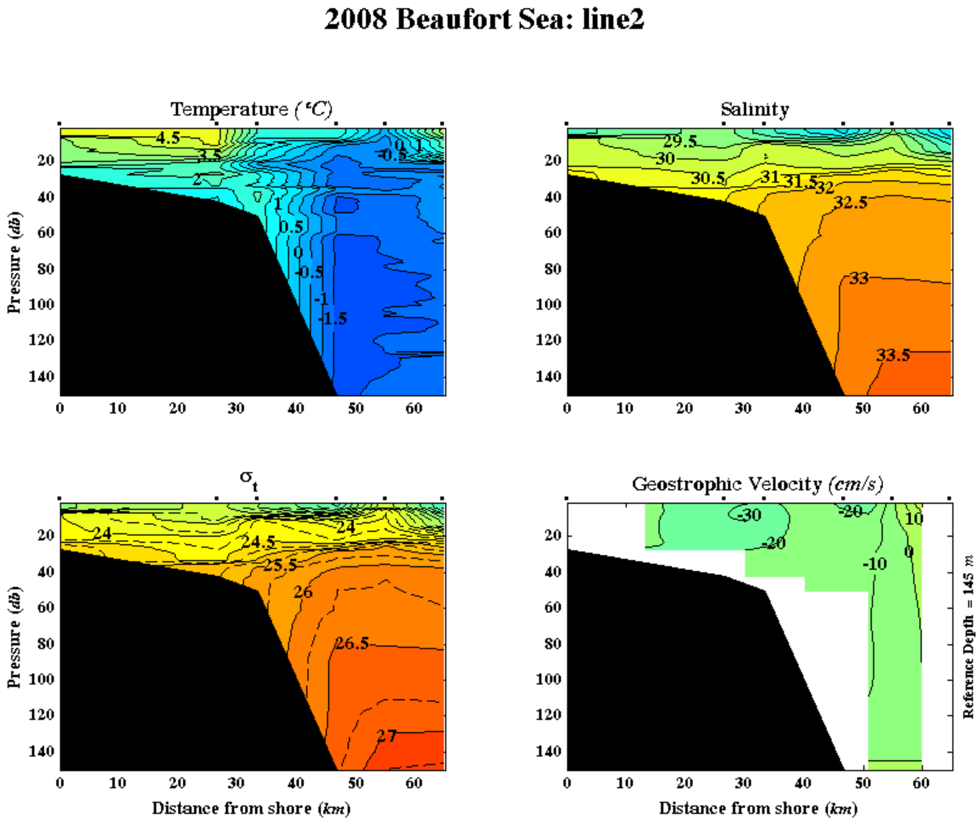


Figure 41. Transect 2 (labeled "line2"). The distribution of temperature (upper left), salinity (upper right), sigma-t (density; lower left), and the relative geostrophic velocity (lower right) along the transect. Black dots at the top of each plot indicate station locations used in the contouring.

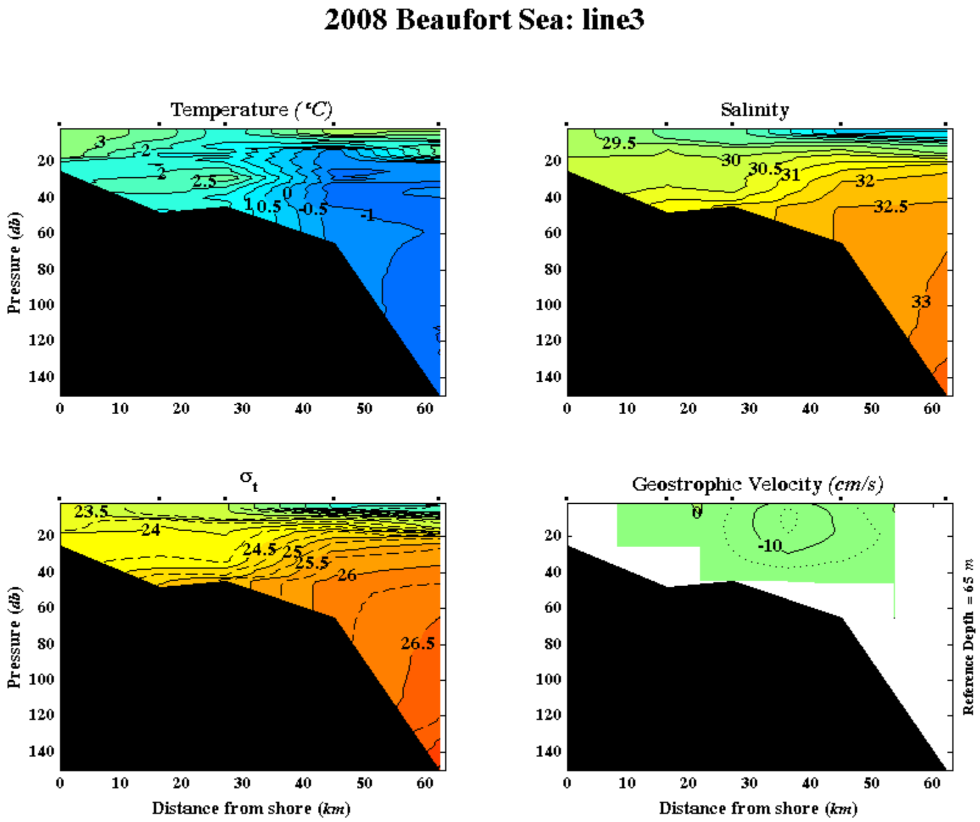


Figure 42. Transect 3 (labeled "line3"). The distribution of temperature (upper left), salinity (upper right), sigma-t (density; lower left), and the relative geostrophic velocity (lower right) along transect. Black dots at the top of each plot indicate station locations used in the contouring.

A insufficient number of stations were occupied along Transect 4 to construct profiles.

Most of the Transect 5 (Figure 42) stations were occupied following the August 13-15 upwelling wind event and the effects of this event are unknown.

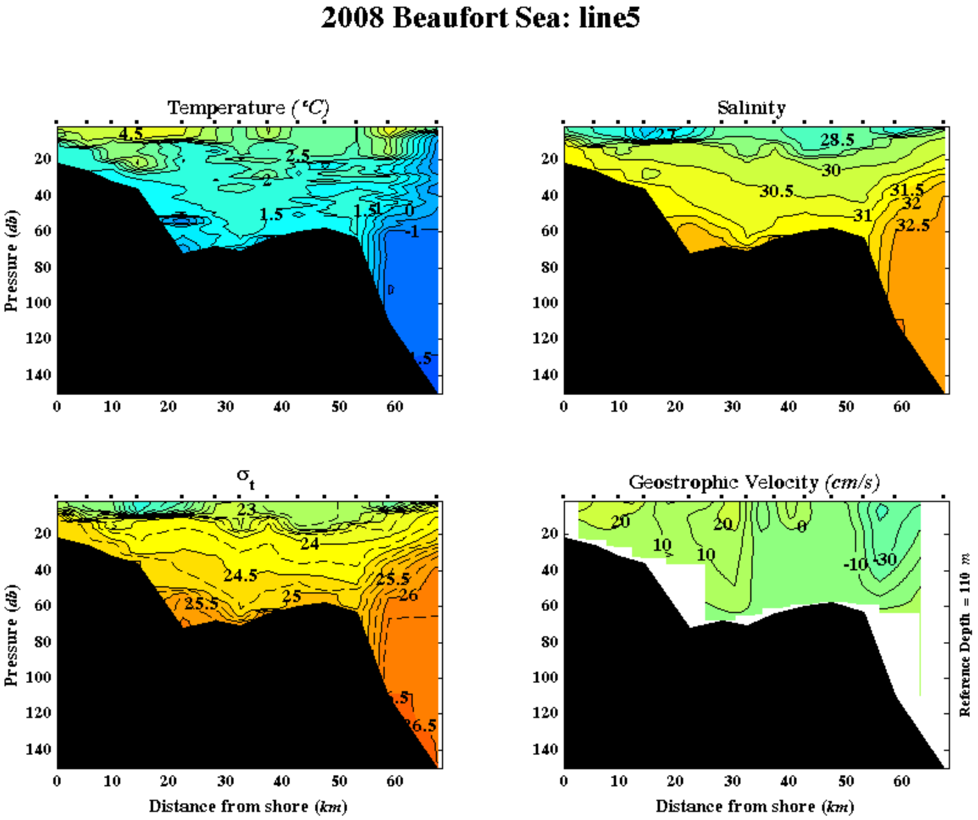


Figure 43. Transect 5 (labeled "line5"). The distribution of temperature (upper left), salinity (upper right), sigma-t (density; lower left), and the relative geostrophic velocity (lower right) along the transect. Black dots at the top of each plot indicate station locations used in the contouring.

Other points of difference between this section (transect 5) and those to the west are that there is a lens of very fresh (27.5) and warm (~4.5°C) water approximately 20 km seaward of the 20 m isobath along Transect 5 (Figure 43).

The final transect shown is comprised of the deeper stations along the slope (Figure 44). These are composed of the deepest stations along the shelfbreak in water depths greater than 250 m (Figure 2). Here we present water properties deeper than 50 m depth, since the surface waters were described for the cross-shelf sections. Two prominent features are evident in the plot. The first is the very cold (-1.5 to -1.0°C) water with salinities between 32.5 and ~34 between 50 and 150 m.

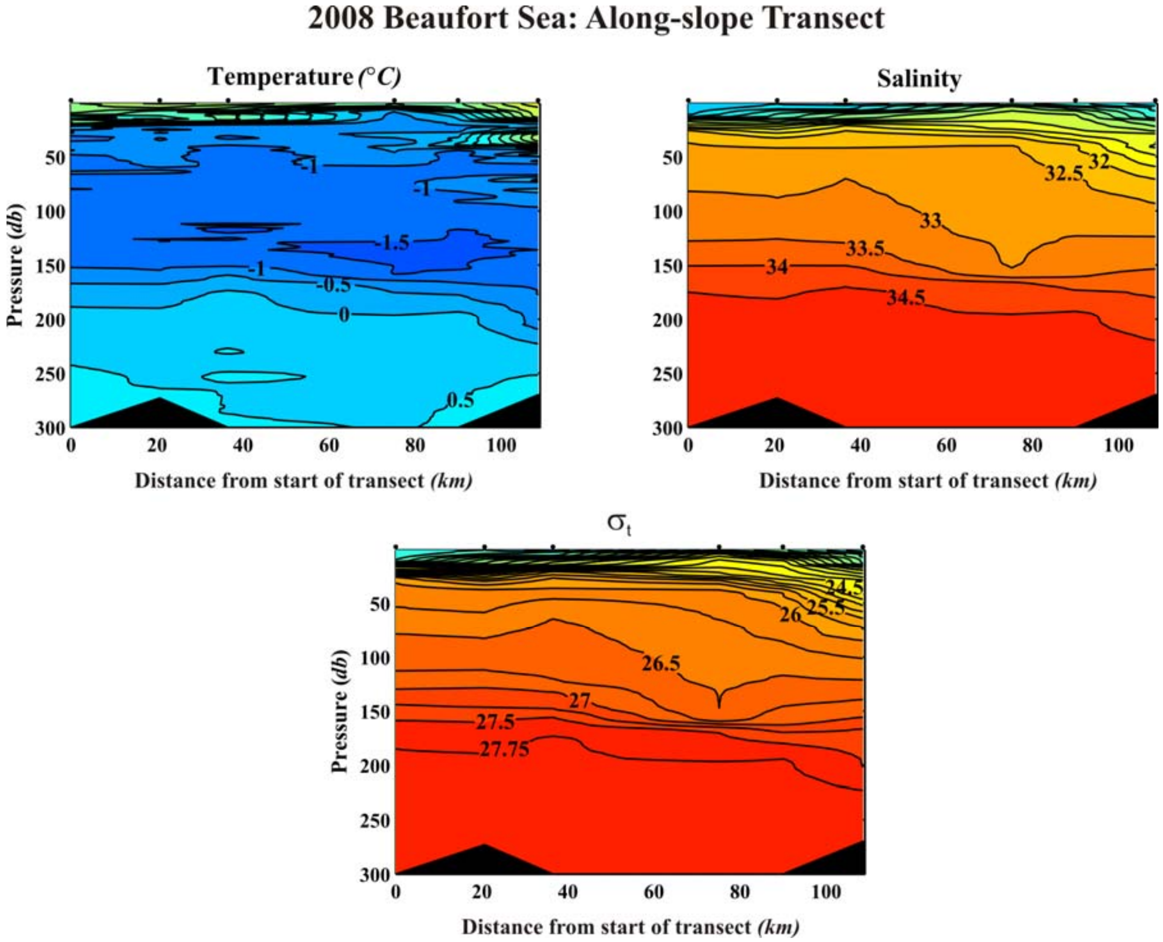


Figure 44. The distribution of temperature (upper left), salinity (upper right), and sigma-t (density; lower panel) from west to east based on measurements along the continental slope (see Figure 2). Black dots at the top of each plot indicate station locations used in the contouring.

Potential temperature-salinity (θ-S) plots composited for each line (Figure 45) show that the coldest waters (near the freezing point and with salinities of between 30 and 33.1) are found along Transects 1 and 2 with the coldest stations found offshore of the shelfbreak.

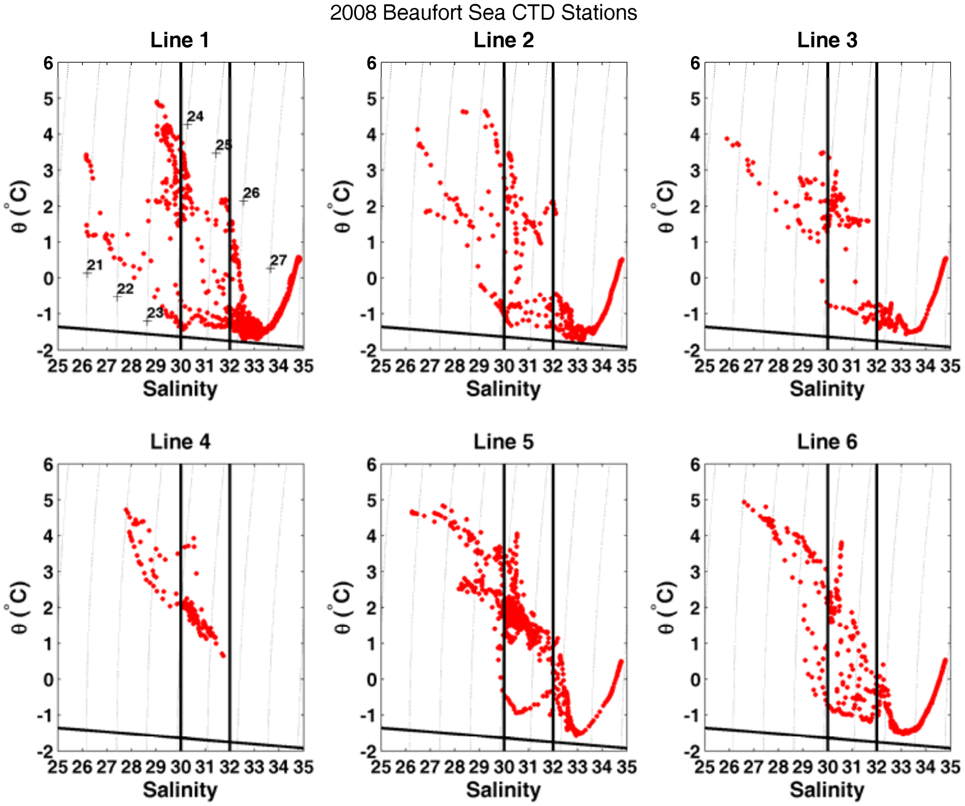


Figure 45. Potential temperature (θ) versus salinity (S) plots for each CTD transect The black vertical bars delineate the region between 30 and 32 in salinity.

The θ-S plots also show a considerable range in temperature for low salinity waters. In general the cooler temperatures are associated with ice melt (although shallow ice melt lens can warm rapidly under calm conditions and sufficient solar heating). Other sources of low-salinity water include contributions from the Chukchi Sea shelf, local rivers, such as the Colville and Meade that empty into or near the study region. In addition, Mackenzie shelf waters might also have contributed to the region during the survey, with these relatively warm waters found offshore and over the shelfbreak (e.g. Figure 43). These waters do spread eastward and have been reported over the basin(Guay and Falkner 1998, Macdonald et al. 1999) and continental slope (Macdonald et al., 1999) west of the Mackenzie shelf. The westward spreading of Mackenzie shelf waters in 2008 is suggested by the AVHRR image from July 25 -28, 2009, which shows relatively warm water emanating from the Mackenzie shelf and spreading westward over the 4-day image sequence (Figure 46). The westward penetration of the plume is presumably due to the generally eastward winds that prevailed throughout July 2008 (not shown). Note that the position of the plume varies rapidly through the sequence, which is likely a result of changing winds and or dynamic instabilities associated with density fronts that delimit the plume boundaries. We were unable to obtain additional AVHRR during the survey period because of pervasive cloud cover from the end of July through August.

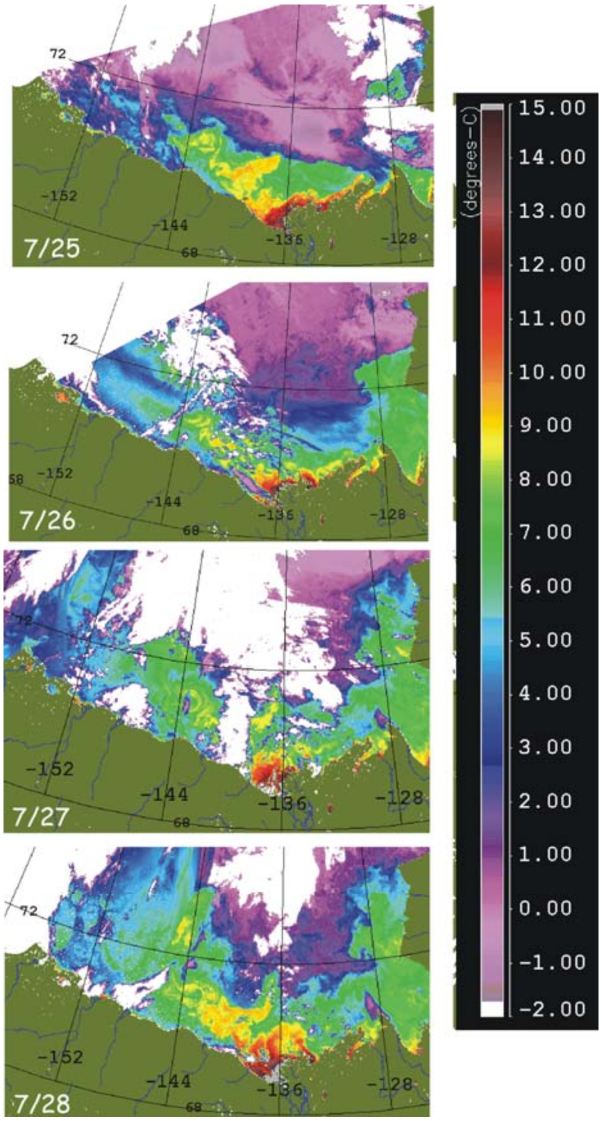


Figure 46. A July 25 – 28 sequence of MODIS SST images of the Beaufort Sea showing the eastward spreading over the Alaskan Beaufort Sea of relatively warm Mackenzie shelf plume waters.

Results of the demersal fish habitat associations

Lined net stations environmental variable correlation resulted in the following:- Bottom temperature was correlated with all of the salinity and density variables ($P \leq 0.10$) (Table 25). Predictably, salinity and density were highly correlated ($R^2 > 0.90$ and $P < 0.01$). Temperature difference and density difference were also correlated ($P = 0.09$).

Unlined net stations environmental variable correlation indicate that- Longitude was significantly correlated with density and salinity difference ($P = 0.03$) (Table 26). Similar to the results for the lined net stations, salinity and density variables were correlated ($P < 0.01$) and temperature difference and density differences were correlated ($P = 0.09$).

Table 25. Correlation matrix of all the environmental variables at the lined net stations. Values in bold indicate significantly correlated relationships ($P < 0.10$). The variable name, R^2, and P-values are listed.

Lined Net *Percent ice removed*	Density Difference (sigma-t)	Salinity Difference (psu)	Bottom Density (sigma-t)	Bottom Salinity (psu)	Bottom Depth (m)	Temperature Difference (°C)	Bottom Temperature (°C)	Longitude (decimal degrees)
Longitude (decimal degrees)								
R^2	0.02	0.03	0.05	0.05	<0.01	<0.01	<0.01	
P-value	0.63	0.61	0.50	0.50	0.98	0.97	0.97	
Bottom Temperature (°C)								
R^2	0.09	0.08	0.01	<0.01	<0.01	**0.49**		
P-value	0.37	0.37	0.76	0.86	0.82	**0.01**		
Temperature Difference (°C)								
R^2	**0.26**	0.22	0.02	0.01	0.04			
P-value	**0.09**	0.12	0.69	0.76	0.54			
Bottom Depth (m)								
R^2	**0.67**	**0.68**	**0.73**	**0.74**				
P-value	**<0.01**	**<0.01**	**<0.01**	**<0.01**				
Bottom Salinity (psu)								
R^2	**0.67**		**1.0**					
P-value	**<0.01**		**<0.01**					
Bottom Density (sigma-t)								
R^2		**0.71**						
P-value		**<0.01**						
Salinity Difference (psu)								
R^2	**1.0**							
P-value	**<0.01**							
Density Difference (sigma-t)								
R^2								
P-value								

Table 26. Correlation matrix of all the environmental variables at the unlined net stations. Values in bold indicate significantly correlated relationships ($P < 0.10$). The variable name, R^2, and *P*-values are listed. Bottom depth was not part of this analysis, see above.

Unlined Net *Bottom depth removed*	Density Difference (sigma-t)	Salinity Difference (psu)	Bottom Density (sigma-t)	Bottom Salinity (psu)	Temperature Difference (°C)	Bottom Temperature (°C)	Longitude (decimal degrees)
Longitude (decimal degrees)							
R^2	**0.46**	**0.49**	0.19	0.18	0.04	0.02	
P-value	**0.03**	**0.03**	0.21	0.21	0.56	0.69	
Bottom Temperature (°C)							
R^2	0.04	0.03	0.2	0.17	**0.36**		
P-value	0.56	0.61	0.2	0.23	**0.07**		
Temperature Difference (°C)							
R^2	**0.32**	0.28	0.26	0.23			
P-value	**0.09**	0.12	0.13	0.16			
Bottom Salinity (psu)							
R^2	**0.67**		**1.0**				
P-value	**<0.01**		**<0.01**				
Bottom Density (sigma-t)							
R^2		**0.67**					
P-value		**<0.01**					
Salinity Difference (psu)							
R^2	**1.0**						
P-value	**<0.01**						
Density Difference (sigma-t)							
R^2							
P-value							

Results for all fish species – lined net

Linear regression and generalized additive model (GAM)

CPUE #/ha
There were no significant correlations between CPUE #/ha and environmental variables.

CPUE kg/ha
The only significant correlation was CPUE kg/ha and bottom temperature (*P* = <0.01), and the correlation was negative (Figure 47 and Table 27). The Cook's Distance less than 1.0, therefore none of the observations were outliers.

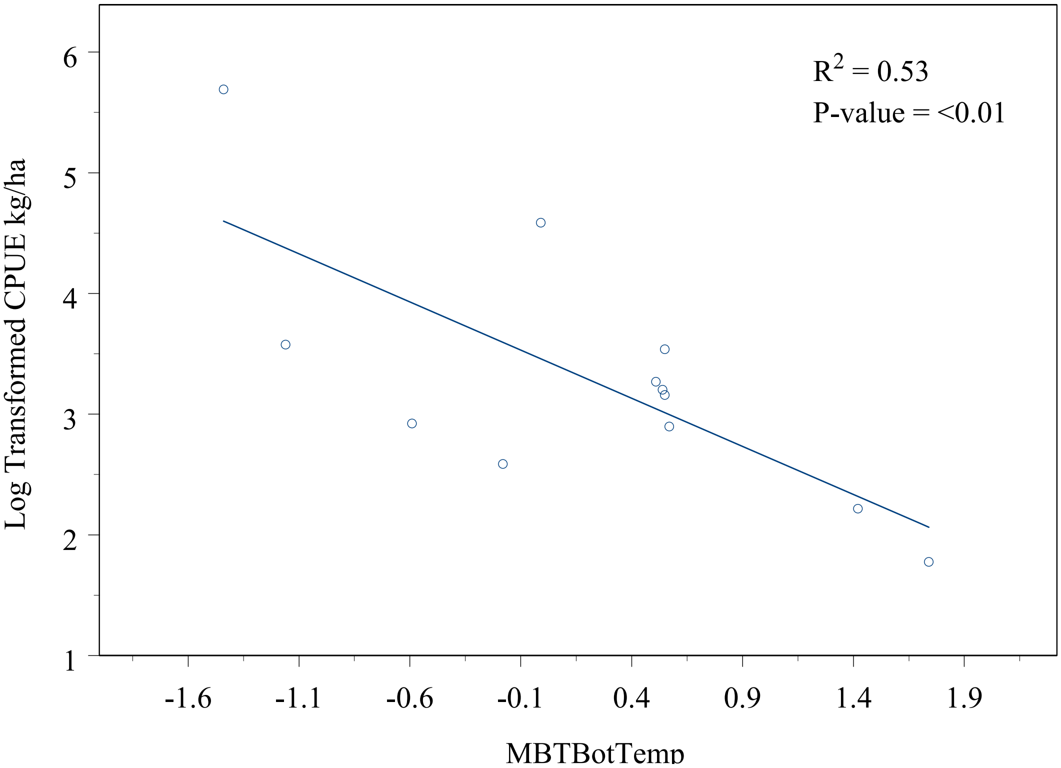


Figure 47. All fish species log transformed CPUE kg/ha and bottom temperature (°C), lined net stations.

Based on linear regression results, the first term in the GAM was bottom temperature ($P < 0.01$). The second term with the lowest *P*-value from the linear regression analysis was density difference ($P = 0.17$). Adding the second term to the GAM lowered the residual deviance but the Cp value increased (Table 28). Adding a third term to the model, longitude ($P = 0.32$), lowered both the residual deviance and Cp values ($F = 16.52$, $P = 0.01$).

Table 27. **Results for all fish species, lined net.** Results of linear regression between environmental variables and all fish species combined, from the lined net stations. Data were log transformed, CPUE #/ha and CPUE kg/ha. R^2 and p-values for each regression are shown. Significant *P*-values and the corresponding R^2 are in bold designating if it is a positive (+) or negative (-) correlation. Variables shaded in gray are correlated with each other; the variables shaded in light green are also correlated with one another. In addition, temperature difference and density difference are correlated.

All Fish Species Lined Net	Longitude (decimal degrees)	Bottom Temperature (°C)	Temperature Difference (°C)	Bottom Depth (m)	Bottom Salinity (psu)	Bottom Density (sigma-t)	Salinity Difference (psu)	Density Difference (sigma-t)
CPUE #/ha – R^2	0.13	0.10	0.05	0.01	< 0.01	< 0.01	< 0.01	< 0.01
CPUE #/ha – *P*-value	0.25	0.33	0.50	0.75	0.99	0.96	0.92	0.88
CPUE kg/ha – R^2	0.10	**0.53 (-)**	0.12	0.03	0.07	0.09	0.18	0.18
CPUE kg/ha – *P*-value	0.32	**<0.01**	0.27	0.57	0.40	0.35	0.17	0.17

Table 28. **Results for all fish species, lined net.** Results of GAM between environmental variables and all fish species, from the lined net stations. The GAM terms are listed in the order of which they went into the model. **Response: CPUE kg/ha**. Significant values are in bold.

GAM Terms	Smoothing Term	Residual deviance	Cp	DF	F	*P*
Bottom Temperature	b-spline linear	2.77	6.72	7		
Bottom Temperature + Density Difference	linear	2.73	7.48	6	0.07	0.8
Bottom Temperature + Density Difference + Longitude	linear	0.64	7.01	5	**16.52**	**0.10**

Results for all invertebrate species – lined net

Linear regression and generalized additive model (GAM)

CPUE kg/ha (no CPUE #/ha for invertebrates)
A significant correlation was found between CPUE kg/ha and bottom temperature, *P* = 0.02 and the correlation was negative (Figure 48 and Table 29) for all invertebrates species, lined net. There was also a significant positive correlation between CPUE kg/ha and the variable temperature difference, *P* = 0.08 (Figure 49 and Table 29). The Cook's Distance on CPUE kg/ha and both bottom temperature and temperature difference was less than 1.0 for all observations.

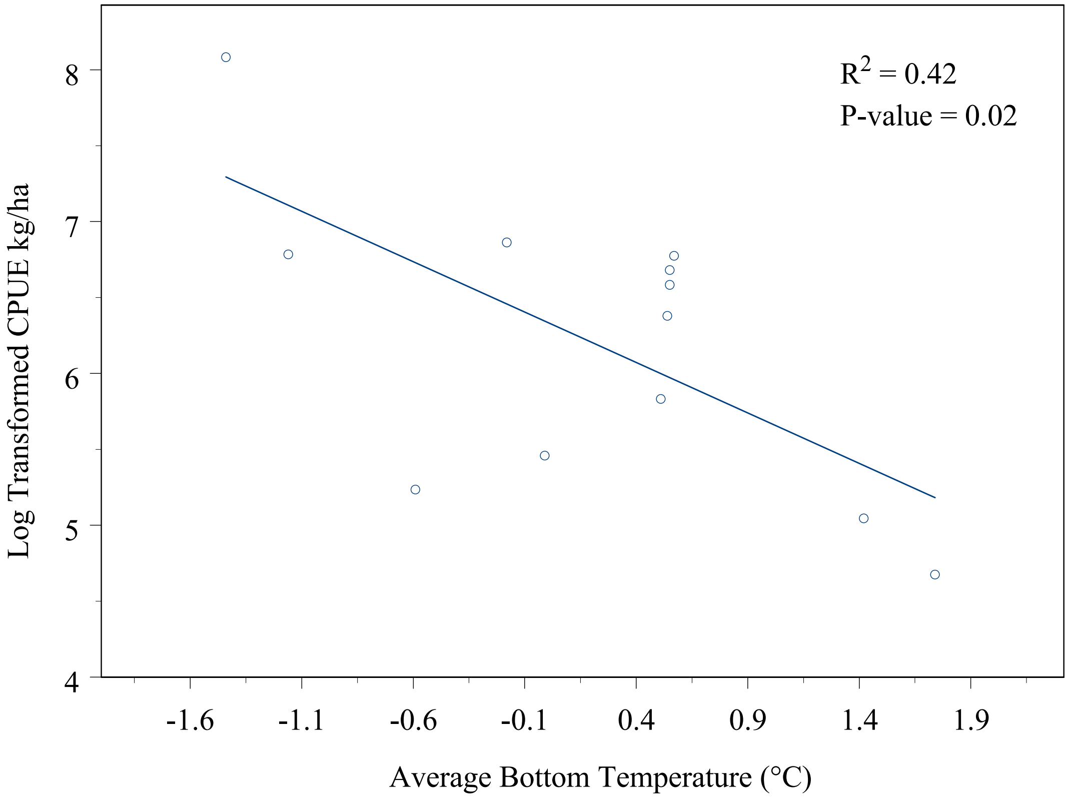


Figure 48. All invertebrate species log transformed CPUE kg/ha and bottom temperature (°C), lined net.

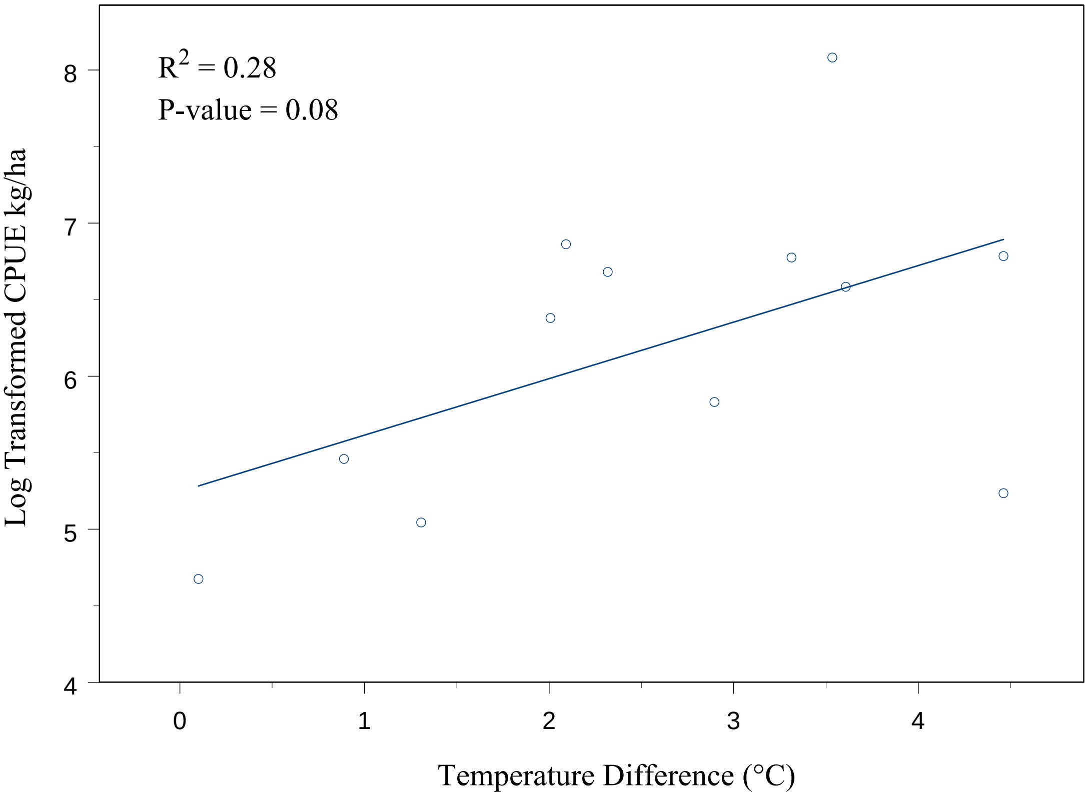


Figure 49. All invertebrate species log transformed CPUE kg/ha and temperature difference (°C), lined net.

Based on linear regression results, the first term in the GAM analysis of "all invertebrates, unlined net" was bottom temperature (*P* = 0.02). The second term with the lowest *P*-value from the linear regression analysis that was not correlated with bottom temperature was bottom density (*P* = 0.14). The third term in the GAM model was longitude (*P* = 0.34). Although bottom depth, bottom salinity, salinity difference and density difference had lower *P*-values than longitude, all of those variables were correlated with bottom density. Adding the second and third terms to the GAM model further reduced the residual deviance and the Cp statistic decreased (Table 30). The three term GAM model was significant in explaining over half the variability in the data (*F* = 5.75, *P* = 0.06).

Table 29. **Results for all invertebrate species, lined net.** Results of linear regression between environmental variables and all invertebrate species combined, from the lined net stations. Data were transformed, by CPUE kg/ha only (invertebrates are not typically counted). R^2 and *P*-values for each regression are shown. Significant *P*-values and the corresponding R^2 are in bold designating if it is a positive (+) or negative (-) correlation. Variables shaded in gray are correlated; the variables shaded in light green are also correlated with one another. In addition, temperature difference and density difference are correlated.

All Invertebrate Species Lined Net	Longitude (decimal degrees)	Bottom Temperature (°C)	Temperature Difference (°C)	Bottom Depth (m)	Bottom Salinity (psu)	Bottom Density (sigma-t)	Salinity Difference (psu)	Density Difference (sigma-t)
CPUE kg/ha – R^2	0.09	**0.42 (-)**	**0.28 (+)**	0.12	0.19	0.21	0.18	0.19
CPUE kg/ha – *P*-value	0.34	**0.02**	**0.08**	0.26	0.16	0.14	0.16	0.15

Table 30. **Results for all invertebrate species, lined net.** Results of GAM between environmental variables and all invertebrate species, from the lined net stations. The GAM terms are listed in the order of which they went into the model. **Response: CPUE kg/ha**. Significant values are in bold.

GAM Terms	Smoothing Term	Residual deviance	Cp	DF	F	*P*
Bottom Temperature	b-spline linear	2.10	5.09	7		
Bottom Temperature + Bottom Density	linear	0.84	4.43	6	**8.91**	**0.02**
Bottom Temperature + Bottom Density + Longitude	linear	0.39	2.36	5	**5.75**	**0.06**

Results for Arctic cod – lined net

Linear regression and generalized additive model (GAM)

CPUE #/ha
There were no significant correlations bewteen CPUE #/ha and environmental variables.

CPUE kg/ha
There was a significant correlation between CPUE kg/ha and bottom temperature (*P* = 0.03), and the correlation was negative between Arctic Cod Lined net CPUE #/ha and environmental variable (Figure 50 and Table 31). The Cook's Distance on all data points was less than 1.0, indicating there are no outliers.

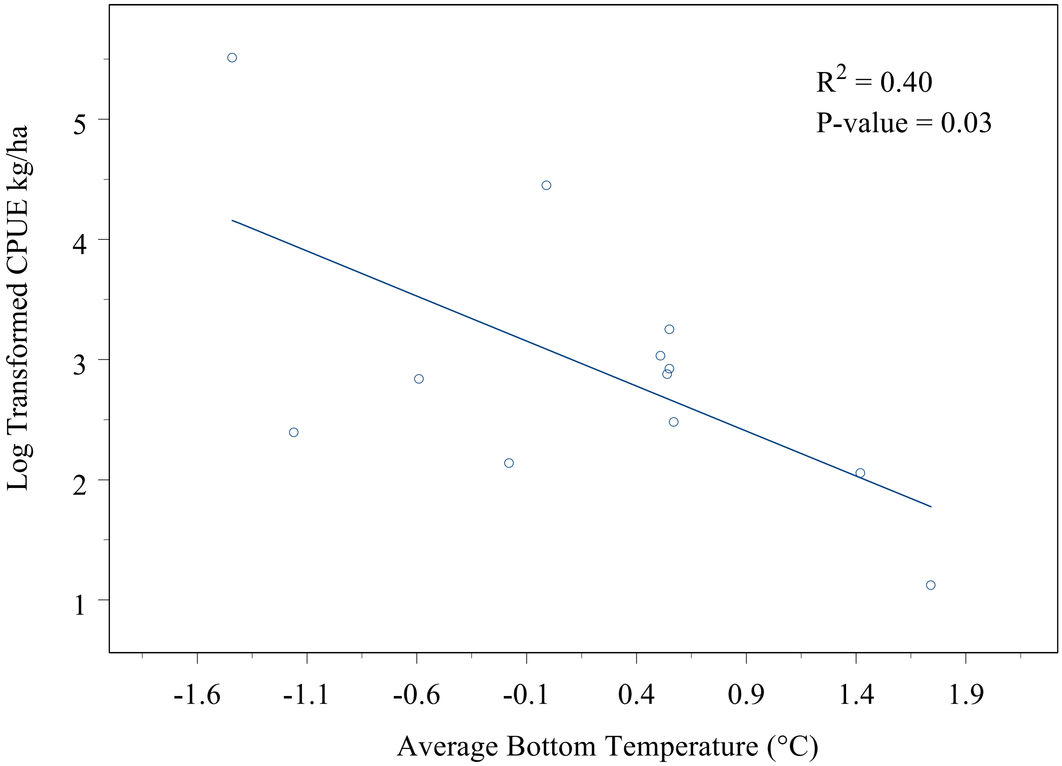


Figure 50. Arctic cod log transformed CPUE kg/ha and bottom temperature (°C), lined net.

Based on linear regression results, the first term in the GAM analysis was bottom temperature (*P* = 0.03). The second term with the lowest *P*-value from the linear regression analysis was density difference (*P* = 0.25). The third term in the GAM model was longitude (*P* = 0.33). Although salinity difference had a lower *P*-value than longitude, that variable was correlated with density difference. Adding the second term to the GAM model lowered the residual deviance but the Cp value increased (Table 32). Adding a third term to the model lowered both the residual deviance and Cp values (*F* = 13.64, *P* = 0.01).

Table 31. **Results for Arctic cod, lined net.** Results of linear regression between environmental variables and Arctic cod, from the lined net stations. Data were log transformed, CPUE #/ha and CPUE kg/ha. R^2 and p-values for each regression are shown. Significant *P*-values and the corresponding R^2 are in bold designating if it is a positive (+) or negative (-) correlation. Variables shaded in gray are correlated; the variables shaded in light green are also correlated with one another. In addition, temperature difference and density difference are correlated.

Arctic cod Lined Net	Longitude (decimal degrees)	Bottom Temperature (°C)	Temperature Difference (°C)	Bottom Depth (m)	Bottom Salinity (psu)	Bottom Density (sigma-t)	Salinity Difference (psu)	Density Difference (sigma-t)
CPUE #/ha – R^2	0.11	0.05	0.05	<0.01	< 0.01	<0.01	< 0.01	< 0.01
CPUE #/ha – *P*-value	0.29	0.47	0.47	0.95	0.80	0.77	0.95	0.99
CPUE kg/ha – R^2	0.09	**0.40 (-)**	0.08	0.02	0.06	0.07	0.13	0.13
CPUE kg/ha – *P*-value	0.33	**0.03**	0.38	0.63	0.45	0.40	0.25	0.25

Table 32. **Results for Arctic cod, lined net.** Results of GAM between environmental variables and Arctic cod, from the lined net stations. The GAM terms are listed in the order of which they went into the model. **Response: CPUE kg/ha**. Significant values are in bold.

GAM Terms	Smoothing Term	Residual deviance	Cp	DF	F	*P*
Bottom Temperature	b-spline linear	5.21	12.66	7		
Bottom Temperature + Density Difference	linear	5.02	13.96	6	0.22	0.65
Bottom Temperature + Density Difference + Longitude	linear	1.34	13.07	5	**13.64**	**0.01**

Results for walleye pollock – lined net

Linear regression and generalized additive model (GAM)

CPUE #/ha

There was a significant correlation between CPUE #/ha (*P* = 0.02) and the independent variable longitude (Figure 51 and Table 33). The relationship was negative, decreasing from west to east in the study area. There were no data points that had a Cook's Distance value greater than 1.0, confirming that there were no outlier observations.

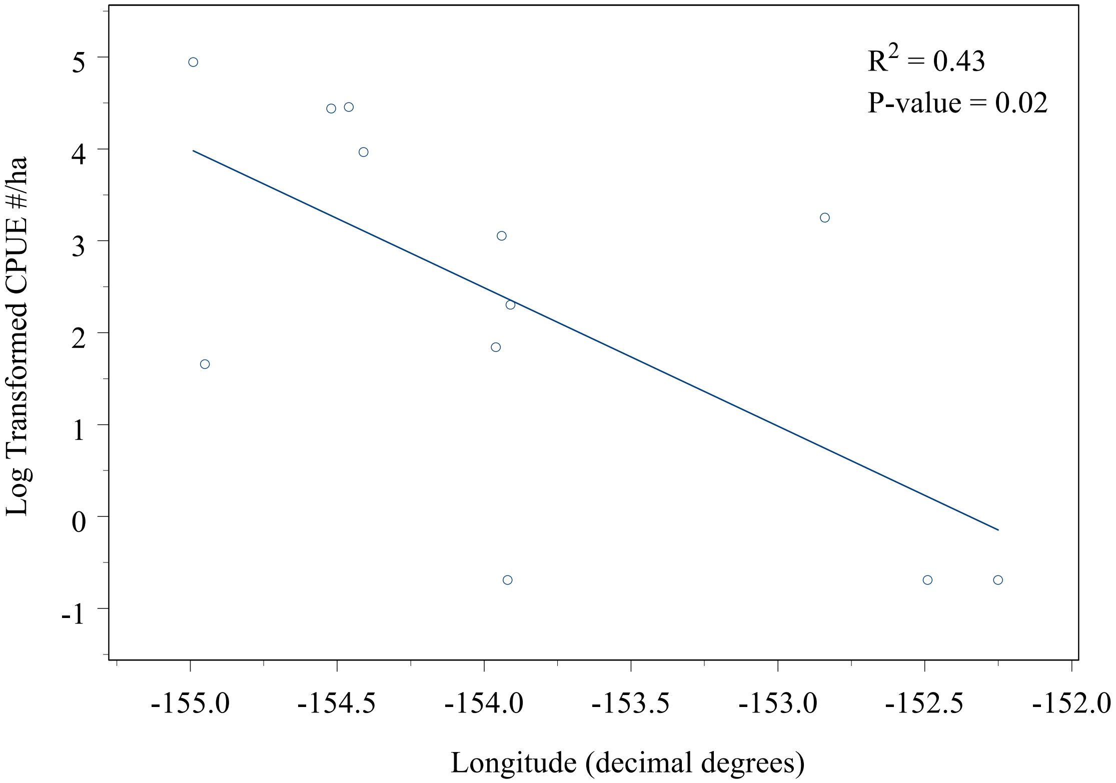


Figure 51. Walleye pollock log transformed CPUE #/ha and longitude (decimal degrees), lined net.

Based on linear regression results, the first term in the GAM analysis was longitude (*P* = 0.02). The second term with the lowest *P*-value from the linear regression analysis was temperature difference (*P* = 0.42). The third term was salinity difference (*P* = 0.88),. The three term GAM model did not significantly explain the variance in the data (*F* = 0.08, *P* = 0.79).

walleye pollock cont.-

CPUE kg/ha

A significant correlation was found for CPUE kg/ha walleye pollock and the independent variable longitude (*P* = 0.02), and the relationship was negative, CPUE kg/ha decreasing from west to east (Figure 52 and Table 33). There were no data points that had a Cook's Distance greater than 1.0.

