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Nearshore Fish Assemblages of the Northeastern Chukchi Sea, Alaska

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ABSTRACT. The Arctic ecosystem is changing rapidly, yet information on nearshore fish assemblages for the northeastern Chukchi Sea is extremely limited. To address this information gap, we sampled nearshore fish assemblages with a beach seine and a small bottom trawl at six stations in the