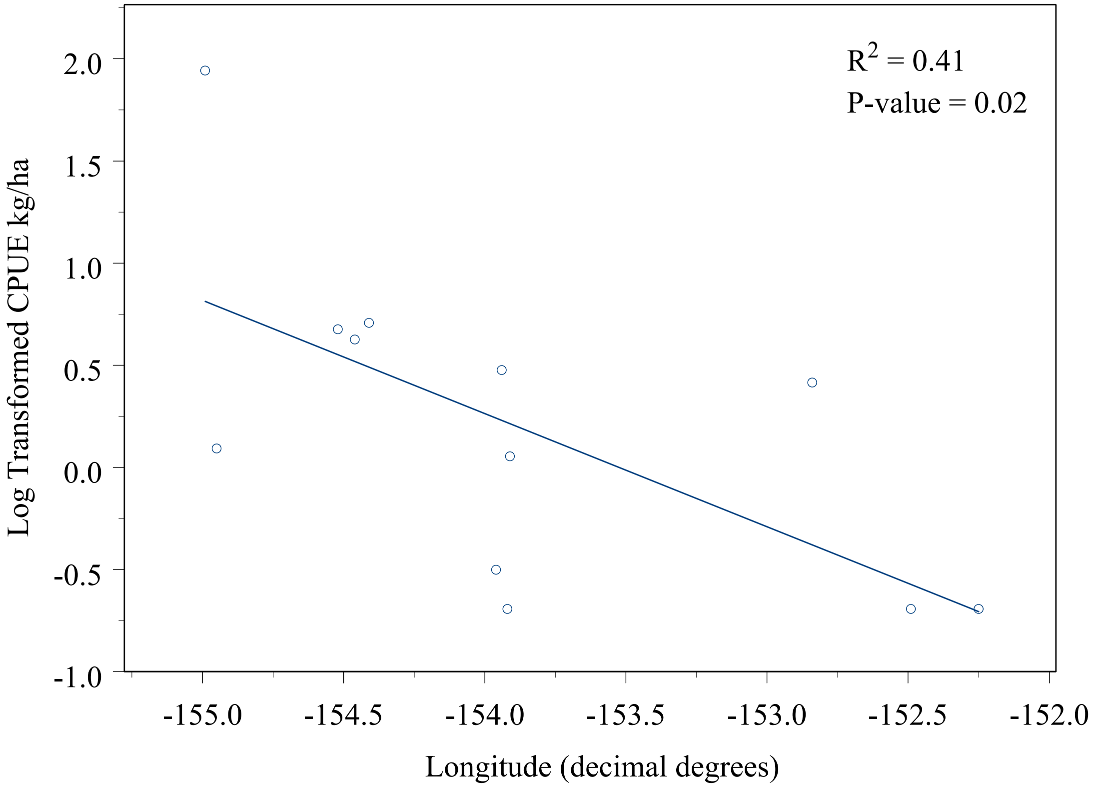


Figure 52. Walleye pollock log transformed CPUE kg/ha and longitude (decimal degrees), lined net.

Based on linear regression results, the first term in the GAM analysis was longitude (*P* = 0.02). The second term with the lowest *P*-value from the linear regression analysis was temperature difference (*P* = 0.42). The third term in the GAM model was salinity difference (*P = 0.43*). The three term GAM model did not significantly explain the variance in the data (*F* = 1.74, *P* = 0.22).

Table 33. **Results for walleye pollock, lined net.** Results of linear regression between environmental variables and walleye pollock, from the lined net stations, CPUE #/ha and CPUE kg/ha. R^2 and p-values for each regression are shown. Significant *P*-values and the corresponding R^2 are in bold designating if it is a positive (+) or negative (-) correlation. Variables shaded in gray are correlated; the variables shaded in light green are also correlated with one another. In addition, temperature difference and density difference are correlated.

Pollock Lined Net	Longitude (decimal degrees)	Bottom Temperature (°C)	Temperature Difference (°C)	Bottom Depth (m)	Bottom Salinity (psu)	Bottom Density (sigma-t)	Salinity Difference (psu)	Density Difference (sigma-t)
CPUE #/ha – R^2	**0.43 (-)**	0.02	0.06	0.01	<0.01	<0.01	<0.01	<0.01
CPUE #/ha – *P*-value	**0.02**	0.68	0.42	0.71	0.82	0.81	0.88	0.92
CPUE kg/ha – R^2	**0.41 (-)**	<0.01	0.07	<0.01	0.02	0.02	0.06	0.05
CPUE kg/ha – *P*-value	**0.02**	1.0	0.42	0.99	0.64	0.64	0.43	0.47

Table 34. **Results for walleye pollock, lined net.** Results of GAM between environmental variables and walleye pollock, from the lined net station. The GAM terms are listed in the order of which they went into the model. Response: **CPUE #/ha**. Significant values are in bold.

GAM Terms	Smoothing Term	Residual deviance	Cp	DF	F	P
Longitude	linear	27.33	38.26	10		
Longitude + Temperature Difference	linear	24.36	40.76	9	1.10	0.32
Longitude + Temperature Difference + Salinity Difference	linear	24.13	45.78	8	0.08	0..79

Table 35. **Results for walleye pollock, lined net.** Results of GAM between environmental variables and walleye pollock, from the lined net stations. The GAM terms are listed in the order of which they went into the model. Response: **CPUE kg/ha**. Significant values are in bold.

GAM Terms	Smoothing Term	Residual deviance	Cp	DF	F	P
Longitude	linear	3.95	5.53	10		
Longitude + Temperature Difference	linear	3.53	5.90	9	1.07	0.33
Longitude + Temperature Difference + Salinity Difference	linear	2.90	6.04	8	1.74	0.22

Results for all eelpouts – lined net

Linear regression and generalized additive model (GAM)

CPUE #/ha

Bottom temperature was significantly correlated with CPUE #/ha All Eelpouts – Lined Net (P <0.01), and the correlation was negative, decreasing CPUE #/ha with increasing bottom temperature (Figure 53 and Table 36). The Cook's Distance was less than 1.0, indicating there were no outliers.

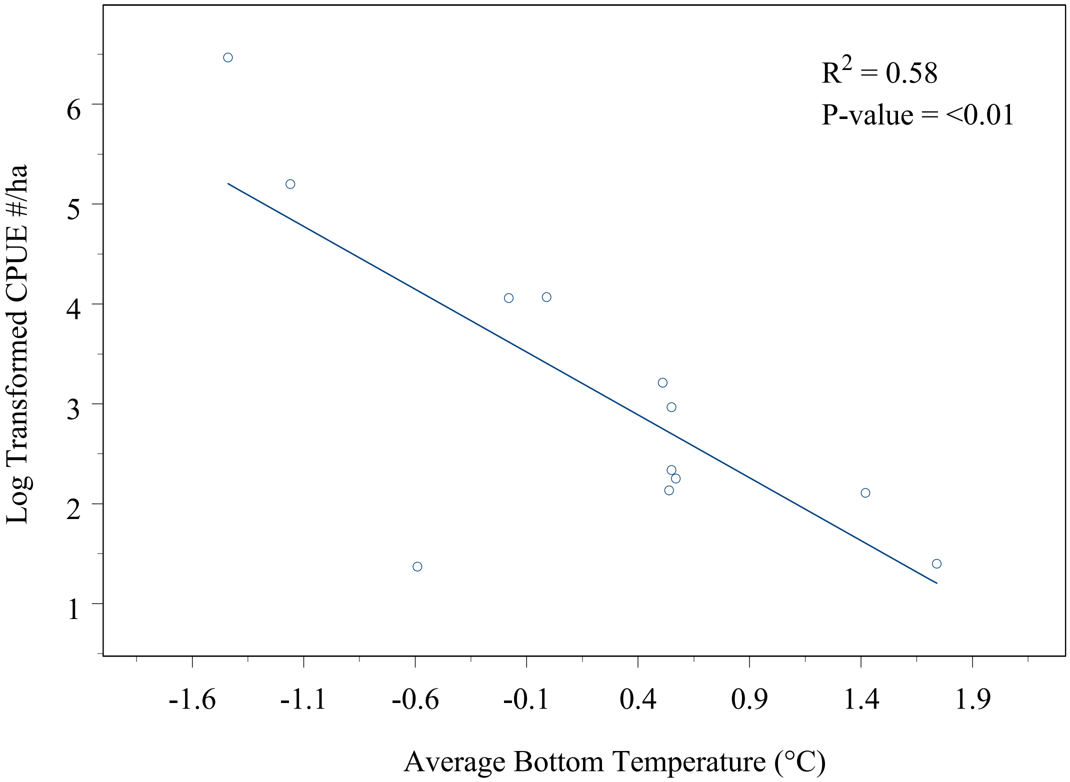


Figure 53. All eelpouts log transformed CPUE #/ha and average bottom temperature (°C), lined net.

Based on linear regression results, the first term in the GAM analysis was bottom temperature (P < 0.01). The second term with the lowest P-value from the linear regression analysis was density difference (P = 0.61). Temperature difference had a lower P-value than density difference, but the former variable was correlated with bottom temperature. The third term in the GAM model was longitude (P = 0.64). Although salinity difference had a lower P-value than longitude, that variable was correlated with density difference.

Adding the second term and third terms, bottom temperature and density, to the GAM model slightly lowered the residual deviance but the Cp values increased with each added term (Table

37), indicating the model was not improved by adding density difference and longitude. The three term GAM model did not significantly explain the variance in the data (*F* = 0.63, *P* = 0.45).

all eelpouts cont.-

CPUE kg/ha

The dependent variable, CPUE kg/ha was also significantly correlated with bottom temperature (*$P = 0.02$*), and the relationship was negative, CPUE kg/ha decreasing with increasing temperature (Figure 54 and Table 36).

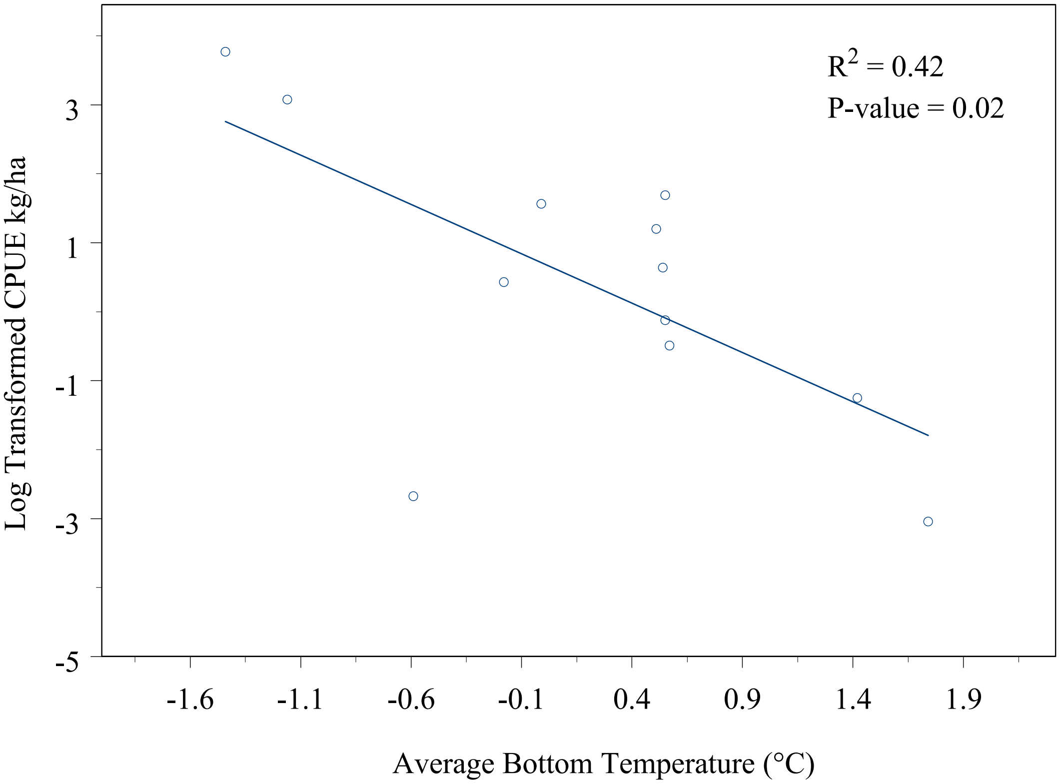


Figure 54. All eelpouts log transformed CPUE kg/ha and average bottom temperature (°C), lined net.

Based on linear regression results, the first term in the GAM analysis was bottom temperature ($P = 0.02$). The second term with the lowest *P*-value from the linear regression analysis was density difference ($P = 0.18$). The third term in the GAM model was longitude ($P = 0.68$). Although bottom depth, bottom salinity, bottom density and salinity difference had lower *P*-values than longitude, those variables were all correlated with density difference. Adding the second term and third terms to the GAM model slightly lowered the residual deviance but the Cp values increased with each added term (Table 38), indicating the model was not improved by adding density difference and longitude. The three term GAM model did not significantly explain the variance in the data ($F = 0.17$, $P = 0.69$).

Table 36. **Results for all eelpouts, lined net.** Results of linear regression between environmental variables and all eelpouts, from the lined net stations, CPUE #/ha and CPUE kg/ha. R^2 and p-values for each regression are shown. Significant *P*-values and the corresponding R^2 are in bold designating if it is a positive (+) or negative (-) correlation. Variables shaded in gray are correlated; the variables shaded in light green are also correlated with one another. In addition, temperature difference and density difference are correlated.

Eelpouts (several species combined) Lined Net	Longitude (decimal degrees)	Bottom Temperature (°C)	Temperature Difference (°C)	Bottom Depth (m)	Bottom Salinity (psu)	Bottom Density (sigma-t)	Salinity Difference (psu)	Density Difference (sigma-t)
CPUE #/ha – R^2	0.02	**0.58 (-)**	0.10	<0.01	<0.01	0.01	0.03	0.03
CPUE #/ha – *P*-value	0.64	**<0.01**	0.33	0.96	0.81	0.74	0.62	0.61
CPUE kg/ha – R^2	0.02	**0.42 (-)**	0.15	0.13	0.12	0.14	0.17	0.18
CPUE kg/ha – *P*-value	0.68	**0.02**	0.22	0.25	0.27	0.24	0.18	0.18

Table 37. **Results for all eelpouts, lined net.** Results of GAM between environmental variables and all eelpouts, from the lined net stations. The GAM terms are listed in the order of which they went into the model. **Response: CPUE #/ha**. Significant values are in bold.

GAM Terms	Smoothing Term	Residual deviance	Cp	DF	F	*P*
Bottom Temperature	linear	11.21	15.69	10		
Bottom Temperature + Density Difference	linear	11.08	18.47	9	0.10	0.76
Bottom Temperature + Density Difference + Longitude	linear	10.27	20.12	8	0.63	0.45

Table 38. **Results for all eelpouts, lined net.** Results of GAM between environmental variables and all eelpouts, from the lined net stations. The GAM terms are listed in the order of which they went into the model. **Response: CPUE kg/ha**. Significant values are in bold.

GAM Terms	Smoothing Term	Residual deviance	Cp	DF	F	*P*
Bottom Temperature	linear	27.23	38.12	10		
Bottom Temperature + Density Difference	linear	24.67	41.10	9	0.93	0.36
Bottom Temperature + Density Difference + Longitude	linear	24.16	46.08	8	0.17	0.69

Results for all sculpins – lined net

Generalized linear model (GLM)

The GLM analysis found bottom depth explained over half the deviance in the presence or absence of sculpins, sampled with the lined net ($P = 0.005$) (Table 39). Bottom salinity, bottom density, salinity difference and density difference were also significantly correlated with the presence/absence of sculpins, however, these independent variables were correlated with bottom depth. Adding longitude to the GLM model accounted for almost all of the variance observed in the presence/absence of sculpins. The null deviance was 8.79 and residual deviance was 0.85 ($F = 30.23$, $P = 0.0004$) with both bottom depth and longitude in the model. Although the residual deviance and *P*-value indicate the two term model was statistically significant it is very likely that the results are due to interactions between independent variables and over fitting the model. Both of these problems are related to the small sample size (n = 11) and thus the two term GLM model is probably not biologically significant.

Table 39. **Results for all sculpins, lined net**. Results of generalized linear models (GLM) of environmental variables and all sculpins, from the lined net stations. The dependent variable is species presence/absence (not CPUE). Model significance compares the residual deviance for each variable to the null deviance and reports a t-value. Numbers in bold are significant. All variables in shaded gray are correlated; the variables shaded in light green are also correlated with one another. In addition, temperature difference and density difference are correlated.

Sculpins (several species combined) Presence / Absence	Longitude (decimal degrees)	Bottom Temperature (°C)	Temperature Difference (°C)	Bottom Depth (m)	Bottom Salinity (psu)	Density (sigma-t)	Salinity Difference (psu)	Density Difference (sigma-t)
Residual Deviance (Null Deviance: 8.789)	8.547	8.013	8.000	**3.293**	**5.833**	**5.807**	**4.840**	**4.886**
F statistic	0.31	0.93	0.92	**12.97**	**3.90**	**3.93**	**7.57**	**7.22**
P-value	0.59	0.36	0.36	**0.005**	**0.08**	**0.08**	**0.02**	**0.02**

Results for opilio crab – lined net

Linear regression and generalized additive model (GAM)

CPUE #/ha

CPUE #/ha was negatively correlated with bottom temperature (*P* <0.01; Figure 55 and Table 40), and positively correlated with temperature difference (*P* = 0.06; Figure 56 and Table 40). CPUE #/ha was also significantly positvely correlated with the group of correlated independent variables: bottom salinity, bottom density, salinity difference and density difference (Table 40). The Cook's Distance for each observation was less than 1.0, indicating there were no outlier observations.

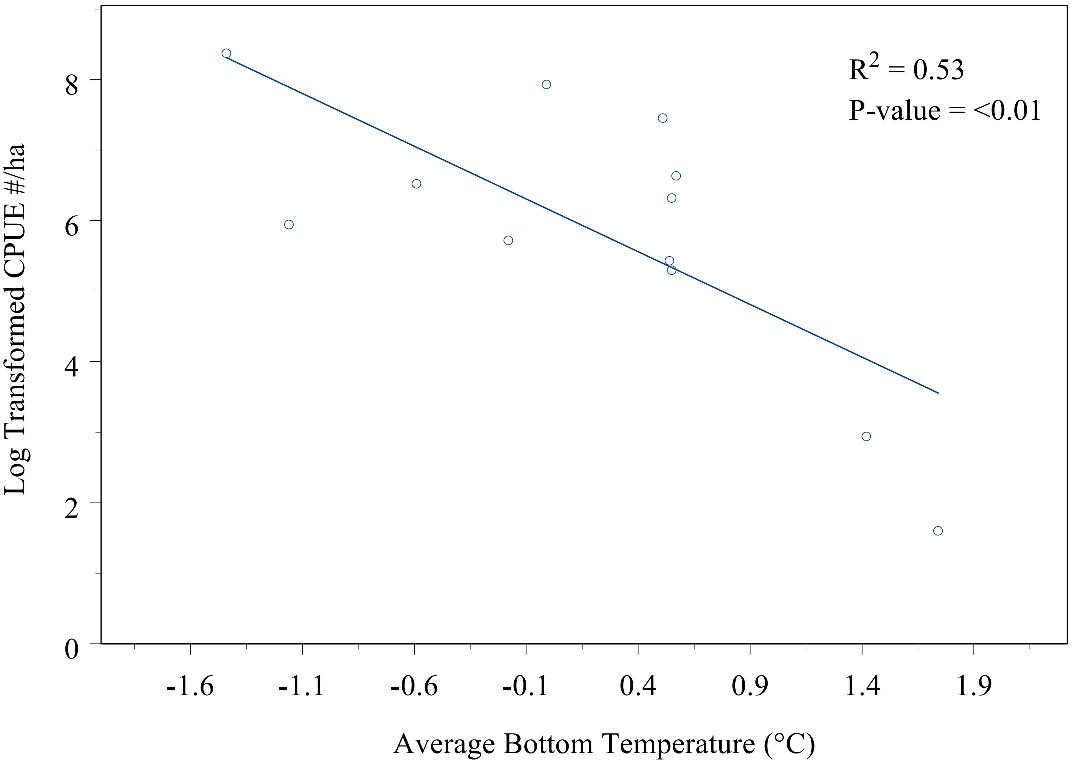


Figure 55. Opilio crab log transformed CPUE #/ha and average bottom temperature (°C), lined net.

Based on linear regression results, the first term in the GAM analysis was bottom temperature (*P* <0.01). Temperature difference was not used in the model because it was correlated with bottom temperature. The second term with the lowest *P*-value from the linear regression analysis was bottom depth (*P* = 0.12). Although salinity and density differences had lower *P*-values, they were correlated with one another and also with temperature difference which was in turn correlated with bottom temperature; therefore bottom depth was used as the second term. The third term in the GAM model was longitude (*P* = 0.49). Adding the second term and third terms to the GAM model lowered both the residual deviance and Cp values with each added term (Table 41). However, the three term GAM model did not significantly explain the variance in the data (*F* = 3.20, *P* = 0.11). The two term GAM was significant in describing most of the variance in the data (*F* = 13.02*, P* = 0.005) (Table 41), indicating the model was improved by adding bottom depth but not longitude.

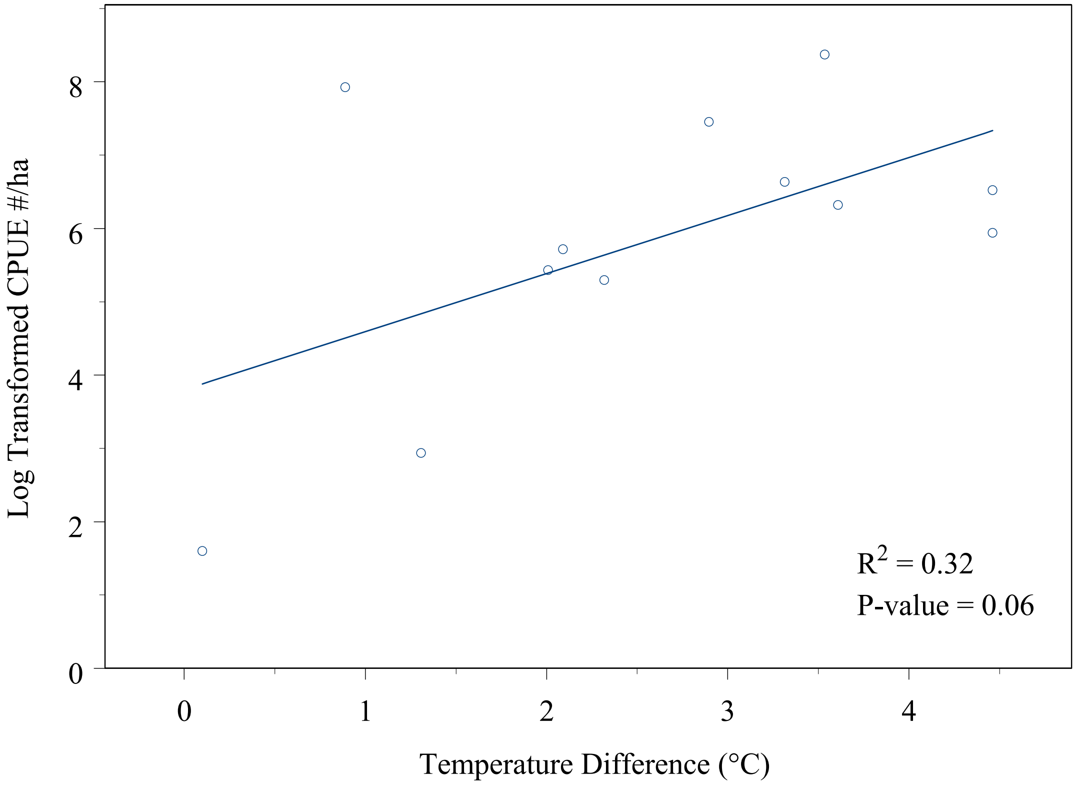


Figure 56. Opilio crab log transformed CPUE #/ha and temperature difference (°C), lined net.

CPUE kg/ha

CPUE kg/ha was positively correlated with bottom depth (Figure 57) and the suite of salinity, and density variables (Table 40). The Cook's Distance on all observations was less than 1.0, indicating there were no outliers.

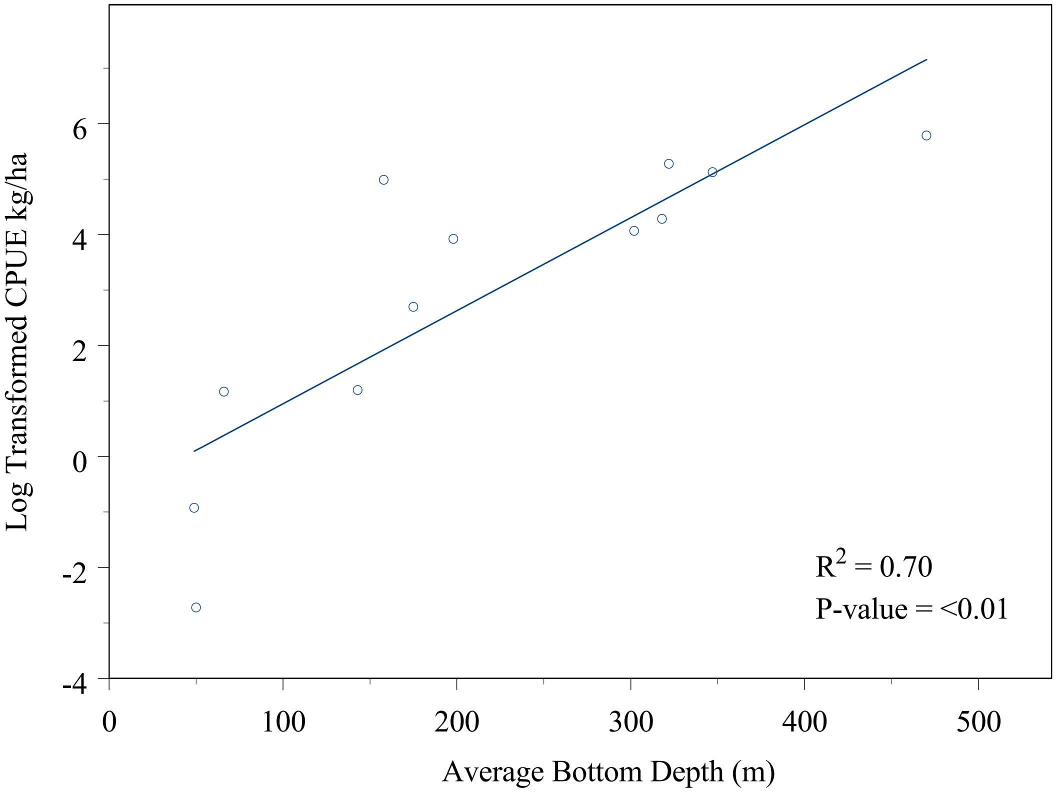


Figure 57. Opilio crab log transformed CPUE kg/ha and bottom depth (m), lined net.

Based on linear regression results, the first term in the GAM analysis was bottom depth (*P* <0.01). Because bottom depth was correlated with bottom salinity, density, salinity difference and density difference, we only used bottom depth in the GAM. The second term used in the GAM model was bottom temperature (*P* = 0.26). Although, temperature difference had a lower *P*-value, it was correlated with density difference which was, in turn, correlated with bottom depth. The third term in the GAM model was longitude (*P* = 0.99). Adding the second term and third terms to the GAM model lowered the residual deviance and the Cp (Table 42). However, the three term GAM model did not significantly explain the variance in the data (*F* = 0.007, *P* = 0.93; Table 42). The two term GAM with bottom depth and bottom temperature as explanatory variables was significant in describing most of the variance in the data (*F* = 11.94, *P* = 0.007; Table 42).

Table 40. **Results for opilio crab, lined net.** Results of linear regression between environmental variables and opilio crab, from the lined net stations, CPUE #/ha and CPUE kg/ha. R^2 and *P*-values for each regression are shown. Significant *P*-values and the corresponding R^2 are in bold designating if it is a positive (+) or negative (-) correlation. Variables shaded in gray are correlated; the variables shaded in light green are also correlated with one another. In addition, temperature difference and density difference are correlated.

Opilio crab Lined Net	Longitude (decimal degrees)	Bottom Temperature (°C)	Temperature Difference (°C)	Bottom Depth (m)	Bottom Salinity (psu)	Bottom Density (sigma-t)	Salinity Difference (psu)	Density Difference (sigma-t)
CPUE #/ha – R^2	0.05	**0.53 (-)**	**0.32 (+)**	0.23	**0.31 (+)**	**0.35 (+)**	**0.55 (+)**	**0.56 (+)**
CPUE #/ha – *P*-value	0.49	**<0.01**	**0.06**	0.12	**0.06**	**0.04**	**<0.01**	**<0.01**
CPUE kg/ha – R^2	<0.01	0.12	0.17	**0.70 (+)**	**0.73 (+)**	**0.75 (+)**	**0.75 (+)**	**0.74 (+)**
CPUE kg/ha – *P*-value	0.99	0.26	0.19	**< 0.01**	**<0.01**	**<0.01**	**< 0.01**	**< 0.01**

Table 41. **Results for opilio crab, lined net.** Results of GAM between environmental variables and opilio crab, from the lined net stations. The GAM terms are listed in the order of which they went into the model. **Response: CPUE #/ha**. Significant values are in bold.

GAM Terms	Smoothing Term	Residual deviance	Cp	DF	F	*P*
Bottom Temperature	linear	19.66	27.52	10		
Bottom Temperature + Bottom Depth	linear	7.89	19.68	9	**13.42**	**0.005**
Bottom Temperature + Bottom Depth + Longitude	linear	5.64	12.65	8	3.20	0.11

Table 42. **Results for opilio crab, lined net.** Results of GAM between environmental variables and opilio crab, from the lined net stations. The GAM terms are listed in the order of which they went into the model. **Response: CPUE kg/ha**. Significant values are in bold.

GAM Terms	Smoothing Term	Residual deviance	Cp	DF	F	*P*
Bottom Depth	linear	23.73	33.22	10		
Bottom Depth + Bottom Temperature	linear	10.20	24.44	9	**11.94**	**0.007**
Bottom Depth + Bottom Temperature + Longitude	linear	10.19	19.26	8	0.007	0.93

Results for all fish species – unlined net

Linear regression and generalized additive model (GAM).

CPUE #/ha

CPUE #/ha was significantly correlated with temperature difference (*P* = 0.01), and the correlation was negative (Figure 58 and Table 43). The Cook's Distance on an outlier was greater than 2.0, indicating that there is a high leverage data point or points. After removing the outlier, the relationship between CPUE #/ha and temperature difference becomes non-significant (*P* = 0.28). In Figure 59, the high leverage data point is circled in red.

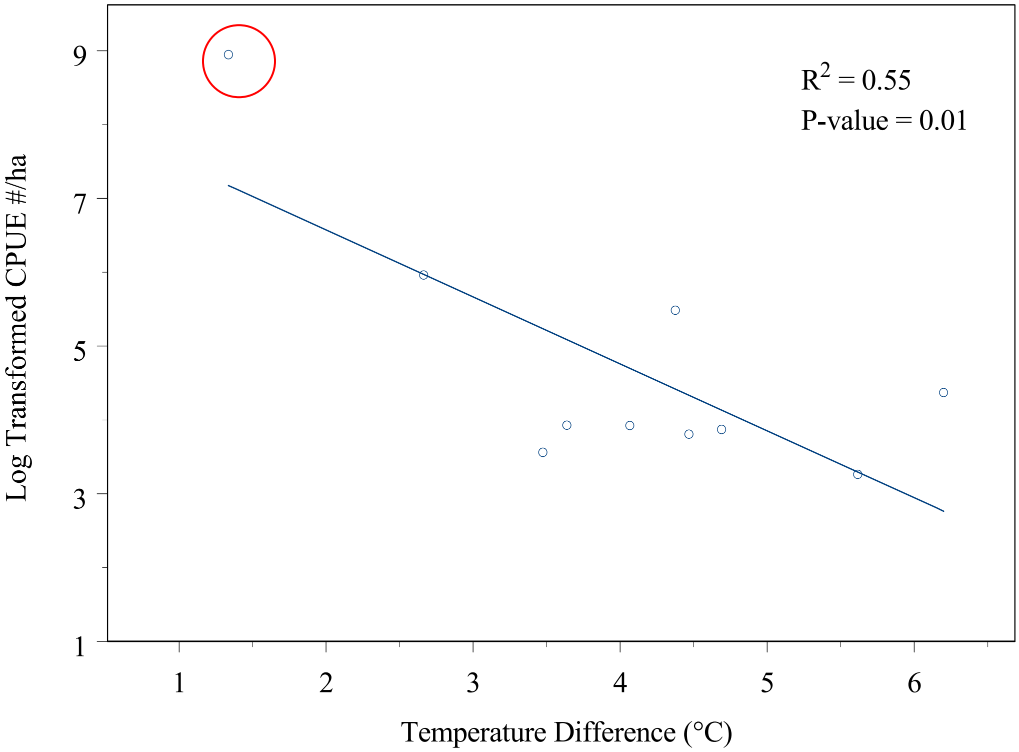


Figure 58. All fish species log transformed CPUE #/ha and temperature difference (°C), unlined net. Note: when removing the data point circled in red (high Cooks' Distance), the relationship becomes non-significant.

Despite the presence of a potential outlier, all data points were used for the GAM analysis because of the low sample size (n=10). Due to the many correlations between independent variables (Table 43), only two rather than three term GAM models were possible. The two GAM terms used in the analysis for CPUE #/ha, in order, were temperature difference with the lowest *P*-value from the linear regression (*P* = 0.01) and longitude with the *P* = 0.74 from the linear regression. Although density difference and salinity difference had lower *P*-values than longitude, those variables are correlated with temperature difference. A linear b-spline smoother was used for both terms. The residual deviance was slightly lowered with the addition of longitude, however, the Cp value increased and the relationship was non-significant (*F* = 0.50, *P* = 0.51; Table 44).

CPUE kg/ha

CPUE kg/ha was significantly correlated with temperature difference (*P* = 0.01) and the correlation was negative (Figure 59 and Table 43). The Cook's Distance on an outlier was greater than 2.0, indicating that there is a high leverage data point or points. After removing the outlier, the relationship between CPUE kg/ha and the independent variable, temperature difference, becomes non-significant (*P* = 0.28). In Figure 60, the high leverage data point is circled in red.

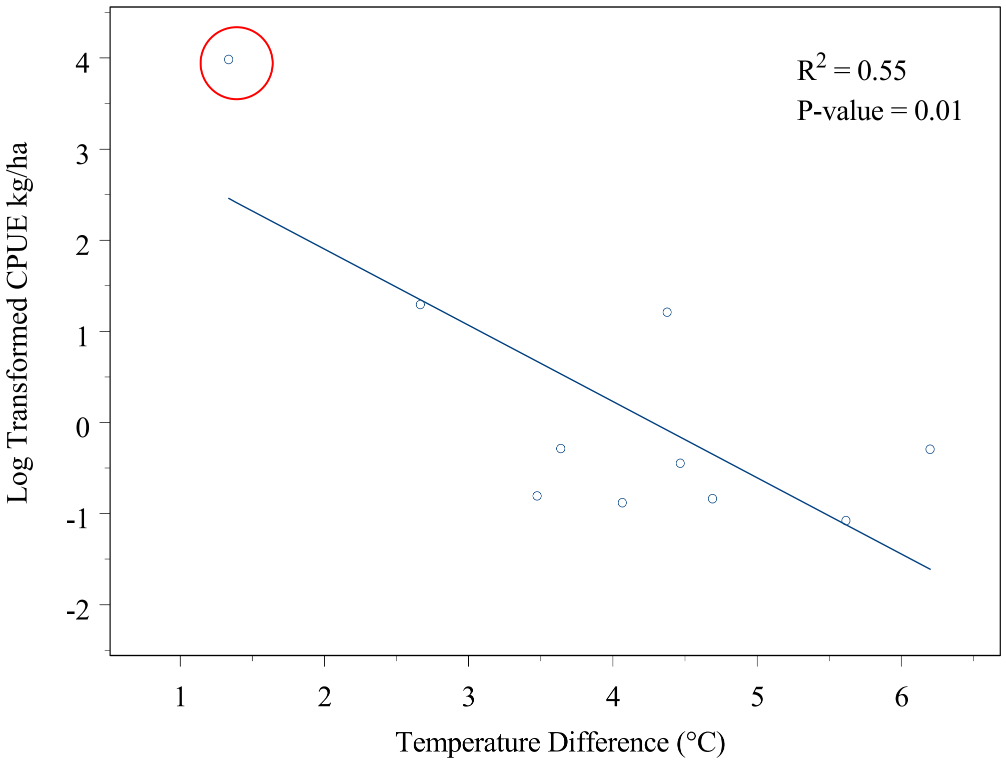


Figure 59. All fish species log transformed CPUE kg/ha and temperature difference (°C), unlined net. The relationship is significant and negatively correlated, CPUE kg/ha decreasing with increasing temperature difference (stratification). Note: when removing the data point circles in red (high Cook's Distance), the relationship becomes non-significant.

Despite the presence of a potential outlier, all data points were used for the GAM analysis because of the low sample size (n=10). Due to the many correlations between independent variables, only two rather than three term GAM models were possible. The two terms in the

GAM model were, in order, temperature difference, with the lowest *P*-value from the linear regression ($P = 0.01$) and longitude, with the $P = 0.82$ from the linear regression. Although density difference and salinity difference had lower *P*-value than longitude, those variables are correlated with temperature difference. A linear b-spline smoother was used for both terms. The GAM model was not significant ($F = 0.23$, $P = 0.65$), even though the residual deviance decreased, the Cp value increased (Table 45).

Table 43. **Results for all fish species, unlined net.** Results of linear regression between environmental variables and all fish species combined, from the unlined net stations. Data were log transformed, CPUE #/ha and CPUE kg/ha. R^2 and *P*-values for each regression are shown. Significant *P*-values and the corresponding R^2 are in bold designating if it is a positive (+) or negative (-) correlation. Results below include all data points. Variables shaded in gray are correlated; the variables shaded in light green are also correlated with one another. In addition, longitude is correlated with salinity and density difference and temperature difference is correlated with density difference.

All Fish Species Unlined Net	Longitude (decimal degrees)	Bottom Temperature (°C)	Temperature Difference (°C)	Bottom Salinity (psu)	Bottom Density (sigma-t)	Salinity Difference (psu)	Density Difference (sigma-t)
CPUE #/ha – R^2	0.01	0.07	**0.55 (-)**	<0.01	<0.01	0.03	0.04
CPUE #/ha – *P*-value	0.74	0.47	**0.01**	0.86	0.80	0.65	0.57
CPUE kg/ha – R^2	<0.01	0.05	**0.55 (-)**	<0.01	<0.01	0.02	0.03
CPUE kg/ha – *P*-value	0.82	0.56	**0.01**	0.97	0.91	0.69	0.61

Table 44. **Results for all fish species, unlined net.** Results of GAM between environmental variables and all fish species, from the unlined net station. The GAM terms are listed in the order of which they went into the model. **Response: CPUE #/ha**. Significant values are in bold.

GAM Terms	Smoothing Term	Residual deviance	Cp	DF	F	*P*
Temperature Difference	b-spline linear	3.83	7.11	7		
Temperature Difference + Longitude	b-spline linear	3.53	7.91	6	0.50	0.51

Table 45. **Results for all fish species, unlined net.** Results of GAM between environmental variables and all fish species, from the unlined net station. The GAM terms are listed in the order of which they went into the model. **Response: CPUE kg/ha**. Significant values are in bold.

GAM Terms	Smoothing Term	Residual deviance	Cp	DF	F	*P*
Temperature Difference	b-spline linear	4.07	7.56	7		
Temperature Difference + Longitude	b-spline linear	3.92	8.57	6	0.23	0.65

Results for all invertebrate species – unlined net

There were no significant linear relationships between environmental variables and CPUE kg/ha of all invertebrate species combined, at the unlined net stations (Table 46). CPUE #/ha was not analyzed because not all invertebrate taxa were practical to innumerate. We used GAM to explore nonlinear relationships between CPUE kg/ha and the non-correlated independent variables; however, there were no significant relationships.

Table 46. **Results for all invertebrate species, unlined net.** Results of linear regression between environmental variables and all invertebrate species combined, from the unlined net stations. Data were log transformed, unlined nets, shown by CPUE #/ha and CPUE kg/ha, R^2 and *P*-values for each variable. Significant *P*-values and the corresponding R^2 are in bold designating if it is a positive (+) or negative (-) correlation. Variables shaded in gray are correlated; the variables shaded in light green are also correlated with one another. In addition, longitude is correlated with salinity and density difference and temperature difference is correlated with density difference.

All Invertebrate Species Unlined Net	Longitude (decimal degrees)	Bottom Temperature (°C)	Temperature Difference (°C)	Bottom Salinity (psu)	Bottom Density (sigma-t)	Salinity Difference (psu)	Density Difference (sigma-t)
CPUE kg/ha – R^2	< 0.01	0.03	0.10	0.04	0.03	0.03	0.02
CPUE kg/ha – *P*-value	1.00	0.64	0.38	0.60	0.64	0.64	0.70

Results for Arctic cod – unlined net

Linear regression and generalized additive model (GAM)

CPUE #/ha

There was a significant correlation between CPUE #/ha and temperature difference (*P* = 0.05), and the correlation was negative (Figure 60 and Table 47). The Cook's Distance on one data point (Figure 61, circled in red) exceeded 2.0 using the log transformed data. After removing this one data point (i.e. outlier), the relationship becomes non-significant (*P* = 0.63).

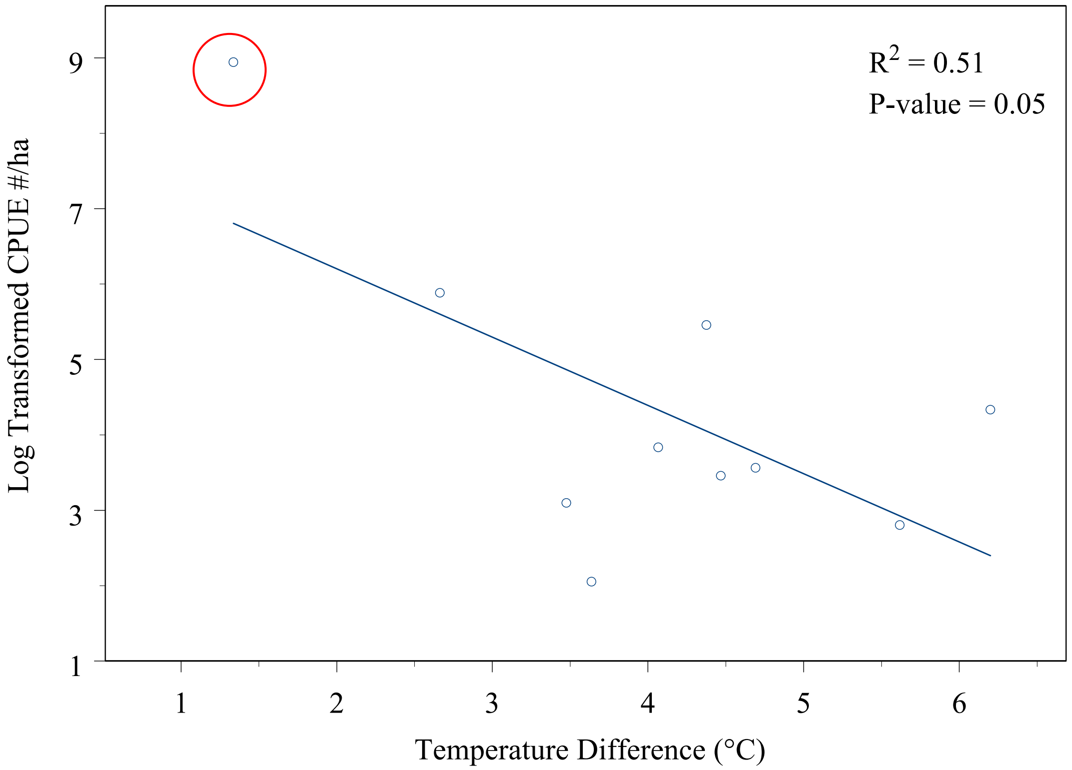


Figure 60. Arctic cod log transformed CPUE #/ha and temperature difference (°C), unlined net. Note: when removing the data point circled in red (high Cooks' Distance), the relationship becomes non-significant.

Despite the presence of a potential outlier, all data points were used for the GAM analysis because of the low sample size (n=10). Due to the many correlations between independent variables, only two rather than three term GAM models were possible. The two terms in the CPUE #/ha GAM model, in order, were temperature difference with the lowest *P*-value from the linear regression (*P* = 0.05) and longitude with the next lowest *P*-value from the linear regression (*P* = 0.51). Although bottom temperature had a lower *P*-value than longitude, this variable was correlated with temperature difference. A linear b-spline smoother was used for temperature difference and a linear smoother was used for longitude. The residual deviance decreased with the addition of the second term but the Cp value increased (Table 48). The GAM model did not significantly explain the variance (*F* = 0.66, *P* = 0.62).

CPUE kg/ha

Temperature difference was negatively correlated with CPUE kg/ha (*P* = 0.05; Figure 61 and Table 47). The Cook's Distance on one observation exceeded 2.0 and when this data point was removed, the significant level dropped (*P* = 0.62), becoming a non-significant correlation.

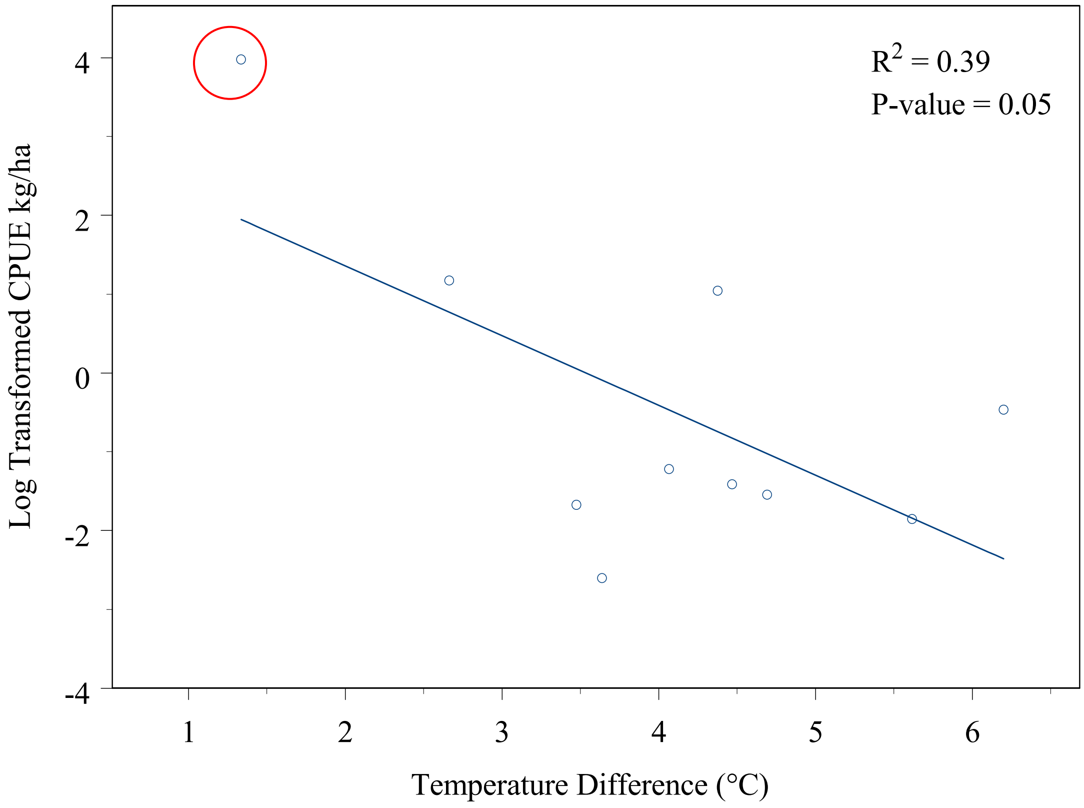


Figure 61. Arctic cod log transformed CPUE kg/ha and temperature difference (°C), unlined net. Note: when removing the data point circled in red (high Cooks' Distance), the relationship becomes non-significant.

Despite the presence of a potential outlier, all data points were used for the GAM analysis because of the low sample size (n=10). Due to the many correlations between independent variables, only two rather than three term GAM models were possible. The two terms in the CPUE kg/ha GAM model, in order, were temperature difference with the lowest *P*-value from the linear regression (*P* = 0.05) and longitude with the next lowest *P*-value from the linear regression (*P* = 0.48). Although bottom temperature had a lower *P*-value than longitude, this variable was correlated with temperature difference. A linear b-spline smoother was used for temperature difference and a linear smoother was used for longitude Similar to CPUE #/ha, the residual deviance decreased but the Cp value increased with the addition of the second term (Table 49), and the GAM was not significant in accounting for the variance observed (*F* = 1.51, *P* = 0.27).

Table 47. **Results for Arctic cod, unlined net.** Results of linear regression between environmental variables and Arctic cod, from the unlined net stations. Data were log transformed, CPUE #/ha and CPUE kg/ha. R^2 and *P*-values for each regression are shown. Significant *P*-values and the corresponding R^2 are in bold designating if it is a positive (+) or negative (-) correlation. Results below include all data points. Variables shaded in gray are correlated; the variables shaded in light green are also correlated with one. In addition, longitude is correlated with salinity and density difference and temperature difference is correlated with density difference.

Arctic cod Unlined Net	Longitude (decimal degrees)	Bottom Temperature (°C)	Temperature Difference (°C)	Bottom Salinity (psu)	Bottom Density (sigma-t)	Salinity Difference (psu)	Density Difference (sigma-t)
CPUE #/ha – R^2	0.06	0.10	**0.51 (-)**	<0.01	<0.01	<0.01	<0.01
CPUE #/ha – *P*-value	0.51	0.38	**0.05**	0.92	0.97	0.97	0.88
CPUE kg/ha – R^2	0.06	0.08	**0.39 (-)**	0.01	0.01	<0.01	<0.01
CPUE kg/ha – *P*-value	0.48	0.44	**0.05**	0.79	0.84	0.94	0.98

Table 48. **Results for Arctic cod, unlined net.** Results of GAM between environmental variables and Arctic cod, from the unlined net station. The GAM terms are listed in the order of which they went into the model. **Response: CPUE #/ha**. Significant values are in bold.

GAM Terms	Smoothing Term	Residual deviance	Cp	DF	F	*P*
Temperature Difference	b-spline linear	11.64	21.61	7		
Temperature Difference + Longitude	linear	9.44	22.74	6	0.66	0.62

Table 49. **Results for Arctic cod, unlined net.** Results of GAM between environmental variables and Arctic cod, from the unlined net station. The GAM terms are listed in the order of which they went into the model. Response: **CPUE kg/ha**. Significant values are in bold.

GAM Terms	Smoothing Term	Residual deviance	Cp	DF	F	*P*
Temperature Difference	b-spline linear	12.94	24.03	7		
Temperature Difference + Longitude	linear	10.34	25.13	6	1.51	0.27

Results for walleye pollock – unlined net

Linear regression and generalized additive model (GAM)

CPUE #/ha
A significant correlation was found between CPUE #/ha and the independent variable, longitude (*P* = 0.07), and the relationship was negative, CPUE #/ha decreasing from west to east in the study area (Figure 62 and Table 50). The salinity and density difference independent variables were also correlated with CPUE #/ha (*P* = 0.08; *P* = 0.10, respectively). The Cook's Distance on the data observations did not exceed 1.0, suggesting there are no outlier data points.

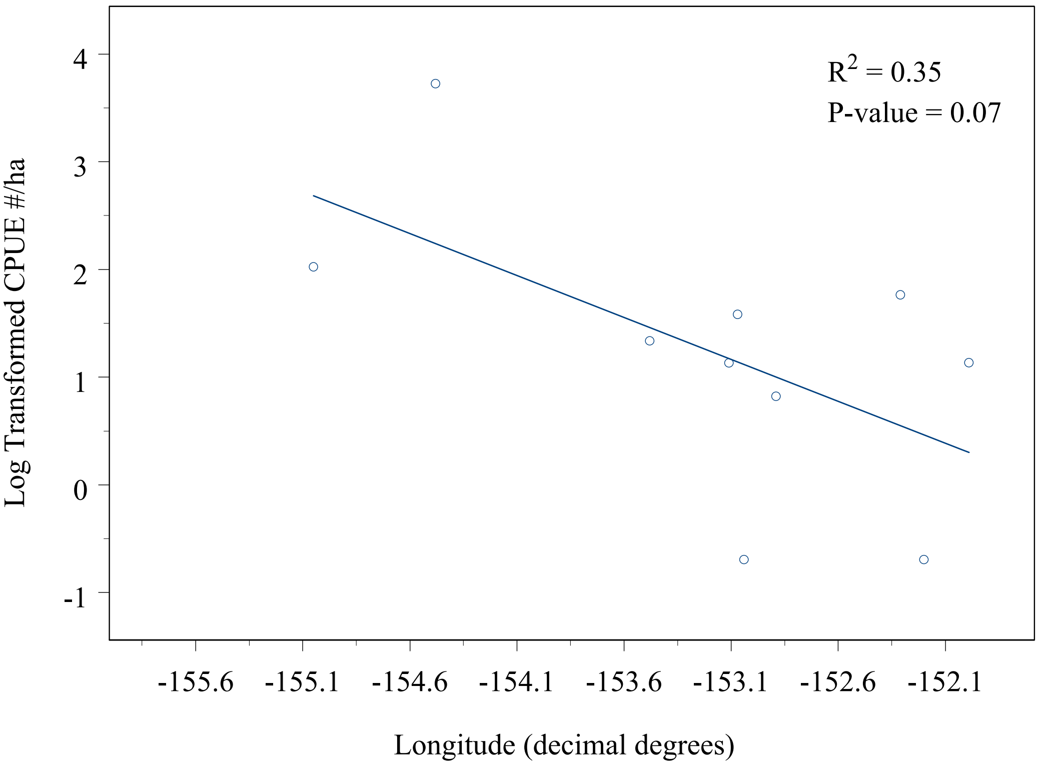


Figure 62. Walleye pollock log transformed CPUE #/ha and longitude (decimal degrees), unlined net.

Because longitude and salinity and density difference were correlated only longitude was used in the GAM analysis. Due to the many correlations between independent variables, only 2 rather than three term GAM models were possible. The two terms in the CPUE #/ha GAM model, in order, were longitude with the lowest *P*-value from the linear regression (*P* = 0.07) and bottom temperature with the one of the next lowest *P*-value from the linear regression (*P* = 0.51). Bottom salinity and density were not chosen for the GAM because they were correlatied with salinity and density differences which were in turn correlated with longitude. A linear smoother was used for both terms in the GAM. The residual deviance decreased but the Cp value increased (Table 51), and the GAM model was not significant (*F* = 1.36, *P* = 0.28)

CPUE kg/ha

CPUE kg/ha was negatively correlated (*P* = 0.06) with longitude, CPUE decreasing from west to east in the study area (Figure 63 and Table 50). The Cook's Distance on a log transformed data observation exceeded 1.0, indicating it was an outlier (Figure 64). When that observation was removed the relationship became non-significant (*P* = 0.17).

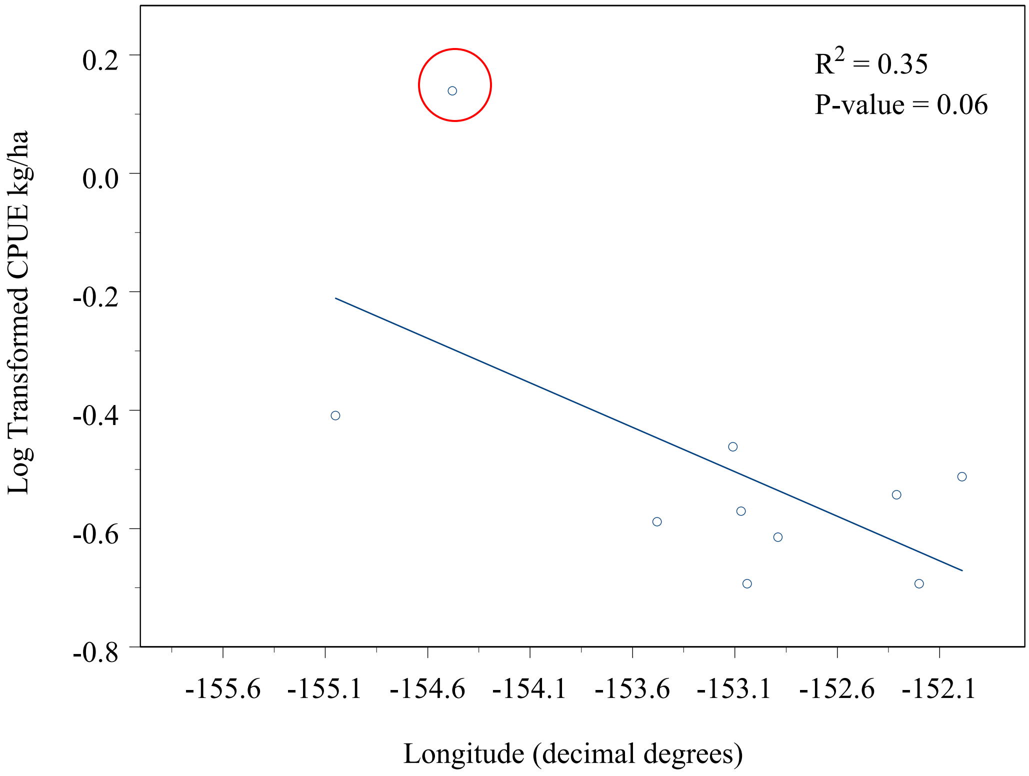


Figure 63. Walleye pollock log transformed CPUE kg/ha and longitude (decimal degrees), unlined net. Note: when removing the data point circled in red (high Cooks' Distance), the relationship becomes non-significant.

Despite the presence of a potential outlier, all data points were used for the GAM analysis because of the low sample size (n=10). Due to the many correlations between independent variables, only two rather than three term GAM models were possible. The two terms in the CPUE kg/ha GAM model, in order, were also longitude with the lowest *P*-value from the linear regression (*P* = 0.06) and bottom temperature with one of the next lowest *P*-value from the linear regression (*P* = 0.43). None of the salinity or density variables were used in the GAM because they are correlated with each other and with longitude. A linear smoother was used for both terms in the GAM. The residual deviance stayed the same with the addition of longitude, but the Cp increased (Table 52). The GAM was not significant (*F = 2.02*, *P = 0.20*).

Table 50. **Results for walleye pollock, unlined net.** Results of linear regression between environmental variables and walleye pollock, from the unlined net stations, CPUE #/ha and CPUE kg/ha. R^2 and *P*-values for each regression are shown. Significant *P*-values and the corresponding R^2 are in bold designating if it is a positive (+) or negative (-) correlation. Variables shaded in gray are correlated; the variables shaded in light green are also correlated with one another. In addition, longitude is correlated with salinity and density difference and temperature difference is correlated with density difference.

Pollock Unlined Net	Longitude (decimal degrees)	Bottom Temperature (°C)	Temperature Difference (°C)	Bottom Salinity (psu)	Bottom Density (sigma-t)	Salinity Difference (psu)	Density Difference (sigma-t)
CPUE #/ha – R^2	**0.35 (-)**	0.06	0.03	0.18	0.16	**0.34 (-)**	**0.31 (-)**
CPUE #/ha – *P*-value	**0.07**	0.51	0.63	0.23	0.24	**0.08**	**0.10**
CPUE kg/ha – R^2	**0.37 (-)**	0.08	<0.01	0.12	0.14	0.29	0.27
CPUE kg/ha – *P*-value	**0.06**	0.43	0.99	0.32	0.23	0.11	0.13

Table 51. **Results for walleye pollock, unlined net.** Results of GAM between environmental variables and walleye pollock, from the unlined net stations. The GAM terms are listed in the order of which they went into the model. Response: **CPUE #/ha**. Significant values are in bold.

GAM Terms	Smoothing Term	Residual deviance	Cp	DF	F	P
Longitude	linear	9.67	14.51	8		
Longitude + Bottom Temperature	linear	8.1	15.36	7	1.36	0.28

Table 52. **Results for walleye pollock, unlined net.** Results of GAM between environmental variables and walleye pollock, from the unlined net stations. The GAM terms are listed in the order of which they went into the model. **Response: CPUE kg/ha**. Significant values are in bold.

GAM Terms	Smoothing Term	Residual deviance	Cp	DF	F	P
Longitude	linear	0.33	0.49	8		
Longitude + Bottom Temperature	linear	0.25	0.50	7	2.02	0.20

Results for all eelpouts – unlined net

Generalized linear model (GLM)

The GLM analysis showed that none of the independent variables alone were significantly correlated with the presence/absence of eelpouts (Table 53). However, the two independent variables, bottom temperature and longitude, together explained approximately 38% of the variance in the presence or absence of eelpouts, unlined net, in the survey area ($F = 5.68$, $P = 0.05$). The null deviance was 6.931 and residual deviance with both bottom depth and longitude was 4.0.

Table 53. **Results for all eelpouts, unlined net.** Results of Generalized Linear Models (GLM) of environmental variables and all eelpouts, from the unlined net stations. The dependent variable is species presence/absence (not CPUE). Model significance compares the residual deviance for each variable to the null deviance and reports a t-value. Numbers in bold are significant. All variables in shaded gray are correlated; the variables shaded in light green are also correlated with one another. In addition, longitude is correlated with salinity and density difference and temperature difference is correlated with density difference.

Eelpouts (several species combined) Presence / Absence	Longitude (decimal degrees)	Bottom Temperature (°C)	Temperature Difference (°C)	Bottom Salinity (psu)	Density (sigma-t)	Salinity Difference (psu)	Density Difference (sigma-t)
Residual Deviance (Null Deviance: 6.931)	5.317	6.793	6.080	6.790	6.822	6.562	6.656
F statistic	3.19	0.22	1.34	0.22	0.17	0.59	0.44
P-value	0.11	0.65	0.28	0.65	0.69	0.46	0.53

Results for all sculpins – unlined net

Linear regression and generalized additive model (GAM)

CPUE #/ha

CPUE #/ha was significantly correlated with temperature difference (*P* = 0.07 and Table 54); the relationship was negative, CPUE #/ha decreasing with increasing temperature difference (more stratification) (Figure 64 and Table 54). Density difference was also correlated with CPUE #/ha, however, this is most likely due to density difference and temperature difference being correlated.

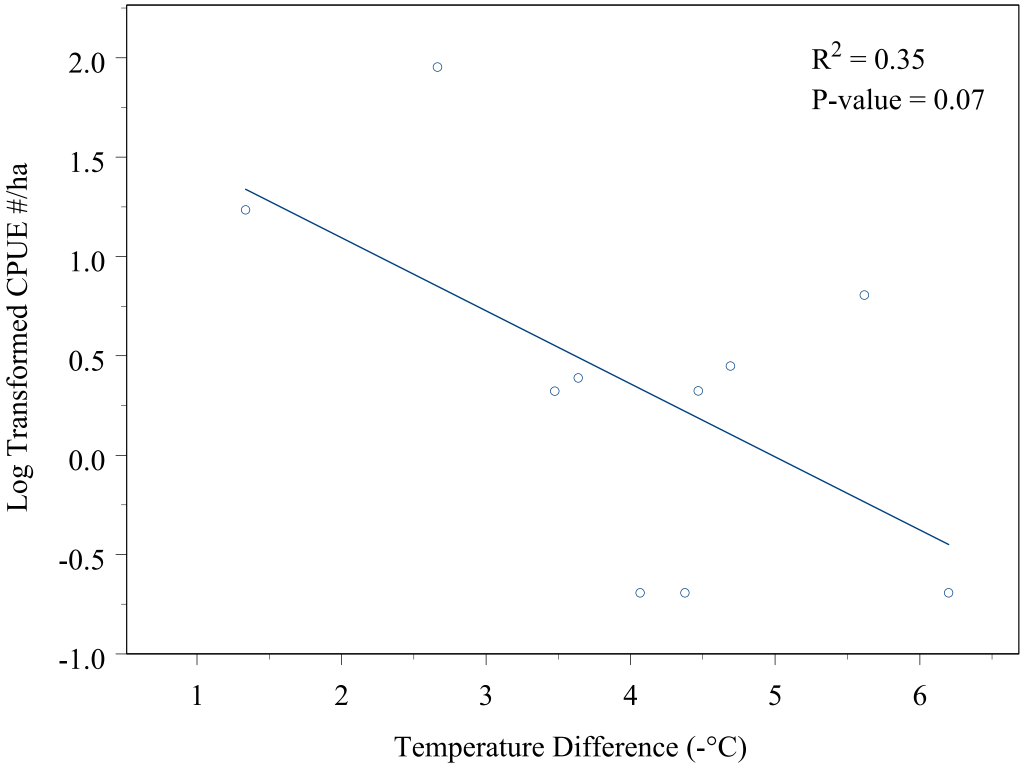


Figure 64. All sculpins log transformed CPUE #/ha and temperature difference (°C), unlined net.

The two GAM terms, in order, are temperature difference with the lowest *P*-value from the linear regression (*P* = 0.07) and salinity difference with one of the next lowest *P*-value from the linear regression (*P* = 0.11). Although density difference had a lower *P*-value, this variable was correlated with temperature difference. A linear smoother was used for both terms. Due to the many correlations between independent variables, only two rather than three term GAM models were possible. The residual deviance decreased with the addition of bottom salinity but the Cp value increased (Table 55). The GAM model was not significant (*F = 0.17*, *P = 0.70*).

CPUE kg/ha

There were no significant relationships between CPUE kg/ha and any of the environmental variables.

Table 54. **Results for all sculpins, unlined net.** Results of linear regression between environmental variables and all sculpins, from the unlined net stations, CPUE #/ha and CPUE kg/ha. R^2 and *P*-values for each regression are shown. Significant *P*-values and the corresponding R^2 are in bold designating if it is a positive (+) or negative (-) correlation. Variables shaded in gray are correlated; the variables shaded in light green are also correlated with one another. In addition, longitude is correlated with salinity and density difference and temperature difference is correlated with density difference.

Sculpins (several species combined) Unlined Net	Longitude (decimal degrees)	Bottom Temperature (°C)	Temperature Difference (°C)	Bottom Salinity (psu)	Density (sigma-t)	Salinity Difference (psu)	Density Difference (sigma-t)
CPUE #/ha – R^2	<0.01	<0.01	**0.35 (-)**	0.15	0.16	0.29	**0.32 (-)**
CPUE #/ha – *P*-value	0.98	0.97	**0.07**	0.23	0.26	0.11	**0.09**
CPUE kg/ha – R^2	<0.01	0.02	0.24	0.04	0.04	0.19	0.20
CPUE kg/ha – *P*-value	0.83	0.74	0.15	0.59	0.56	0.21	0.19

Table 55. **Results for all sculpins, unlined net.** Results of GAM between environmental variables and all sculpins, from the unlined net stations. The GAM terms are listed in the order of which they went into the model. **Response: CPUE #/ha**. Significant values are in bold.

GAM Terms	Smoothing Term	Residual deviance	Cp	DF	F	*P*
Temperature Difference	linear	4.46	6.69	8		
Temperature Difference + Salinity Difference	linear	3.97	7.31	7	0.87	0.38

Results for opilio crab – unlined net

Linear regression and generalized additive model (GAM)

CPUE #/ha
There were no correlations between CPUE #/ha and any of the environmental variables.

CPUE kg/ha
There were positive correlations between CPUE kg/ha and bottom salinity (*P* = 0.04) and bottom density (*P* = 0.05) (Figure 65 and Table 56). The Cook's Distance on one observation exceeded 1.0, indicating it was an outlier (Figure 66). When the data point was removed, the relationship became non-significant for both bottom salinity (*P* = 0.62) and bottom density (*P* = 0.61).

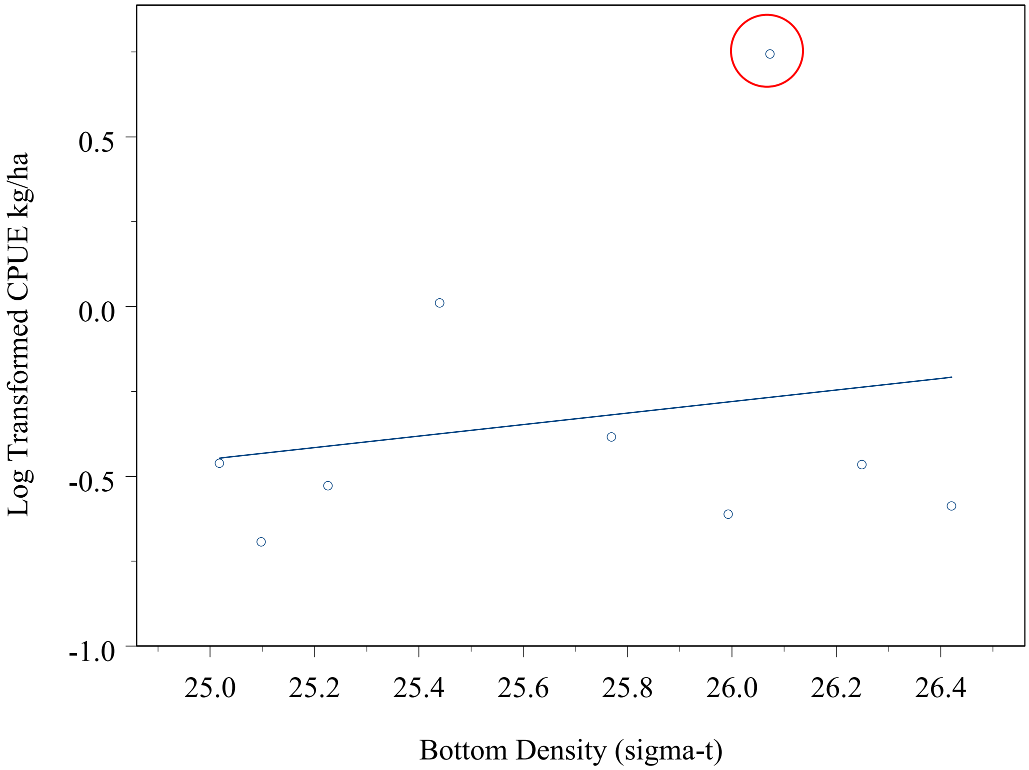


Figure 65. Opilio crab log transformed CPUE kg/ha and bottom density (sigma-t), unlined net. Note: when removing the data point circled in red (high Cooks' Distance), the relationship becomes non-significant

Despite the presence of a potential outliers, all data points were used for the GAM analysis because of the low sample size (n=10). Due to the many correlations between independent variables, only two rather than three term GAM models were possible. The two terms in the GAM model, in order, were bottom salinity with the lowest *P*-value from the linear regression (*P* = 0.04) and longitude with the one of the next lowest *P*-values from the linear regression (*P* =

0.47) (linear). Because bottom salinity and bottom density were correlated only one of the two variables was used in the GAM. Similarly salinity difference and density difference were not chosen for the second term because they were correlated with bottom salinity and density. Both the residual deviance and Cp values decreased with the addition of the second term (Table 57). The GAM model was significant (*F* = 12.66, *P* = 0.01).

Table 56. **Results for opilio crab, unlined net.** Results of linear regression between environmental variables and opilio crab, from the unlined net stations, CPUE #/ha and CPUE kg/ha. R^2 and *P*-values for each regression are shown. Significant *P*-values and the corresponding R^2 are in bold designating if it is a positive (+) or negative (-) correlation. Variables shaded in gray are correlated; the variables shaded in light green are also correlated with one another. In addition, longitude is correlated with salinity and density difference and temperature difference is correlated with density difference.

Opilio crab Unlined Net	Longitude (decimal degrees)	Bottom Temperature (°C)	Temperature Difference (°C)	Bottom Salinity (psu)	Bottom Density (sigma-t)	Salinity Difference (psu)	Density Difference (sigma-t)
CPUE #/ha – R^2	0.19	<0.01	0.11	0.20	0.20	0.06	0.08
CPUE #/ha – *P*-value	0.21	0.89	0.34	0.19	0.20	0.48	0.44
CPUE kg/ha – R^2	0.07	<0.01	0.03	**0.42 (+)**	**0.40 (+)**	0.16	0.16
CPUE kg/ha – *P*-value	0.47	0.79	0.65	**0.04**	**0.05**	0.26	0.26

Table 57. **Results for opilio crab, unlined net.** Results of GAM between environmental variables and opilio crab, from the unlined net stations. The GAM terms are listed in the order of which they went into the model. **Response: CPUE kg/ha**. Significant values are in bold.

GAM Terms	Smoothing Term	Residual deviance	Cp	DF	F	P
Bottom Salinity	linear	1.56	2.45	7		
Bottom Salinity + Longitude	linear	0.50	1.84	6	**12.66**	**0.01**

Pelagic fish habitat associations

For young-of-the-year (YOY) fish and yearling-and-older (year-plus) Arctic cod, we tested both biological and standard oceanographic predictors. YOY fish density was not related to any biological oceanographic parameters under the linear or GAM model scenarios (Table 58). Using standard predictors, five variables were significant (bottom temperature, bottom salinity, salinity difference, density, and density difference) in the GAM model (Table 58), but there were concerns about this dataset given heterogeneous variance that was unimproved by data transformation.

Year-plus Arctic cod models run with biological predictors provided different results depending on whether zero values were included for nearshore areas where year-plus estimates were not made. When zero values were included, the general linear model found no significant biological predictors of year-plus Arctic cod density (Table 59) and the GAM found a significant relationship with only temperature below the mixed layer depth (Table 59). When zero values were excluded, the linear model suggested a significant relationship between year-plus Arctic cod density and bottom depth, mixed layer depth (MLD), mean temperature below the MLD, and mean salinity below the MLD (Table 59). Using standard predictors, the general linear model found no significant standard predictors of year-plus Arctic cod density when zero values were excluded (Table 59). The GAM found a significant relationship with bottom temperature and salinity difference (Table 59) but there were concerns about data variance that could not be normalized by data transformation. When zero values were removed, the general linear model found no relationship between year-plus Arctic cod density and the standard predictors (Table 59). Due to the low sample size (n=10) relative to the number of predictors (n=8), it was not appropriate to run the GAM on the zero -excluded datasets.

Table 58. Model fits for YOY density versus oceanographic parameters. ***n*** is the number of data points, **Predictor** refers to the "biological" or "standard" oceanographic variables listed in the text (* denotes a significant relationship), **F** is the F statistic for the model, *df* are the number of degrees of freedom for the F distribution (# parameters, remaining degrees of freedom for test), ***P*** is the p-value for the model fit, $_{Adj.}R^2$ is the fit to the model accounting for the number of predictors in the model, and **Relationship** is the model that was used and/or comments on the fit.

Response variable	*n*	Predictor	F	df	*P*	$_{Adj.}R^2$	Relationship
YOY Density *Biological predictors*	19	Mean.Temperature.below.MLD	2.597	1,17	0.13	0.08	Linear model Lowest AIC
YOY Density *Biological predictors*	19	log(Bottom.Depth) Mixed.Layer.Depth log(Depth.N.2.max) Mean.Temperature.above.MLD Mean.Salinity.above.MLD Mean.Temperature.below.MLD Mean.Salinity.below.MLD Longitude			> 0.05	0.38	GAM
YOY Density *Standard predictors*	19	log(Bottom.Depth)		1,17	0.16	0.06	Linear model Lowest AIC
YOY Density *Standard predictors*	19	Longitude				0.37	GAM
		Bottom.Temperature*			0.04		
		Delta.Surface.Bottom.Temperature					
		Bottom.Depth					
		Bottom.Salinity*			0.05		
		Delta.Surface.Bottom.Salinity*			0.03		
		Bottom.Sigma.T*			0.04		
		Delta.Surface.Bottom.Density*			0.04		

Table 59. Model fits for YAO density versus oceanographic parameters. ***n*** is the number of data points, **Predictor** refers to the "biological" or "standard" oceanographic variables listed in the text (* denotes a significant relationship), **F** is the F statistic for the model, **df** are the number of degrees of freedom for the F distribution (# parameters, remaining degrees of freedom for test), ***P*** is the p-value for the model fit, $_{Adj.}R^2$ is the fit to the model accounting for the number of predictors in the model, and **Relationship** is the model that was used and/or comments on the fit.

Response variable	*n*	Predictor	F	df	*P*	$_{Adj.}R^2$	Relationship
YAO Density	19	log(Bottom.Depth)			> 0.05	0.32	General linear model
Includes 0 values		Mixed.Layer.Depth					Quasipoisson
Biological predictors		log(Depth.N.2.max)					AIC cannot be used
		Mean.Temperature.above.MLD					
		Mean.Salinity.above.MLD					
		Mean.Temperature.below.MLD					
		Mean.Salinity.below.MLD					
		Longitude					
YAO	19	log(Bottom.Depth)				0.42	GAM
Includes 0 values		Mixed.Layer.Depth					
Biological predictors		log(Depth.N.2.max)					
		Mean.Temperature.above.MLD					
		Mean.Salinity.above.MLD					
		Mean.Temperature.below.MLD*			0.04		Concave, max at ~2ºC
		Mean.Salinity.below.MLD					
		Longitude					
YAO	10	Bottom.Depth*	16.12	4,5	0	0.87	General linear model
Excludes 0 values		Mixed.Layer.Depth*					Lowest AIC
Biological predictors		Mean.Temperature.below.MLD*					
		Mean.Salinity.below.MLD*					

Table 59 cont.- Model fits for YAO density versus oceanographic parameters. ***n*** is the number of data points, **Predictor** refers to the "biological" or "standard" oceanographic variables listed in the text (* denotes a significant relationship), **F** is the F statistic for the model, **df** are the number of degrees of freedom for the F distribution (# parameters, remaining degrees of freedom for test), ***P*** is the p-value for the model fit, $_{Adj.}R^2$ is the fit to the model accounting for the number of predictors in the model, and **Relationship** is the model that was used and/or comments on the fit.

Response variable	*n*	Predictor	F	df	*P*	$_{Adj.}R^2$	Relationship
YAO Density	19	Longitude			> 0.05	0.29	General linear model
Includes 0 values		Bottom.Temperature					Lowest AIC
Standard predictors		Delta.Surface.Bottom.Temperature					
		Bottom.Depth					
		Bottom.Salinity					
		Delta.Surface.Bottom.Salinity					
		Bottom.Sigma.T					
		Delta.Surface.Bottom.Density					
YAO Density	19	Longitude				0.68	GAM
Includes 0 values		Bottom.Temperature*			0.02		
Standard predictors		Delta.Surface.Bottom.Temperature					
		Bottom.Depth					
		Bottom.Salinity					
		Delta.Surface.Bottom.Salinity*			0.01		
		Bottom.Sigma.T					
		Delta.Surface.Bottom.Density					
YAO	10	Longitude	10.1	8,1	0.24		General linear model
Excludes 0 values		Bottom.Temperature					Lowest AIC
Standard predictors		Delta.Surface.Bottom.Temperature					
		Bottom.Depth					
		Bottom.Salinity					
		Delta.Surface.Bottom.Salinity					
		Bottom.Sigma.T					
		Delta.Surface.Bottom.Density					

Discussion

Our 2008 survey was the first dedicated survey of the offshore marine fish and invertebrates of the Beaufort Sea. The most recent previous offshore survey of any kind was an opportunistic bottom trawl survey conducted in 1976-77 (Frost and Lowry 1983). Our survey was thus a pilot survey to provide recommendations for future monitoring methods in addition to baseline data against which to compare future anthropogenic and climate impacts. Because it was a pilot survey, different techniques were employed to assess fish abundance. It is important to note that density, abundance, and biomass estimates from the bottom trawl and acoustic/midwater trawl surveys targeted different sections of the water column, used different sampling gears, and followed disparate sampling strategies and analytic paths.

Demersal fish and benthic invertebrates

We report fish density (catch-per-unit-effort, CPUE) and abundance by depth but not for all depths combined. This is because, by coincidence, the deeper depth (100-500 m) was sampled with the lined 3.8 cm (1.5") mesh net and the shallower depth (40- 100 m) was sampled primarily with the unlined net with 10.16 cm (4") mesh in the wings and body and 8.89 cm (3.5") mesh in the sidewings. The gear type was changed because all the lined nets were damaged by the time the ice cleared out of the survey area and we could access the shallower waters. A qualitative comparison of CPUE for all lined vs. unlined trawls does show that both the total volume of fauna captured and the number of species observed was greater for the lined net. However, this pattern could also be due to geographic location (shallow vs. deep strata). As an insight into gear performance, we conducted two sets of paired trawls, one with the lined net and one with the un-lined net in approximately the same location (but separated by several days). The catch was higher for the lined net for both fish and invertebrates, dramatically so for the invertebrates. So, the abundance and density of fish and invertebrates in the deeper 100-500 meter depth is probably biased high, compared to the catch in the shallower 40-100 meter depth.

Not surprisingly, Arctic cod were the most abundant fish caught during this survey, both numerically and by weight. Arctic cod are known to be a major component of the Beaufort Sea fish community and important prey for higher trophic levels such as seabirds (Hobson 1993) and marine mammals (Bradstreet and Cross 1982, Bradstreet et al. 1986, Welch 1992). They are also the dominant consumer of zooplankton (Atkinson and Percy 1992) and are thus an important conduit for secondary production (Welch 1992). One of the earliest documented records of Arctic cod in the Alaskan Beaufort Sea is from 1951 (University of British Columbia, N.J. Wilimovsky, H.A. Fehlmann) and they were the most abundant fish during the 1976-77 opportunistic trawl survey (Frost and Lowry 1983). Previous studies in nearshore, often brackish waters have documented the distribution of Arctic cod (Craig 1984, Craig et al. 1982, Jarvela and Thorsteinson 1999, Moulton and Tarbox 1987), but our study is the first to thoroughly map the distribution of Arctic cod in offshore marine waters. Yearling-and-older (year-plus) Arctic cod were most abundant offshore of the shelf-break (100 m). It is possible that the apparent off-shelf distribution of year-plus demersal Arctic cod was an artifact of bottom trawl net type. However, the acoustic data (confirmed by midwater trawls) similarly showed that year-plus cod were most abundant and widespread off-shelf and three bottom trawls conducted with the lined net on the shelf caught less cod than the offshore trawls.

Arctic cod lengths indicated that most of the fish were likely sub-adults, although there was a second mode of larger, likely adult fish. Analysis of Arctic cod otoliths is underway and will allow us to confirm the age distribution of the fish. Larger Arctic cod were distributed primarily in the deeper depth and the smaller cod primarily in the shallower depth. (Frost and Lowry 1983) documented a similar distribution pattern from their 1976-77 survey. They report that Arctic cod found in water deeper than 100 m had a mean length of 11.4 cm (in this study, fork length was 13.2 cm in the bottom trawl and 10.3 cm in the midwater trawl). Whereas cod in water less than 100 m had a mean length of 8.1 cm (10.2 cm in the bottom trawl and 11.6 cm in the midwater trawl in this study).

Other numerically abundant species in the bottom trawls included eelpouts (seven species) and sculpins (eight species), although sculpins made up a small fraction of the total weight of fish captured. Eelpouts and sculpins were also numerically abundant in the catches from the 1976-77 survey (Frost and Lowry 1983), although there appears to have been a shift in the relative species composition of the two groups of fish. Similar species of eelpouts was found in both the 1976-77 survey and our 2008 survey. However, marbled eelpout (*Lycodes raridens*) was the most abundant during the present survey and Canadian eelpout (*Lycodes polaris*) was the most abundant during the previous survey. Common sculpin species during the 2008 survey were warty sculpin (*Myoxocephalus verrucosus*) and ribbed sculpin (*Triglops pingeli*). The most common sculpin species caught during the 1976-77 survey were twohorn sculpin (*Icelus bicornis*) and spatulate sculpin (*Icelus spatula*). In fact, twohorn sculpin was the second most abundant species overall in the 1976-77 survey and we did not catch any of that species in 2008. It is not impossible that some of these species were mis-identified in the field, however all our species identifications were confirmed by examination of voucher specimens and/or genetic barcoding (J. Orr and D. Stevenson, AFSC; and K. Mecklenburg pers. com.).

The density (CPUE) of eelpouts, from the bottom trawls, was greater offshore of 100 m than inshore. Some of this difference could have been due to the bias resulting from trawling exclusively with the lined net offshore. However, three stations sampled with the lined net inshore showed low CPUE of eelpouts. As eelpouts are found within the 0.5 m acoustic deadzone, no inferences on eelpout inshore-offshore distributions can be made from the pelagic survey. Sculpins are the only group of species that show a distribution pattern that may be unrelated to net type (lined vs. unlined). Nearly all of the trawls in the offshore depth (lined net) had zero catches of sculpins, whereas the inshore depth (unlined net) had catches with a consistently higher CPUE. The expectation is that catches of these small fish would be greater in the lined net, not less. Furthermore, the three stations that were sampled with the lined net inshore had the highest sculpin CPUE.

Agglomerative clustering analysis highlighted five clusters of co-occurring species. Some of these species groups had distinctive inshore vs. offshore distributions. Eelpouts, Bering flounder snailfish, walleye pollock and Greenland turbot co-occurred and this cluster was found only in the deeper depth. These species could co-occur as a result of shared prey or as a result of predator-prey relations. The association of Greenland turbot and walleye pollock is likely a result of the latter. Walleye pollock is the dominant prey of Greenland turbot in the Bering Sea (Lang et al. 2005). The other three species in this cluster (eelpouts, Bering flounder and snailfish) likely co-occur as a result of shared prey. In the Bering Sea, they typically consume benthic invertebrate prey such as shrimp, polychaetes and mysids (Aydin et al. 2008). Unfortunately, food habits data for these species do not exist for the Beaufort Sea region such that further study is needed to confirm these relationships. Clusters in which sculpins were dominant were primarily distributed in the shallow depth. Sculpins of the Arctic burrow into sand and sand-mud bottoms with salinities of 32-35 ppt, sometimes as low as 16-30 ppt, feeding on small benthic amphipods and polychaetes (Fedorov 1986). The nearshore distribution of this cluster, dominated by sculpins, may be driven by a preference for muddy substrate, small benthic prey and a preference/tolerance for low salinity water. More detailed study of substrate type and the distribution of small benthic invertebrates is needed to test this hypothesis. The cluster that was comprised of the only three shallow trawls that occurred with a lined net had the highest diversity of species and occurred only in the western half of the study area. This could be an indication that the areas closer to shore are characterized by a greater diversity of habitat (substrate and prey). However, it is important to note that the spatial distribution of lined vs. unlined trawl stations could have influenced the results, in spite of the fact that the cluster analysis was conducted on species presence/absence data (as opposed to CPUE or catch abundance).

Invertebrates dominated the bottom trawl catches both in terms of abundance and species diversity. The possible inflation of catch due to the lined net was greater for invertebrates than for fish. Notched brittle stars (*Ophiura sarsi*) were the most abundant species captured, followed closely by opilio crab (*Chionoecetes opilio*). In the 1977 survey, notched brittle stars were also reported to be the most abundant invertebrate captured (Frost and Lowry 1983) and dominated the catch west of longitude 154°. The top 24 species in our survey had significantly higher biomass in the offshore depth than the inshore depth, but this could have been an artifact of sampling the offshore depth with the lined net. Interestingly, three of the top 24 species caught in our 2008 survey (*Halocynthia aurantium*, *Pagurus trigonocheirus*, and *Hyas coarctatus*) had higher biomass and CPUE estimates in the 40-100 m depth (unlined net) than in the deeper depth (lined net), indicating habitat differences or depth preference for these species of invertebrates that were independent of the expected bias due to net type.

The size and depth distribution of opilio crab (*Chionoecetes opilio*) were unexpected, based on previous studies in the Bering and Chukchi Seas. In 1990 and 1991, 48 stations were sampled in the northeast Chukchi Sea to examine the distribution and abundance of opilio crab (Paul et al. 1997). Opilio crabs were found at all stations, with the highest abundance and mean crab weight occurring in the stations directly west of Pt. Barrow. However, carapace width of these crabs ranged from 20-74 mm, as compared to the measured opilio crab in our Beaufort survey that ranged from 55-119 mm. Opilio crab were caught in the 1977 Beaufort Sea survey (Frost and Lowry 1983), however, maximum carapace width was 75 mm. The legal minimum carapace width for the commercial opilio crab fishery in the Bering Sea is 78 mm, and the minimum commercially viable width is 101 mm. So, our survey is the first to document opilio crab of commercial size in the North American Arctic. Recently, *Chionoecetes opilio* have been observed in the northeast Atlantic’s Barents Sea (Alvsvåg et al. 2008). Evidence of juveniles below 50 mm carapace width confirms that the population is established and reproductive with adult crabs ranging in size from 50 mm to 136 mm (Alvsvåg et al. 2008). The presence of female crabs with egss during the 2008 Beaufort Sea Survey is further evidence that this population also is reproductive. The main population of crab found in the Barents Sea survey was located in waters less than 2°C, with depth ranges from 80 to 350 m (Alvsvåg et al. 2008). The fact that Frost and Lowry (1983) only caught small opilio crab may be due to the fact that only one tow was made in water deeper than 200 m. We found the highest CPUE and the largest crabs by carapace width and weight in water depths greater than 300 m. This result was also unexpected as surveys in the Bering and Chukchi Seas indicate that opilio crabs are found predominatly in waters less than 200 m in depth.

Changes in the species composition of the fish community since 1977 may have occurred. Bering flounder (*Hippoglossoides robustus*), walleye pollock (*Theragra chalcogramma*), and Pacific cod (*Gadus macrocephalus*) were caught in our 2008 survey but not the earlier Frost and Lowry (1983) survey. These are species that are abundant in the Bering Sea and are commercially valuable. In addition, our 2008 survey was the first to document commercial-sized opilio crab (*Chionoecetes opilio*) in the North American Arctic. Previous surveys caught smaller-sized crab (Barber et al. 1997, Frost and Lowry 1983). We also document or confirm extensions to the known ranges of four species of fish: walleye pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), festive snailfish (*Liparis marmoratus*), and eyeshade sculpin (*Nautichthys pribilovius*). The Chukchi Sea survey in 1990 reported Pacific cod at 3 stations located between 68°N and 69°N. Festive snailfish are a relatively rare species, only 1 specimen has been recorded in the NE Bering Sea near St. Lawrence Island at 63°00'N, 169°20'W (Busby and Chernova 2001). Previous to this record, the species had only been documented in the Sea of Okhotsk. The northernmost record of the eyeshade sculpin previous to our survey was in the north Chukchi Sea, west of Point Barrow (Barber et al. 1997).

We caught walleye pollock as far north as 71°59'N, 154°25'W. The domestic groundfish fishery off Alaska is the largest fishery by volume in the U.S. and walleye pollock make up the dominant portion of that catch (Hiatt et al. 2008). Pollock were recorded as far north as 71°23'N during a 2004 survey of the Chukchi Sea (Mecklenburg et al. 2007) and a specimen was collected at 69°26'N, during a 1990 survey of the Chukchi Sea on the *Ocean Hope III* (unpublished data; cruise 90-2). Two specimens were collected in the Beaufort Sea near the mouth of the Elson lagoon, east of Point Barrow at approximately 71°31'N, 156°32'W in 1951 and 1954 (University of British Columbia: N. J. Wilimovsky, J. E. Bohlke; D. Wohlschlag, and W. C. Freihofer). However, the specimens are missing and identification as walleye pollock is uncertain (K. Mecklenburg, pers.com). We found pollock in moderate densities (compared to other species) throughout the survey area, so if the Elson lagoon samples collected in 1954 were correctly identified as pollock our results confirm the range extension and document that the species may be widespread in the Beaufort Sea. Analysis of pollock otoliths showed that most of the fish caught during our 2008 survey were sub-adults, age 2. In 1990, an ichthyoplankton survey in the Chukchi Sea (Echeverria 1995) found juvenile walleye pollock northwest of Barrow. During the RUSALCA survey of the Chukchi Sea in 2004, Mecklenburg et al. (2007) recorded lengths of pollock ranging from 102-168 mm total length (TL), indicating that these fish were likely sub-adults. So, although pollock are occurring in Arctic seas, fish of spawning age or size have not yet been documented and the origins of the juvenile fish are not known. The fact that the pollock we caught in the Beaufort Sea were smaller at age than pollock in the Bering

Sea may provide evidence that the fish were spawned in cold Arctic waters or were transported into such waters shortly after spawning. The size difference is manifested first at age-2: age-1 pollock from the Bering and Beaufort Seas were similar in size. This lends support to the latter hypothesis, that fish were spawned in north Pacific waters and transported into the Arctic sometime during their first year of life.

The summer of 2007 saw the largest recession of sea ice since recording began (Boe et al. 2009, Greene et al. 2008, Stroeve et al. 2007, Stroeve et al. 2008). Trends of ocean warming and declines in Arctic sea ice increase the potential for the northward migration of fish and invertebrate species. Several factors have contributed to shifts in observed trends in Arctic ice cover over the last few decades. Both lengthened periods of open water, and an increase in sea surface temperatures have contributed to delays in the Arctic autumn and winter ice growth (Stroeve et al. 2007). Longer periods of open water may offer opportunities for a more northerly migration of fish species during the autumn months. Northerly extensions of fish ranges have been predicted to result from ocean warming (IASC 2004, Mueter et al. 2009, Mueter and Litzow 2008). For example, walleye pollock were predicted to expand northward in a warming climate, primarily due to the lessening extent of ice and more favorable temperatures over longer time periods (Strickland and Sibley 1984). Similarly, many Atlantic and North Sea fish communities have shown a northward trend in distributions over the last several decades (Beare et al. 2004, Perry et al. 2005). Despite the potential northward shift in the distribution of some species, the fish community of the Beaufort and Chukchi Seas is still distinct from the Bering Sea. Arctic cod are a dominant component of the Beaufort and Chukchi Sea fish communities, whereas pollock, Pacific cod and flatfish dominate the Bering Sea. We document the presence of pollock and commercial-sized opilio crab in the Beaufort Sea, but their densities are far lower than in the Bering Sea.

Pelagic fish

Although previous acoustic assessments of yearling-and-older (year-plus) Arctic cod have occurred in the both the Canadian and American portions of the Beaufort Sea (Benoit et al. 2008, Crawford and Jorgenson 1996, Crawford and Jorgenson 1993, Moulton and Tarbox 1987), these previous studies have focused primarily on overwintering or schooling fish in semi-protected bays. This study is, to our knowledge, the first systematic, open water assessment of year-plus Arctic cod. This study also appears to be the first summertime systematic assessment of young-of-the-year (YOY) fish including Arctic cod.

The most abundant species observed during the pelagic survey was Arctic cod. With the exception of a few rare species (mostly near-bottom) captured in the midwater trawl, year-plus Arctic cod dominated the pelagic region. Similarly, YOY Arctic cod were captured more frequently and in higher numbers than either YOY fish from the sculpin family, Cottidae, or YOY *Lumpenus* sp., a species of eelblenny. For that reason, we infer that YOY Arctic cod was the dominant YOY species. Both YOY fish and year-plus Arctic cod had identifiable acoustic patterns on echograms that were combined with targeted trawling to classify backscatter in species and age-group categories.

Young-of-the-year fish dominated areas with water depths less than 75 m and were observed in near surface waters throughout the survey area. The observation of high densities along the entire easternmost transect is consistent with YOY presence over the continental shelf as the shelf widened at the eastern end of the survey area. Unidentified sculpins (Cottidae) were more frequently captured in the 40-100 m depth and dominated the single near-surface trawl in the 100-500 m depth. Additional trawling effort in near-surface waters would clarify whether these sculpins are consistently found in the offshore region. Density distribution plots for YOY fish suggested that near-surface densities in the 100-500 m depth may increase from west to east.

Yearling-and-older (year-plus) Arctic cod densities were highest at water depths greater than 100 m, with peak densities occurring at approximately 200 m depth. However, some high year-plus Arctic cod densities were detected in the 40-100 m depth due to the presence of dense year-plus schools. Interestingly, year-plus within these schools had higher mean lengths than year-plus found in layers within the 100-500 m depths. Diet analysis of Arctic cod found in these large schools compared to those found in deeper water would clarify whether they were using the 40-100 m depth to feed on YOY fish. The concentration of year-plus Arctic cod in the vicinity of the shelf break between the 100 and 300 m contours was striking as it coincides with observed foraging patterns by beluga whales (*Delphinapterus leucas*) along the continental slope (Moore 2000, Suydam et al. 2001).

The highest densities of both YOY fish and year-plus Arctic cod were found at the ends of transects (shallow southern end for YOY, deeper northern end for year-plus) and on cross-transects, at depths of 200 – 400 m. This observation suggests that acoustic transects did not extend far enough in either northern or southern directions to capture the entire extent of YOY fish or year-plus Arctic cod distributions. Since nearshore regions may be important nursery habitat for YOY, a dedicated nearshore survey of YOY fish is needed. Additional effort is also needed to examine the potential importance of offshore near-surface regions for YOY fish and to quantify the relative contribution of offshore regions to YOY recruitment.

Density estimates of YOY fish and year-plus Arctic cod are based on expected mean target strengths derived from this study. At each analytic step used to determine the target strength to length relationship, conservative choices were made to ensure that the resulting density estimates would also be conservative. As an example, a larger mean target strength was used in the calculation of YOY total fish density as it was based exclusively on YOY Arctic cod, which were longer than either *Lumpenus* sp. or Cottidae YOY. A smaller mean target strength would have resulted if the value was calculated using all three species, which would have increased the total YOY fish density estimate. Additional studies of YOY and year-plus Arctic cod, YOY *Lumpenus* sp., and YOY Cottidae target strength are needed to increase accuracy and precision of density, abundance, and resulting biomass estimates. The limited information available that describes methods used for single target detections in other studies of Arctic cod restricts our ability to compare reported target strength measurements and corresponding density estimates. The use of Sawada's N_v index (Sawada et al. 1993) to avoid detecting multiple fish targets as single echoes in this study may be unique among acoustic studies of Arctic cod. The detection of multiple fish as single echoes would bias target strength estimates high, leading to the false conclusion that any estimated fish length, based on target strength to length relationships, was larger than it actually was. In that case, resulting density estimates, using inflated target strength values, would be biased low.

Previous acoustic surveys of year-plus Arctic cod in the Beaufort Sea focused on characterizing schools or overwintering aggregations, so direct comparison with the current study are limited. In a 2004 survey of overwintering Arctic cod in the Canadian Beaufort (Franklin Bay), Benoit et al. (2008) reported that year-plus Arctic cod densities ranged from 72×10^3 to $19{,}610 \times 10^3$ #/ha. The Benoit et al. (2008) data characterized a small spatial location between February and April. Fish lengths used to estimate densities by Benoit et al. (2008) included larger fish than those sampled in this study. In a second set of studies, Crawford and Jorgenson (1993, 1996) examined year-plus Arctic cod densities in two locations: Resolute Bay (Crawford and Jorgenson 1993; Canadian Beaufort Sea, surveyed 1986) and in Allen Bay (Crawford and Jorgenson 1996, Canadian Beaufort Sea, surveyed 1989-1990). Sampling for both studies was conducted during August and targeted schooling aggregations of year-plus Arctic cod. In Resolute Bay, year-plus densities ranged from 6×10^3 to 159×10^3 #/ha (Crawford and Jorgenson 1993). In Allen Bay, within school year-plus densities were between 20×10^3 and $83{,}250 \times 10^3$ #/ha (Crawford and Jorgenson 1996). Finally Moulton and Tarbox (1987) quantified year-plus Arctic cod densities near Prudhoe Bay (American Beaufort Sea, surveyed 1978-1979) in water <10 m deep. Converting their volumetric estimates to areal estimates, Moulton and Tarbox (1987) found year-plus densities that ranged between 0 and $22{,}691 \times 10^3$ #/ha. Echograms presented in Moulton and Tarbox (1987) suggest that fish were present in small schools. As a caveat, echo counting methods used in Moulton and Tarbox (1987) may have resulted in the potential detection of multiple YOY targets as single year-plus fish, thereby biasing their year-plus Arctic cod density estimates high. As a comparison, our maximum year-plus Arctic cod density (155×10^3 #/ha) occurred in a dense region of the year-plus layer within the 100-500 m depth. This density corresponds to the maximum density within schools measured by Crawford and Jorgenson (1993) in Resolute Bay but is far less than maximum densities reported by Benoit et al. (2008) and Moulton and Tarbox (1987).

Although results from the acoustic/midwater trawling survey are assumed to be representative of YOY fish and year-plus Arctic cod distributions within the 20-500 m depth range in the Beaufort Sea, three caveats are noteworthy. First, the extent of the survey area was limited relative to the entire Beaufort Sea shelf. Given the limited extent of the survey, it is not possible to detect and describe large-scale patterns in distribution. Second, our observations of year-plus Arctic cod distribution may indicate an association with oceanographic conditions (e.g. Chukchi Sea water inflow). If this is true, spatial distribution of year-plus Arctic cod may be influenced more by oceanographic than by bathymetric characteristics.

Comparison of demersal trawl and pelagic acoustic methods

Relationships between acoustic estimates of yearling-and-older (year-plus) Arctic cod density and bottom trawl estimates were related to whether the year-plus Arctic cod layer was in contact with the bottom (categorical bottom depth predictor). When the year-plus Arctic cod layer was in contact with the bottom (generally <300 m bottom depth) there was a positive relationship between acoustic and bottom trawl estimates. Bottom trawl estimates of year-plus Arctic cod sometimes were higher than acoustic estimates, but a positive relationship existed. In contrast, in regions greater than 300 m bottom depth where the layer was located off bottom there was a negative, or no, relationship between the acoustic and bottom trawl survey estimates. This finding suggests that while the bottom trawl may be an appropriate assessment tool for year-plus Arctic cod in regions where the year-plus layer is in contact with the bottom, it cannot provide quantitative estimates of density in deep offshore regions. Further, the acoustic survey results suggested that within the study area the maximum densities of year-plus Artic cod were located in regions that were not effectively surveyed by the bottom trawl gear. GAM models suggested that there was an increasing, nonlinear trend in year-plus Arctic cod density with depth. Had our survey extended into deeper water, the line may have hit an asymptote and decreased after the 300-350 m depth mark. In contrast, GAM results suggested that there was no relationship between bottom trawl CPUE and bottom depth and delineating trawls into lined and unlined nets did not suggest separate relationships.

Fish habitat (physical oceanography)

Winds during the field program were generally variable with moderate speeds of 3-7 m s^{-1}. In general the wind conditions favored a relatively steady outflow of Chukchi Sea shelf water to the northeast through Barrow Canyon and along the Beaufort Sea shelfbreak and the inner shelf north and east of Pt. Barrow (Okkonen *In press*). These winds likely resulted in the distribution of cold Chukchi Sea water in the deeper areas of the study area (greater than 100m depth) described below. However, there were two periods of relatively strong northeasterly winds including August 7 (7-12 m s^{-1}) and August 13-15 (12-15 m s^{-1}). Pickart et al. (2010), found on average, that an easterly wind speed of 6-7 m s^{-1} results in a significant upwelling event in the Beaufort shelfbreak current, as measured by salinity changes, which lags the winds by about 18 hours, whereas the current response lags the winds by about 8 hours. These time scales are similar to those reported by (Weingartner et al. 1998) for the Northeast Chukchi Sea. In particular they noted that flow in Barrow Canyon reversed to southward (upcanyon) when northeasterly winds exceeded about 6 m s^{-1}. Winds were substantially strong and persistent enough during the August 13-15 wind event to possibly reduce or even reverse the flow in Barrow Canyon and induce upwelling along the Beaufort Sea shelfbreak.

Evidence for this Chukchi Sea outflow is found in the cold and high salinity water that was observed offshore of the shelf break on the western transects. Although winds were generally from the southwest during the survey, there was a period of sufficiently strong and prolonged northeasterly winds that caused an upwelling event. The effects of the upwelling were evident along the transects sampled after the wind event. The bottom-trapped thermohaline front was more diffuse and was shifted shoreward and cold and high salinity water was observed inshore and towards the surface.

The prevailing winds in the Beaufort Sea are from the northeast and force a westward wind-driven flow over the shelf and an onshore and westward drift of first- and multi-year sea ice from the basin onto the shelf. On average, the wind-field promotes upwelling onto the shelf of nutrient laden sub-surface waters from the shelfbreak with this process probably being critical to maintaining the shelf nutrient supply on an annual basis. There is however substantial seasonal variation in the alongshore wind stress as summarized in the form of monthly statistics using the archived National Weather Service wind record in Barrow from 1949-2005. The statistics plotted in Figure 66 are based on the alongshore component of the winds, which accounts for most of the variance in the winds and which are primarily responsible for forcing shelf circulations. On a monthly basis the majority of the alongshore winds are westward (upwelling favorable) with the westward wind stress being stronger than eastward (downwelling-favorable) winds. Westward winds are strongest in late fall and early winter and occur most frequently in October and November and in March. The frequency of eastward winds, such as those that dominated during our survey, peaks in August, although westward wind stress is stronger than eastward stress in summer.

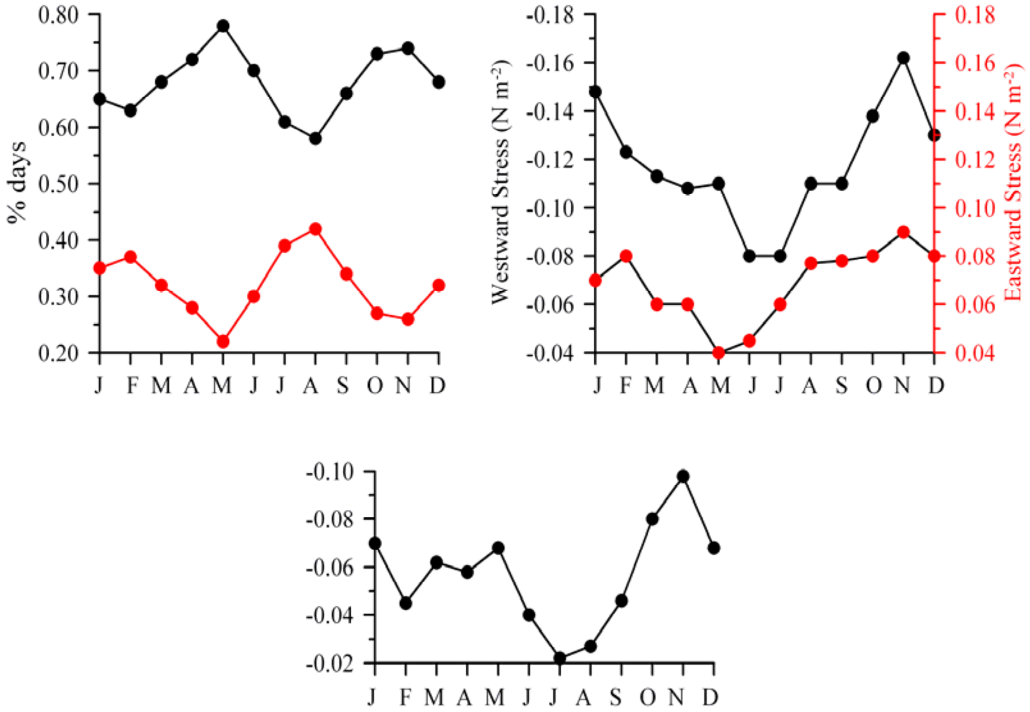


Figure 66**.** Mean monthly wind statistics of the alongshore winds based on the 1949 – 2005 National Weather Service observations from Barrow Alaska. Upper left panel shows the percentage of days in a month in which there are westward (upwelling-favorable; black circles) and eastward (downwelling-favorable; red circles) winds. The upper right panel shows the mean monthly wind stress for eastward and westward winds. The bottom panel shows the mean monthly wind stress (which is westward in all months).

The occurrence of Pacific Ocean-derived waters (modified on the Bering and Chukchi shelves) that exit the Chukchi shelf through Barrow Canyon and into the Beaufort Sea has been documented previously (Aagaard and Roach 1990, Mountain et al. 1976, Pickart et al. 2005, Weingartner et al. 1998, Weingartner et al. 2005b, Woodgate et al. 2005b). Some of this outflow continues eastward (in the surface layer in summer) and/or as a subsurface current along the Beaufort shelfbreak and slope and contributes to the upper halocline of the Canada Basin (Aagaard 1984, Mountain et al. 1976, Pickart 2004, Pickart et al. 2005) and some appears to spread westward and/or offshore in the polar mixed layer (Shimada et al. 2001). However, some of the canyon outflow rounds Pt. Barrow and continues onto the inner portion of the Beaufort shelf, although the frequency and the extent to which this occurs are unknown.

The differences between transects 2 and 3 may be because portions of these lines were sampled after the strong upwelling event of August 13-15. Note in particular that along both transects the 31 isohaline extends to within about 10 km of the 20 m isobath, whereas along Transect 1, this isohaline is approximately 20 km seaward of the 20 m isobath. are readily apparent, e.g. note the upward bowing of the isohalines and isotherms beginning within 30 km of the 20 m isobath which has brought cold (2°C), salty (31) water inshore and to within 10 m of the surface at the innermost station (Figure 43).

Curiously, however, the saltier (31.5-32.5) isohalines that comprise the shelfbreak front along transect 5 intersect the bottom along the 60 m (or deeper) isobaths. These depths are approximately 40 m deeper than the depths in which the same isohalines intersect the bottom along Transect 1 (e.g. Figure 40). The data suggest that the upwelling event has split the shelfbreak front such that the shallower isohalines have migrated inshore and upward following classic upwelling behavior, whereas the deeper isohalines have moved deeper. The reasons for this apparent split are unclear; however, we note that while the salinities of the water masses comprising the shelfbreak front along Transect 5 are identical to those along the front in Transect 1. The temperatures within the shelfbreak front along Transect 1 are, however, colder (approximately-1°C) than those along Transect 5 suggesting that these water masses have different mixing histories as they flow along the shelfbreak.

We suspect that the lens of very fresh (27.5) and warm (approximately 4.5°C) water approximately 20 km seaward of the 20 m isobath along Transect 5 (Figure 43).this might be a filament or eddy of riverine water that was formed to the east of this section, since it is not found along any other line. Finally, as with the other sections, the near-surface waters at the offshore end of the line are also quite fresh and suggest the influence of ice melt waters in this area.

These very cold (-1.5 to -1.0°C) water with salinities between 32.5 and approximately 34 between 50 and 150 m (figure 20 waters were formed in winter on the Bering-Chukchi shelves and comprise the cold upper halocline of the Canada Basin. Below approximately 150 m depth, salinity and temperature increase rapidly over the next 50 m and such that below 200 m salinities are 34.5 – 34.7 and temperatures are between 0 and 0.5°C. These relatively warm, salty waters are derived from the Atlantic Ocean.

The cold, salty water along Transects 1 and 2 with the coldest stations found offshore of the shelfbreak was most likely formed on the Chukchi Sea shelf during the previous winter (Weingartner et al. 2005b) during the formation of sea ice. These winter-origin waters continue to drain offshore throughout spring and summer (Pickart et al. 2005, Weingartner et al. 2005b) with the most likely points of egress being Barrow Canyon in the northeast Chukchi Sea and Herald Valley on the western shelf (Russian EEZ). Some of this water flows eastward along the slope and apparently warms since the temperatures in this salinity range have increased slightly as evident in the θ-S panels for Transects 3, 5, and 6. The source of the heat must be through vertical mixing, either with warmer and fresher water at shallower depths or with saltier and warmer water from deeper depths. The figure also indicates that water types in the 30 - 32 salinity range (delineated by vertical bars in Figure 45) span a broad temperature range (-1.3 to 4^{o} C). The coldest waters in this salinity range occur over and seaward of the shelfbreak, while the warmer waters are inshore of the shelfbreak. Nevertheless these water types have similar densities so that they can mix laterally along isopycnal (constant density) surfaces.

Note that the coldest waters (near the freezing point) range between 32.5 and 33.3. These are associated with the Arctic Ocean's permanent halocline, which in the study area can vary in depth from between 80 and 150 m. Beneath the halocline, salinities and temperatures both increase and this is indicative of the warmer and saltier waters of Atlantic Ocean origin that occupy the Arctic Ocean basin.

For the most part shelf waters (<~60 m) have salinities <32.3 and range in temperature from ~-1°C - <6°C.A more refined analysis of water mass origin would require an in-depth elucidation and analyses of geochemical properties of each water type.

In addition to winds, sea ice and river outflow influenced water mass properties during our study. Evidence of recent ice melt was found in cold, low salinity waters in the upper few meters of the water column. Along the western transects there was a pronounced shallow surface haline front at the 40-50 m depth contour, separating offshore ice melt waters from warmer, saltier waters nearshore. River outflow water influenced water column properties in the eastern portion of our study area. There was a lens of very low salinity, warm water 20 km seaward of the 20 m isobath along the easternmost oceanographic transect. This apparent river water was not observed along the transects to the west and could have originated from local rivers such as the Colville or the Meade. The Meade River enters into Dease Inlet, whose mouth is about 25 km from the innermost station on Line 1. The Colville River delta and Harrison Bay is approximately 90 km east of Transect 7, and the Mackenzie delta is approximately 600 km east of the sampling area. The water could also have been the result of westward transport of Mackenzie River water. Satellite-derived surface temperature images from July 2008 showed the Mackenzie River plume penetrating into our study area.

Alaskan Beaufort Sea water properties are known to be controlled by the annual freeze-thaw cycle and inflows from the oceanic and coastal boundaries. In winter temperatures are at or near the freezing point (except perhaps after upwelling events that bring warm water from the Atlantic layer onto the outer shelf). Near-freezing waters remain on the shelf year-round, although in the near-shore, highly stratified plume temperatures can be 5-10°C above the freezing point.

Salinities (hence density) vary widely in space and time. Shelf salinities are between 32 and 33 in winter, with higher values (33-40) in some of the coastal lagoons. During the spring freshet, river waters spread offshore beneath the landfast ice in highly stratified, thin (1 -2 m) plumes, although it is not known how far offshore the plumes spread. Plume salinities are greater than 5, whereas the salinity in the waters offshore or beneath the plume is 32-33. Once the landfast ice detaches from the coast, plume and ambient waters mix. The freshwater is carried offshore during upwelling events or in filaments generated by instabilities, or it is advected alongshore in a coastal current under downwelling favorable winds. The hydrographic and circulation structure of the Alaskan Beaufort Sea are poorly understood but probably complicated because of the diverse water sources feeding this shelf. For example, the different water sources applied at the lateral boundaries (Pacific waters in the west and Mackenzie shelf waters in the east) suggest that there are alongshelf gradients in both density and nutrients that affect circulation and biological production patterns. Similarly, cross-shelf differences are probably quite large. In summer and fall, these gradients are established by river runoff, ice melt, and shelfbreak processes, while in winter the shelfbreak processes and the landfast/pack ice boundary likely lead to spatial heterogeneity. How these gradients affect biological production patterns remains unknown.

Although there are few measurements in this area, the year-round discharge from the Mackenzie River may profoundly influence the eastern Alaskan Beaufort Sea (Carmack et al. 1989, Macdonald and Carmack 1991, Macdonald et al. 1999). Mackenzie shelf waters have been detected throughout much of the Canada basin, including the continental slope of the Chukchi and western Beaufort Sea as far as 160^{o}W longitude (Guay and Falkner 1998, Macdonald et al. 1999). It is likely that the prevailing northeasterly winds force Mackenzie shelf waters onto the Alaskan Beaufort Sea.

Much of the oceanographic data were collected at the same stations that demersal and midwater fish were sampled with nets, thus providing a high degree of spatial and temporal coherence between the two physical and biological data sets. Additional CTD data along transects 1 and 5 were collected independent of the fish trawling, and the assembled data show consistent and realistic across shelf gradients despite the temporal lag between adjacent CTD stations.

Fish distribution and habitat associations

Habitat associations were evaluated for both bottom trawl (demersal) and acoustic (pelagic) datasets. Several of the environmental variables we chose to examine with regard to benthic and pelagic fish distribution were correlated with each other. Not surprisingly the salinity and density variables were correlated and these were all in turn correlated with bottom depth. Bottom temperature and temperature difference (surface to bottom) were also correlated. In addition, temperature difference and density difference were correlated.

Finally, at the benthic stations sampled with the unlined net longitude was correlated with salinity and density variables. Because it is not statistically valid to include correlated independent variables in multivariate analyses such as GAM, these correlations among environmental variables resulted in only a limited number of variables being available for the GAMs. None of the two- or three-term GAMs for the benthic fish species were statistically significant. This is not surprising given the small sample size, the potential for over-fitting the models and possible interactions between independent variables. For example, temperature difference for "all fish species - lined net" in the linear regression had a lower *P*-value than longitude, that variable was correlated with bottom temperature and so was not used in the GAM. Although the Cp and *P*-values indicate the three term model was statistically significant it is very likely that the results were due to interactions between independent variables and over fitting the model. Both of these problems are related to the small sample size and thus the three term GAM model is probably not biologically significant. The three term GAM model for "all invertebrates - lined net" was significant in explaining over half the variability in the data. The two term GAM model also explained a significant amount of the spatial variability in density of opilio crab.

Small sample sizes were also of concern in the analysis of YOY fish and year-plus Arctic cod. In the GAM for YOY pelagic fish, there were concerns about this dataset as there was heterogeneous variance that was unimproved by data transformation. Similarly the year-plus Arctic cod GAM had variance that could not be normalized by data transformation.
Density by weight of all benthic fish was significantly negatively correlated with bottom temperature at the lined net stations. The same was true for benthic Arctic cod, which is not unexpected given that approx. 94% of the total weight and numbers of fish caught were Arctic cod.

For pelagic yearling-and-older (year-plus) Arctic cod, the linear model using the zero-excluded dataset (in our opinion the most robust given that zero values in the nearshore were analytically-not biologically-derived) suggested that year-plus Arctic cod are significantly associated with offshore regions with a fully-formed below- mixed layer depth (MLD) region and cold, saline water. Given visual observations of the data, this was our original interpretation of year-plus Arctic cod distribution. Interestingly, although surface and bottom parameters (i.e. temperature and salinity) were correlated with MLD attributes, the model run using the standard predictors did not find a significant relationship between year-plus distribution and oceanography. This suggests that the attributes of the below-MLD water mass may not have been well-captured by the surface and bottom descriptors.

All benthic fish and Arctic cod densities (both by weight and number) at the unlined net stations were significantly negatively correlated with surface to bottom temperature difference, greater fish densities occurring in more mixed waters. All but one of the unlined net stations were at bottom depths less than 100 m, so this result may indicate that Arctic cod prefer well-mixed water on the shelf. Mixing of the water column can bring nutrients to the surface resulting in increased primary and secondary production and potentially increased fish prey density.

Adult Arctic cod in both benthic and pelagic habitats apparently prefer the very cold winter water that emanates from the Chukchi Sea. This is the region of the cold halocline that characterized Chukchi Sea outflow through Barrow canyon and fish distributions and model results suggest that the fish prefer these low temperatures. The Chukchi Sea outflow of cold, winter-formed waters are also rich in dissolved and particulate organic carbon, with this water carried offshore into the halocline (Mathis et al. 2007, Pickart et al. 2005). Previous studies in the marine coastal habitat have similarly shown that arctic cod prefer waters that are cold (-1 to 3

°C) and of high salinity (27-32 ppt; Craig 1984). However, information about cod in this habitat is scarce compared to information on their use of nearshore, brackish water habitats. Arctic cod are also one of the dominant fish species found in brackish nearshore waters, along with other marine fish such as fourhorn sculpin and anadromous fish such as cisco and char (Craig 1984; Craig et al 1987; Moulton and Tarbox 1987). Arctic cod winter under nearshore ice (where not frozen to the seafloor) and in brackish waters of river deltas (Craig 1984). The numbers of cod in nearshore waters increases as the open-water season progresses, with fish moving offshore between July and August (Craig 1984, Frost and Lowry 1983 Moulton and Tarbox 1987). Our observations of arctic cod throughout the marine offshore habitat (deeper than 40m) are consistent with this pattern. Our study and the previous studies cited above support the idea that fishes in coastal waters of the Beaufort Sea are euryhaline – "freshwater" species sometimes enter marine waters and "marine" species such as arctic cod sometimes enter brackish waters (Craig 1984).

Based on both linear and GAM models, YOY pelagic fish (Arctic cod, sculpins, and eelblenny) were not found in association with particular oceanographic or physical attributes, suggesting that they are relatively ubiquitous throughout the study area. In the nearshore regions <50-75 m, they occupy the entire water column while in water greater than 75 m they are found in the near-surface (i.e. <50-75 m from the surface) water.

Our observations of Arctic cod distribution relative to water temperature and water column mixing may reflect foraging habitat selection. Differences in nearshore brackish and offshore marine habitats have been shown to be reflected in Arctic cod diets. In the nearshore habitat, cod prey on epibenthic mysids and amphipods (Craig 1984). In offshore marine waters, they prey on copepods and amphipods (Frost and Lowry 1983). Arctic cod are also common along sea ice margins, feeding on ice-associated invertebrates (Cobb et al. 2008). Whether the distribution of cod prey among nearshore, offshore and ice-edge habitats drives the seasonal movement and distribution of arctic cod is not known at this time, but would be a fruitful area of future study. Moulton and Tarbox (1987) found that cod were distributed shoreward of a transition zone between brackish and marine water where prey organisms may have been concentrated. In the Chukchi Sea arctic cod densities were greatest in Bering Shelf water perhaps due to a higher abundance of zooplankton, compared to Alaska coastal water and Chukchi water (Gillespie et al. 1997). So there is some evidence that arctic cod may select habitat based on prey abundance.

The density of walleye pollock was significantly related to longitude throughout the survey area (i.e. at both lined and unlined net stations), with fish density decreasing from west to east. This pattern would be consistent with a relatively recent introduction of pollock into the Beaufort Sea from the south and west (Bering and Chukchi Seas). The most recent previous confirmed northerly expansion of the range of pollock was documented during a 2004 survey of the Chukchi Sea (Mecklenburg et al. 2007). If this hypothesis is true, then future surveys of the Beaufort Sea could show further expansion of the range of pollock to the east.

Eelpout density at the lined net stations was negatively correlated with bottom temperature. Similar to Arctic cod, these species apparently prefer cold water in the off-shelf portion of the study area. The GLM for eelpouts from the unlined net stations (primarily on the shelf) showed significant relationships with temperature and longitude. On the shelf, eelpouts were more likely to be present in warmer water in the eastern part of the study area. These apparent habitat preferences could be driven by the distribution of their prey. Eelpouts in the Bering Sea typically consume benthic invertebrate prey such as shrimp, polychaetes and mysids (Aydin et al. 2008). Unfortunately, food habits data for eelpouts do not exist for the Beaufort Sea region. Further study of the prey preferences of eelpouts and the distribution of their prey is needed to interpret these patterns.

Sculpins were more likely to be present in shallower water as indicated by the GLM from the lined net station data. In fact, virtually no sculpins were caught where bottom depth exceeded 100 m. In addition, sculpin density on the shelf (the unlined net stations) was significantly related to temperature and density difference, being more numerous in relatively mixed water. Mixing can bring nutrients towards the surface and fuel primary production which would eventually result in increased fish prey productivity. Sculpins of the Arctic burrow into sand and sand-mud bottoms feeding on small benthic amphipods and polychaetes (Fedorov 1986). The nearshore distribution of sculpins may be driven by a preference for muddy substrate and small benthic prey. More detailed study of substrate type and the distribution of small benthic invertebrates is needed to test this hypothesis.

Benthic invertebrate density (all species combined) was significantly related to bottom temperature, bottom density and longitude, as indicated by the GAM. Invertebrates were more abundant in colder and denser water in the western portion of the survey area. The density of *Opilio* crab (by weight and number) at the lined net stations was significantly associated with bottom temperature and bottom depth, as indicated by the GAM. Crab densities were greater in cold waters and deeper depths. The distribution of *Opilio* on the shelf, sampled with the unlined nets, was apparently driven by bottom salinity and longitude, with more crabs associated with higher salinity waters towards the west. These patterns in the distribution of benthic invertebrates may reflect increased productivity of cold Chukchi Sea waters transported up Barrow Canyon into the Beaufort Sea (Mathis et al. 2007, Pickart et al. 2005). The diversity of invertebrate species sampled makes it difficult to form more specific hypotheses about particular prey or habitat selection processes driving the patterns. However, previous studies have suggested a metabolic explanation for the distribution of *Oplio* crab. *Opilio* crab on the Scotian Shelf are similarly most abundant in relatively cold water (Tremblay 1997), and the authors suggest that this is because at warmer temperatures metabolic costs are greater than consumption (Foyle et al. 1989). Further study of the metabolic and consumption rates of Beaufort Sea *Opilio* are required to test this hypothesis.

An additional explanation for the high catches of benthic fish and invertebrates offshore of 100 m depth is that the inner shelf may suffer from ice grounding in winter, which could reduce habitat area for benthos. Sea ice may cover the shelf throughout the year, although over the last decade most of the shelf has been ice-free from late July through early October. The Beaufort Sea ice cover consists of two components; drifting pack ice over the middle and outer shelf and the virtually immobile landfast ice on the inner shelf. Landfast ice first forms in October and is anchored to the coast. It then rapidly extends some 20-40 km offshore to eventually cover ~25% of the shelf area and remains in place through June (Barnes et al. 1984a). Landfast ice is relatively smooth adjacent to the coast but can be highly deformed offshore and ridging increases throughout winter (Tucker-III et al. 1979). Deformation can, however, vary considerably along the shelf and it appears that the landfast ice zone on the Mackenzie shelf is less deformed than on the Alaskan Beaufort shelf (Tucker-III et al. 1979). Ice keels can gouge the seafloor (Barnes et al. 1984a) and form piles of grounded ice, stamukhi, along the seaward edge of the landfast ice. Stamukhi can be described according to this process. Landfast ice is anchored to the coast at the bottom along the 2 m isobath. Grounded ice may occur anywhere on the shallower portions of the shelf, but frequently grounding occurs along the 20 m isobath. Here ice ridging frequently develops and the ice keels often encounter the bottom and become immobile or scour the seabed. As the ridges develop at the edge of the landfast ice, they tend to build as more pack ice collides and deforms with previous grounded ridges and the landfast ice limit. The result is a complex series of grounded ice and ridges that forms the stamuhki zone. The stamukhi may be important in protecting the inner shelf from forcing by the drifting pack ice (Reimnitz and Kempema 1984). It seems likely that persistent gouging by ice in shallow water could disturb, and thus affect, the composition of benthic communities. However, little is known about the direct effects of sea ice gouging on benthic habitat.

Recommendation for Future Monitoring Methods

"Based on results of the survey, recommend methods for future monitoring that could provide time-series and data trend information necessary to support offshore development decisions and serve as a proto-type fisheries component of future MMS or other ocean observing systems." (from the Memorandum of Understanding).

Recommendations are to use the same methods as used in this pilot. In order to facilitate the use of the same methods in future studies, the detailed review of the methods used in this study can be found in Appendix VIII

As stated in the earlier discussion, additional effort is also needed to examine the potential importance of offshore near-surface regions for YOY fish and to quantify the relative contribution of offshore regions to YOY recruitment.

Literature Cited

Aagaard, K., and Roach, A.T. 1990. Arctic ocean-shelf exchange: Measurements in Barrow Canyon. . Journal of Geophysical Research **95**: 18163-18175.

Aagaard, K. 1984. The Beaufort undercurrent. *In* The Alaska Beaufort Sea. *Edited by* P.W. Barnes, D.M. Schell and E. Reimnitz. Academic Press, Orlando. pp. 47-72.

Acuna, E., and Kotwicki, S. 2004. 2003 Bottom trawl survey of the eastern Bering Sea continental shelf. U.S. Department of Commerce NOAA-NMFS-AFSC Processed Report 2004-02.

Alverson, D.L., and W.T. Pereyra. 1969. Demersal fish explorations in the northeastern Pacific Ocean -- An evaluation of exploratory fishing methods and analytical approaches to stock size and yield forecasts. Journal of the Fisheries Research Board of Canada 26:1985-2001.

Alvsvåg, J., Agnalt, A.L., and Jørstad, K.E. 2008. Evidence for a permanent establishment of the snow crab (*Chionoecetes opilio*) in the Barents Sea. Biological Invasasions **11**: 587-595.

Ashjian, C.J., Okkonen, S.R., and Campbell, R.G. 2009. Mooring and broad-scale oceanography. *In* Bowhead Whale Feeding Ecology Study (BOWFEST) in the western Beaufort Sea; 2008 Annual Report. MMS-4500000120. *Edited by* D. Rugh. National Marine Mammal Laboratory, Alaska Fisheries Science Center, NMML, NOAA, 7600 Sand Point Way NE Seattle WA, Seattle. pp. 38-48.

Ashjian, C.J., Sherr, E.B., Campbell, R.G., Sherr, B.F., Plourde, S., Hill, V.J., and Cota, G.F. 2006. Mesozooplankton-microbial food web interactions in western Arctic shelf and basin regions. EOS Transaction of the American Geophysical Union **87**(36, suppl.).

Atkinson, E.G., and Percy, J.E. 1992. Diet comparison among demersal marine fish from the Canadian Arctic. Polar Biology **11**(8): 567-573.

Aydin, K., S. Gaichas, I. Ortiz, D. Kinzey, and N. Friday 2008. A comparison of the Bering Sea, Gulf of Alaska, and Aleutian Islands large marine ecosystems through food web modeling. U.S. Department of Commerce NOAA Tech. Memo. NMFS-AFSC-178.

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

Barnes, P.W., Rearic, D.M., and Reimnitz, E. 1984a. Ice gouging characteristics and processes. Academic Press, New York.

Beare, D.J., Burns, F., Greig, A., Jones, E.G., Peach, K., Kienzle, M., McKenzie, E., and Reid, D.G. 2004. Long-term increases in prevalence of North Sea fishes having southern biogeographic affinities. Marine Ecology Progress Series **284**: 269-278.

Benoit, D., Simard, Y., and Fortier, L. 2008. Hydroacoustic detection of large winter aggregations of Arctic cod (*Borgeogadus saida*) at depth in ice-covered Franklin Bay (Beaufort Sea). Journal of Geophysical Research **113**: C06S90, doi:10.1029/2007JC004276

Boe, J., Hall, A., and Qu, X. 2009. September sea-ice cover in the Arctic Ocean projected to vanish by 2100. Nature Geoscience Letters **advanced online publication**.

Bond, W.A., and Erickson, R.N. 1997. Coastal migration of arctic ciscoes in the eastern Beaufort Sea. *In* Fish ecology in arctic North America. American Fisheries Society, Bethesda. pp. 155-164.

Bradstreet, M.S.W., and Cross, W.E. 1982. Trophic relationships at high arctic ice edges. Arctic **35**: 1-12.

Bradstreet, M.S.W., Finley, K.J., Sekerak, A.D., Griffiths, W.B., Evans, C.R., Fabijan, F.F., and Stallard, H.E. 1986. Aspects of the biology of Arctic cod (*Boreogadus saida*) in arctic marine food chains. Canadian Technical Report of Fisheries and Aquatic Sciences **1491**.

Britt, L., and Martin, M. 2001. 1999 Gulf of Alaska bottom trawl survey. U.S. Department of Commerce NOAA Tech. Memo. NMFS-AFSC-121.

Busby, M.S., and Chernova, N.V. 2001. Redescription of the festive snailfish, *Liparis marmoratus* (Scorpaeniformes: Liparidae), with a new record from the northern Bering Sea. Ichthyological Research **48**: 187-191.

Carey, A.G., Boudrias, M.A., Kern, J.C., and Ruff, R.E. 1984. Selected ecological studies on continental shelf benthos and sea ice fauna in the southwestern Beaufort Sea *In* U.S. Department of Commerce, NOAA/OCSEAP Final Reports of Principal Investigators **23**: 1-164.

Carmack, E.C., Macdonald, R.W., and Papdakis, J.E. 1989. Water mass structure and boundaries in the Mackenzie Shelf Estuary. Journal of Geophysical Research **94**: 18043-18055.

Cobb, D., H. Fast, et al. (2008). Beaufort Sea Large Ocean Management Area: Ecosystem Overview and Assessment Report. DFO. Canadian Technical Report of Fisheries and Aquatic Sciences 2780.

Cook, D. R. 1977. Detection of influential observation in linear regression. Technometrics 19(1): 15-18.

Craig, P.C. 1984. Fish use of coastal waters of the Alaska Beaufort Sea: a review. Transactions of the American Fisheries Society **113**(3): 265-282.

Craig, P.C., Griffiths, W.B., Haldorson, L., and McElderry, H. 1982. Ecological studies of Arctic cod (*Boreogadus saida*) in Beaufort Sea coastal waters, Alaska. Canadian Journal of Aquatic and Fisheries Sciences **39**: 395-406.

Crawford, R.E., and Jorgenson, J.K. 1996. Quantitative studies of Arctic cod (*Boreogadus saida*) schools: important energy stores in the Arctic food web. Arctic **49**: 181-193.

Crawford, R.E., and Jorgenson, J.K. 1993. Schooling behavior of Arctic cod, *Boreogadus saida*, in relation to drifting pack ice. Environmental Biology of Fishes **36**: 345-357.

Echeverria, T.W. 1995. Sea-ice conditions and the distribution of walleye pollock (*Theragra chalcogramma*) on the Bering and Chukchi Shelf *In* Climate change and northern fish populations. *Edited by* R.J.B. (Ed.), Victoria. pp. 131-136.

Engås, A., Løkkeborg, S., Ona, E., and Soldal, A.V. 1996. Effects of seismic shooting on local abundance and catch rates of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*). Candian Journal of Fisheries and Aquatic Sciences **53**: 2283-2249.

Engås, A., and Godø, O.R. 1989. The effect of different sweep lengths on the length composition of bottom-sampling trawl catches. ICES Journal of Marine Science **45**: 269-276.

Fedorov, V.V. 1986. Cottidae. *In* Fishes of the Northeastern Atlantic and the Mediterranean. *Edited by* M.-L.B. P.J.P. Whitehead, J-C. Hureau, J. Nielsen, and E. Tortonese, UNESCO, Paris.

Foote, K.G., Knudsen, H.P., Vestnes, G., MacLennan, D.N., and Simmonds, E.J. 1987. Calibration of acoustic instruments for fish density estimation: a practical guide. ICES Cooperative Research Report Number 144.

Foyle, T. P., R. K. O'Dor, and R. W. Elner. 1989. Energetically defining the thermal limits of the snow crab. Journal of Experimental Biology **145**: 371–393.

Frost, K.J., and Lowry, L.F. 1981. Distribution, growth, and foods of Arctic cod (*Boreogadus saida*) in the Bering, Chukchi and Beaufort Seas. Canadian Field Naturalist **95**: 186-191.

Frost, K.J., and Lowry, L.F. 1983. Demersal fishes and invertebrates trawled in the northeastern Chukchi and western Beaufort Seas 1976-1977, U.S. Department of Commerce NMFS-SSRF-764.

Gallaway, B.J., Felchhelm, R.G., Griffiths, W.B., and Cole, J.G. 1997. Population dynamics of broad whitefish in the Prudhoe Bay region, Alaska. *In* Fish Ecology in Arctic North America. *Edited by* J.B. Reynolds. American Fisheries Society Symposium 19, Bethesda. pp.194-207.

Gillespie, J. G., Smith, R.L., Barbour, E., and Barber, W.E. 1997. Distribution, abundance, and growth of Arctic cod in the Northeastern Chukchi Sea. *In* Fish Ecology in Arctic North America. *Edited by* J. B. Reynolds. American Fisheries Society Symposium 19, Bethesda. pp.81-89.

Greene, C.H., Pershing, A.J., Cronin, T.M., and Ceci, N. 2008. Arctic climate change and its impacts on the ecology of the north Atlantic. Ecology **89**(11): S24-S38.

Guay, C.K., and Falkner, K.K. 1998. A survey of dissolved barium in the estuaries of major Arctic rivers and adjacent seas. Continental Shelf Research **8**: 859-882.

Gunderson, D.R. 1993. Surveys of Fisheries Resources. New York: Wiley and Sons, Inc.

Hiatt, T., Felthoven, R., Dalton, M., Gaber-Yonts, B., Haynie, A., Lew, D., Sepez, J., Seung, C., and Staff of Northern Economics, I. 2008. Stock assessment and fishery evaluation report for the groundfish fisheries of the Gulf of Alaska and Bering Sea/Aleutian Islands area: economic status of the groundfish fisheries off Alaska, 2007, Seattle, WA.

Hobson, K.A. 1993. Trophic relationships among high Arctic seabirds: insights from tissue-dependent stable-isotope models. Marine Ecology Progress Series **95**: 7-18.

IASC. 2004. Arctic Climate Impact Assessment, Cambridge University Press, Cambridge, UK.

Itoh, M.K., Shimada, T., McLaughlin, F., Carmack, E., and Nishino, S. *In press*. Interannual variability of Pacific winter water inflow through Barrow Canyon from 2000 to 2006. Journal of Geophysical Research.

Jarvela, L.E., and Thorsteinson, L.K. 1999. The epipelagic fish community of Beaufort Sea coastal waters, Alaska. Arctic **52**(1): 80-94.

Jarvela, L.E., and Thorsteinson, L.K. 1997. Movements and temperature occupancy of sonically tracked dolly varden and arctic ciscoes in Camden Bay, Alaska. *In* Fish ecology in Arctic North America. *Edited by* J.B. Reynolds. American Fisheries Society, Bethesda. pp. 165-174.

Kaufman, L., and Rousseeuw, P.J. 1990. Finding Groups in Data. John Wiley and Sons, Inc., New York.

Lang, G. M., Livingston, P. A., and Dodd, K. A. 2005. Groundfish food habits and predation on commercially important prey species in the eastern Bering Sea from 1977 through 2001. NOAA Tech. Memo. NMFS-AFSC-158.

Lauth, R., and Acuna, E. 2007. Results of the 2006 eastern Bering Sea continental shelf bottom trawl survey of groudfish and invertebrate resources. NOAA-AFSC Tech Memo-176. pp 176.

Macdonald, R.W., Carmack, E.C., McLaughlin, F.A., Falkner, K.K., and Swift, J.H. 1999. Connections among ice, runoff, and atmospheric forcing in the Beaufort Gyre. Geophysical Research Letters **26**: 2223-2226.

Macdonald, R.W., and Carmack, E.C. 1991. The role of large-scale under-ice topography in separating estuary and ocean on an arctic shelf. Atmosphere-Ocean **29**: 37-51.

Main, J., and Sangster, G.I. 1981. A study of the fish capture process in a bottom trawl by direct observations from a towed underwater vehicle. Scottish Fishery Research Report **23.** pp 21.

Mamylov, V.S. 2003. About the Comparison of fish distribution densities estimated using trawl and acoustic methods. Report on Improvement of instrumental methods for stock assessment of marine organisms, Russian-Norwegian Workshop, 11-14 November 2003, PINRO, Murmansk, Russia.

Maslanik, J.A., Fowler, C., Stroeve, J., Drobot, S., Zwally, J., Yi, D., and Emery, W. 2007. A younger, thinner Arctic ice cover: Increased potential for rapid, extensive sea-ice loss. Geophysical Research Letters **34**(L24501).

Mathis, J.T., Pickart, R.S., Hansell, D.A., Kadko, D., and Bates, N.R. 2007. Eddy transport of organic carbon and nutrients from the Chukchi Shelf: Impact on the upper halocline of the western Arctic Ocean. Journal of Geophysical Research **112**: C05011, doi: 05010.01029/02006JC003899.

Matthews, J.B. 1981. Observations of surface and bottom currents in the Beaufort Sea near Prudhoe Bay, Alaska. Journal of Geophyisical Research **86**(C7): 6653-6660.

Mecklenburg, C.W., Stein, D.L., Sheiko, B.A., Chernova, N.V., Mecklenburg, T.A., and Holladay, B.A. 2007. Russian-American long term census of the Arctic: benthic fishes trawled in the Chukchi Sea and Bering Strait, August 2004. Northwest Naturalist **88**: 168-187.

Moore, S.E. 2000. Variability of cetacean distribution and habitat selection in the Alaskan Arctic, autumn 1982-91. Arctic **53**: 448-460.

Moulton, L.L., Philo, L.E., and George, J.C. 1997. Some reproductive characteristics of least ciscoes and humpback whitefish in Dease Inlet, Alaska. *In* Fish ecology in arctic North America. *Edited by* J.B. Reynolds. American Fisheries Society, Bethesda. pp. 119-126.

Moulton, L.L., and Tarbox, K.E. 1987. Analysis of arctic cod movements in the Beaufort Sea nearshore region, 1978-79. Arctic **40**(1): 43-49.

Mountain, D.G., Coachman, L.K., and Aagaard, K. 1976. On the flow through Barrow Canyon. Journal of Physical Oceanography **6**: 461-470.

Mueter, F.J., Broms, C., Drinkwater, K.F., Friedland, K.D., Hare, J.A., Hunt Jr., G. L., Melle, W., and Taylor, M. 2009. Ecosystem responses to recent oceanographic variability in high-latitude Northern Hemisphere ecosystems. Progress in Oceanography **81**: 93-110.

Mueter, F.J., and Litzow, M.A. 2008. Sea ice retreat alters the biogeography of the Bering sea continental shelf. Ecological Applications **18**(2): 309-320.

Nakashima, B. S. 1990. Escapement from a Diamond IX midwater trawl during acoustic surveys for capeplin (*Mallotus villosus*) in the Northwest Atlantic. J. Cons. Inst. Explor. Mer. 47: 76-82.

Okkonen, S.R. 2008. Exchange between Elson Lagoon and the nearshore Beaufort Sea and its role in the aggregation of zooplankton. OCS Study MMS 1008-010.

Ott, R.L. 1993. An introduction to statistical methods and data analysis. Duxbury Press, Belmont, California.

Parker-Stetter, S.L., Rudstam, L.G., Sullivan, P.J., and Warner, D.M. 2009. Standard operating procedures for fisheries acoustic surveys in the Great Lakes. Great Lakes Fisheries Commission Special Publication (2009-01).

Paul, J.M., Paul, A.J., and Barber, W.E. 1997. Reproductive biology and distribution of the snow crab from the northeastern Chukchi Sea. American Fisheries Society Symposium 19: 287-294.

Perry, A.L., Low, P.J., Ellis, J.R., and Reynolds, J.D. 2005. Climate change and distribution shifts in marine fishes. Science **308**: 1912-1915.

Pickart, R.S. 2004. Shelfbreak circulation in the Alaskan Beaufort Sea: mean structure and variability. Journal of Geophyisical Research **109**: 1-14.

Pickart, R.S., Weingartner, T., Pratt, L.J., Zimmermann, S., and Torres, D.J. 2005. Flow of winter-transformed Pacific water into the western Arctic. . Deep-Sea Research, Pt. II **52**: 3175 - 3198.

Pickart, R.S., Pratt, L.J., Torres, D.J., Whitledge, T.E., Proshutinsky, A.Y., Aagaard, K., Agnew, T.A., Moore, G.W.K., and Dail, H.J. 2010. Evolution and dynamics of flow through Herald Valley in the western Chukchi Sea. Deep-Sea Research II **57**(1-2): 5-26.

Reimnitz, E., and Kempema, E.W. 1984. Pack ice interaction with stamukhi shoal. *In* The Alaskan Beaufort Sea: Ecosystems and Environment. *Edited by* D.M.S. P. W. Barnes, and E. Reimnitz (ed.). Academic Press, New York. pp. 159-184.

Ricker, W.E. 1973. Linear regressions in fishery research. Journal of Fisheries Research Board Canada **30**: 409-434.

Rudstam, L.G., Parker-Stetter, S.L., Sullivan, P.J., and Warner, D.M. 2009. Towards a standard operating procedure for fishery acoustic surveys in the Laurentian Great Lakes, North America. ICES Journal of Marine Science **66**: 1391-1397.

Sawada, K., Furusawa, M., and Williamson, N.J. 1993. Conditions for the precise measurement of fish target strength *in situ*. Journal of the Marine Acoustical Society of Japan **20**: 73-79.

Scheaffer, R.L., III, W.M., and Ott, R.L. 1996. Elementary Survey Sampling 5th Edition. Duxbury Press, London, U. K. .

Shimada, K., Carmack, E.C., Hatakeyama, K., and Takizawa, T. 2001. Varieties of shallow temperature maximum waters in the western Canadian Basin of the Arctic Ocean. Geophysical Research Letters **28**: 3441-3444.

Slotte, A., Hansen, K., Dalen, J., and Ona, E. 2004. Acoustic mapping of pelagic fish distribution and abundance in relation to a seismic shooting area off the Norwegian west coast. Fisheries Research **67**: 143-150.

Stauffer, G. 2004. NOAA protocols for groundfish bottom trawl surveys of the nation's fishery resources. U.S. Departmen of Commerce NOAA Tech. Report NMFS-F/SPO-65: 205.

Strickland, R., and Sibley, T. 1984. Projected effects of CO2-induced climate change on the Alaska pollock (Theragra chalcogramma) fishery in the Bering Sea and the Gulf of Alaska., Report prepared for U.S. Department of Energy, Carbon Dioxide Indirect Effects Program.

Stroeve, J., Serreze, M., Drobot, S., Gearheard, S., Holland, M., Maslanik, J.A., Meier, W., and Scambos, T. 2008. Arctic sea ice extent plummets in 2007. EOS Transaction of the American Geophysical Union **89**: 13-14.

Stroeve, J., Holland, M.M., Meier, W., Scambos, T., and Serreze, M. 2007. Arctic sea ice decline: Faster than forecast. Geophysical Research Letters **43**(L09501).

Suydam, R. S., Lowry, L.F., Frost, K.J., O'Corry-Crowe, G.M., and Jr., D.P. 2001. Satellite tracking of eastern Chukchi Sea beluga whales into the Arctic Ocean. Arctic **54**: 237-243.

Tremblay, M. J. 1997. Snow Crab (*Chionoecetes opilio*) Distribution Limits and Abundance Trends on the Scotian Shelf. Journal of Northwest Atlantic Fishery Science **21**: 7-22.

Tucker-III, W. B., Weeks, W.F., and Frank, M. 1979. Sea Ice ridging over the Alaskan continental shelf. Journal of Geophysical Research **84**: 4885-4897.

Underwood, T. J., Palmer, D.E., Thorpe, L.A., and Osborne, B.M. 1997. Weight-length relationships and condition of dolly varden in coastal waters of the Arctic National Wildlife Refuge, Alaska. *In* Fish ecology in arctic North America. *Edited by* J.B. Reynolds. American Fisheries Society, Bethesda. pp. 295-309.

Wardle, C.S. 1986. Fish behavior and fishing gear *In* The Behavior of Teleost Fishes. *Edited by* T.J. Pitcher. John Hopkins University Press, Baltimore. pp. 463-495.

Walsh, S.J. 1991. Diel variation in availability and vulnerability of fish to a survey trawl. Journal of Applied Ichthyology **7**: 147-159.

Weingartner, T., Okkonen, S.R., and Danielson, S.L. 2005 and 2005b. Circulation and Water Property Variations in the Nearshore Alaskan Beaufort Sea, Final Report. OCS Study MMS 2005-028.

Weingartner, T., Cavalieri, D.J., Aagaard, K., and Sasaki, Y. 1998. Circulation, dense water formation, and outflow on the northeast Chukchi shelf. Journal of Geophysical Research **103**: 7647-7661.

Welch, H.E., Bergmann, M.A., Siferd, T.D., Martin, K.A., Curtis, M.F., Crawford, R.E., Conover, R.J., and Hop, H. 1992. Energy flow through the marine ecosystem of the Lancaster Sound Region, Arctic Canada. Arctic **45**(4): 343-357.

Woodgate, R.A., Aagaard, K., and Weingartner, T. 2005b. A Year in the Physical Oceanography of the Chukchi Sea: moored measurements from autumn 1990-91. Deep-Sea Research II **52**: 3116-314

Appendix I – Database table documentation

Database: BSS_Database2008
Beaufort Sea Offshore Marine Fish Survey, 2008
Alaska Fisheries Science Center (AFSC) and Minerals Management Service (MMS)
OCS Study MMS 2008-062

*All table and field descriptions found in this document are also stored within the BSS_Database2008.

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Table: tblAllStationLocations

Description: Bottom, midwater, CTD, and Bongo basic haul information; vessel, station, haul number, latitude (DD) and longitude (DD). All postitions are at start of event (start of net fishing, CTD cast, start of Bongo tow).

	Field Name **(PK)** Primary Key	**Description**	**Type**	**Length**
	Cruise	200801, year 2008, 1 leg	Long Integer	4
	Vessel	Ocean Explorer was used for the 2008 Beaufort sea survey (148)	Long Integer	4
(PK)	Station	Location where event took place	Long Integer	4
(PK)	Haul	Bottom hauls were from 1-26. Midwater hauls from 101 - 128; CTD and bongo events have descriptive haul fields	Text	50
	LatDD	Latitude is in decimal degrees. This latitude represents the EQ location (start location) for all events - North	Double	8
	LongDD	Longitude is in decimal degrees. This longitude represents the EQ location (start location) for all events - West	Double	8
	EventDescription	Bottom tow, midwater tow, CTD cast or bongo	Text	50

Data Quality:

This table only contains location information for all “events” that took place during the 2008 Beaufort Sea survey. The locations are “start” locations for each event. For bottom hauls, this location (lat/long) corresponds to the “Event” field, code “4” in the “tblBotEvent”.

Table: tblBotCatch

Description: Bottom haul; total catch weight and numbers of fish and invertebrates from bottom hauls

Field Name **(PK)** Primary Key	**Description**	**Type**	**Length**
Cruise	200801, year 2008, 1 leg.	Long Integer	4
Vessel	Ocean Explorer was used for the 2008 Beaufort sea survey (148).	Integer	2
Haul	Bottom hauls were from 1-26. If a haul does not appear in this table, there was no catch associated with it.	Text	50
SpeciesCode	Corresponds to the species in the "tblSpeciesList" table.	Long Integer	4
SpeciesLatinName	Latin name for species; corresponds to the species in the "tblSpeciesList" table	Text	50
VoucherNumber	Number that corresponds to specimens that were vouchered in formalin for future identification.	Integer	2
FishInvert	Whether the species is an invertebrate or fish.	Text	50
NonSubSubWeight	This is a subsample of the subsample. It only applies to invertebrates and trawl 3, this was not	Double	8

	done with fish any other haul. These are the measured weights from field.		
NonSubSubNumber	This is a subsample of the subsample. It only applies to invertebrates and trawl 3, this was not done with fish in any other haul. These are actual numbers from field.	Double	8
NonSubsampleWeight	Weight of the sample that was not counted and weighed. For example count and weigh 50 Arctic cod for average weight and weigh the rest of the Arctic cod (because there are 1,000 in sample, takes too long to count.	Double	8
SubSampleWeight	Weight of the subsample. Everything that was weighed was also counted. Corresponds to SubSampleNumbers. If there is an entry in "NonSubSubWeight", this is an extrapolated weight from that.	Double	8
SubSampleNumbers	Count of the subsample. Everything that was counted was also weighed. Corresponds to SubSampleWeight. If there is an entry in "NonSubSubNumber", this is an extrapolated number from that.	Double	8
CalculatedWeight	Calculated weight from NonSubsample Weight. Extraplates subsample nonsub weight up to the subsample level.	Double	8
CalculatedNumbers	Calculated numbers from NonSubsample Numbers. Extraplates subsample nonsub numbers up to the subsample level.	Double	8
TotalWeight	Total weght of the species in the catch. Calculated from the the subsample weight.	Double	8
TotalNumbers	Total numbers of the species in the catch. Calculated from the subsample numbers.	Double	8
SampledAll	"Y" for yes if the species was entirely counted and weighed in the total catch (no extrapolations) and "N" for no if the species was extrapolated from the subsample.	Text	4
AverageWeight	Calculated from the counts and weights.	Double	8
Comment	Comments about the catch/species.	Text	255

Data Quality:

This is where the catch information for the bottom trawls is stored. The location information for these hauls is found in both the “tblBotEvent” and the “tblAllStationLocations” only. There are a few hauls that appear in “tblBotHaul” and “tblAllStationLocations” that do not appear in the “tblBotCatch” table which means no catch was associated with that haul, either due to gear loss or damage. This table should be examined with the “tblBotHaul” so the reader is aware of gear type differences and gear performance codes associated with all the bottom catches. In particular, haul 3 was very large and highly diverse. In addition to collecting a random “subsample”, we “subsampled” the “subsample”. For example for the fish species Boreogadus saida (Arctic cod) in haul 3, the number of fish listed in the “SubSampleNumber” field is 5,163. This number was extrapolated from a “subsample” of a “subsample”. Situations in which high counts appear (>300) in the “SubSampleNumbers” field implies that is an extrapolated number from a “subsample” of a “subsample”, which is most common for invertebrate species (only appears in haul 3 for Arctic cod). The remaining data entries that appear in the fields “SubSampleWeight” and “SubSampleNumbers” are actual counts and weights from randomly selected subsamples of the entire catch. Also the reader should note that if a species did not appear in a particular haul, it does not appear in this table. This is important in estimating fish abundance and densities (e.g. zero catches). NOTE: All invertebrate data is preliminary. The vouchered invertebrate specimens (excluding crab) have not been verified as of August, 2009.

Table: tblBotEvent

Description: Bottom haul; all events recorded in wheelhouse and their associated lat/long. Includes, EQ (net starts fishing), HB (haul back), etc.

Field Name **(PK)** Primary Key	**Description**	**Type**	**Length**
Cruise	200801, year 2008, 1 leg	Long Integer	4
Vessel	Ocean Explorer was used for the 2008 Beaufort sea survey	Long Integer	4
Haul	Bottom hauls were from 1 - 26. Each haul has an event associated with it. See "tblBotEvent".	Text	50
DateTime	Date and Time event began	Date/Time	8
Event	See "tblBotEventCode" for a list of codes	Long Integer	4
PositionMethod	GPS - USGlobalsat MR-350	Text	255
LatDD	Latitude is in decimal degrees	Text	255
LongDD	Longitude is in decimal degrees	Text	255
Comment	Comments about the haul	Text	255

Data Quality:

This table describes events that take place during a single bottom trawl and the associated location and time the event took place. In conjunction with this table, "tblBotEventCode" should also be viewed for code definitions. This table and the "tblAllStationLocations" are the only 2 tables that have the haul location information (latitude/longitude). To assign a location to a bottom trawl using this table, the reader for example can choose event code "4" for the start of the haul or event code "6" for the end location of the haul. Event codes "4" and "6" are the ones most commonly used.

Table: tblBotEventCode

Description: Bottom haul; code table for the "tblEvent" table

Field Name **(PK)** Primary Key	**Description**	**Type**	**Length**
ID	Primary key	Auto Number	4
Event	Number code that corresponds to the code in field "Event" in "tblBotHaul"; recording begins at the start of a haul and ends when the trawl doors are on deck	Long Integer	4
Definition	"Event" code definition	Text	100

Data Quality:

Corresponds to the "tblBotEvent".

Table: tblBotHaul

Description: Bottom haul; all information pertaining to haul and net mensuration; includes area swept (no location information stored in this table).

	Field Name **(PK)** Primary Key	**Description**	**Type**	**Length**
	Cruise	200801, year 2008, 1 leg	Long Integer	4
	Vessel	Ocean Explorer was used for the 2008 Beaufort sea survey (148)	Long Integer	4
(PK)	Station	Location where an event took place (can be bottom tow or midwater tow)	Long Integer	4
(PK)	Haul	Bottom hauls ranged from 1 - 26	Text	50
	Date	Date the haul occurred (Alaska daylight time -8 from GMT)	Date/Time	8
	Time	Time the haul started - NOT the time net was on bottom (EQ) in Alaska Daylight Time (-8)	Date/Time	8
	Comment	Comments about the haul and haul performance	Text	250
	NetType	Lined or unlined net. Hauls 1-15 were with a lined net (see field description "Accessories" - code 122 - for a liner description; the unlined nets were standard 83-112 - see field description "Gear"	Text	50
	DoorUsed	Code 15 from AFSC / RACE ADP code book, supplementary table, "Gear Accessories"; 6' x 9' steel V-doors (standardized to 1800 lbs after 1988), double 30 fm 5/8" dandylines, 1.28" mesh codend liner, 24" chain extension between lower dandyline and footrope.	Long Integer	4
	Skipper	Captain of the F/V Ocean Explorer	Text	255
	HaulType	All bottom tows were standard bottom tows as those conducted on Eastern Bering Sea surveys	Text	255
	Performance	This code corresponds to the table "tblBotHaulPerformCode"; see this table for code definitions	Text	255
	BottomType	Was "qualitatively" estimated by viewing the echo sounder and examinging what substrate was found in the catch	Text	255
	BottomTypeMethod	Was "qualitatively" estimated by viewing the echo sounder and examinging what substrate was found in the catch	Text	255
	DistanceFished	Distance net was on bottom "fishing"; using all RACE methods of calculating and estimating distance fished	Text	255
	DistanceFishedMethod	Lat/Long's are converted to a nautical mile value; a 21 span running mean smoother is applied to each point between begin/end of tow. Distance is calculated as Pythagorean distance between each pair of smoothed points; then summed for distance fished	Text	255
	AreaSweptkm2	Calculated by taking "DistanceFished" * "AvgNetSpread" / 1000 (for km2)	Double	8
	AvgNetSpread	The average, in meters, of the horizontal net opening (based on ping "values" recorded by NETMIND during tow operations).	Text	255

NetMensuration	The net mensuration gear used was NETMIND form Northstar Technical Inc. (http://www.northstar-technical.com/)	Text	255
NetSpreadPings	The number of pings recorded in NETMIND from the net sensors on the net; the signal is transmitted to the hydrophone lowered from the side of the vessel into the water during tow operations. Min of 13 pings, in general for good net spread data	Text	255
NetSpreadStdDev	The standard deviation of the mean values from the net spread (recorded from hydrophone during tow)	Text	255
AvgNetHeight	The average, in meters, of the net height (based on ping "values" recorded by NETMIND during tow operations)	Text	255
NetHeightPings	The number of pings recorded in NETMIND per tow (see field description "NetSpreadPings" above)	Text	255
NetHeightStdDev	The standard deviation of the mean values from the net height (recorded from hydrophone during tow)	Text	255
AvgGearDepth	Average depth obtained from the SBE 39, Seabird Electronics Inc.: http://www.seabird.com/products/spec_sheets/39data.htm	Text	255
GearDepthMethod	Obtained from the SBE 39 depth recorder (http://www.seabird.com/products/spec_sheets/39data.htm)	Text	255
AvgBottomDepth	Obtained from the SBE 39 depth recorder and the net mensuration sensors - NETMIND (http://www.seabird.com/products/spec_sheets/39data.htm and http://www.northstar-technical.com/)	Text	255
BottomDepthMethod	Obtained from the SBE 39 depth recorder and the net mensuration sensors - NETMIND (http://www.seabird.com/products/spec_sheets/39data.htm and http://www.northstar-technical.com/)	Text	255
WireOut	In meters; amount of wire from vessels main wires (connected to trawl doors) for net to obtain bottom depth; recorded by skipper based on measured wire calibration	Text	255
WireOutMethod	Autotrawl readout in wheelhouse that was calibrated by cable meter (i.e. wire marking)	Text	255
Gear	Eastern trawl; 112' footrope; 83' headrope; 4" mesh #60 thread (#48 prior to approx 1984) wings / body; 3.5" mesh (#96) intermediate / codend; 41 floats on headrope - 8" diameter; mean path width - 17.0 m, no range, mean vertical - 2.3 m - range	Long Integer	4
Accessories	Code 122 = tickler chain, hula and 1.5" liner covering entire bottom body, wings, complete top and bottom of the intermediate and codend (with 30 mesh overlap with standard 1.25" liner extending 65 meshes up from conded. Code 15 = 6'x9' steel doors, double	Text	255
BottomContactMethod	AFSC - RACE bottom contact sensor	Text	255
SurfaceTemp	Temperature recorded in °C	Text	255
SurfaceTempMethod	SBE 39 depth recorder	Text	255
GearTemp	Temperature recorded in °C	Text	255
GearTempMethod	SBE 39 depth recorder	Text	255
WindSpeed	In knots; Estimated by the scientist recording haul data; QUALITATIVE data (on 2008 Beaufort Sea survey it was Libby Logerwell)	Text	255
WindSpeedMethod	Estimated by the scientist recording haul data; QUALITATIVE data (on 2008 Beaufort Sea survey	Text	255

	it was Libby Logerwell)		
WindDirection	In degrees; Estimated by the scientist recording haul data; QUALITATIVE data (on 2008 Beaufort Sea survey it was Libby Logerwell)	Text	255
WindDirectionMethod	From vessels magnetic compass; Estimated by the scientist recording haul data; QUALITATIVE data (on 2008 Beaufort Sea survey it was Libby Logerwell)	Text	255
WaveHeight	In meters; Estimated by the scientist recording haul data; QUALITATIVE data (on 2008 Beaufort Sea survey it was Libby Logerwell)	Text	255
WaveHeightMethod	Estimated by the scientist recording haul data; QUALITATIVE data (on 2008 Beaufort Sea survey it was Libby Logerwell)	Text	255
WaveDirection	Estimated by the scientist recording haul data; QUALITATIVE data (on 2008 Beaufort Sea survey it was Libby Logerwell)	Text	255
WaveDirectionMethod	From vessels magnetic compass; Estimated by the scientist recording haul data; QUALITATIVE data (on 2008 Beaufort Sea survey it was Libby Logerwell)	Text	255
SwellHeight	In meters; Estimated by the scientist recording haul data; QUALITATIVE data (on 2008 Beaufort Sea survey it was Libby Logerwell)	Text	255
SwellHeightMethod	Estimated by the scientist recording haul data; QUALITATIVE data (on 2008 Beaufort Sea survey it was Libby Logerwell)	Text	255
SwellDirection	In degrees; Estimated by the scientist recording haul data; QUALITATIVE data (on 2008 Beaufort Sea survey it was Libby Logerwell)	Text	255
SwellDirectionMethod	From vessels magnetic compass; Estimated by the scientist recording haul data; QUALITATIVE data (on 2008 Beaufort Sea survey it was Libby Logerwell)	Text	255
RecorderName	Libby Logerwell	Text	255
TimeZone	Alaska daylight time which is -8 hours from GMT	Text	255
SpeedMethod	from vessel	Text	255

Data Quality:
There are no haul locations in this table (see above). All methods of data collection and recording in this table followed the Alaska Fisheries Science Center’s RACE Division protocols (Stauffer 2004).
Note: the field “NetType” and “Accessories” are the only 2 fields in the database that inform the reader which hauls used each of the 2 gear types. In the field “Accessories”, code “122” refers to net specifications found in the RACE ADP Codebook. In the field “NetType”, states whether that haul used a net that was lined or unlined; see the MMS Final Report for differences in catches due to gear type.

Table: tblBotHaulPerformCode

Description: Bottom haul; codes from the AFSC / RACE ADP code book under performance codes.

	Field Name **(PK)** Primary Key	Description	Type	Length
(PK)	ID		Auto Number	4
	Performance	Performance code from AFSC / RACE ADP codebook.	Text	50
	Definition	Definition of performance codes.	Text	50

Data Quality:

Corresponds to “tblBotHaul”.

Table: tblBotLength

Description: Bottom haul; lengths from fish species in the bottom hauls

Field Name **(PK)** Primary Key	Description	Type	Length
Cruise	200801, year 2008, 1 leg	Long Integer	4
Vessel	Ocean Explorer was used for the 2008 Beaufort sea survey (148)	Integer	2
Haul	Bottom haul numbers were from 1 - 26	Text	50
SpeciesCode	Corresponds to the species in the "tblSpeciesList" table	Long Integer	4
Sex	1=male, 2=female, 3=undetermined; a fish was left "unsexed" if the gonads were small or under-developed and there was not 100% confidence in determining sex.	Integer	2
Length	All fish were measured in centimeters and then converted to millimeters in the database; lengths in this table are in mm; LENGTHS FROM THE "tblBotSpecimen" ARE INCLUDED IN THIS TABLE.	Integer	2

Data Quality:

Note: Lengths from the “tblBotSpecimen” are also included in this table.

Table: tblBotSpecimen

Description: Bottom haul; specimens collected from bottom hauls that include otoliths, ovaries and stomachs.

	Field Name **(PK)** Primary Key	**Description**	**Type**	**Length**
	Cruise	200801, year 2008, 1 leg	Long Integer	4
	Vessel	Ocean Explorer was used for the 2008 Beaufort sea survey (148)	Integer	2
	Haul	Bottom haul numbers are from 1-26	Text	50
	SpeciesCode	corresponds to the species in the "tblSpeciesList" table.	Long Integer	4
	Sex	1=male, 2=female, 3=undetermined; a fish was left "unsexed" if the gonads were small or under-developed and there was not 100% confidence in determining sex.	Integer	2
	Length	LENGTHS RECORDED FOR BOTTOM TOWS IN THIS TABLE ARE ALSO INCLUDED IN THE "tblBotLength".	Integer	2
	Weight	in grams	Long Integer	4
(PK)	SpecNumber	corresponds with the otolith vial for ageing, length and weight	Integer	2
	MatCode	maturity code. field may be filled in future ovary analysis for a subset of the specimens	Integer	2
	SubsampleType	1=random subsample of the species; ~20-30 fish were randomly selected for sexing, length, weight and removal of otoliths (for ageing)	Integer	2
	AgeStructure	1=yes, otoliths were collected; stored at the Alaska Fisheries Science Center, Seattle, WA	Integer	2
	EntryOrder	autonumber	Auto Number	

Data Quality:

Note: Lengths from the “tblBotLength” are also included in this table.

Table: tblBotSpeciesOccur

Description: Bottom haul; a table that shows which hauls fish species occur in; includes those species that were ID'd in the lab but could not be updated by species in the tblBotCatch table; this is ONLY for the bottom tows.

	Field Name **(PK)** Primary Key	**Description**	**Type**	**Length**
(PK)	Haul	Pertains only to bottom tows and the fish species that occurred in these tows. Some species listed in this table are lumped at the genus level in the tblBotCatch (i.e. *Liparis* sp.) but were ID in the lab and split out in the table. Common names are under “Description”.	Text	255
	Artediellus scaber	hamecon	Long Integer	4
	Aspidophoroides olriki	Arctic alligatorfish	Double	8

Boreogadus saida	Arctic cod	Double	8
Careproctus sp cf rastrinus (Orr et al)	salmon snailfish	Double	8
Eleginus gracilis	saffron cod	Double	8
Eumesogrammus praecisus	fourline snakeblenny	Double	8
Eumicrotremus derjugini	leatherfin lumpsucker	Double	8
Gadus macrocephalus	Pacific cod	Double	8
Gymnelus viridis	fish doctor	Double	8
Gymnocanthus tricuspis	Arctic staghorn sculpin	Double	8
Hippoglossoides robustus	Bering flounder	Double	8
Icelus spatula	spatulate sculpin	Double	8
Liparis fabricii	gelatinous seasnail	Double	8
Liparis gibbus	variegated snailfish	Double	8
Liparis marmoratus	festive snailfish	Double	8
Lumpenus fabricii	slender eelblenny	Double	8
Lumpenus maculates	daubed shanny	Double	8
Lumpenus medius	stout eelblenny	Double	8
Lycodes mucosus	saddled eelpout	Double	8
Lycodes polaris	Canadian eelpout	Double	8
Lycodes raridens	marbled eelpout	Double	8
Lycodes rossi	threespot eelpout	Double	8
Lycodes sp	unid. eelpout	Double	8
Mallotus villosus	capelin	Double	8
Myoxocephalus verrucosus	warty sculpin	Double	8
Nautichthys pribilovius	eyeshade sculpin	Double	8
Reinhardtius hippoglossoides	Greenland turbot	Double	8
Theragra chalcogramma	walleye pollock	Double	8

Table: tblBotSpeciesOccur

Triglops nybelini	bigeye sculpin	Double	8
Triglops pingeli	ribbed sculpin	Double	8
Lycodes seminudus	longear eelpout	Double	8
Liparis tunicatus	kelp snailfish	Double	8
Enophrys diceraus	antlered sculpin	Long Integer	4
Cottidae	sculpin family	Long Integer	4

Data Quality:

All species of fish that occurred in the 2008 Beaufort Sea bottom trawl survey are found in this table. However, 2 species, *Lycodes seminudus* and *Liparis tunicatus* are not found in the “tblBotCatch” as they were identified in the laboratory but we were not able to assign them to the haul on the species level, but assigned them on the genus level (they were incorporated in with *Lycodes* sp. and *Liparis* sp.).

Table: tblBSSSpeciesKey

Description: Bottom haul; list of all species by latin name, common name and whether it is a fish or invertebrate (invert).

	Field Name **(PK)** Primary Key	Description	Type	Length
	SpeciesLatinName	Species Latin name; species found during the Beaufort sea survey, 2008	Text	50
	SpeciesComName	Species common name	Text	72
	SpeciesCode	From RACE ADP 2008 codebook, with changes.	Long Integer	4
	FishInvert	Whether it is a fish or invertebrate species	Text	50

Data Quality:

This is a species list excerpted from the “tblRACESpeciesList”. These are species that occurred on the Beaufort Sea survey, 2008. The field “SpeciesCode” corresponds with the same field in the “tblRACESpeciesList”. In several cases, no common name exists. It is recommended to use the Latin name.

Table: tblCTDBonHaul

Description: CTD and Bongo haul information and data.

	Field Name **(PK)** Primary Key	Description	Type	Length
	Cruise	200801, year 2008, 1 leg	Long Integer	4
	Vessel	Ocean Explorer was used for the 2008 Beaufort sea survey (148)	Long Integer	4
(PK)	Station	Station at which a bottom haul and/or bongo and/or CTD cast occurred	Double	8
(PK)	Haul	Field that connects to sample identification for shipment to Poland for data analysis; HaulID consists of Cruise, Station, Haul (obsolete), GearAbrv, and Net	Text	255
	GearAbrv	Gear used (bongo or CTD); definitions found in the "tblCTDBonGearDict" table	Text	255
	Net	Net number from which the bongo sample came from (1 or 2) and 20 or 60 cm	Text	255
	Comments	Comments about the performance CTD and bongo casts	Text	255
	AlternateStation	Whether a CTD or Bongo cast plus the consecutive number e.g. CTD002 = 2nd CTD cast of the	Text	255
	Mesh	Whether the bongo net mesh size was 150 or 333 microns.	Double	8
	GMTDate	GMT date (Alaska time is -8 from this date)	Date/Time	8
	GMTTime	GMT time (Alaska time is -8 from this time)	Date/Time	8
	BottomDepth	Bottom depth in meters, from the ship's depth sounder	Double	8
	GeographicArea	Ocean basin in which survey was conducted	Text	255
	LatDD	In decimal degrees	Double	8

HemLat	Hemisphere for latitude data (e.g. North or South)	Text	255
LongDD	In decimal degrees	Double	8
HemLong	Hemisphere for longitude data (e.g. East or West)	Text	255
Performance	Performance of the specific gear/net. Things that may affect the performance are holes in net, bad flow meter readings, missing information, bad wire angles, lost sample, etc. See COD Manual_KB.doc for definitions	Text	255
Flowmeter	The identification number of the flowmeter used	Double	8
FlowmeterRevs	Total flowmeter count of revolutions from the gear/net	Double	8
MinGearDepth	Minimum depth at which gear/net was deployed	Double	8
MaxGearDepth	Maximum depth at which gear/net was deployed. Determined from wire out for CTD and from wire out and wire angle for Bongo. Wire angle measured manually with "skillet-shaped" angle	Double	8
MinWireOut	Minimum wire let out	Double	8

Table: tblCTDBonHaul

MaxWireOut	Maximum wire let out, only recorded for Bongo tows. For CTDs maximum wire out is the same as MaxGearDepth.	Double	8
TowMinutes	TowMinutes and TowSeconds together show the amount of time that gear was sampling in the water. Only recorded for Bongo tows.	Double	8
TowSeconds	TowMinutes and TowSeconds together show the amount of time that gear was sampling in the water. Only recorded for Bongo tows.	Double	8
CalibrationFactor	Calibration factor of flowmeter used for tow. Needed for calculation of volume filtered.	Double	8
StandardHaulFactorA	Haul factor used to calculate catch per 10 m2	Double	8
StandardHaulFactorB	Haul factor used to calculate catch per 1000 m3	Double	8
VolumeFiltered	The volume filtered by the gear in m3	Double	8
TowTimeInSeconds	Total tow time in seconds. Used for calculation of volume	Double	8
RevsPerSecond	Average revolutions per second of plow meter during tow. Used to calculate volume	Double	8

Data Quality:

This is all data associated with a CTD cast or Bongo tow. As of August, 2009 the bongo tow data were not available for analysis (e.g. zooplankton species). The principal investigator Tom Weingartner has all oceanographic data used in the MMS Final Report from the Beaufort Sea survey 2008.

Table: tblMarineMammalSightings

Description: Marine mammal sightings from the Alaska Fisheries Science Center’s Platforms of Opportunity Program (POP).

Field Name (PK) Primary Key	Description	Type	Length
Cruise	200801, year 2008, 1 leg.	Double	8
Vessel	Ocean Explorer was used for the 2008 Beaufort Sea survey (148).	Double	8
Date	Date the marine mammal was sighted, in ADT	Date/Time	8
Time	Time the marine mammal was sighted, in ADT	Date/Time	8
LatDD	Latitude in decimal degrees	Double	8
LongDD	Longitude in decimal degrees	Double	8
Species	Common name of marine mammal sighted	Text	255
EstNumber	Number estimated to be see by the observer, this is NOT an absolute number, only an estimate of the number of individuals.	Double	8
Behavior	Behavior that the marine mammal was seen doing during the observation	Text	255
Comment	General comment about the observation	Text	255

Data Quality:

These are marine mammal sightings, with estimated numbers observed in transit to/from the survey grounds in the Beaufort Sea, during July/August 2008. The data were not collected formally by transects or time.

Table: tblRACESpeciesList

Description: Alaska Fisheries Science Center’s RACE Division species list of all fish and invertebrate species from Bering Sea (Beaufort included); includes code, latin name and common name when available.

Field Name (PK) Primary Key	Description	Type	Length
SpeciesCode	Species code that relates to the AFSC / RACE division database	Decimal	8
SpeciesLatinName	Species current Latin name.	Text	72
SpeciesComName	Species common name, highly variable. Most often based on Mecklenburg 2007, Fishes of Alaska	Text	72

Data Quality:

This list is merely provided for future invertebrate voucher analysis or clarification on species name/codes. The field “SpeciesCode” corresponds to the same field in “tblBSSSpeciesKey”.

Appendix II – Review of Beaufort Sea Fish Studies

Several studies have been published on the near shore freshwater and anadromous fishes of the Beaufort Sea, especially in the Prudhoe Bay vicinity. This brief review focuses on a few specifics; marine fish species that may be encountered in the offshore marine waters of the Beaufort Sea, the gear used in past surveys, and a general overview (when available) of qualitative observations (e.g. schooling Arctic cod in bays during the summer months).

Frost, K. J., and L. F. Lowry. 1983. Demersal fishes and invertebrates trawled in the northeastern Chukchi and western Beaufort seas 1976 – 1977. U.S. Dep. Commer., NOAA Tech. Rep. NMFS-SSRF-764, 22 p.

The only known fish survey specifically targeting the offshore Beaufort Sea was in 1976 and 1977 by Frost and Lowry (1983). Frost and Lowry (1983) primarily sampled fish within the benthic habitat and used semi-balloon otter trawls. The head ropes measured 4.9 and 5.8 m with 31.75 mm stretch mesh webbing and a 6.5 mm mesh liner in the cod ends. Sampling depths primarily ranged from 40 to 150 m, however 1 tow was made at 400 m. Sampling locations ranged from 70° to 72°N and from the northeastern Chukchi Sea (164°W) to the eastern US portion of the Beaufort Sea (141°W). Towing time when net was on the bottom ranged from 5-10 minutes.

A total of 33 tows were conducted of which 14 occurred within the vicinity of the 2008 survey area (Figure 1). The survey area, in general, only encompassed offshore marine waters; tows were not conducted in the coastal or brackish waters, therefore the majority of species encountered were entirely marine. A total of 19 fish species or groups (listed below) and 238 invertebrate species were identified from the surveys conducted in both 1976 and 1977. Arctic cod (*Boreogadus saida*), Canadian eelpout (*Lycodes polaris*) and twohorn sculpin (*Icelus bicornis*) accounted for 65% of all the fishes caught in the tows. Combining all species, fish fork lengths (FL) ranged from 25 mm to 245 mm. Biological information, such as stomach contents and reproductive descriptions are summarized in Frost and Lowry (1983) for the most commonly caught species (Arctic cod, Canadian eelpout, twohorn sculpin, hamecon, Arctic alligatorfish, snailfish sp., leatherfin lumpsucker, fish doctor and spatulate sculpin).

The most common invertebrates encountered during the survey were (in order of decreasing abundance) gastropods, amphipods, polychaetes, echinoderms, bivalves, ectoprocts and shrimps. Two major invertebrate community types were identified; east of 150°W was mostly dominated by the scallop *Delectopecten groenlandicus* and the crinoid *Heliometra glacialis* (Frost and Lowry 1983). Sea cucumbers, sea urchins and several sp. of brittle stars were also found within this community and in general, the habitat was rocky (Frost and Lowry 1983).

Fish species (latin and common) reported in Frost and Lowry (1983). An asterisk indicates species of highest abundance by number. The species common names in **bold** *overlap with the Beaufort Sea 2008 Survey.*

Boreocogadus saida	**Arctic cod***
Lycodes polaris	**Canadian eelpout***
Icelus bicornis	**Twohorn sculpin***
Artediellus scaber	**Hamecon**
Aspidophoroides olriki	**Arctic alligatorfish**
Liparis sp.	**Snailfish**
Eumicrotremus derjugini	**Leatherfin lumpsucker**
Gymnelis viridis	**Fish doctor**
Icelus spatula	**Spatulate sculpin**
Lumpenus fabricii	**Slender eelblenny**
Lycodes raridens	**Eelpout**
Gymnocanthus tricuspis	**Arctic staghorn sculpin**
Eumesogrammus praecisus	**Fourline snakeblenny**
Triglops pingeli	**Ribbed sculpin**
Lycodes mucosus	**Saddled eelpout**
Lycodes rossi	**Threespot eelpout**
Arctogadus glacialis	Polar cod
Lumpenus medius	**Stout eelblenny**
Lumpenus maculates	**Daubed shanny**

Barber, W. E., R. L. Smith, M. Vallarino, and R. M. Meyer. 1997. Demersal fish assemblages of the northeastern Chukchi Sea, Alaska. Fish., Bull. 95:195-209.

Barber et al. (1997) conducted a fish survey in the Chukchi Sea in 1990 and 1991. The primary focus of this study was to document the distribution and abundance of Arctic fishes in the Chukchi as well as relate fish assemblages to oceanographic variables. The survey extended to the northeast Chukchi Sea and overlapped, to a small extent, with the Frost and Lowry (1983) survey in 1976 and 1977 (Figure 2). For the purposes of this brief review, only stations in the northeastern Chukchi by Barber et al. (1997) were examined (Figure 1, stations 25-29 and 91-32 to 91-35).

The duration of each tow was 30 minutes using the standard 83-112 otter trawl with a 25.2 meter head-rope. The head-rope on the small otter trawl used in Frost and Lowry (1983) measured 4.9 – 5.8 meters. The mesh liner in the 83-112 codend is 31 mm. A total of 64 tows were made in 1990 (48) and 1991 (16 that included 8 that were sampled in 1990).

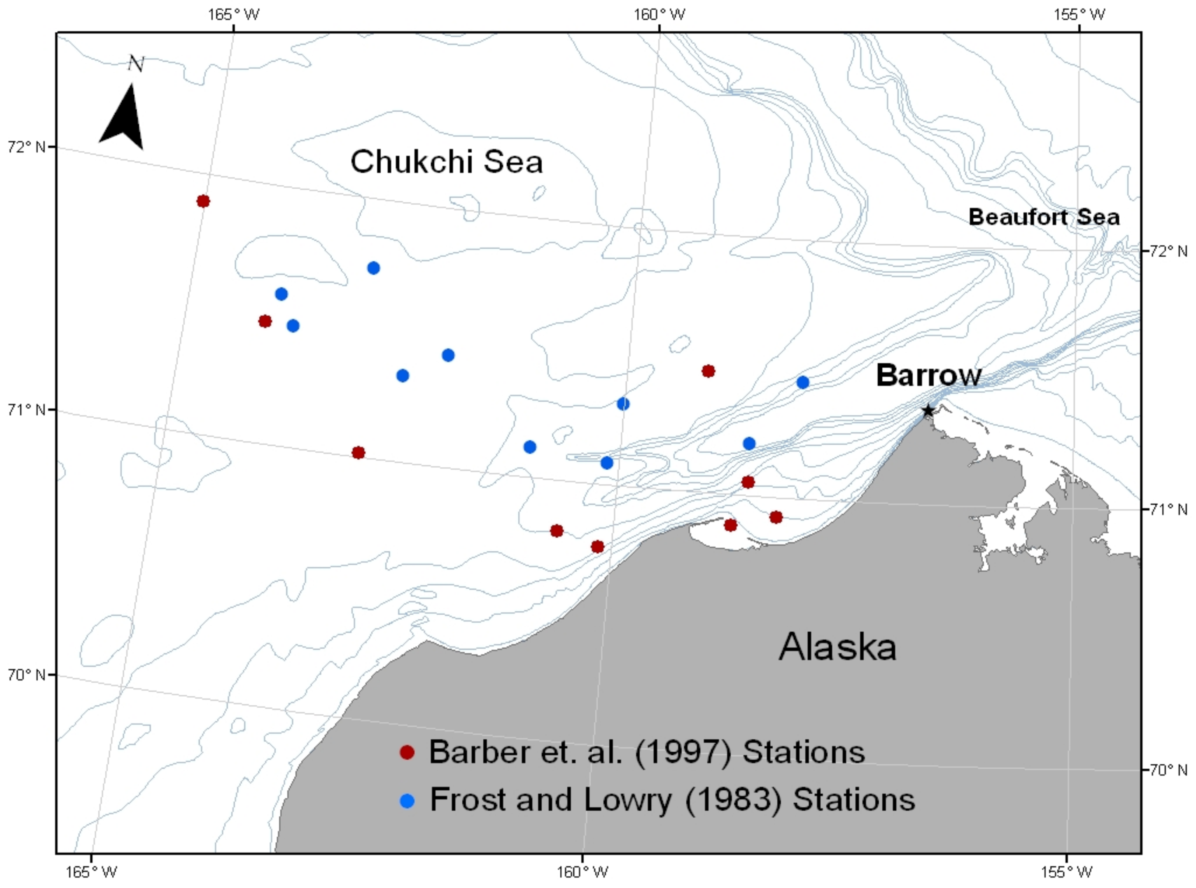


Figure 1 Survey stations were estimated from Figure 1 in Barber et al. (1997). Survey station locations are from Table 1 in Frost and Lowry (1983).

The most abundant species by number and weight was *Boreogadus saida* (Arctic cod). Arctic cod comprised 76% of the total estimated mean abundance (no. fish/km^2) captured in 1990 and 61% in 1991 (Table1, Barber et al. 1997). However, the northeast stations were comprised of substantially fewer numbers of fish/biomass than all other areas (Figure 2, Barber et al. 1997). The number of species observed for the northeastern stations were (stations located in assemblages 2, 3 and 6 in Table 3, Barber et al. 1997) were between 6 and 11. The species found in these stations (in addition to others within that assemblage) are summarized below.

Fish length was not reported in Barber et al. (1997) for any of the listed species.

Species found in the northeastern Chukchi Sea, summarized from Table 3 in Barber et al. 1997 (assemblages 2, 3 and 6). The species common names in **bold** *overlap with the species found in the Frost and Lowry (1983) study, and the Beaufort Sea 2008 Survey. An asterisk indicates species of highest abundance by weight.*

Boreocogadus saida	**Arctic cod ***
Eleginus gracilis	**Saffron cod**
Myoxocephalus sp.	**Sculpin sp.**
Gymnocanthus tricuspis	**Arctic staghorn sculpin**
Hippoglossoides robustus	**Bering flounder**
Myoxocephalus verrucosus	**Warty sculpin**
Artediellus scaber	**Hamecon**
Lumpenus fabricii	**Daubed shanny**
Lycodes polaris	**Canadian eelpout**
Lycodes raridens	**Raridens eelpout**
Podothecus acipenserinus	**Alligator fish**
Gadus macrocephalus	**Pacific cod**
Liparis gibbus	**Variegated snailfish**

Jarvela, L. E., and L. K. Thorsteinson. 1999. The Epipelagic Fish Community of Beaufort Sea Coastal Waters, Alaska. Arctic, 52(1):80-94.

The focus of this research was to identify temporal and spatial patterns in marine fish that inhabit open-water zones in the near shore Beaufort Sea. Specifically addressed were marine fish community compositions, species distribution and abundance, and age-length relationships.

The study area extended from the Colville River delta (~151°30'N) to Barter Island (~143°N), from shoreline to about 30 km. Their study area was divided into a "West" and "East" sector.

The study area was sampled in 1988 with a purse seine and in 1990 and 1991 with a surface tow net. The purse seine was made to specifically target small fish in shallow water and was made with a 19 mm stretch mesh and a 6.3 mm mesh for the bunt (analogous to a codend); the purse seine was held open for 10 to 20 minutes. At total of 41 seines were completed in 1988.

The surface tow net consisted of 50.8 mm mesh from the opening, decreasing to 7.9 mm at the bag. The net was towed between 2 vessels for 10 minutes. A total of 28 stations were towed with a net in 1990 and 35 stations in 1991.

Catches included many "zeros" and had large variance-to-mean ratios. "*Total catches were much larger during the open water year (1990), in which marine conditions prevailed, in contrast to heavy ice years where heavy pack ice was present and brackish water prevailed for a longer period of time (Jarvela and Thorsteinson, 1999").*

Arctic cod, capelin and Arctic cisco dominated the catch in all 3 years (Table 3, Jarvela and Thorsteinson, 1999). On average, Arctic cod and capelin CPUEs in the west sector were larger than those in the east sector in all 3 years. Age-0 capelin, liparids (snailfish) and Arctic cisco dominated all the catches and age-0 Arctic cod dominated the catch in 1990 and 1991(fish age-1 + comprised 7% and 2% of catches in 1990 and 1991, respectively). Based on this, Jarvela and Thorsteinson (1999) concluded that Arctic cod, in general, segregate into discrete size or age groups.

In general, surface waters across the West and East sectors were uniform in species richness and composition. It is not common to find Dolly Varden or Arctic cisco in offshore waters. Combining all species, the range of fork lengths were 10 mm (Liparid larvae) to 172 mm (Arctic cod).

Fish species that occurred across the study area for all 3 years are summarized below from Table 3 in Jarvela and Thorsteinson (1999). The species common names in **bold** *overlap with the species found in the Frost and Lowry (1983) study and the Beaufort Sea 2008 Survey.*

Boreogadus saida	**Arctic cod**
Mallotus villosus	**Capelin**
Coregonus autumnalis	Arctic cisco
Liparis sp. larvae	**Snailfish larvae**
Pungitius pungitius	Ninespine stickleback
Myoxocephalus quadricornis	**Fourhorn sculpin**
Salvelinus malma	Dolly Varden
Cottid larvae	**Sculpin larvae**
Lumpenus sp.	**Eelblennies**
Liparis tunicatus	**Kelp snailfish**
Liopsetta glacialis	Arctic Flounder
Gymnocanthus tricuspis	**Arctic staghorn sculpin**
Ammodytes hexapterus	Pacific sand lance
Artediellus uncinatus	Arctic hookear sculpin
Osmerus mordax	Rainbow smelt
Agonus acipenserinus	Sturgeon poacher

Moulton, L. L., and K. E. Tarbox. 1987. Analysis of Arctic Cod Movements in the Beaufort Sea Near shore Region, 1978 – 79. Arctic, 40(1):43-49.

The primary focus of this study was to assess distribution and abundance patterns of Arctic cod near Prudhoe Bay using hydroacoustic and trawl net.

However, in addition to Arctic cod, all fish captured in the net were identified and counted. All trawls were made on the bottom and towing duration was 15 minutes. A 3 m semi-balloon otter trawl was used with 13 mm square mesh in the body and 3 mm mesh in the codend. A total of 33 tows were made in 1978, 43 in July 1979 and 32 in August 1979.

Hydroacoustic data were primarily collected on north-south transects in water depths greater than 4 m. For specific details on verifying acoustic targets with nets, see Moulton and Tarbox, 1987.

Arctic cod dominated the trawl catches at 98% of the total with traces of kelp snailfish, fourhorn sculpin, Pacific sandlance, capelin, rainbow smelt and least cisco. The length frequency of the Arctic cod indicated that more than likely only age-1 fish were represented in the trawls (very few older fish were captured). Based on the otter trawl captures there is, in general, an offshore movement of Arctic cod between July and August (1979).

Craig, P. C. 1984. Fish use of coastal waters of the Alaskan Beaufort Sea: A review. Trans. Am. Fish. Soc., 113(3):265-282.

This paper reviews research on near shore fishes of the Beaufort. In this summary, the primary focus is on the fish found in brackish near shore habitats which comprises a portion of the review within Craig 1984.

Species are listed from most abundant to least abundant by numbers. The species common names in **bold** *overlap with those found in Frost and Lowry (1983) and the Beaufort Sea 2008 Survey. Species listed below with the † symbol comprises 90% of the total abundance fishes caught along the Alaskan and Yukon Territory coastlines (several references cited with in Craig (1984)*

Coregonus autumnalis	Arctic cisco†
Coregonus sardinella	Least cisco†
Salvelinus alpinus	Arctic char†
Boreogadus saida	**Arctic cod†**
Myoxocephalus quadricornis	**Fourhorn sculpin†**
Coregonus nasus	Broad whitefish
Coregonus pidschian	Humpback whitefish
Liopsetta glacialis	Arcitc flounder
Osmerus mordax	Rainbow smelt

The author summarizes patterns in species distribution and movement in Simpson Lagoon, located within the Barrier Islands west of Prudhoe Bay, between the Colville and Sagavanirktok rivers

It was found that these anadromous fish densities ranged significantly from within Simpson Lagoon (brackish) to marine offshore waters, with the greatest abundance occurring in the warm, turbid waters of the lagoon and few fish occurring in marine waters on the seaward side of the barrier islands. Many fish use this corridor where the highest concentrations of fish occur within 100 m of shore; however, this is influenced by sea state, oceanographic properties (i.e., temperature and salinity), extent of the brackish water, and water depth. Arctic char were the most abundant anadromous fish on the seaward side of the barrier islands.

One note of interest on habitats; there is a documented area of rocky bottom near Prudhoe Bay (as opposed to the predominance of sand and mud in the Beaufort Sea) termed the “Boulder Patch” near Stefansson Sound. There is a relatively low abundance of fish and diversity; however, this habitat is home to marine species that spawn on hard substrate and numerous invertebrates.

Welch, H. E., R. E. Crawford, and H. Hop. 1993. Occurrence of Arctic Cod (*Boreogadus saida*) Schools and Their Vulnerability to Predation in the Canadian High Arctic. Arctic, 46(4):331-339.

The authors document large schools of Arctic cod near shore during the open water season. On occasion these large aggregations are close to shore and visible to people on land. There has been some debate as to whether these events are rare or occur on an annual basis. It has also been documented (through local knowledge) that large schools of fish have been found stranded on beaches, possibly driven by whales.

Arctic cod schools were documented in Allen, Resolute, and Radstock bays, Barrow straight, in Northwest Territories, Canada. Schools sizes were estimated via areal views when schools of cod were shallow and could be seen clearly. For deeper schools of fish, subjective estimates were made via a boat mounted depth finder. School composition was estimated from small otter trawls (5 m wide, 5 cm intermediate mesh and 1.3 cm mesh cod end liner), cast nets (2 cm mesh), dip nets and trap nets.

All large open water schools observed were fish age 2+ with mean ages at 3-4+. Schooling cod were present continuously within Allen Bay for 7-8 weeks during July, August and September. These large schools of cod draw in a wide variety of marine mammals and seabirds. The authors estimate biomass on one day in August, 1989 (Table 3) to be approximately 25, 800 tons (combining all the schools of cod determined by the echo sounder in Allen Bay, Cornwallis Island).

These large schools of Arctic cod undergo intense predation by seabirds and marine mammals and are therefore important prey items in these ecosystems.

Craig, P., and L. Haldorson. 1986. Pacific Salmon in the North American Arctic. Arctic 39(1):2-7.

All 5 Pacific salmonid species occur in Arctic waters; however, only pink and chum salmon have maintained populations north of Point Hope, Alaska (although all 5 have occurred at some time or other north of Point Hope). Of these 2 species, 85% of catches are composed of pink salmon.

The authors estimate that salmon comprise 0-4% of the total sample catch of fishes caught in Arctic waters (based on other studies from 1970 to 1984). The authors captured actively migrating pink salmon from Simpson lagoon, located ~50 km west of Prudhoe Bay. In 1977 no salmon were caught and 118 were captured in 1978, using directional nets, 95% of the salmon captured were moving in an eastward direction.

Little is known about the marine phase of pink or chum salmon in the Arctic (do they migrate to the Bering and overwinter or remain offshore in the Beaufort Sea?). There is evidence based on few tag recoveries that chum salmon spawned in Arctic rivers can migrate as far south as the Gulf of Alaska (Neave 1964, as cited in Craig and Haldorson 1986).

Griffiths, W. B., R. G. Fechhelm, B. J. Gallaway, L. R. Martin, and W. J. Wilson. 1998. Abundance of Selected Fish Species in Relation to Temperature and Salinity Patterns in the Sagavanirktok Delta, Alaska, Following Construction of the Endicott Causeway. Arctic 51(2):94-104.

The authors estimate abundance of four species of marine fish (Arctic cod, fourhorn sculpin, Arctic flounder and saffron cod) and two species of freshwater fish (round whitefish and Arctic grayling) in the vicinity of Endicott Causeway near Prudhoe Bay. Fish were collected via 4 Fyke nets near the Sagavanirktok river delta (Figure 6) from 1985 to 1993. Abundance calculations were based on mean CPUE for each net, totaling 4 estimates for each year and species. Concentration on the four observed marine species, their abundance and observed relationship to temperature and salinity will be the primary focus of this brief summary. The impetus for this study was the concern that oceanographic conditions such as temperature and salinity might change in favor or a more "marine" type environment, thus favoring marine species. Increased abundances of marine species would be indicative that changes enacted by causeway construction may play a role.

Many of the citations that occur within Griffiths et al. 1998 concentrate on near shore surveys that took place during open-water seasons; however only one offshore survey of the Beaufort Sea marine species mentioned below has occurred (see Frost and Lowry 1983).

Arctic cod –
The abundance of Arctic cod increased in the first 3 years after construction of the Endicott causeway, however abundance did not increase over time (between 1985 and 1993). Arctic cod abundance estimates were widely variable among years and locations along the Beaufort Sea coast (as cited by other studies in Griffiths et al. 1998). Arctic cod are can be found inshore, as well as offshore during the open water season. It was concluded by the authors that Arctic cod habitat use in the vicinity of the Endicott causeway did not change as a result in changing temperatures and salinity.

Fourhorn sculpin –
Fourhorn sculpin can occur in both near shore and offshore waters of the Beaufort Sea (as cited in Griffiths et al. 1998). Griffiths et al. 1998 concluded that fourhorn sculpin abundance was positively correlated with salinity levels (Table 1 in Griffiths et al. 1998); however they did not see an increase in abundance, due to higher salinity levels caused by the construction of the Endicott causeway.

Arctic flounder –
The Arctic flounder can be found in shallow coastal waters during the open water season where it can reside in low-salinity habitats (as cited in Griffiths et al. 1998). During the first 5 years post constructions, abundance of Arctic flounder in the vicinity of the Endicott causeway was low. From 1990 to 1993, CPUE increased within the Griffiths et al. 1998 study area. Based on length frequency and age data, the authors conclude that this increase in abundance was possibly due to a large over-winter survival rate of the 1989 year class rather than changes in oceanographic conditions near the causeway that would favor marine species (i.e. increased salinity).

Saffron cod –
The abundance levels of saffron cod within the Griffiths et al. 1998 study area varied, but were relatively low over all years compared to the Arctic cod, fourhorn sculpin and Arctic flounder. There was no significant relationship detected for saffron cod and temperature/salinity in the Endicott causeway study area.

Mecklenburg, C. W., D. L. Stein, B. A. Shieko, N. V. Chernova, T. A. Mecklengurg, and B. A. Holladay. 2007. Russian-American long term census of the Arctic: benthic fishes trawled in the Chukchi Sea and Bering Strait, August 2004. Northwest. Nat. 88:168-187.

An otter trawl with a 7.1 m headrope and a 37-mm stretch mesh liner was used to capture adult and large juvenile fishes. Bottom towing times varied from 10 to 15 minutes. A 3.05 m plumbstaff beam trawl with a 7-mm mesh lining in the body and 4-mm mesh codend was used to capture small adult and juvenile fishes. Towing time on the bottom varied form 1 to 5 minutes.

Depths varied from 34 to 101 meters; there were 26 otter trawls and 19 beam trawls at 17 different stations. Bottom substrate most commonly encountered at stations was sand and mud.

A total of 3,193 fish specimens were collected that included 33 species. The 4 species: Arctic staghorn sculpin (*Gymnocanthus tricuspis*), shorthorn sculpin (*Myoxocephalus scorpius*), Bering flounder (*Hippoglossoides robustus*) and Arctic cod (*Boreogadus saida*) accounted for 79% of all fishes caught. Fish length varied from 20 to 403 mm TL.

All species found on the survey are described in detail (numbers and at what station) that include voucher and station number, range extent (previous and current) and substrate association.

Majewski, A.R., J.D. Reist, B.J. Park, J.E. Sareault, and M.K. Lowdon. 2009. Fish catch data from offshore sites in the Mackenzie River estuary and Beaufort Sea during the open water season, July and August, 2005, aboard the CCGS *Nahidik*. Canadian Data Report Fisheries Aquatic Sciences 1204: vii + 53 p.

This study took place in the Canadian Beaufort Sea, from the Mackenzie River estuary (~10 m isobath) into the marine offshore waters, approximately 50-60 nautical miles offshore (~50 m isobath). The gear types employed were a multimesh gill net, a midwater trawl, benthic sled and a box core. Stations where gear was deployed occurred along two transects. The report states that "fishing activities were exploratory in nature", therefore no quantitative estimates of species biomass were made. The report summarizes species catch, timing, location, depth, gear type and a suite of biological parameters (e.g. length, maturity). NO fish were captured in the midwater trawls and only 1 fish was captured in the box core sampling. All summaries of fish reported below were captured in the benthic trawl.

A total of 18 species were captured at 17 stations (2 transects), which included 167 adult and late juvenile fish and 651 larval and early juvenile fish. Pacific herring made up 37.72% of the total adult and late juvenile catch, and they were only caught in the gill nets. Arctic cod were the most abundant larval and juvenile fish captured (n=485), making up 74.39% of the total and those were only caught in the midwater trawl.

The species common names in **bold** *overlap with those found in Frost and Lowry (1983) and the Beaufort Sea 2008 Survey.*

Clupea pallasii	Pacific herring
Myoxocephalus quadricornis	**Fourhorn sculpin**
Osmerus mordax	rainbow smelt
Coregonus autumnalis	Arctic cisco
Eleginus gracilis	**saffron cod**
Platichthys stellatus	starry flounder
Boreogadus saida	**Arctic cod**
Gymnocanthus tricuspis	**Arctic staghorn sculpin**
Liparis tunicatus	**kelp snailfish**
Liparis fabricii	**gelatinous seasnail**
Ulcina olrikii	**Arctic alligatorfish**
Triglops pingelii	**Ribbed sculpin**
Lumpenus fabricii	**slender eelblenny**
sculpin species unid.	***Icelus* sp.**
snailfish species unid.	***Liparis* sp.**
cod/pollock/whitefish etc.	**Gadidae (genus species not known)**
Anisarchus medius	stout eelblenny
Gymnelus hemifasciatus	halfbarred pout
Icelus spatula	**spatulate sculpin**
Lycodes rossi	**threespot eelpout**
juvenile eelpout unid.	**juvenile *Lycodes* sp.**
Lycodes polaris	**Canadian eelpout**

Majewski, A.R., J.D. Reist, B.J. Park, J.E. Sareault, and M.K. Lowdon. 2009. Fish catch data from offshore sites in the Mackenzie River estuary and Beaufort Sea during the open water season, August 2006, aboard the CCGS *Nahidik*. Canadian Data Report Fisheries Aquatic Sciences 1218: vi + 37 p.

Similar to the 2005 survey by the same authors, this study took place in the Canadian Beaufort Sea, from the Mackenzie River estuary (~10 m isobath) into the marine offshore waters, approximately 50-60 nautical miles offshore, in water depths that ranged from 11 to 225 m. The gear types employed were a benthic trawl and a midwater trawl. Stations where gear was deployed occurred along two transects. There appears to be little or no overlap between these 2 transects in Mackenzie Bay and near Hershel Island, and those transects in the 2005 survey. The report states that "fishing activities were exploratory in nature", therefore no quantitative estimates of species biomass were made. The report summarizes species catch, timing, location, depth, gear type and a suite of biological parameters (e.g. length, maturity).

A total of 619 adult and late juveniles from 17 species were collected. Arctic cod were the most abundant species captured (by number) and made up 38.18% of the total catch at 13 of the 14 stations. Stout eelblennies were the second most common species (by number) captured during the survey. Stout eelblennies were not found on the Beaufort Sea 2008 Survey.

The species common names in **bold** *overlap with those found in Frost and Lowry (1983) and the Beaufort Sea 2008 Survey.*

Boreogadus saida	**Arctic cod**
Gymnocanthus tricuspis	**Arctic staghorn sculpin**
Liparis fabricii	**gelatinous seasnail**
Ulcina olrikii	**Arctic alligatorfish**
Triglops pingelii	**Ribbed sculpin**
Lumpenus fabricii	**slender eelblenny**
Anisarchus medius	stout eelblenny
Lycodes rossi	**threespot eelpout**
Icelus spatula	**spatulate sculpin**
Icelus bicornis	twohorn sculpin
Gymnelus viridis	**fish doctor**
Leptoclinus maculates	daubed shanny
Lycodes reticulatus	Arctic eelpout
Lycodes marisalbi	White sea eelpout
Artediellus scaber	**hamecon**
Lycodes polaris	**Canadian eelpout**

Appendix III – CTD cast data

Table III.1. CTD casts and bongo tows, latitude and longitude, date, time, and depth.

Station	CTD #	Bongo #	Date (GMT)	Time (GMT)	Bottom Depth (m)	Latitude	Longitude
1	CTD001	BON001	8/6/2008	23:49	445	71.89	-154.95
2	CTD002	BON002	8/7/2008	4:20	300	71.84	-154.96
3	CTD003	BON003	8/7/2008	5:19	300	71.79	-154.97
4	CTD004	BON004	8/7/2008	18:21	200	71.74	-154.98
5	CTD005	BON005	8/8/2008	1:44	357	71.90	-153.89
7	CTD006	BON006	8/9/2008	2:24	158	71.81	-154.46
9	CTD008	BON007	8/10/2008	1:00	275	71.97	-154.41
13	CTD009	BON009	8/10/2008	18:53	190	71.88	-154.45
15	CTD010	BON010	8/11/2008	3:38	333	71.72	-152.85
16	CTD011	BON011	8/11/2008	18:41	333	71.66	-152.48
18	CTD012	BON012	8/12/2008	1:41	187	71.52	-152.21
19	CTD013	BON013	8/12/2008	21:45	66	71.75	-153.94
20	CTD014	BON014	8/13/2008	2:10	50	71.69	-154.49
21	CTD015		8/13/2008	17:50	47	71.59	-153.99
22	CTD016	BON015	8/13/2008	20:56	47	71.48	-153.94
24	CTD017	BON016	8/14/2008	3:48	31	71.35	-154.13
25	CTD018		8/14/2008	17:53	40	71.25	-153.12
26	CTD019	BON017	8/14/2008	22:50	75	71.37	-153.06
27	CTD020	BON018	8/15/2008	0:16	72	71.32	-153.09
28		BON019	8/15/2008	2:22	64	71.45	-153.03
29	CTD022		8/15/2008	2:54	72	71.41	-153.04
30	CTD023		8/15/2008	3:44	60	71.50	-153.01
31	CTD024		8/15/2008	4:11	58	71.55	-153.00
32	CTD025		8/15/2008	4:42	63	71.60	-152.98
34	CTD026	BON020	8/15/2008	19:03	49	71.28	-152.30
35	CTD027	BON021	8/15/2008	22:09	85	71.36	-151.99
37	CTD028	BON022	8/16/2008	16:22	44	71.58	-155.06
38	CTD029	BON023	8/16/2008	18:36	20	71.37	-155.08
39	CTD030		8/16/2008	19:16	21	71.41	-155.08
40	CTD031	BON024	8/16/2008	19:45	24	71.46	-155.06
41	CTD032		8/16/2008	20:30	27	71.51	-155.06
42	CTD033	BON025	8/16/2008	21:33	56	71.62	-155.03
43	CTD034		8/16/2008	22:07	90	71.66	-156.00
44	CTD035		8/16/2008	22:42	150	71.71	-154.99
46	CTD036		8/17/2008	3:14	457	71.89	-154.95
47	CTD037		8/17/2008	16:40	26	71.51	-155.06
48	CTD038		8/17/2008	22:21	42	71.63	-154.52
49	CTD039	BON026	8/18/2008	19:01	25	71.20	-153.60
51	CTD040		8/18/2008	22:07	57	71.42	-153.53
52	CTD041	BON027	8/19/2008	0:07	52	71.55	-153.49
53	CTD042	BON028	8/19/2008	4:05	112	71.65	-152.97
55	CTD043	BON029	8/19/2008	16:28	63	71.46	-153.04
57	CTD044		8/19/2008	20:33	32	71.21	-153.12
58	CTD045	BON030	8/19/2008	21:00	26	71.17	-153.13
59	CTD046		8/19/2008	21:36	22	71.12	-153.14

Station	CTD #	Bongo #	Date (GMT)	Time (GMT)	Bottom Depth (m)	Latitude	Longitude
60	CTD047		8/19/2008	23:19	25	71.15	-152.68
61	CTD048	BON031	8/20/2008	5:14	225	71.63	-152.46
62	CTD049	BON032	8/20/2008	16:35	36	71.20	-152.21
63	CTD050	BON033	8/20/2008	18:37	63	71.36	-152.13
64	CTD051		8/20/2008	21:42	267	71.52	-152.07
66	CTD052	BON034	8/21/2008	3:28	59	71.53	-152.87
67	CTD053	BON035	8/21/2008	15:33	52	71.55	-153.49
68	CTD054	BON036	8/21/2008	19:37	26	71.39	-154.58
69	CTD055	BON037	8/21/2008	21:40	21	71.41	-155.07
70	CTD056	BON038	8/22/2008	0:39	102	71.67	-154.99
71	CTD057		8/22/2008	4:30	297	71.78	-154.99

Appendix IV – Net mensuration data and trawl design and rigging

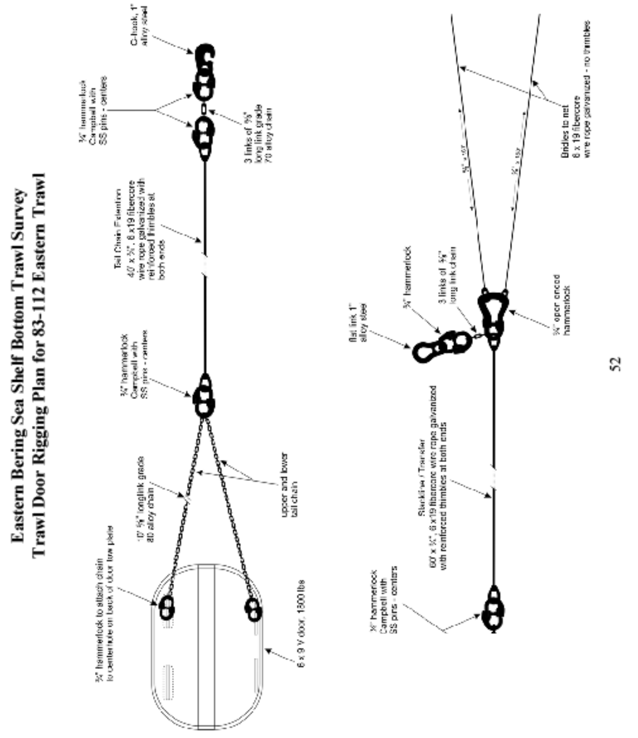
Table IV.1. Net mensuration data from all bottom trawls. Area swept was calculated from distance fished and average net spread. Net spread for hauls 6, 18 and 23 was calculated from a regression on wire out (Lauth and Acuna, 2007), because there was not a sufficient number of net spread observations collected due to instrument failure. Missing net height data are due to instrument failure.

			Net spread (m)		Net height (m)			
Haul	Distance fished (km)	Area swept (km^2)	Average	Standard deviation	Average	Standard deviation	Mean head rope depth (m)	Wire out (m)
1	3.65	0.052	14.4	2.07	5.1	1.13	423	not recorded
2	1.16	0.019	16.4	0.78	3.1	0.13	467	1052
3	1.39	0.023	16.3	0.98	3.4	0.84	195	549
4	1.34	0.021	15.8	0.43	2.6	0.3	344	823
5	1.30	0.020	15.4	0.29	3.1	0.3	140	411
6	1.48	0.027	18.2		3.2	0.18	155	457
7	1.67	0.027	16.1	0.5	3.7	1.05	318	823
8	1.44	0.023	15.6	0.72	2.7	0.13	315	732
9	1.57	0.024	15.5	0.45	2.9	0.42	299	777
10	1.58	0.024	15.4	0.78	2.8	0.49	172	503
11	1.41	0.020	14.4	1.15	2.5		63	229
12	1.58	0.022	14.1	1.22	3.4	0.54	47	183
13	1.41	0.021	14.6	1.66	3.0	0.52	46	183
14	1.18	0.019	15.8	3.09	2.4	0.85	39	183
15	1.49	0.023	15.7	2.65			40	183
16	0.46	0.008	16.7	2.6			40	183
17	0.51	0.009	18.0	0.92			72	229
18	0.60	0.010	17.1				61	229
19	0.50	0.007	13.9	1.9			28	183
20	0.62	0.009	15.2	2.38	2.8	0.87	47	183
21	0.69	0.012	16.7	1.69	2.5		80	274
22	0.78	0.013	16.9	3.2	2.6	1.03	175	503
23	0.69	0.011	16.5		1.3	0.38	43	183
24	0.64	0.010	16.1	1.64	3.9	0.84	46	183
25	0.70	0.011	16.2	2.07	2.5	0.74	57	229
26	0.55	0.009	16.5	0.72	2.3	0.27	50	183

Trawl door detail, rigging, footrope plan and frame lines exerted from Stauffer, 2004.

NOAA Fisheries Trawl Survey Protocols

Eastern Bering Sea Shelf Bottom Trawl Survey
Trawl Door Rigging Plan for 83-112 Eastern Trawl



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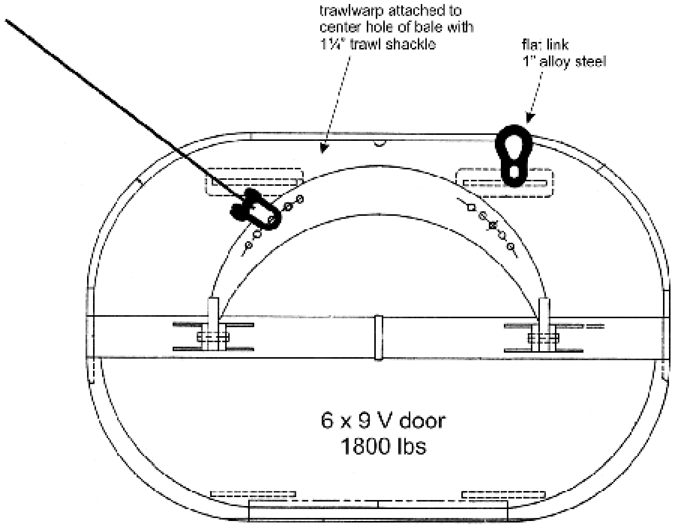
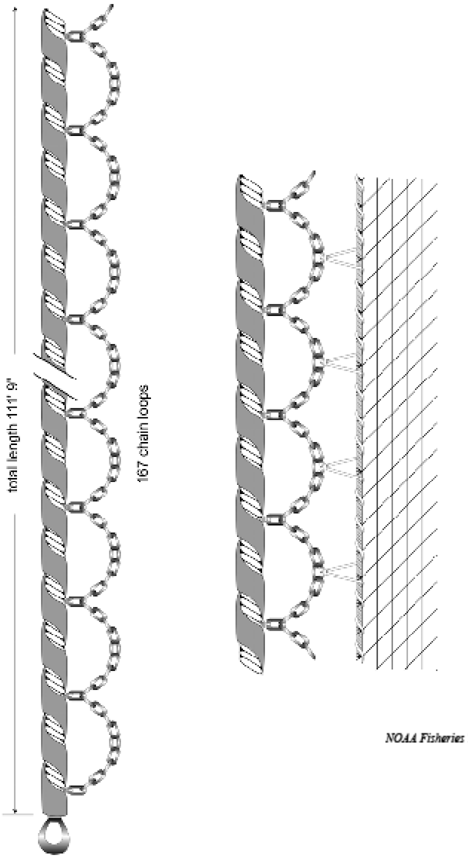
Alaska Fisheries Science Center

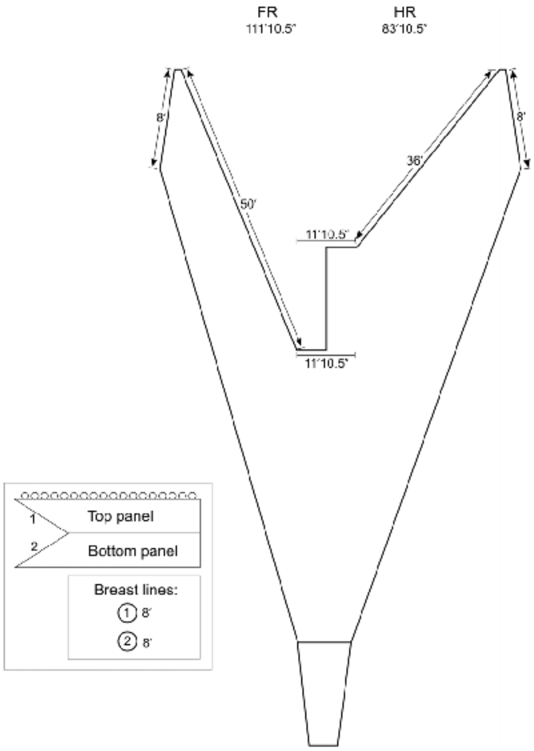
Eastern Bering Sea Shelf Bottom Trawl Survey
Trawl Door Rigging Plan Detail for 83-112 Eastern Trawl
Sole Manufacturer NET Systems, Inc., Bainbridge Island, WA



Eastern Bering Sea Shelf Bottom Trawl Survey
Footrope Construction Plan for 83-112 Eastern Trawl



Eastern Bering Sea Shelf Bottom Trawl Survey
Framing Lines for 83-112 Eastern Trawl



Appendix V – Sample size and final destination of biological samples

Table V.1. Sample sizes for biological collections by species and the type of sample collected. An * indicates the sample was a subsample of the total number of samples collected.

Species	Sex	Length	Weight	Gonads	Stomach	Otoliths	Genetics	Total
Arctic cod	1,493	1,493	753*	~120*	95	1,210*	N/A	1,493
Bering flounder	27	27	27	N/A	27	N/A	N/A	27
Greenland turbot	10	10	10	N/A	10	N/A	N/A	10
Pacific cod	2	2	2	N/A	N/A	N/A	N/A	2
walleye pollock	99	99	99	N/A	N/A	95	95	99

All vouchered fish specimens collected on the Beaufort Sea Survey 2008 are located in the University of Washington's Burke Museum Ichthyology Collection.
http://www.washington.edu/burkemuseum/collections/ichthyology/index.php
Approximately 152 specimens are vouchered at the University of Washington; contact Katherine Maslenikov at (206) 543-3816 or email at: pearsonk@u.washington.edu for a complete list of catalog numbers for each specimen.

All vouchered invertebrates collected on the Beaufort Sea Survey 2008 are located at the University of Alaska Fairbanks (UAF). The contact person for the collection is Dr. Bodil Bluhm, Research Assistant Professor at UAF. http://www.uaf.edu/

Two speces of crabs, *Chionoecetes opilio* and *Hyas coarctatus*, were collected for a special project at NOAA's Alaska Fisheries Science Center, Seattle, WA (see "Special Projects" in Methods). The contact person is Dr. Frank Morado of the RACE division's Pathobiology Laboratory.

Several species of fish were collected for genetic barcoding, Fish Barcode of Life Initiative, FISH-BOL, (see "Special Projects" in Methods). The contact person for this special project is Catherine W. Mecklenburg, Research Associate, Department of Ichthyology, Point Stephens Research, Auke Bay, AK.

All Arctic cod otoliths (age structures) collected on the Beaufort Sea Survey 2008 were aged and are currently stored at NOAA's Alaska Fisheries Science Center, Seattle, WA. The contact person is Dr. Thomas Helser, Manager of the Age and Growth Program.

Walleye pollock otoliths collected on the Beaufort Sea Survey 2008 were aged and are currently stored at NOAA's Alaska Fisheries Science Center, Seattle, WA. The contact person is Dr. Thomas Helser, Manager of the Age and Growth Program.

Walleye pollock genetic fin clips collected on the Beaufort Sea Survey 2008 are currently stored at NOAA's Alaska Fisheries Science Center, Seattle, WA. The contact person is Dr. Mike Canino, of the RACE division's Genetic Laboratory.

Approximately 20 Arctic cod fin clips were sent to the University of Victoria BC, Victoria, British Columbia. The contact person is Dr. John Nelson, Institute of Ocean Sciences, Department of Biology.

Stomachs of three fish species were collected during the Beaufort Sea Survey 2008 and are currently stored at NOAA's Alaska Fisheries Science Center, Seattle, WA. The fish species are Arctic cod, Bering flounder, and Greenland turbot. The contact person is Dr. Kerim Aydin, Manager of AFSC Resource Ecology and Ecosystem Modeling Program.

Stable isotope samples from fish species and bongo tows collected during the Beaufort Sea Survey 2008 are currently stored at the NOAA's Alaska Fisheries Science Center, Seattle, WA. The contact person is Dr. Kerim Aydin, Manager of AFSC Resource Ecology and Ecosystem Modeling Program.

Arctic cod ovaries collected during the Beaufort Sea Survey 2008 are currently stored at the NOAA's Alaska Fisheries Science Center, Seattle, WA. The contact person is Dr. Elizabeth Logerwell of AFSC Status of Stocks and Multispecies Assessment Program.

Fish species were collected for acoustics (target strength) during the Beaufort Sea Survey 2008 and are currently stored at the University of Washington's, School of Aquatic and Fishery Sciences. The contact person is Dr. Sandra Parker-Stetter of the Fisheries Acoustics Research Laboratory.

Approximately 20 juvenile Arctic cod collected during the Beaufort Sea Survey 2008 are currently stored at the Mineral Management Service (MMS), Anchorage, AK. The contact person is Kate Wedemeyer of MMS, Anchorage, AK.

Appendix VI – Auxiliary studies

Bitter crab syndrome in Beaufort Sea snow (Chionoecetes opilio) and Arctic lyre (Hyas coarctacus) crabs.

J. Frank Morado, Pamela C. Jensen, and Amelia Whitcomb

Background

Bitter crab syndrome is a fatal disease of North Pacific Tanner crabs that is caused by a parasitic dinoflagellate of the genus *Hematodinium* Chatton and Poisson 1931. The disease was diagnosed in the North Pacific after lots of southeast Alaska Tanner crabs, *Chionoecetes bairdi*, were rejected by processors for possessing a bitter flavor and "chalky" appearance (Meyers et al. 1987). The estimated economic loss to fishers as a result of the initial disease episode was $175,758 (US). Since the southeast Alaska epizootic, the disease has been reported throughout the Northern Hemisphere with increased frequency and severity. For example, in the North Pacific and in addition to southeast Alaska, the disease has been documented in Gulf of Alaska Tanner crabs, eastern Bering Sea, Norton Sound and Chukchi Sea snow crabs, *C. opilio*, eastern Bering Sea Arctic lyre crabs, *Hyas coarctacus*, and in red, *Paralithodes camtschaticus*, and blue, *P. platypus,* king crabs from the Sea of Okhotsk (Meyers et al. 1996, Ryazanova 2008). Currently, over 40 species of crustaceans are known to be infected of which several species are of economic importance.

In an effort to continue monitoring the prevalence and distribution of the disease, we requested opportunistic samples of Beaufort Sea snow and Arctic lyre crabs. Presence of the disease would extend the known distribution of the disease east of the Chukchi Sea.

Methods

Intact specimens were placed in plastic bags with species and station identification data. All or several specimens of the same species were placed in common bags to conserve freezer space. Frozen samples were shipped to Seattle upon completion of the survey.

Upon arrival, crabs were partially thawed and their sex, size (carapace width for *C. opilio*, carapace length for *H. coarctacus*) and shell condition was noted. Skeletal muscle of the approximate size of a rice grain was removed from a periopod of each crab and placed in 100% ethanol. DNA extraction and conventional polymerase chain reaction (cPCR) sample processing was performed as previously described (Jensen et al. in press). Crabs are identified as positive when two bands, one of 187 bp and the other of approximately 1682 bp in length were amplified and visualized on 2% agarose gels stained with SYBR® Green.

Results

A total of 85 snow and 50 Arctic lyre crabs were collected during the survey. Of these, 4 (5%) snow crabs and 1 (2%) Arctic lyre crab met our criteria for infection by the parasitic dinoflagellate. Amplification of only the short band occurred in another 13 snow and 12 Arctic lyre crabs, but because the long band was not evident, these are not considered to be infected.

Discussion

The results of this study extend the range of the disease east of the Chukchi Sea, the area previously known to harbor *Hematodinium* infected snow crabs. We were also able to confirm the presence of the disease in Beaufort Sea Arctic lyre crabs. The data do not otherwise permit an examination of host/disease relationships, but do emphasize the need for further collections. At the present time, the Beaufort Sea prevalences are similar to disease prevalences in eastern Bering Sea snow and Arctic lyre crabs, but the prevalence in Beaufort Sea snow crab is considerably lower than that reported in Chukchi Sea snow crabs from the 1990's.

Literature Cited

Jensen, P.C., K. Califf, V. Lowe, L Hauser, and J.F. Morado. 2009. Molecular detection of *Hematodinium* sp. in Northeast Pacific *Chionoecetes* spp. and evidence of two northern hemisphere *Hematodinium* species. Dis. Aquat. Org. (in press).

Meyers TR, Koeneman TM, Botelho C, Short S (1987) Bitter crab disease: A fatal dinoflagellate infection and marketing problem for Alaskan Tanner crabs *Chionoecetes bairdi*. Dis. Aquat. Org. 3:195-216.

Meyers TR, Morado JF, Sparks AK, Bishop GH, Pearson T, Urban D, Jackson D (1996) Distribution of Bitter Crab Syndrome in Tanner crabs (*Chionoecetes bairdi, C. opilio*) from the Gulf of Alaska and the Bering Sea. Dis. Aquat. Org. 26:221-227.

Ryazanova, T.V. 2008. Bitter Crab Syndrome in Two Species of King Crabs from the Sea of Okhotsk. Russian J. Mar. Biol. 34:411–414.

Platforms of Opportunity Program – Marine Mammals

Marine mammals were observed while en route to/from the survey grounds and during the survey. Data were collected for the Platform of Opportunity Program (POP) in the AFSCs National Marine Mammal Laboratory (NMML).

In the case of the gray whale sightings, individuals were too numerous to accurately count, therefore were estimated. Sightings include one Steller Sea lion, gray whale (~93), bearded seal (10), polar bear (4), and ice seal (~25). Figure VI.1 summarizes the location of marine mammal sightings (the one Steller sea lion sighting is not shown) and Table IV.1 summarizes all of the marine mammal sightings and behaviors observed.

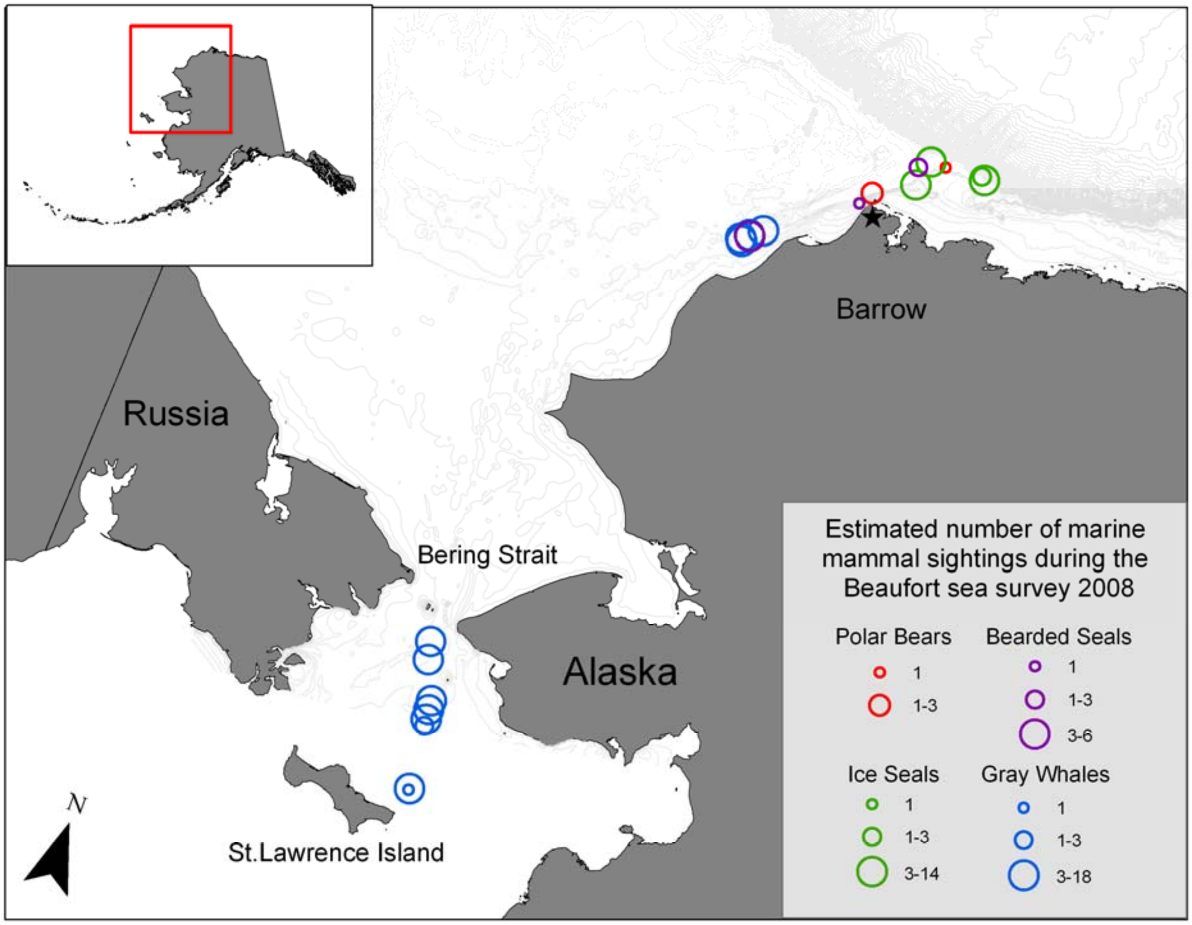


Figure VI.1. Marine mammal sightings during the Beaufort Sea survey, 2008.

Table VI.1. Marine mammal observations collected opportunistically on route to and from the survey grounds and during the survey. Data were collected for the Platform of Opportunity Program (POP) in the AFSCs National Marine Mammal Laboratory (NMML). Gray whale individuals were often too numerous to count precisely, therefore the numbers presented are estimates.

Date (ADT)	Time (ADT)	Latitude (N)	Longitude (W)	Species	Number	Behavior	Comments
7/31/2008	21:12	57.9	167.467	steller sea lion	2	Jug handle; porpoising	
8/1/2008	13:13	63.6	168.467	gray whale	1	Blow visible from distance	
8/1/2008	13:19	63.61667	168.45	gray whale	4	Blow visible from distance	
8/2/2008	18:11	64.38333	168.433	gray whale	2	Blow visible from distance; tail fluke	
8/2/2008	18:45	64.46667	168.417	gray whale	12	Blow visible form distance	
8/2/2008	19:22	64.58333	168.4	gray whale	6	Blow visible form distance; tail fluke	
8/2/2008	20:07	64.7	168.383	gray whale	18	Blow visible form distance; tail fluke	
8/4/2008	16:41	70.8	161.183	gray whale	18	Blow visible form distance; tail fluke	
8/4/2008	17:25	70.85	160.883	gray whale	4	Blow visible form distance; tail fluke	
8/5/2008	8:52	71.33333	157.033	bearded seal	1		Mature adult?
8/5/2008	12:27	71.46667	156.583	polar bear	3	Walking on ice	Female? and 2 cubs (large)
8/6/2008	5:20	71.8	153.9	polar bear	1	Swimming towards ice edge	
	14:38	71.8	154.9	bearded seal	3		2 adults and 1 juvenile
8/10/2008	7:34	71.86667	154.433	ice seal	5		
8/11/2008	7:43	71.68333	152.567	ice seal	2		
8/11/2008	8:00	71.63333	152.467	ice seal	14		
8/11/2008	6:00	71.58333	155	ice seal	4	Swimming and bobbing	
8/22/2008	13:00	70.91667	160.417	gray whale	5	Blow visible; breaching; tail fluke	
8/22/2008	14:20	70.83333	160.867	bearded seal	6		
8/22/2008	15:12	70.76667	161.15	gray whale	7	Diving; leaving mud plumes	
8/24/2008	12:11	65.16667	168.717	gray whale	6		
8/24/2008	11:46	65.38333	168.767	gray whale	11		

Marine bird and mammal surveys conducted during AFSC marine fish surveys in the Beaufort Sea and transit routes, August 2008

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Background

It is the long-term goal of the U.S. Fish and Wildlife Service (USFWS) to update and expand data in the North Pacific Pelagic Seabird Database (NPPSD) for all waters of Alaska. The USFWS collects data on seabird distribution and abundance for the NPPSD by using vessels of opportunity to conduct pelagic surveys. Marine bird and mammal surveys were conducted during the Alaska Fisheries Science Center's (AFSC) July 27 – August 30, 2008 marine fish survey of offshore waters of the Beaufort Sea (E. Logerwell, Principal Investigator). The AFSC project was part of the Status of Stocks and Multispecies Assessment (SSMA) Program and was funded by the Mineral Management Service (MMS). Surveys were conducted onboard the F/V *Ocean Explorer*, under charter with AFSC. The 155 ft vessel transited from Dutch Harbor, Alaska to the Beaufort Sea study area and returned to Dutch Harbor. Data on the distribution and abundance of seabirds were collected during the transit to and from Dutch Harbor and during the acoustic transects, when conditions allowed (Figure VI.2).

This project was a collaboration between the AFSC and USFWS; AFSC personnel conducted the surveys using the protocol and data entry program provided by USFWS. Data were summarized for this report by Kathy Kuletz (USFWS), and raw and processed data were submitted to MMS. These data will also be archived in the NPPSD, and will be available under NPPSD version 2.1 (USFWS and USGS, Anchorage, Alaska). This report summarizes seabird and marine mammal data for the 2008 Beaufort Sea cruise, with a focus on the Beaufort Sea study area.

Methods

Data collection

Surveys were conducted on 14 days between August 1-25, 2008, with the Beaufort Sea surveys occurring on August 6 and 16-20. We surveyed marine birds and mammals from the starboard side of the bridge using standard survey protocol (USFWS 2008) during daylight hours while the vessel was underway. One observer scanned the water ahead of the ship using hand-held binoculars and recorded all birds and mammals within a 300-m arc, extending 90^0 from the bow to the beam. We used strip transect methodology with three distance bins extending from the center line: 0-100 m, 101- 200 m, 201-300 m. Unusual sightings beyond the 300 m transect ('off transect') were also recorded for rare birds, large bird flocks, and mammals. We noted the animal's behavior (flying, on water, foraging, on ice). Birds on the water were counted continuously, whereas flying birds were recorded during quick 'Scans' of the transect window at approximately 1-min intervals. Foraging birds were considered the functional equivalent of birds on the water and thus were counted continuously, even if the birds were hovering or surface plunging.

We entered observations directly into a laptop computer using the DLOG2 program (Ford Ecological Consultants, Inc.) with a GPS interface from the ship's system. Location data from the GPS were automatically written to the program in 20 second intervals (Figure VI.2), as well as our entries on weather conditions, Beaufort Sea State, ice type and coverage, and glare conditions. At the beginning of each transect we recorded wind speed and direction, air temperature, and sea surface temperature. Data were exported into an Excel spreadsheet for editing and minor corrections.

Opportunistic marine mammal sightings were also recorded in collaboration with the Platforms of Opportunity program at the National Marine Mammal Laboratory (NMML). The date, time, location, species and number of animals observed were recorded by all personnel whenever possible. These opportunistic sightings were not included in this report, but are archived with the NMML.

Data processing

Survey transect width and track lines from the GPS entries were used to measure km^2 of survey effort, and this was used to calculate overall bird densities (birds or mammals • km^{-2}). For the Beaufort study area, which had more intensive coverage (Figure VI.3) we processed the raw data with a program developed by MR written in 'R' (R Development Core Team 2008). This program divided the transects into 3km bins and calculated bird density per bin; bin densities were then used to calculate mean density. For a small portion of the data, transect widths were reduced to 200 m or 100 m because of fog or poor visibility; for these segments we used the recorded transect width to calculate densities. Due to segmentation of original transects, not all segments were exactly 3-km in length.

To determine water depths associated with bird observations in the Beaufort study area we used ArcGIS to overlay bathymetric coverage with bird locations. Seabird-ice association was based on the DLOG record of ice coverage recorded along the transect during the survey.

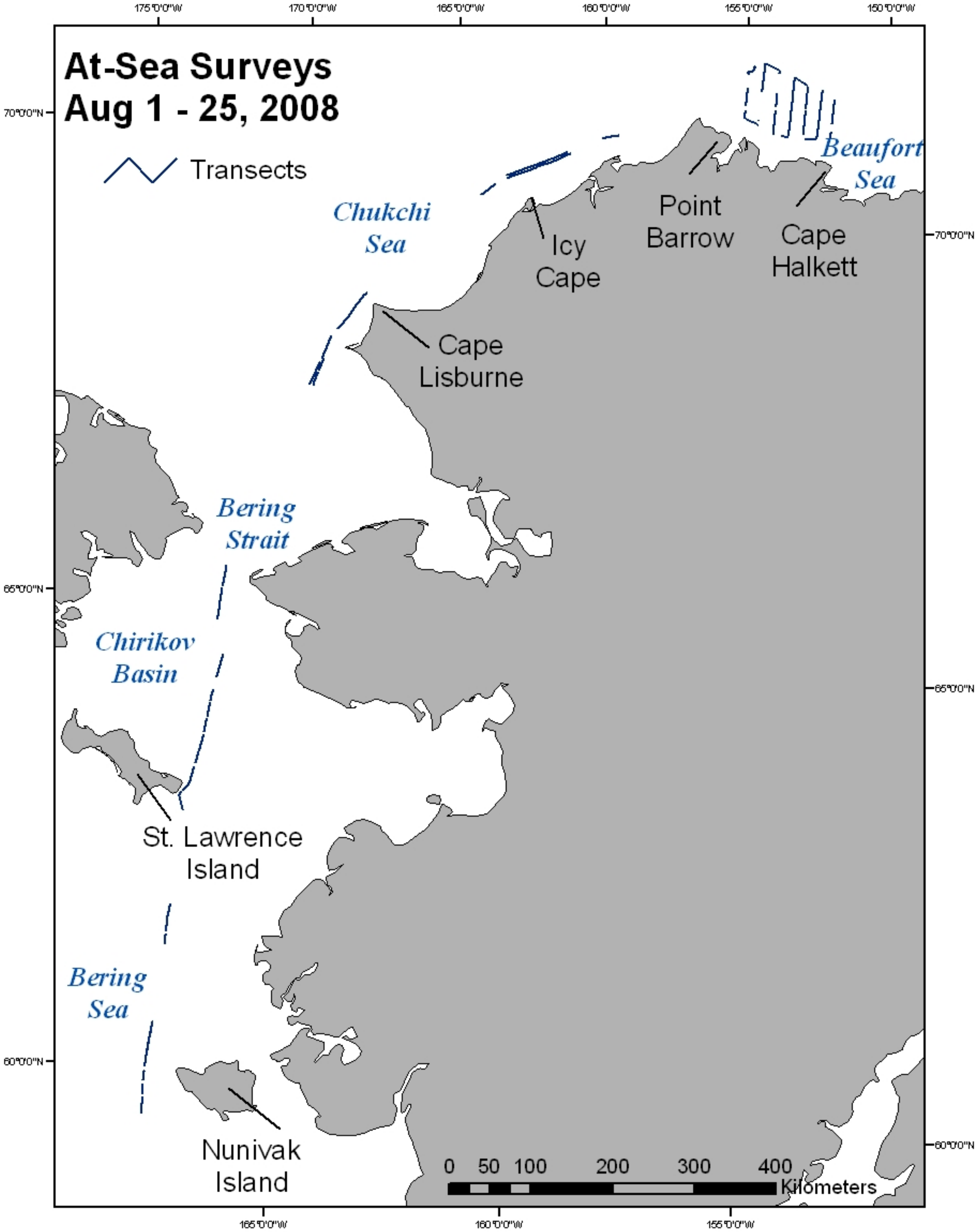

Figure VI.2. Seabird transects during transit and in the Beaufort Sea study area.

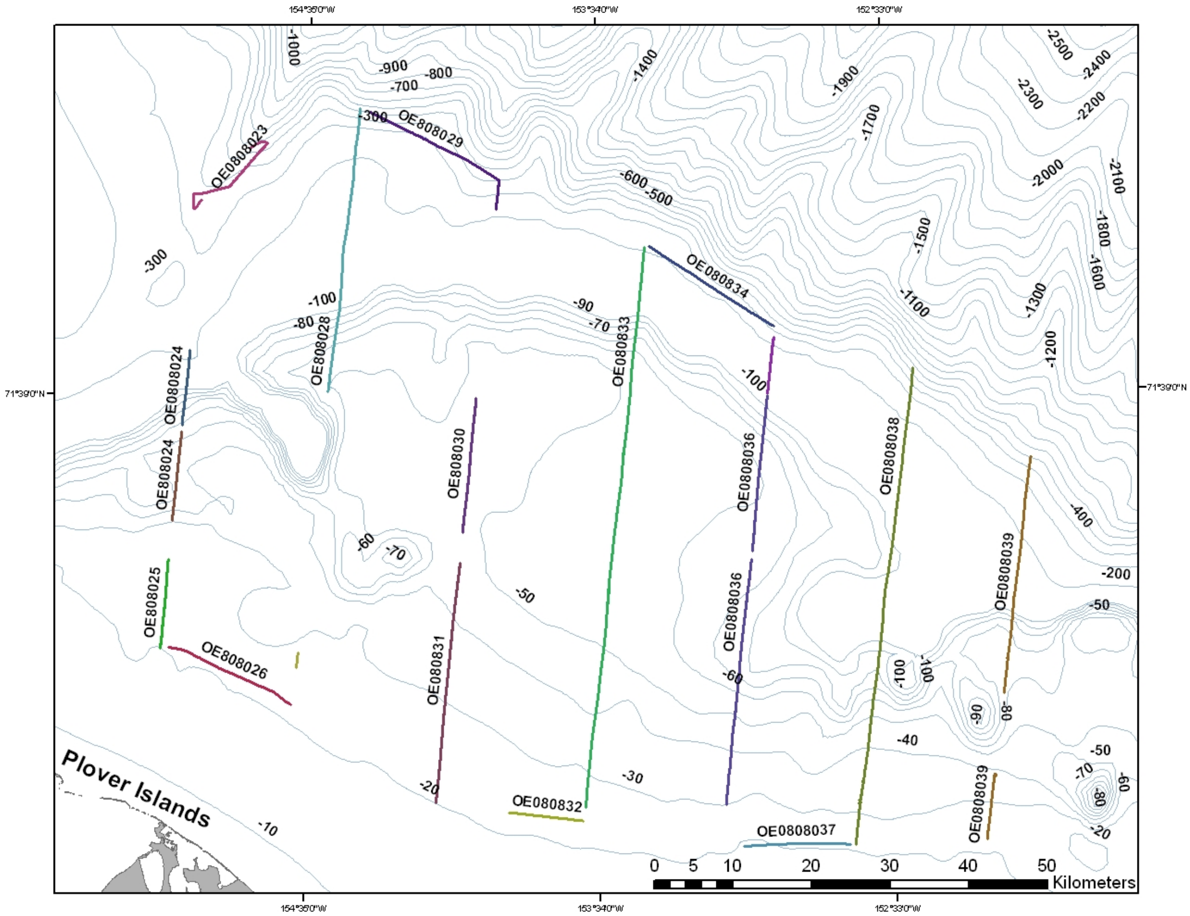

Figure VI.3. Seabird transects in the Beaufort Sea. Depth contours labeled in meters.

Results

Marine Birds

We surveyed a total of 1,245 km, including 428 km in the Bering Sea, 361 km in the Chukchi Sea, and 456 km in the Beaufort Sea study area (Figure VI.2). On transect we recorded 2,921 birds of 23 identified species (Table IV.1). We encountered the highest densities and greatest species diversity (19 identified species, plus unidentified phalaropes [*Phalaropus spp*]) in the Bering Sea. The Bering Sea avifauna was dominated by least auklets (*Aethia pusilla*; 28 %), murres (*Uria spp*; 23 %), shearwaters (short-tailed shearwater [*Puffinus tenuirostris*] identified; 13 %) and lower numbers of northern fulmars (*Fulmarus glacialis*), black-legged kittiwakes (*Rissa tridactyla*), and tufted puffins (*Fratercula cirrhata*) (Table IV.1). Murres, particularly thick-billed murres (*U. lomvia*) were found in all three regions, particularly near Nunivak Island in the Bering Sea and Cape Lisburne in the Chukchi Sea (Figure VI.4).

In the Chukchi Sea we identified 13 species plus unidentified loons (*Gavia spp*), phalaropes, and guillemots (*Cepphus spp*). Predominate birds in the Chukchi were murres (33 %), *Aethia* auklets (primarily crested auklets [*A. cristatella*] identified; 27 %) and phalaropes (red phalaropes [*Phalaropus fulicaria*] identified; 14 %). The Beaufort Sea study area had the lowest overall bird density and fewer species (7 identified, plus unidentified loons and phalaropes), and predominate species were terns (arctic terns [*Sterna paradisaea*] identified; 41%), black-legged kittiwakes (26 %) and phalaropes (16 %).

Table VI.1. Marine birds recorded on transect during surveys from July 27 to August 30, 2008.

		Number on transect				Percent of total within region		
Common Name	Scientific Name	Bering Sea	Chukchi Sea	Beaufort Sea	Total	Bering Sea	Chukchi Sea	Beaufort Sea
Unidentified Loon	*Gavia spp.*		1	2	3		0.12	0.29
Northern Fulmar	*Fulmarus glacialis*	127	30		157	9.30	3.47	
Short-tailed Shearwater	*Puffinus tenuirostris*	32	50		82	2.34	5.78	
Unidentified Shearwater	*Procellariidae spp.*	156	32		188	11.42	3.61	
Fork-tailed Storm-petrel	*Oceanodroma furcata*	1			1	0.07		
Pelagic Cormorant	*Phalacrocorax pelagicus*	3			3	0.22		
Unidentified Duck	*Anatidae spp.*		2		2		0.23	
Surf Scoter	*Melanitta perspicillata*			2	2			0.29
Red Phalarope	*Phalaropus fulicaria*		8		8		0.92	
Unidentified Phalarope	*Phalaropus spp.*	8	110	113	231	0.59	12.72	16.38
Unidentified Shorebird	Charadrii (suborder)	1		35	36	0.07		5.07
Pomarine Jaeger	*Stercorarius pomarinus*	5	9		14	0.37	1.04	
Parasitic Jaeger	*Stercorarius parasiticus*	1		5	6	0.07		0.72
Unidentified Jaeger	*Stercorarius spp.*	1	1	4	6	0.07	0.12	0.58
Glaucous Gull	*Larus hyperboreus*	2	3	35	40	0.15	0.35	5.07
Glaucous-winged Gull	*Larus glaucescens*	1			1	0.07		
Black-legged Kittiwake	*Rissa tridactyla*	60	60	181	301	4.39	6.94	26.23
Unidentified Kittiwake	*Rissa spp.*	15	5		20	1.10	0.58	
Sabine's Gull	*Xema sabini*	1	3	4	8	0.07	0.35	0.58
Unidentified Gull	*Larinae spp.*	25	5	7	37	1.83	0.58	1.01
Arctic Tern	*Sterna paradisaea*			261	261			37.83
Unidentified Tern	*Sterninae spp.*			24	24			3.48
Common Murre	*Uria aalge*	11	6		17	0.81	0.69	
Thick-billed Murre	*Uria lomvia*	30	116	2	148	2.20	13.41	0.29
Unidentified Murre	*Uria spp.*	292	164	15	471	21.38	18.96	2.17
Pigeon Guillemot	*Cepphus columba*	2			2	0.15		
Unidentified Guillemot	*Cepphus spp.*		2		2		0.23	
Cassin's Auklet	*Ptychoramphus aleuticus*	1			1	0.07		
Parakeet Auklet	*Aethia psittacula*	20			20	1.46		
Crested Auklet	*Aethia cristatella*	7	37		44	0.51	4.28	
Least Auklet	*Aethia pusilla*	386			386	28.26		
Whiskered Auklet	*Aethia pygmaea*		2		2		0.23	
Horned Puffin	*Fratercula corniculata*	25	7		32	1.83	0.81	
Tufted Puffin	*Fratercula cirrhata*	60	2		62	4.39	0.23	
Unid.small dark alcid	*Aethia spp.*	56	193		249	4.10	22.31	
Unidentified Alcid	Family Alcidae	35	15		50	2.56	1.73	
Unidentified Bird	*Aves*	2	2		4	0.15	0.23	
Grand Total		1366	865	690	2921			

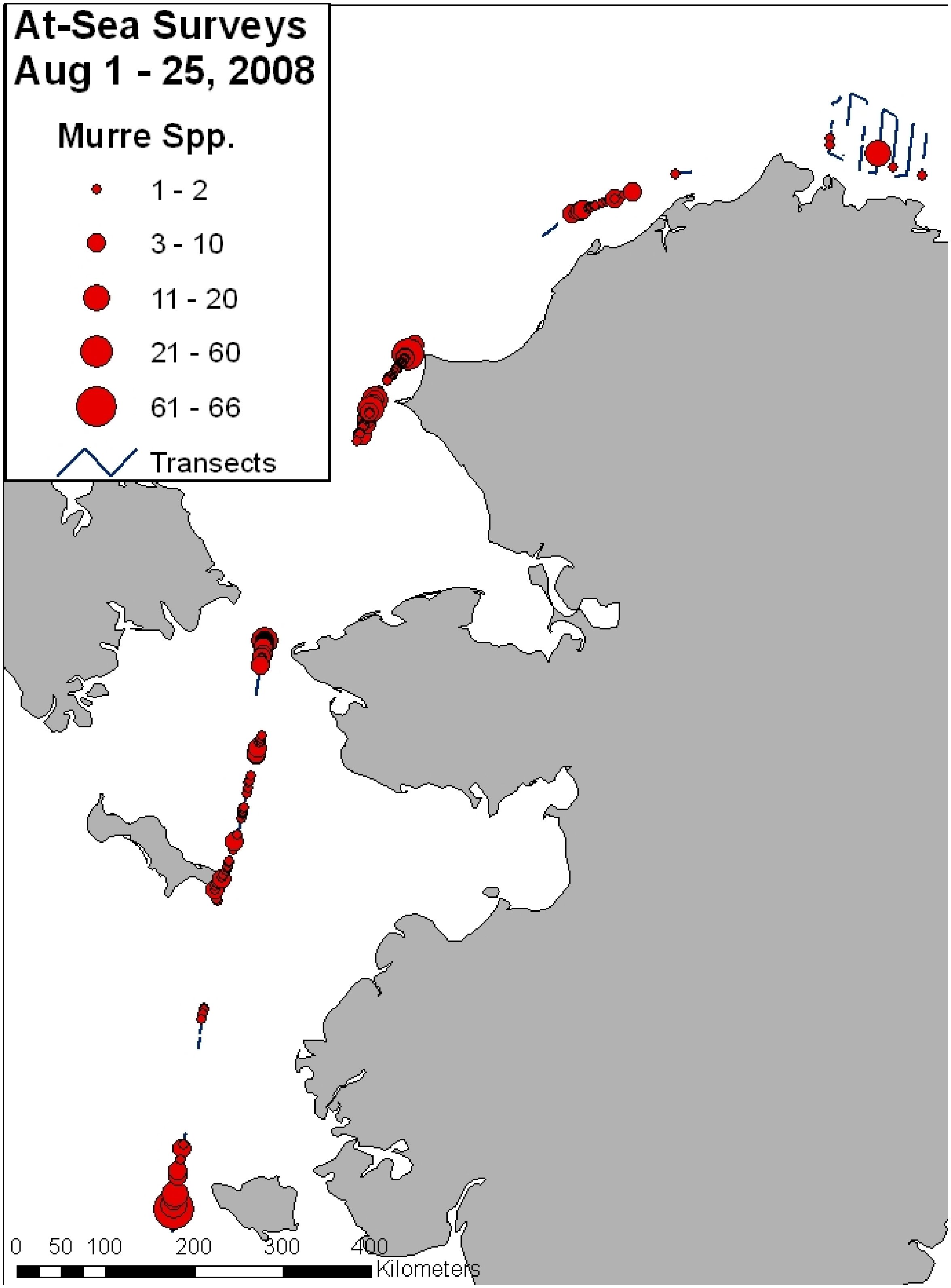

Figure VI.4. The distribution of murres (# birds/km^2) during transit and in the Beaufort Sea study area.

In the Beaufort study area, we recorded 690 birds on transect. Using the binned transect segments (N = 159), densities (birds • km^{-2}) ranged from means of 0.01 for unidentified loons to 3.05 for arctic terns (Table IV.2). The remaining two abundant species had densities of 2.23 for black-legged kittiwakes and 1.20 for unidentified phalaropes. The majority of birds (53 %) were recorded in the mid-shelf domain (50 -100 m depth), followed by offshore (100-500 m deep) and lowest numbers in inner-shelf waters (20 – 50 m deep) (Table IV.2). Among the three most abundant species, terns were primarily distributed in the offshore (59%) and mid-shelf regions (38 %), with the largest aggregations near the shelf breaks of 300 m and 50 m contours (Figure VI.5). Black-legged kittiwakes were most abundant in the inner (44 %) and mid-shelf (50 %) regions, and were more widely distributed throughout these two domains (Figure VI.6). Phalaropes were very patchy (Figure VI.7), being observed in high abundances at just two locations in the mid-shelf domain, with 94 % of observations in water ~50 m deep (Table IV.2).

The percentage of ice coverage we encountered was generally low, with the majority of water ice-free on or near the transects. The Beaufort study area had surface water ice coverages of 10-20 %, primarily of new and small floe categories (based on the NOAA ice guide). The species most frequently associated with ice was the arctic tern, with 40 % of their observations occurring near ice, primarily ice coverage of 20 % small floes. The phalaropes were also associated with the ice, with 18 % of their observations occurring in ice coverage of 10 % medium floes. Other birds occasionally recorded near ice included glaucous gull (*Larus hyperboreus*) and Sabine's gull (*Xema sabini*).

Marine Mammals (Note: data does overlap with Platforms of Opportunity Program)

We recorded a total of 23 marine mammals of 3 identified species on transect during the entire cruise, with gray whales (*Eschrichtius robustus*) the most frequent observation (Table IV.3). Gray whales were observed (apparently feeding) during the transit to and from the study area, with the highest numbers in the Chirikov Basin of the North Bering Sea (11 on transect and 15 off transect). No confirmed bowhead whale sightings were made during the transit or in the study area. Off transect observations also included an adult polar bear (presumably female) and two cubs on the ice near Pt. Barrow. A swimming polar bear was also observed in the same area. Three of the gray whales and the bearded seals (*Erignathus barbatus*) were also recorded near or on ice, respectively.

In the Beaufort Sea study area the only marine mammal observations on transect were one unidentified pinniped and two unidentified whales. The pinniped was in the offshore domain (100 m depth) and the whales were in the inner-domain (40 m depth) (Table IV.2).

Table VI.2. Marine birds and mammals recorded on transect in the western Beaufort Sea, August 6-25, 2008

Marine Birds	Off shelf				Outer shelf					Inner shelf				Percent of	Average
	-400	-300	-200	-100	-90	-80	-70	-60	-50	-40	-30	-20	Total	Total	Density
Unidentified Loon								1		1			2	0.29	0.0106
Surf Scoter												2	2	0.29	0.0795
Unidentified Phalarope		1	5				2		105				113	16.38	1.1950
Unidentified Shorebird				15		20							35	5.07	0.3719
Parasitic Jaeger									5				5	0.72	0.0635
Unidentified Jaeger								1				3	4	0.58	0.0428
Glaucous Gull	2	3	1	4	1			4	4	3	7	6	35	5.07	0.3771
Black-legged Kittiwake		3	4	5	12		26	23	29	24	38	17	181	26.23	2.2327
Sabine's Gull		1						3					4	0.58	0.0428
Unidentified Gull	1	2							4				7	1.01	0.0739
Arctic Tern		104	7	43	10				89	8			261	37.83	3.0516
Unidentified Tern		6	1			1	16						24	3.48	0.2581
Thick-billed Murre											2		2	0.29	0.0215
Unidentified Murre									11	3		1	15	2.17	0.1960
Total Birds	3	120	18	67	23	21	44	32	247	39	47	29	690		
Percent of Total by Depth	0.43	17.39	2.61	9.71	3.33	3.04	6.38	4.64	35.80	5.65	6.81	4.20			
Percent of Total by Strata	30.14				53.19					16.67					
Marine Mammals															
Unidentified Whale										2			2		
Unidentified Pinniped				1									1		

Table VI.3. Marine mammals recorded during transit to and surveys in the Beaufort Sea, July 27 - August 30, 2008.

		Bering Sea	Chukchi Sea	Beaufort Sea	Grand Total
Unidentified Porpoise	*Phocoenidae spp.*	1			1
Gray Whale	*Eschrichtius robustus*	11	3		14
Unidentified Whale	*Cetacea spp.*	1		2	3
Steller Sea Lion	*Eumetopias jubatus*	1			1
Bearded Seal	*Erignathus barbatus*		1		1
Unidentified Pinniped	*Pinnipedia spp.*		2	1	3
Total marine mammals		14	6	3	23

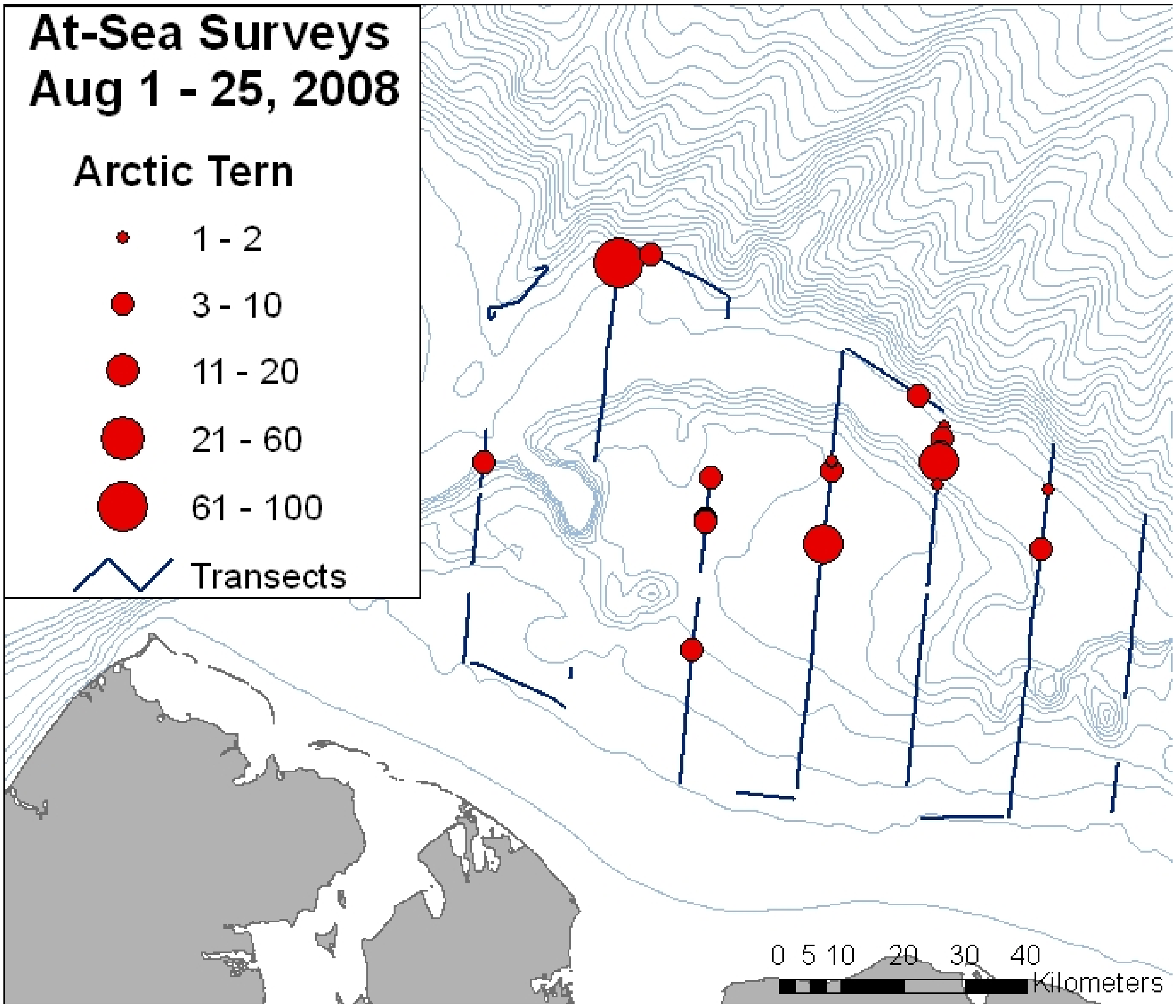

Figure VI.5. Distribution of Arctic terns (# birds/km^2) in the Beaufort Sea study area.

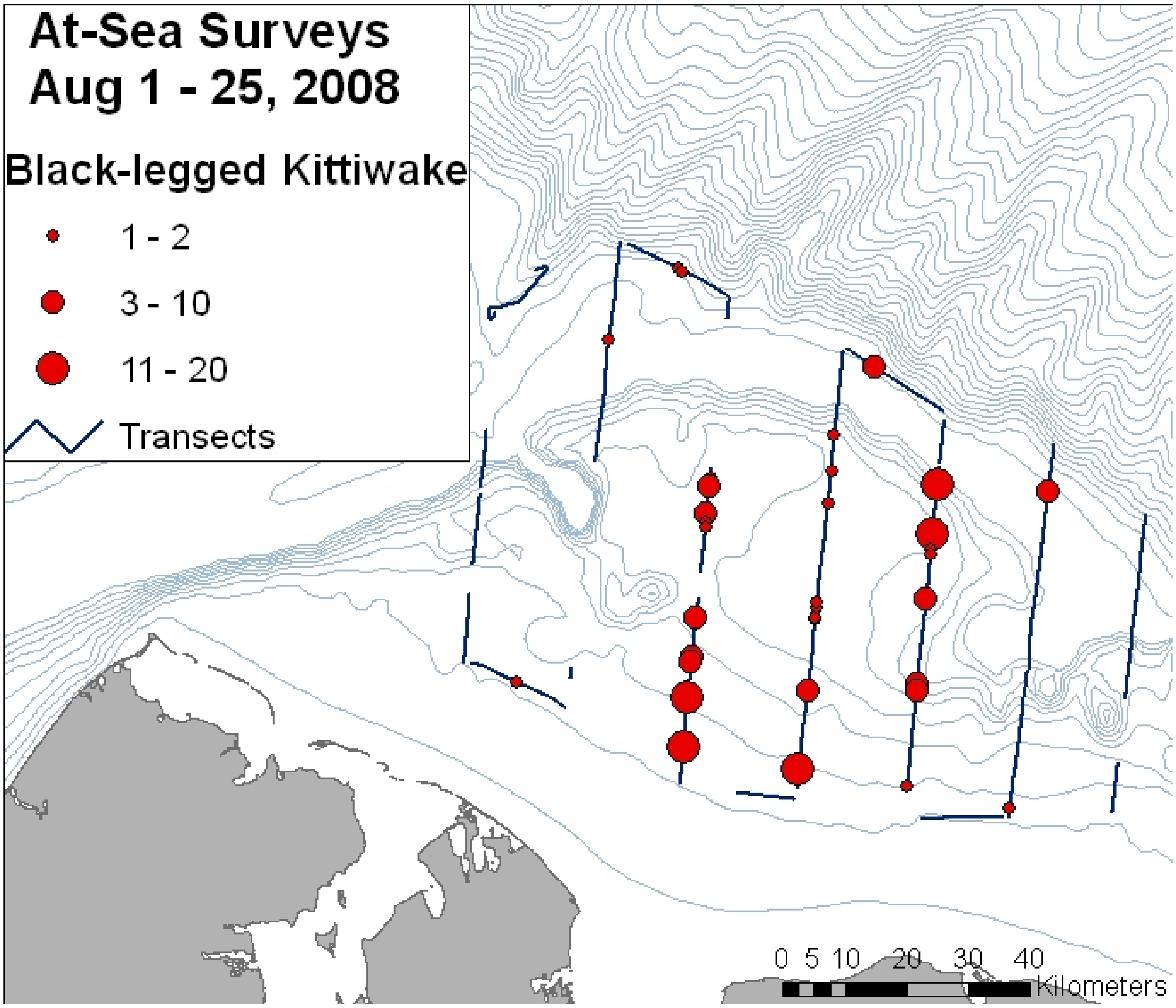

Figure VI.6. Distribution of black-legged kittiwakes (# birds/km^2) in the Beaufort Sea study area.

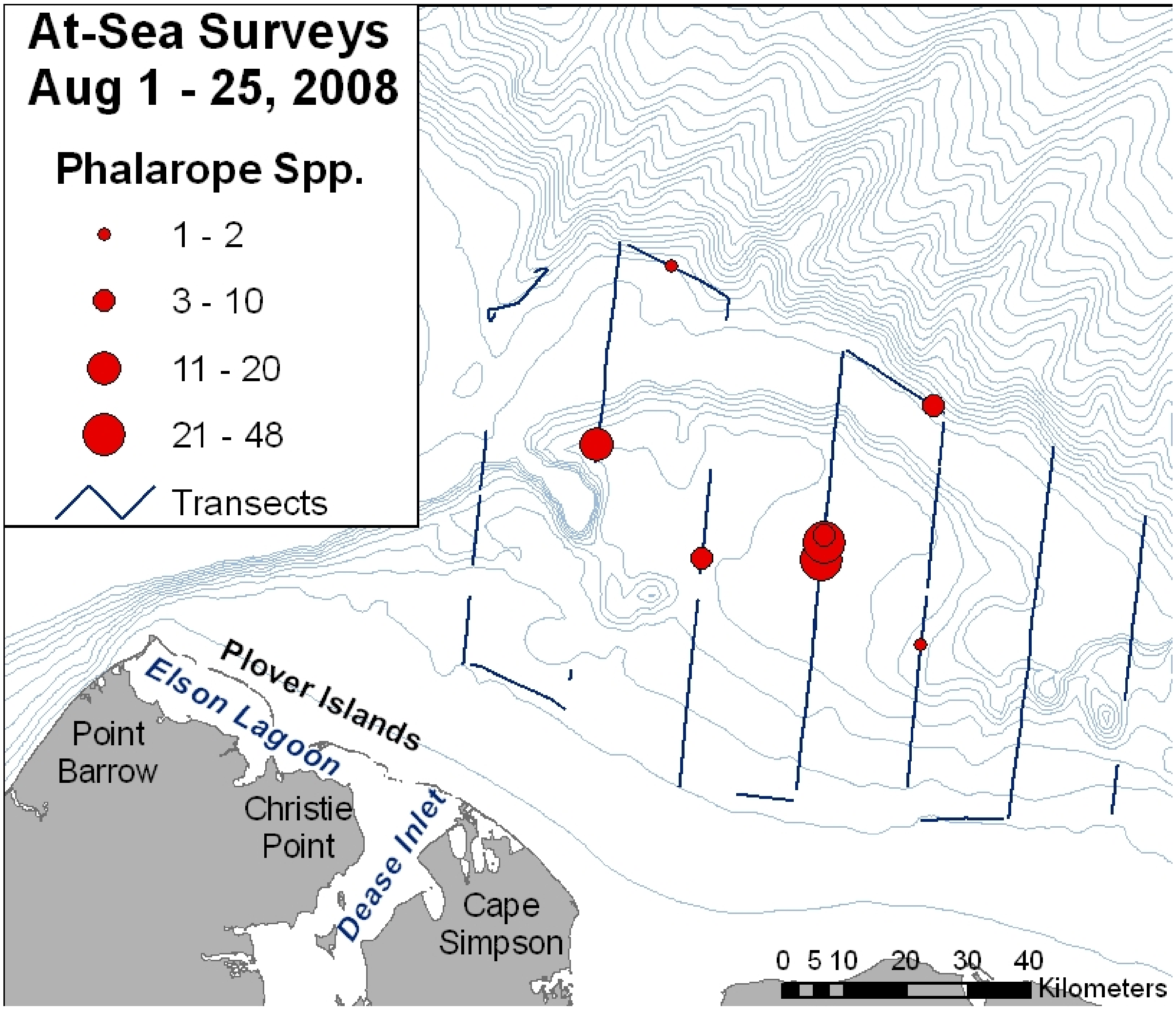

Figure VI.7. Distribution of phalaropes (# birds/km^2) in the Beaufort Sea study area.

Discussion

The late July through August period of this study coincided with post breeding dispersal and migration for the more abundant species groups we observed in the Beaufort Sea – phalaropes, arctic terns, and black-legged kittiwakes. Red phalaropes (identified in our surveys) and red-necked phalaropes (*P. lobatus*) nest in the tundra throughout western Alaska and the arctic coastal plain, but the red phalarope nests farther north and migrates in more pelagic waters than other phalaropes (Tracy et al. 2002). Little is known about red phalarope migratory routes because of their remote, offshore habits, but they arrive in the arctic coast nesting grounds by early June. In the late summer, females leave nesting areas prior to males, but during our August surveys, adults of both sexes and juveniles were likely starting their westward offshore staging and migration (Johnson and Herter 1989). By mid-August, large groups of phalaropes have been documented moving west past Pt. Barrow (Watson and Divoky 1974) and pelagic surveys between 2006 and 2008 recorded them offshore in the same region (Kuletz et al. 2008). Together these data improve our knowledge of the northern migratory patterns and habitat use of this species. Red phalaropes are known to forage in association with ice and at ocean convergences or fronts, where food is abundant near the surface. At sea they consume primarily copepods, larval fish, and amphipods, and are known to take advantage of the plumes of crustacea brought to the surface by foraging gray whales (Tracy et al. 2002).

Arctic terns also nest throughout the arctic coastal plain, with documented colonies along the Beaufort coast, particularly along the Plover Islands east of Pt Barrow. However, birds raising chicks typically forage < 20 km from their colonies (Hatch 2002), and we observed terns much farther than that from the nearest coast. Their post breeding migration is westward from the Beaufort Sea to the Chukchi Sea, occurring from late July to early September, with a peak in mid-August (Hatch 2002), thus our surveys corresponded to peak migration in this region. Terns feed at the water's surface, plunging for small fish to 150 mm long, euphausiids and amphipods caught in currents near the surface, and during this early migratory period are known to feed at euphausiid swarms near Pt. Barrow (Hatch 2002). We observed terns primarily near shelf breaks, which may create fronts that concentrate prey near the surface.

Black-legged kittiwakes have a few small breeding colonies along the Chukchi and Beaufort coasts, but the large colonies are at Cape Lisburne and farther south (USFWS 2006). The kittiwakes we observed were likely post-breeding or non-breeding birds. During the ice-free months, black-legged kittiwakes are common in pelagic waters of the western Beaufort Sea (Divoky 1983). In the Chukchi and Beaufort seas, black-legged kittiwakes feed heavily on arctic cod (Bradstreet 1980), although during the summer adults may consume more amphipods and euphausiids (Hobson 1993). Black-legged kittiwakes feed at the surface, primarily on a variety of small fish, although they will also feed on euphausiids and other macrozoolankton (Baird 1994).

Our data indicate that in the western Beaufort, phalaropes, terns, and kittiwakes forage in offshore waters during this migratory or post-breeding period. At this time they appear to be the most abundant birds in Beaufort waters with depths greater than 20 m, but highest densities are found in deeper waters, particularly at shelf breaks. During USFWS aerial surveys of the Beaufort coastal areas, Fischer and Larned (2004) found few kittiwakes or shorebirds (< 1 % of total birds), rather the nearshore areas supported large numbers of benthic-feeding eiders, scoters and long-tailed ducks (*Clangula hyemalis*). In more pelagic waters we found a very different avifauna predominated by surface feeders, with two of those three species being primarily piscivorous, but also opportunistic foragers on macrozooplankton.

The offshore waters of the Beaufort Sea may be an important pre-migratory staging and foraging area for phalaropes and arctic terns, both of which must prepare for extreme migrations to distant southern hemisphere wintering areas. Another long-distance migrant is the gray whale, which we only identified in the Chukchi and Bering Seas. Our surveys substantiate the importance of the Chirikov Basin, in the north Bering Sea, and to a lesser extent the Chukchi Sea, as feeding grounds for gray whales in late summer.

Climate change could affect timing of migration, and there is little information on seabird distribution during the migration and over-winter phases. At sea surveys that capture these critical phases, especially in areas with little data, allow managers to identify seasonally important habitats. Seabirds and many shorebirds are typically monitored at breeding colonies or nesting grounds, yet they spend most of the year dispersed offshore. At-sea surveys can be used to identify relative abundances of marine birds and their distribution with respect to pelagic habitats. Even during the breeding season, seabirds may feed 20-100 km from their colonies (Coulson 2002), and they are most susceptible when foraging on the water (King and Sanger 1979). Pelagic surveys provide current information on the spatial and temporal distribution of birds at sea to address conservation issues related to fisheries, vessel traffic, oil exploration, and catastrophic spills.

Literature Cited

Baird, P. H. 1994. Black-legged Kittiwake (Rissa tridactyla). In The Birds of North America, no. 92 (A. Poole and F. Gill, Eds.). Academy of Natural Sciences, Philadelphia, and American Ornithologists' Union, Washington, D.C.

Bradstreet. M. S. W. 1980. Thick-billed murres and black guillemots in the Barrow Strait area, N.W.T., during spring: diets and food availability along ice edges. Can. J. 2001.58: 2120-2140.

Coulson, J.C. 2002. Colonial breeding in seabirds. Pages 87-113 in Schreiber and Burger (editors), Biology of Marine Birds, CRC Press, New York.

Divoky, G.J. 1983. The pelagic and nearshore birds of the Alaskan Beaufort Sea. Pages 397-513 In: Envir. Assess. Alaskan Cont. Shelf, Final Rep., Princ. Invest., Vol 23. BLM/NOAA, OCSEAP, Juneau, Alaska.

Fischer, J. B., and W. W. Larned. 2004. Summer Distribution of Marine Birds in the Western Beaufort Sea. Arctic, Vol. 57(2): 143– 159.

Hatch, J. J. 2002. Arctic Tern (Sterna paradisaea). In The Birds of North America, no. 707 (A. Poole and F. Gill, Eds.). The Birds of North America, Inc., Philadelphia, PA.

Hobson, Keith A. 1993. Trophic relationships among high Arctic seabirds: insights from tissue-dependent stable-isotope models. Mar. Ecol. Progr. Ser. 95:7-18.

Johnson, S.R. and D.R. Herter. 1989. The Birds of the Beaufort Sea. BP Exploration (Alaska) Inc. Anchorage, Alaska.

King, J.G., and G.A. Sanger. 1979. Oil vulnerability index for marine oriented birds. Pages 227-239 in J.C. Bartonek and D.N. Nettleship (eds.), Conservation of marine birds of North America. U.S. Fish and Wildlife Service, Wildlife Research Report 11:1-319.

Kuletz, Kathy J., Elizabeth A. Labunski, Martin Renner, and David B. Irons. 2008. The North Pacific Pelagic Seabird Observer Program. North Pacific Research Board Final Report, Project No. 637.

R Development Core Team: 2007, R: A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna, Austria.

Tracy, D.M., D. Schamel, and J. Dale. 2002. Red Phalarope (*Phalaropus fulicarius*). In the Birds of North America, No. 698 (A. Poole and F. Gill, eds.). The Birds of North America, Inc., Philadelphia, PA.

USFWS-MBM 2008. Migratory Bird Management (Region 7) Methods Manual for Seabird and Marine Mammal Surveys. Unpublished manual, U.S. Fish and Wildlife Service, Anchorage, Alaska.

U.S. Fish and Wildlife Service. 2006. Beringian Seabird Colony Catalog- computer database and Colony Status Record archives. U.S. Fish and Wildl. Serv., Migr. Bird Manage., Anchorage, AK.

Watson, G.E. and G.J. Divoky. 1974. Marine birds of the western Beaufort Sea. Pages 681-695 In: J.C. Reed and J.E. Sater (eds.), The coast and shelf of the Beaufort Sea. Arctic Inst. of North America, Washington, D.C.

Appendix VII – Under-ice sampling workshop

WORKSHOP SYNTHESIS

After the workshop, the report authors (Rand and Logerwell) constructed the following two scenarios for surveys of fish distributions in the Beaufort Sea during the winter ice-covered season. The scenarios are based on informal discussions conducted throughout the workshop and the report authors' synthesis of the material presented by the participants. These scenarios do not represent all possible methods for conducting winter fish surveys, and details such as sample size, sampling gear (i.e., AUV vs. ROV), survey costs, etc. should be regarded as preliminary. The goal of the scenarios is to provide a very broad and general overview of the resources required to conduct a winter survey in the Beaufort Sea and the kind of data that could reasonably be obtained, in other words, a starting point. The first scenario is of a survey of fish distributions on the shelf, involving a team of scientists occupying temporary ice camps (SCENARIO A). It is the more expensive of the two scenarios. The second scenario is of a survey in nearshore waters involving periodic sampling by local fishers (SCENARIO B). This scenario is expected to be less expensive than the first.

SCENARIO A

Study design

This scenario represents the most comprehensive sampling of the OCS Planning Area in the ice-covered season and consequently is the most expensive. The under-ice marine survey will occur in three stages. Initially, local residents in Beaufort Sea villages will be interviewed on their knowledge of marine fish species types and distribution to identify species seasonality and habitats. Local residents will also be recruited to conduct passive fishing (pots, traps) under the ice through the ice-covered season. Time lapse cameras will also be installed on existing stationary Beaufort Sea moorings. The second component will use the results of the initial sampling to design a pilot survey using both passive gear and active surveys by divers and underwater vehicles to estimate spatial and temporal patterns of fish abundance. The third component, an active under-ice survey will evaluate Arctic cod abundance in three types of habitats on the under surface of the ice (smooth, rough, and creviced). These surveys will be performed by DIDSON sonar, a remotely operated vehicle (ROV) and scuba diver transects. Once the under-ice habitat has been evaluated, estimates of Arctic cod abundance will be calculated. Each survey component will collect physical, chemical, biological and other environmental data necessary to evaluate and test the significance of independent variables that potentially affect fish presence and distribution. The pilot study will provide statistical hypothesis testing between the open water, ROV and dive surveys, providing a baseline for subsequent surveys and provide sampling statistics, including variance estimators, for future time-series analysis.

Logistics

First stage – local knowledge, passive sampling and time-lapse cameras

For the initial passive fishing under the ice, ice augers would be needed, but depending on the sampling gear, the holes would only need to be 12-24 inches in diameter. Fish sampling gear (pots and traps) would be lightweight, portable and relatively inexpensive. The majority of the project costs for this stage would be for fishers' transit to the sampling sites (e.g. fuel for snow machines) and compensation for their time and effort. In addition, project scientists would need to make several trips to North Slope communities for interviewing, training, project monitoring and outreach. Costs for this component would be expected to be on the order of 100,000's of dollars.

Two sets of cameras with IR lights and measuring lasers would need to be purchased for deployment on moorings. Additional requirements would be underwater housing and data feed cables designed for extreme cold temperatures. The total cost would be approximately $50,000.

Second stage – pilot survey
Depending on the success of the first stage of the project, local fishermen could implement the passive sampling component of the pilot survey. The costs would thus be similar to the first stage, on the order of 100,000's of dollars.

A dive team of three people (minimum) would be required for the active sampling during the pilot survey. Ice-approved equipment including communication equipment would be needed. A shelter would need to be constructed at the dive site. A chartered helicopter would need to be available for evacuation to a hyperbaric chamber, at a cost of about $6,000/day plus $1,500/hour of flight time.

A medium-sized ROV could be leased for the project, along with an operator. Other requirements include a shelter for launch and retrieval of the ROV. Two sets of video cameras with IR lights and measuring lasers would need to be purchased, along with underwater housing and data feed cables designed for extreme cold temperatures. The total cost would be approximately $50,000.

An Ice Camp would be required to support the active sampling. In addition to basic camping equipment, a gas-powered generator for living and science activities would be needed. However, it is the logistic costs of setting up and maintaining an ice camp that are most important to address. Helicopter support would cost on the order of $6,000/day plus $1,500/hour of flight time. For purposes of cost estimation we assume that each site requires 4 days occupation (including camp setup and removal), with a daily average crew size of 6 people on the ice and 6 people onshore (housed in Prudhoe Bay, for example). We also consider 6 helicopter trips/day for camp setup and take down (2 days) and 4 trips/day for the two days of sampling effort for a total of 20 helicopter flights/station. The helicopter operations alone amount to about $900,000 with the science costs (field staffing, sample collection, data processing, and reporting) being the same order of magnitude if 30 stations are occupied.

Third stage – active Arctic cod survey
The first step in the Arctic cod survey would be an aerial survey of ice habitat types. In addition to a survey airplane, still (digital) cameras and photographers would be needed. The price of the aerial survey will depend on the number of days it takes to survey the OCS. A generous allocation for bad weather days should be provided. The cost of an aerial survey can be expected to be on the order of $80,000 or more.

In addition to leasing the ROV, two sets of DIDSON cameras would need to be purchased, along with underwater housing and data feed cables designed for extreme cold temperatures. The total cost would be approximately $160,000.

As in the pilot survey, a dive team of three people would be required for the active sampling during this stage (with helicopter support). Also required would be a shelter for deploying the ROV and an Ice Camp to support the entire field party.

Based on the preliminary cost estimates described above, the annual cost of Scenario A would be over $2,000,000.

SCENARIO B

Survey design
This scenario does not replicate the 2008 summer survey effort in the OCS, but it is less costly than the scenario described above.

This fish survey would be accomplished by periodic (e.g. bi-weekly) sampling through the ice by local fishers. Stations inshore of the 20m isobath, which defines the stamukhi zone (or the edge of the landfast ice) could be reached by snow machine, Rologon, or sled dog teams. The survey design would be a collaborative effort by local fishers and project scientists, and thus would take advantage of the traditional ecological knowledge afforded by the fishers' experience. The fishers would design the sampling gear (e.g., gill nets, hook and line, etc.) and the scientists would train the fishers on methods of catch processing and data recording (counting, weighing, measuring and preserving specimens). The relatively high frequency of sampling would help to compensate for the expected low catch rates.

This survey design would provide information on fish species presence/absence and habitat association. Although an abundance estimate analogous to the summer survey would not be possible, this survey could provide an index of relative abundance within the 20 m isobath. In addition, temporal changes in fish presence or abundance at the scale of weeks-months could be documented.

Logistics
The logistic complexity and costs for this scenario would be much lower than for the first scenario. Ice camps would not be required, because the stations would be close enough to shore to be sampled over the course of several day-long trips. Ice augers would be needed, but depending on the sampling gear, the holes would only need to be 12-24 inches in diameter. Fish sampling gear (e.g. nets, hook and line, etc.) would likely be lightweight, portable and relatively inexpensive. The majority of the project costs would be for fishers' transit to the sampling sites (e.g. fuel for snow machines) and compensation for their time and effort. In addition, project scientists would need to make several trips to North Slope communities for training, project monitoring and outreach.

Total project costs for this scenario would be expected to be on the order of 100,000's of dollars.

Appendix VIII -- **Recommendations for future monitoring methods**

"Based on results of the survey, recommend methods for future monitoring that could provide time-series and data trend information necessary to support offshore development decisions and serve as a proto-type fisheries component of future MMS or other ocean observing systems." (from the Memorandum of Understanding).

Recommendations are to use the same methods as used in this pilot. As stated in the earlier discussion, additional effort is also needed to examine the potential importance of offshore near-surface regions for YOY fish and to quantify the relative contribution of offshore regions to YOY recruitment.

Vessel

The survey was conducted from a 155-foot commercial trawler. This type of vessel proved to be a good platform for a survey of this kind as it had the berthing, fuel and water-making and storage capacity to support 6 scientists and 6 vessel crew for 35 days without re-fueling or re-provisioning. This vessel was limited in its ability to go ashore (if re-supply or fueling were needed) due to the vessel draft (4 to 6 m). It would also be difficult if not impossible to sample in water less than 20 meters depth due to vessel draft and maneuverability. The vessel had two net reels, allowing us to deploy bottom and midwater trawls without re-rigging nets. It should be noted that due to U.S. Coast Guard regulations, no more than 6 science crew can participate in a research cruise on board a chartered fishing vessel. This is not the case on a NOAA vessel such as the *Miller Freeman* or *Oscar Dyson*, where more than 6 scientists can participate. There was ample storage for scientific supplies and equipment. The vessel had good sea-worthiness, although winds were mild during the 2008 survey. However, this was a fishing vessel and not designed for breaking through large amounts of ice, as were encountered on the way to the survey grounds. Moving the survey to a later time period (1-2 weeks after our survey began) may lessen the chance of heavy ice encounters. There was sufficient deck space for sorting and weighing the catch and space was available to mount the AFSC portable winch that was used to deploy the CTD and plankton nets.

Table 60 illustrates the characteristics of a variety of vessels that might be employed for a future Beaufort Sea fish and oceanographic survey. A commercial trawler is more limited than a NOAA research vessel or an ice-breaker in terms of the number of scientists it can support and the oceanographic and acoustic equipment likely to be available. A trawler has an advantage over an ice-breaker in that the latter generally cannot tow medium to large benthic or midwater trawls. It is often true that commercial trawlers, operating under a charter or contract, have more flexibility in the scheduling of days at sea than do NOAA vessels and ice-breakers. Commercial trawlers and NOAA vessels have a disadvantage over ice-breakers in that they cannot operate in ice-covered waters. All three of these types of vessels have similar seaworthiness and depth ranges. The launch is much reduced in seaworthiness, range, and scientific personnel accomodation. The advantage of a launch is its relatively low cost of operation and the ability to conduct operations at more frequent intervals (e.g., short multiple day trips conducted throughout the ice-free season).

Table 60. Comparison of characteristics of different research vessels with regard to conducting fish and oceanographic surveys in the Beaufort Sea.

Vessel	Season	Seaworthiness	Range/ duration	Personnel accomodations	Depth	Trawling	Acoustics	Oceanography	Scientific accomodations
Commercial trawler (~100 ft.)	ice-free only	winds to ~ 35 knts	21-35 days	6 scientists	> 20m	Commercial and research bottom and pelagic trawls	Limited or no scientific acoustics	Limited or no oceanographic sampling	No dedicated lab spaces or freezer
NOAA research vessel (~200 ft.)	ice-free only	winds to ~ 35 knts	40 days	15 scientists	> 20m	Research bottom and pelagic trawls	Scientific acoustics	Scientific oceanographic sampling	Dedicated lab spaces and freezer
Ice-breaker	ice-free and ice-covered	winds to ~ 35 knts	40 days	35 scientists	> 20m	Limited or no fish trawling	Scientific acoustics	Scientific oceanographic sampling	Dedicated lab spaces and freezer
Launch (~ 35 ft.)	ice-free only	winds to ~20 knts	7 days	3 scientists	< 20m	Small bottom and pelagic trawls	No scientific acoustics	Scientific oceanographic sampling	No dedicated lab spaces or freezer

Vessel = Examples of types of vessels
Season = Seasons in which surveys could be done
Seaworthiness = Winds speeds in which scientific operations could be conducted
Range/duration = Number of days vessel could operate without re-fueling or re-provisioning
Personnel accomodations = Number of scientists that could live and work on vessel
Depth = Bottom depths over which vessel could operate
Trawling = Types of bottom and/or pelagic fish trawls that could be deployed
Acoustics = Types of acoustic system that could be employed
Oceanography = Types of oceanographic sampling (physics and zooplankton) that can be conducted
Scientific accomodations = Whether dedicated scientific laboratory space would be available (e.g. wet labs, computer labs, acoustic labs, specimen freezers, etc.)

Survey design and methods

Station and transect spacing

This survey plan was for seven acoustic transects spaced 10 nmi (18.52 km) apart and 25 bottom trawl stations dispersed along the transects among three depth strata (20-40 m, 40-100 m, and 100-500 m). The starting point for the acoustic transects and the bottom trawl station grid was randomly selected. The number of bottom trawl stations was selected based on coefficients of variation (CVs) observed during AFSC Eastern Bering Sea (EBS) bottom trawl surveys (approximately 0.22). CVs (both net types combined) observed during the 2008 Beaufort Sea survey exceeded those from EBS surveys. Ideal bottom trawl sample sizes for the Beaufort Sea survey would range from 55 to an unrealistically large 14,253 (Table 10), depending on the required CV and the delta values specified (percent difference between the estimated and true mean). The unusually high CVs are attributed to the fact that a codend liner was not used in bottom trawl sampling net during the latter half of the survey. The lack of a codend liner resulted in systematically lower catches during the latter half of the survey. Future monitoring studies will require additional analysis of catch variability and target sample size to determine the ideal number of bottom trawls in a given area. During the acoustic survey, the midwater trawl was used to verify the species and length distributions of observed targets (i.e. fish). No CV calculations were made for the midwater trawl as net samples were not used in acoustic-based density estimates. In this survey, twenty-eight midwater trawl collections were made. Additional midwater trawling effort is recommended for future surveys if an objective is to classify and separate young-of-the-year (YOY) species and for target strength evaluation (see below). Additional midwater trawl effort would also allow the presence of other pelagic species (e.g. capelin) to be examined.

Acoustic observations of YOY fish and yearling-and-older (year-plus) Arctic cod density distributions indicated that survey transects (bounded in the south by the 20 m contour and in the north by the 500 m contour) did not capture the full extent of YOY or year-plus distributions. The highest densities of YOY fish and year-plus Arctic cod were observed at the ends of transects and along cross-transects. A complete survey of Arctic cod would necessitate extending transects into deeper water for year-plus fish and to shallower water for YOY fish. A dedicated nearshore (20 m and less) acoustic-trawling survey of YOY is warranted. Such a dedicated nearshore survey would also facilitate the development of acoustic techniques to separate YOY fish and year-plus Arctic cod that vertically overlap (i.e. not vertically separated in the water column) in the 20-40 m depth depth.

A cursory geostatistical analysis of the YOY fish and year-plus Arctic cod density distribution data suggested that the 18.52 km (10 nmi) transect spacing used in this study did not detect spatial patterns in the data. Directional empirical variograms for both YOY and year-plus are relatively flat, indicating that there was little autocorrelation in density values. The lack of autocorrelation suggests that density distributions of YOY fish and year-plus Arctic cod was uniform within the study area or that the 18.52 km (10 nmi) transect spacing was too coarse to detect spatial patterns.

Bottom trawl field methods and data analyses (demersal fish sampling)

Comparing the bottom trawl results of the present survey to the previous survey of offshore marine fish in the Beaufort Sea (Frost and Lowry 1983) was hampered by the lack of catch-per-unit-effort (CPUE) data from the previous survey and by differences in gear type. Net mensuration and gear standardization (i.e. maintaining consistent trawl net and hardware design among surveys) are recommended for an on-going monitoring study. Net mensuration would provide data on area swept by the net and thus CPUE. Gear standardization would allow for comparisons between survey years without bias due to changes in gear type. A research survey conducted without standardized gear and net mensuration would only be able to document fish species presence and would not be comparable to other survey results.

The distribution and abundance of adult and juvenile demersal fish was assessed with a 83-112 eastern otter trawl with a 25.3 m headrope and a 34.1 m footrope (a.k.a. "bottom trawl"). This net is the standard for Alaska Fisheries Science Center (AFSC) bottom trawl surveys of the Bering Sea shelf (Acuna and Kotwicki 2004), and Chukchi Sea (Barber et al. 1997). The primary bottom trawl nets were lined throughout with 1.5-inch mesh to insure catches of smaller fish typical of the Arctic.

The otter trawl is the most widely used type of bottom trawl in commercial fisheries, and their success is due to the herding action of the trawl doors and sweeplines. The trawl doors, sweeplines and the mud and sand clouds they produce upon contact with the bottom have been shown to produce strong visual and auditory stimuli that result in herding fish and invertebrates into the net (Main and Sangster 1981, Wardle 1986). Experimental work has shown that the effectiveness of the herding action of the sweeplines depends on the size of the fish (Engås and Godø 1989). In addition, some fish are able to escape beneath the footrope of the trawl. This is particularly true for flatfish species such as plaice (*Hippoglossoides platessoides*), although escapement has been shown to be reduced at night (Walsh 1991). In general, the sampling effectiveness of the otter trawl varies with depth, season, time of day, ambient light and response to noise produced by the survey vessel and gear.

The other bottom trawl gear that was considered before the field survey was a beam trawl. Beam trawls are designed to catch small fish (<20 cm) and do not require net mensuration because the beam holds the horizontal opening constant. The beam trawl is a smaller net, with smaller meshes and it fishes very close to the bottom, potentially "scooping up" benthic invertebrates. The decision to conduct the survey with the 83-112 eastern otter trawl was so that results could be comparable to previous, contemporary and/or future AFSC trawl surveys of the Bering and Chukchi Seas.

Before committing a monitoring study of the Beaufort Sea to a particular gear type, some gear development work will be required. The intention of the present bottom trawl survey design was to sample all stations with a lined 83-112 bottom trawl net. The presumption was that the lined net would catch small arctic fishes more effectively than an unlined 83-112. While the lined net did appear to catch small fish effectively, the nets were highly susceptible to damage caused by large catches, heavy mud and boulders. One helpful modification that was employed during the present survey was to shorten tow times from 30 minutes (the standard for AFSC Bering Sea surveys) to 15 minutes or less. However, even at these shorter tow times all lined nets were eventually damaged. Recommendations for strengthening the lined 83-112 for future surveys are: 1) heavier riblines to cope with weight of rocks and large catches, 2) stronger attachment of the net to the footrope and headrope, and 3) guard mesh in the bosom and belly panel with a light-weight mesh inside that can break away in case of rocks or mud in the belly of the net (Darin Vanderpol, pers. com., captain of the F/V *Ocean Explorer*). Strengthening the lined 83-112 will be particularly important if future surveys intend to sample in waters shallower than 40 m. The bottom at these depths appeared to be excessively hard and rocky, such that even a strengthened 82-112 might nonetheless be inappropriate gear to use.

See "*Station and transect spacing*" above for discussion of demersal fish survey design.

The original data analysis plan was designed to estimate demersal fish and dominant benthic invertebrate biomass from bottom trawl data using the area-swept method (Alverson and Pereyra 1969). For each species, catch-per-unit-effort (CPUE) was calculated for each tow by dividing catch numbers and weight (kg) by the area swept by the tow (km^2). A mean CPUE for each depth was calculated as the mean of the individual tow CPUE (including zero catches) within that depth. Biomass and abundance estimates were calculated by multiplying each depth mean CPUE by the depth area (Britt and Martin 2001).

The original data analysis plan also called for statistical tests for differences in demersal fish abundance (numbers and biomass) among strata (e.g. ANOVA or non-parametric rank-sums tests). This would have allowed us to evaluate the null hypothesis that the abundance of species does not vary across habitat. Data on depth, water temperature, salinity, etc. would have been used to characterize the three habitats (strata). Statistical analyses of the environmental and fish data, such as ANOVA, would have allowed us to test the significance of the independent variables that may affect demersal fish abundance. However, it was not possible to conduct the hypothesis testing as originally proposed because gear type (lined vs. unlined trawls) and tow time (15 vs. 5 minutes) were thoroughly confounded with each other and with survey strata (shelf, slope and rise). With the exception of one station, all the rise stations (bottom depths 101-500 m) were sampled with the lined net and tows were 15 minutes long. Nearly all the shelf/slope stations (9 out of 12 stations in bottom depths 40-100 m) were sampled with the unlined net and were 5 minutes long. This confounding was not intentional but was the result of the fact that only the rise stations were free of ice early in the survey and so we sampled them first with the lined net. When the ice cleared out of the shelf/slope area we had damaged all the lined nets and were forced to complete the survey with the unlined net. Tow time was reduced to 5 minutes when we switched to the unlined net to minimize the chance of damaging our last remaining bottom trawl net. In summary, the sample collection order imposed by practical constraints during the cruise (ice cover and availability of nets) prevented collection of the data as originally planned. The data as collected had a confounding of gear type, tow time and survey strata that made it impossible to statistically examine or control for the effects of gear type and tow time on catch density. Thus we could not test for differences in benthic fish and invertebrate density among survey strata or for the effects of habitat characteristics as originally proposed. This is the case for both parametric tests such as ANOVA or non-parametric tests such as a rank-sum test.

We thus revised the data analysis plan, and proposed to attempt a test of the effects of habitat on benthic fish and invertebrate density using General Additive Models (GAM). We analysed data from stations sampled with the lined net (all of which were towed for 15 minutes), separately from those sampled with the unlined net. This analysis was designed to test the null hypothesis that habitat characteristics do not effect benthic fish and invertebrate density without the problems associated with variable net type and tow duration. The dependent variable was fish or invertebrate density (#/ha or kg/ha). Independent habitat variables included depth, bottom temperature, salinity, stratification and longitude. Which variables were included in the final model depended on whether they are correlated with each other and how many degrees of freedom the appropriate GAM smoother allowed. "Patchiness" in the fish and invertebrate catch data (low sample size and increasing variance with increasing means) was managed by log-transforming the data. In cases where there was a zero observation, 0.5 was added to all data observation points in that group, and then the values were log transformed. For some species the number of zero observations was so exceptionally high that it was not appropriate to use GAM techniques on transformed data. In these instances, it was more appropriate to examine the presence/absence of the species rather than density with a generalized linear model (GLM), assuming a poisson distribution with a log link.

Acoustic field methods and data analysis (pelagic fish survey)

Pelagic fish distributions were assessed using acoustic methods. Adult and juvenile fish were surveyed with a calibrated Simrad ES60 echosounder with a 38kHz split beam transducer, the frequency typically used for fish surveys. Acoustics is ideal for assessing pelagic fish distributions, but due to the acoustic "dead zone" near the bottom (0.5 m), this method is limited in its use for assessing bottom fish. For many fish targets, the gas in the swim bladder is responsible for most of the acoustic signal, such that fish that lack a swim bladder are poor candidates for acoustic surveys. The data are collected continuously such that patchiness along transects can be measured (this is difficult with bottom trawl data). The physics of sound are well understood and can be used to quantify the level of acoustic energy in the returning echoes. However, acoustic systems used in surveys are not capable of discriminating among different species of fish, so target identification with trawls is an integral part of an acoustic survey. Noise can cause bias in the acoustic data, so noise levels in the system should be reduced through proper system engineering. Sources of noise include ship noise, internal noise introduced by the echosounder's amplifier and processing circuitry, ocean noise such as breaking waves and intermittent biological noise caused by fish and marine mammals. While many of the noise sources can be minimized by ship and electronic design, noise can never be eliminated entirely. In addition, acoustic energy can be lost due to attenuation by air bubbles entrained along the hull of the ships. This source of error can be avoided with careful location and mounting of the transducer. For more details regarding sources of acoustic survey bias and methods of minimizing them, see Gunderson 1993.

Midwater trawling is the method most commonly used for acoustic target identification. The ability of fish avoid midwater trawls can be remedied with the use of trawls with large openings, towed at high speeds. However, large mesh sizes used in the wings of some midwater trawls means small fish can escape the net. Nakashima (1990) evaluated the selectivity of a large midwater net by attaching sampling bags outside the net and comparing the catches with those in the cod end. Fish that were smaller than the meshes escaped from the trawl in significant numbers. As a consequence, acoustic surveys are best suited for situations where the fish aggregations are dominated by species with a narrow size range. In situations where multiple species are present, a relatively large number of trawls will be required to achieve species identification.

The preferred make and model echosounder for future studies is a Simrad splitbeam EK60 echosounder, but an ES60 transceiver is also acceptable. In either case, the transceiver box must be physically accessible to allow the inspection of grounding and to potentially create a second output display. Because of depth penetration requirements, 38 kHz is the optimal acoustic frequency. If a second frequency is available, 120 kHz provides a reasonable contrast but will be limited to depths shallower than 300 m. In addition to an updated Simrad transceiver, it is also imperative to know the model and location of the acoustic transducer. During the current survey, the vessel had an updated Simrad ES60 transceiver but had an old 38 kHz transducer mounted in the hull. As this was not known until the time of the survey, additional time was required to process the acoustic data after the survey. Known location(s) of the transducer in the vessel hull will reduce the amount of time required to set up calibration equipment.

As most AC vessel generators produce electrical noise that can be detected by the echosounder, it is recommended that a vessel noise profile be generated under all operating conditions (e.g. running at various speeds, trawling, etc.). This procedure will assist in the identification of noise sources and can be used to determine an optimal, acoustically-quiet, survey speed. Since noise characteristics of any vessel are rarely known, both AC and DC power sources and a separate ground should be available for the echosounder. Availability of an AC power conditioner is optimal and recommended. A separate ground and an electrical line conditioner will improve performance of the ship's echosounder after the survey.

The vessel's acoustic system must be calibrated using the final equipment configuration, including grounding location, power source, and cables used between the transceiver and the operating computer. Ideally, this calibration will occur before the survey, with sufficient time to process the data and make necessary adjustments to equipment settings. If time permits, a second calibration is recommended following the survey to detect any changes in equipment performance that occurred.

To increase the ability to measure target strengths of individual fish, future acoustic surveys should incorporate stationary daytime sounding to observe single targets and possibly use a drop-transducer (acoustic transducer using a shorter pulse duration lowered to depth) to obtain target strength measurements. High Arctic cod densities within aggregations and layers limited our ability to collect single target data. If Arctic cod target strength values must be obtained from the edges of schools or layers, future surveys should dedicate midwater trawl sampling the edges and middle of aggregations to verify that the length distribution of Arctic cod is consistent throughout the aggregation. Ideally a closing cod-end net combined with net depth-monitoring is recommended to provide definitive length samples through the water column.

Future midwater trawl sampling to support acoustic-based density and abundance estimates should collect length and weight information from young-of-the-year (YOY) Arctic cod to establish a length to weight regression for Arctic cod. A relationship between yearling-and-lder (year-plus) Arctic cod length and weight was developed from bottom trawl samples, but this analysis did not include YOY-sized individuals. Development of a length to weight relationship specifically for YOY Arctic cod, or extending the range of values in the year-plus relationship, would make the calculation YOY Arctic cod biomass within the survey area consistent with the year-plus calculations.

A larger midwater trawl is recommended for future pelagic surveys of year-plus Arctic cod. Midwater nets such as an Aleutian wing trawl (AWT), Polish rope trawl, or Cantrawl are recommended alternatives. The AWT was considered before the field survey, but the decision was made not to use it because doors different from the ones used to fish the 83-112 bottom trawl net would be required. This would necessitate changing doors between bottom and pelagic net deployments, which would consume valuable survey time. Because the research vessel had two net reels there was no need to change nets themselves between bottom and pelagic net tows. Due to its size and the need to fish the net slowly because of the large trawl doors, catches in the Marinovich midwater trawl used in the current study were small and year-plus Arctic cod were observed on the vessel's third wire display to be avoiding the net. On the positive side, the small size of the Marinovich allowed it to be fished in a tow-yo fashion and near bottom, which permitted sampling of near-bottom year-plus Arctic cod layers.

Even though YOY fish and euphausiids were caught in the midwater trawl, selectivity and escapement through the Marinovich meshes was unknown. For that reason, a smaller Methot-style net is also recommended for future studies that target YOY fish or large invertebrates. However, an advantage of the Marinovich trawl used in the current study was that the use of trawl doors made near-surface deployments very stable.

It is recommended that all nets be equipped with net mensuration equipment. Depth and dimensions of the Marinovich trawl used in this study were monitored using the vessel's third wire system. In future studies, other instruments, such as the Netmind system used for the bottom trawl, would allow for more careful real-time monitoring of net dimensions and the ability to record these dimensions while the net fished.

See "*Station and transect spacing*" above for discussion of pelagic fish survey design.

Densities of pelagic fish (predominantly Arctic cod) were calculated scaling the exported acoustic backscatter values with estimates of Arctic cod target strengths. When scaling to density, mean target strengths for Arctic cod within the 20-40, 40-100, and 100-500 m depth strata were calculated by converting the mean fork length (within the depth) to target strength using a target strength to length relationship. Different from the bottom trawl sampling, there were no limitations to acoustic sampling in the rocky/muddy 20-40 m depth depth. Density estimates were made for 1-kilometer analytic bins along the north-south transects and the connecting east-west cross-transects. We used a Pearson's Chi-Squared test to statistically evaluate differences in mean fish densities among depth strata (<40, 40-100, 100-500 m).

We used linear models and General Additive Models (GAM) to evaluate relationships between pelagic Arctic cod densities with oceanographic characterizations of the habitat. Due to spatial correlation in both the acoustic and oceanographic data, this analysis used individual CTD casts paired with collocated acoustic data. A 3 km radius around each CTD location was considered a "point" observation. Independent variables included longitude, bottom depth, salinity, density, temperature and mixed layer depth. The response variables, fish densities, were log transformed to reduce issues of heteroscedasticity in the regression models. Some environmental variables were also log transformed to help stabilize model variance. The young-of-the-year (YOY) fish models (comparing density to biological and standard predictors) were run using a simple linear model (with normal error structure) and a GAM. The two model types were run for comparison. For the linear model, the optimal model was selected using AIC criteria. This procedure produces a global model that includes all possible combinations of variables as a starting point, but variable deletions are used to find the model with the lowest AIC score. The GAM was run on the same dataset, but the number of knots in the smoother was limited due to the small sample size. For the yearling-and-older (year-plus) Arctic cod density models, the presence of zero values in the nearshore where year-plus densities were not estimated complicated the analysis. When zero values were included in the model run, general linear models were used but when zero values were excluded from the model run, linear models were chosen. Models comparing year-plus density to environmental predictors were performed using linear models (simple or general) and GAMs (for comparison) both including and excluding the nearshore zero values. We consider the models with zero values excluded to be the most appropriate given that zero values are artificial (i.e., analytic not biological).

Fish habitat (phycial oceanography)

The best oceanographic data were collected within the same day along a given transect. This type of near synoptic sampling is ideal for resolving oceanographic patterns and for relating water properties to fish distributions. More survey time dedicated to oceanographic sampling would thus be recommended. In addition, it would have been advantageous to have an Acoustic Doppler Current Profiler (ADCP) on board to measure the flow field at the time of fish catch.

An important consideration when designing future studies and when interpreting the data collected here is that the Beaufort Sea changes rapidly and that there are many different water masses with widely varying properties. These different water masses represent different fish habitats. In particular there is no reason to think that the water mass distributions in the western Beaufort Sea are similar to the central and eastern Beaufort Sea. For example, there likely will be less influence of the Bering-Chukchi water and more influence from the Mackenzie shelf further east.

Quality control and disposition of samples and/or data

We prepared a detailed Cruise Plan and submitted it for review by AFSC Division Directors and NOAA Marine and Aviation Operations (NMAO) before the field season.

All field data (including inventory of samples taken) were entered and error-checked daily at sea. Additonal details regarding entry of field data at sea are found in the Methods section of this report (under "Fish and habitat methods", "Demersal fish and pelagic trawl data entry").

All field data (including inventory of samples taken) were entered and error-checked daily at sea. Additonal details regarding entry of field data at sea are found in the Methods section of this report (under "Fish, invertebrate and habitat data collection methods, Demersal fish and pelagic trawl data entry"). The field data and inventory of samples taken was entered into databases upon return to Alaska Fisheries Science Center (AFSC) and University of Washington and error-checked again. The taxonomic identification of all voucher specimens was confirmed or revised (if necessary) in the laboratory at AFSC. Details of sample collection methods are found in the Methods section of this report (under "Fish, invertebrate and habitat data collection methods). The eventual disposition of all specimens is detailed in Appendix V.

NOAA conforms to the guidelines set forth in the Federal Data Quality Act. The following link contains the explicit NOAA guidelines for data quality and dispersion: http://www.noaanews.noaa.gov/stories/iq.htm

A Cruise Report was completed immediately after the end of the cruise. The Cruise Report contained an overview of the study and objectives, a description of sampling methods, scientific personnel, a detailed cruise schedule, and preliminary results. The Cruise Plan was posted on the Alaska Fisheries Science Center website. Results from the survey were presented to MMS in quarterly Progress Reports, to the scientific community at professional conferences and to Beaufort Sea communities at local meetings.

Survey Planning

Scientific staffing

An unexpected result of the survey was the high invertebrate catch biomass and diversity. Our science team was comprised predominantly of fish biologists, with only one scientist dedicated to sampling the invertebrate catch. This scientist was required to spend more time on deck than the rest of the science party to identify and quantify the species composition of the invertebrate catch. Future surveys should consider including more invertebrate species biologists if that component of the catch is to be properly sampled. It proved to be essential to have a fish biologist on board who was well experienced in fish taxonomy. It was important to identify as many species correctly as possible in the field, even though all species were verified in the laboratory from examination of voucher specimens. In the few instances were species were not identified in the field but were identified in the laboratory, it impossible to assign weights and numbers to the catch of those species.

Logistics

The 35-day vessel charter included one day at the start and end of the charter to un-pack/pack the gear. Three days were required for acoustic set-up and calibration, two at the start of the survey and one at the end. Two days were required at the beginning of the survey to diagnose and fix noise issues on the acoustic system that occurred because of the vessel's acoustic and electrical configuration. There were seven transit days from Dutch Harbor to the survey grounds and six transit days in return, for a total of 13 transit days. There was an additional day of transit to the survey area because of heavy ice around Pt. Barrow that slowed vessel progress substantially. The survey itself took 16 days to complete. No survey days were lost to weather.

One challenge for the 2008 survey was the presence of substantial amounts of sea ice on the survey grounds when we arrived on August 6. All stations with water depths <100 m were inaccessible until the ice cleared out on August 13. The start date of the survey was based loosely on the long-term summer ice conditions, and on external scheduling conflicts. In retrospect it would have been better to determine the start date based on the seasonal forecast of ice break up that is available from the National Ice Center (http://www.natice.noaa.gov/).

Supporting vessel operations in the arctic is challenging. Barrow has no facilities for large vessels and shallow alongside depths at the causeway make Prudhoe Bay unfavorable. While Nome should not be completely ruled out for a future "jumping off" port, Dutch Harbor, because of the fishing industry presence, has the best infrastructure for vessel/equipment staging, provisioning and fueling. Early in the planning of this project we considered staging out of either Barrow or Deadhorse/Prudhoe. A site visit to Barrow quickly eliminated Barrow because there are neither port facilities nor good small boat landing/launching areas that could be considered "all weather". Barrow is the North Slope Borough headquarters, and, as such, is home for north slope search and rescue, medical facilities and other government functions. Any north coast at-sea emergencies that require assistance must be coordinated through the Barrow Police Department and the search and rescue unit, so it is important to keep these two organizations apprised of planned offshore activities. Coast Guard presence in Barrow is extremely limited, although the Coast Guard is exploring ways to increase their presence there. Re-fueling a vessel anywhere on the north coast is weather dependent and must be done by barge service. Crowley Maritime currently provides fuel barge service to north slope communities during the ice-free months, so re-fueling would have to be coordinated through Crowley.
The Deadhorse/Prudhoe Bay area was not visited. Examination of area nautical charts and several phone conversations with on-site personnel quickly eliminated Deadhorse/Prudhoe Bay as a staging port. While it would not be impossible to stage people and equipment out of Deadhorse/Prudhoe, the shallow water depths at the causeway in Prudhoe Bay dictate extensive use of small boats for personnel and equipment transfers. Adverse weather conditions or the presence of ice could easily halt any small boat operations.

Nome was briefly considered as a potential personnel staging port in order to decrease the amount of time the science party was required to spend transiting from Dutch Harbor to the project area. However, due to the limited amount of vessel time available and the additional time required for transit and a port call in Nome, we decided that Nome was not a viable option. Nome has made considerable improvements to their port facility over the last several years, so it may be possibile to use Nome as a staging port. However, it must be pointed out that Nome's fuel supply is barged from Dutch Harbor, so fuel will be more expensive. Alongside depths at the causeway are approximately 22 feet. For the foreseeable future, Dutch Harbor is the recommended port of departure for arctic at-sea operations.

Safety

Emergency contact phone numbers (as of August 2008):

North Slope Borough (Barrow)	Police	907-852-6111
	Search and Rescue	907-852-2822 or 800-830-2822
	Hospital	907-852-4611
Prudhoe Bay (BP)	Security Dispatch	907-659-5631
	Duty Officer	907-659-4437
	Emergency	907-659-5300
	Alaska Clean Seas	907-659-2405
U.S. Coast Guard, Juneau, D17 Command Center		907-463-2001

The U.S. Coast Guard currently does not have a regular presence in the Beaufort Sea. So, for the 2008 survey the emergency plan was to contact the North Slope Borough (NSB) Search and Rescue (SAR) unit directly in case of serious injury/illness which requires medevac. After hours contact would be initiated with NSB Police, who would contact the SAR duty pilot. Consult would be made with medical personnel at the hospital. If a helicopter evacuation from the vessel was required, a chartered aircraft would have to be arranged through British Petroleum (BP) in Prudhoe Bay. The oil companies typically have hoist-equipped helicopters under contract. The full range of BP assets, including helicopters, small boats, and coordination team, can be accessed by calling the BP emergency number, and this would include both medical and non-medical emergencies, such as fire, flooding and other emergencies that can occur at sea. Ultimately, all medical emergencies would be coordinated through the SAR unit at Barrow because they have the air ambulance and medical assets.

Should the U.S. Coast Guard have helos in Barrow and/or a vessel (such as the USCGC HEALY) in the area, requests for emergency assistance from USCG would be coordinated through the District 17 Command Center, phone number above.

There is no routinely available water taxi or helo evac service at Prudhoe Bay. It is possible to use the causeway (west dock) at Prudhoe Bay to conduct personnel transfers if necessary, but this should not be a routine occurrence. The survey vessel's small boat would have to be used. Security requests that a courtesy call be made to advise them if personnel are coming ashore. If the survey is a federal activity and personnel are government employees, no other actions are needed (per Mr. Ramoth).

Contigency planning

A total of 35 days was scheduled for the survey. This total includes three days for set-up and breakdown of the survey vessel (two days before the survey and one day after), one day to mark trawl wires and test gear, two days for acoustic calibration, one day for bad weather and 12 days for round-trip transit. The weather did not cause any delays during the 2008 survey, although heavy ice pack around Pt. Barrow on the transit to the study area increased our total round-trip transit time to 13 days. Ice coverage also hindered our ability to sample nearshore stations during the first week of the survey. The details are described below:

6 Aug. Encountered fairly dense ice around Pt. Barrow. Floes appeared to be multi-year ice (not flat pancakes). Spent the entire night and day picking our way through. Sighted a female Polar bear with two cubs midday (1227 local time). Ice resulted in about a one-day delay in transit.

7-11 Aug. Much of the survey area was still covered with ice. Bottom tows conducted in deepest depth (100-500 m), at times as close as 0.25 nmi from the ice or even in low density (~3/10) ice. Some midwater tows also conducted in the offshore depth when ice prevented access to new bottom trawl stations.

12 Aug. Were finally able to conduct some bottom trawls at stations less than 100 m depth (in the middle depth). We were required to navigate through the ice to reach open water on the mid-shelf and were fishing within 0.5 to 3 nmi of ice.

13 Aug. Mid-shelf region at Line 3 was clear of ice. Ice not encountered in densities requiring a change in survey plans for the duration of the cruise.

Ice coverage maps were examined whenever they were updated (generally, every two days). Maps were faxed to the vessel from Seattle. It was important to monitor ice coverage to insure that the vessel had clear passage out of the Beaufort Sea after the survey.

Multiple trawls, net sensors and zooplankton nets were on board in case of damage to nets during the survey. Similarly, a spare CTD was on board in case of damage to any of the components of that instrument. The only gear that suffered damage during the survey were the 83-112 bottom nets. In short, all three lined bottom trawls were damaged sufficiently to become unusable after nine days of survey (6-14 August). The remainder of the survey was conducted with the two un-lined bottom nets, one of which was damaged on 15 August. The cause of the damage to the bottom nets was either heavy rocks, mud or a mixture of both. The details are described below:

6 Aug. First trawl, in 350-400 m of water, using lined 83-112 (net # LL16), 30 minute tow. Cod-end ripped out. Replaced with another lined net (#1) and trawled again for 30 minutes. Caught a large net of opilio crabs.

7 Aug. Trawl 3 was deployed in 200 m water, net hung up briefly 15 minutes into the tow and was hauled back immediately. There were large rocks in the cod-end. There was a 10-12 foot tear in the belly of the net, behind the bosom. Net was repaired. Reduced tow time to 15 minutes. Bottom looks hard and flat, perhaps with some rock piles (hard to tell for sure).

8 Aug. Trawl 6 was in 160 m of water. Cod-end so full of mud that it was too heavy to lift without damaging net. Weight estimated volumetrically. No net damage.

13 Aug. Trawl 13 was along Line 3 (middle of survey grounds). It was difficult to find good bottom (very rocky and/or muddy). We had to drop two stations offshore of this one due to bad bottom. Catch was comprised of seastars and mud.

During Trawl 14 we lost the net. The captain felt it grab 13 minutes into the tow and hauled it back immediately. The net had torn off at the poly line holding the net to the head and foot ropes. The doors were covered with mud. The captain grappled for the net and recovered all of it, including the cod-end. No sensors were lost. The recovered net was also covered in mud. Bottom looks soft and somewhat "lumpy", although the skipper was targeting a relatively flat spot. We likely hit a lump of mud right at the end of the tow.

14 Aug. Trawl 15 was set in 40 m water depth. The captain said that the net was extremely heavy during haulback. The cod-end ripped out before we could get it on deck. This was our third and last lined 83-112. The bottom was level (no major changes in overall depth), but was not uniformly flat.

Trawl 16 was made with an un-lined 83-112 (net #10), and tow duration was cut to 5 minutes. The cod-end was full of rocks.

We scouted the inshore end of the transect, Line 5, (<50 m) for a tow. Bottom looked similar to the rocky bottom at Trawl 16 and we decided not to trawl in that area.

All tows were 5 minutes long for the remainder of the survey.

15 Aug. Trawl 19 was set in 30 m depth. We thought the bottom appeared flat and hard, but it turned out to be heavy mud. The net hung up briefly at haulback and tore from the bosom to the footrope. We replaced the net with an un-lined 83-112 (our second and final un-lined net). The bottom looks soft and "lumpy".

Trawl 20 was conducted in 50 m of water. The bottom appeared hard and flat. The cod-end came on deck full of rocks and the net tore when we were lifting it. The net was mended.
Last six bottom trawls conducted without incident.

Necessary permits-Federal

Scientific Research Permits (SRP)
A SRP is required for any scientific research activity occurring in the Exclusive Economic Zone (EEZ) that is conducted or controlled by NMFS and that would otherwise meet the definition of fishing under the Magnuson-Stevens Act (MSA). "Conducted or controlled by NMFS" means NMFS research conducted from NOAA vessels and NMFS chartered vessels operating under contracts or other approved agreements, or vessels whoe research activity is otherwise directed by NMFS. The definition of "scientific research activity" is lengthy and defined in 50 CFR 600.745 (a) but there are elements of this definition that one should be aware of. Those elements are: 1) scientific research activity does not include the collection and retention of fish outside the scope of the applicable research plan, or testing of fishing gear; 2) data collection designed to capture and land quantities of fish or invertebrates for product development, market research,

and/or public display are not scientific research activities and must be permitted under exempted fishing procedures; and 3) it has been determined that the sale of fish taken and retained during a scientific research activity is not fishing, however, fishing independent of actual scientific research activity, such as compensation for the use of the vessel, is not scientific research activity and must be permitted under expemted fishing procedures.

To obtain an SRP for a research activity, one must submit a scientific research plan with the request for the SRP to the appropriate Regional Administrator. Submission of the request to the Regional Administrator acknowledges that the proposed research is approved and sanctioned by the NMFS Center's Science and Research Director. The Regional Administrator will then review the scientific research plan to ensure the scientific research activity is adequately described, and to make necessary determinations (including any determinations dealing with marine mammals and Section 7 of the Endangered Species Act) to insure the scientific research plan is consistent with the applicable regulation, national policy, and other applicable law. The determinations shall include the appropriate NEPA document, generally a categorical exclusion, if supported by the facts. For research conducted in Alaska, the request should be submitted to the Regional Administrator for the Alaska Region.

At a minimum scientific research plans should include:

1. a description of the nature and objectives of the project, including the hypothesis or hypotheses to be tested;
2. the experimental design of the project, including a description of the methods to be used, the type and class of any vessel(s) to be used, and description of the sampling gear;
3. the geographical area(s) in which the project is to be conducted;
4. the expected date of first appearance and final departure of the research vessel(s) to be used, and deployment and removal of equipment;
5. the expected quantity and species of fish to be taken and their intended disposition, and, if significan amount of a managed species of species otherwise restricted by size or sex are needed, an explanation of such need;
6. the name, address, telephone and FAX numbers of the sponsoring organization and its director
7. the name, address, telephone and FAX number, and curriculum vitae of the person in charge of the research project on board the vessel; and
8. the identity of any vessel(s) to be used, including the vessel's name, official documentation number and IRCS, home port, and name, address, and telephone number of the owner and master.

Once the SRP is issued, a copy should be provided to the chief scientist(s) or field party chief(s) who will be on board the vessel(s) conducting the research. They should make sure a copy is available on the vessel at all times. The responsible Division/Lab or program should also forward a copy of the permit and research plan to appropriate regional NMFS Enforcement, US Coast Guard, and state offices. If there is a change in vessels or dates of operation, a request shall be sent to the Regional Office to amend the SRP and then make sure Enforcement, USCG, etc. are also provided the amended SRP.

The 2008 Beaufort Sea survey was conducted under a Scientific Research Permit (SRP). Information on other types of permits is supplied below for the use of future survey planning.

Letters of Acknowledgement of Scientific Research (LOA)

An LOA is issued for non-NMFS controlled research activities conducted under the MSA. A “non-NMFS controlled” activity is one when neither the vessel nor the research activity on board is controlled by either NMFS or NMFS contracted personnel. Examples would be foreign, state, academic, or private organization research vessels. Since scientific research is not “fishing” and it is outside the control of the MSA, NMFS can only request that non-NMFS parties submit a scientific research plan and request an LOA for their scientific activity. The request and research plan should be submitted to the appropriate Regional Science and Research Director. The research plan is reviewed at the Center and an LOA issued if it is determined that the activity is scientific research and there are no likely adverse impacts upon marine mammals or other protected species. Copies of the LOA are provided to NMFS Enforcement, the USCG, NMFS Region, and state agencies. If there are concerns that the activity is not research or that there may be adverse impacts on marine mammals or protected resources, the Center Director can suggest that the research plan be modified but the sponsoring organization is not obligated to make any changes nor are they required to have an LOA to proceed with their research activity. The value of the LOA is to indicate to the enforcement agencies that the Regional Science and Research Director believes the activity is scientific research and not a guise of fishing.

Exempted Fishing Permits (EFP)

An EFP is required for any fishing that would otherwise be in violation of the MSA or other fisheries laws of their implementing regulations and is not considered and exempted educational activity. An EFP is also required when otherwise prohibited fishing is authorized for a vessel as compensation for conducting a NMFS contracted resource survey (this does not apply to or include fish taken during the resource survey or research activity). There is a lengthy process for issuance of an EFP which includes publishing of a Federal Register Notice, review by the appropriate fishery management council, review by the appropriate NMFS Regional Administrator, and NMFS headquarters. There a quite a number of special circumstances and thus procedures listed under the guidelines for EFPs. These include: non-controversial EFPs, controversial EFPs, emergency EFPs, EFPs for compensation fishing, observer programs, and vessel-of-opportunity programs.

Exempted Educational Activity (EEA)

An EEA is required for fishing that would otherwise be in violation of the MSA or other fisheries laws that is part of an activity conducted by an educational institution for educational purposes.

Public Display

Collecting fish for public display requires an EFP unless they are collected under an SRP or EEA for study and then subsequent display. In considering whether an EEA or EFP is needed for the collection of fish for public display, the guideline is that if the collector will be retaining the fish and placing them on display for a fee, the activity is considered fishing and would thus require an EFP. An EEA could not be issued under those circumstances.

Necessary permits-State

A State permit is required for either federal or non-federal operations: 1) within the territorial (3-mile) waters, or 2) landing fish or other organisms in the state of Alaska, even if taken outside territorial waters. A Fish Resource Permit is issued by the State of Alaska Department of Fish and Game. A Study Plan or Research Proposal explaining the purpose and need, the objective, and the procedures to be used must be included with the permit application. The application also requires the following specific information:

1. the species, number and disposition of the fish to be captured;
2. period of time the permit is requested (valid only for dates within a calendar year)
3. means by which the fish will be obtained
4. location of study
5. a brief purpose statement
6. final disposition of collected specimens (specimens may not be consumed, sold, traded, bartered, or used in any commercial manner)
7. names of people who will participate in field collections under terms of the permit (if applicant is representing a corporation or institution, a certification of affiliation may be required)

Completed applications for marine environment collections (and permits involving propagation) are submitted to:
Alaska Department of Fish and Game
Division of Commercial Fisheries
Attn: Sara Conrad
P.O. Box 115526
Juneau, AK 99811-5526
sara.conrad@alaska.gov

Applications for freshwater and estuarine environment collections are submitted to:
Alaska Department of Fish and Game
Attn: Bob Piorkowski
Division of Sport Fish-RTS/FR Permits
P.O. Box 115526
Juneau, AK 99811-5526
robert.piorkowski@alaska.gov

For the 2008 Beaufort Sea survey, the Chief Scientist (Logerwell) was included on the Alaska Fisheries Science Center (AFSC) State Fish Resource Permit for 2008.

Necessary permits-Local

No local permits were required for the survey. However, the coastal communities adjacent to the survey area were notified well in advance of the survey and provided the opportunity to comment on any potential conflicts between the survey and community use of coastal waters.

Subsistence activities

The Alaska Eskimo Whaling Commission was contacted to establish that the survey would not interfere with subsistance whaling activities. Whaling typically takes place in September in the area near Cross Island (longitude 148° W). Our survey was conducted between August 6 and 22 between longitudes 152° W and 155° W, so conflicting with the whaling activities was not an issue. In addition, the coastal communities adjacent to the survey area were notified well in advance of the survey and provided the opportunity to comment on any potential conflicts between the survey and other uses of coastal waters, such as fishing. No concerns were voiced.

Coordination with related projects

Oceanographic and hydrophone moorings

Robert Pickart (Woods Hole Oceanographic Institution) and Kate Stafford (Applied Physics Laboratory, University of Washington) deployed oceanographic and hydrophone moorings between 156 °W and 150 °W across the shelf as part of two National Ocean Partnership Program (NOPP) field studies. All but three of the moorings were deployed from the USCG Cutter Healy from 7-13 August 2008. The three remaining nearshore moorings were deployed from the R/V Annika Marine from 8-11 August. Dr. Pickart contacted us on behalf of himself and Dr. Stafford in late July 2008 and we shared with him our transect locations, trawl station locations, dates of the survey, survey vessel name and our at-sea contact information. We plotted the mooring locations on our charts and avoided trawling within several miles of the moorings. After the field season Dr. Pickart sent us a short cruise report describing what they had accomplished and showing CTD sections. We likewise sent him a cruise report and a data file with the locations of the CTD stations that we occupied. Tom Weingartner is also a P.I. on the Pickart NOPP project so the two data sets will be available for a combined analysis of physical oceanographic conditions on the Beaufort Sea shelf.

Bowhead whale survey

David Rugh (AFSC National Marine Mammal Laboratory) contacted us to discuss possible conflicts between their Bowhead whale aerial surveys, part of the "Bowhead Whale Feeding Ecology Study, BOWFEST", funded by MMS. We provided him with our survey plan (dates, objectives, location, etc.) and he provided us with the 2008 field schedule. Fortunately, although the areas of our Beaufort fish survey and the BOWFEST aerial surveys overlapped, the timing did not. The aerial surveys took place 26 August to 19 September 2008, after we had left the survey grounds (on 22 August). In an effort to assure information exchange, project P.I. Logerwell presented the results of the fish survey at a BOWFEST workshop held in Anchorage on 20 January 2009.

Funding

The funded portion of this survey does not reflect the substantial personnel and equipment assets provided by NOAA-NMFS-AFSC at no cost to MMS. For example, all survey nets, rigging, net mensuration and associated equipment and electronics were provided by the Resource Assessment and Conservation Engineering Division (RACE), AFSC, at no cost to MMS. The portable winch that made the oceanographic and zooplankton collections possible was also provided by RACE. RACE personnel participated in survey preparation, equipment assembly and post-survey data management. The expertise and experience of the RACE personnel was invaluable and was key to the success of this project. Additional matching personnel salaries included that of the AFSC project P.I. The table below details the matching costs provided by AFSC (Table 61).

Table 61. Estimates of AFSC matching costs for the 2008 Beaufort Sea Survey.

Item	Value
Salaries	
AFSC P.I.	$105,191
Equipment and supplies	
Bottom trawl nets	$100,000
Net mensuration instruments	$72,250
Midwater trawl net	$14,000
Trawl doors	$50,000
Field computers	$3,178
Survey supplies	$1,000
CTDs	$20,000
Portable plankton winch	$45,000
Bongo nets	$1,000
TOTAL	$411,619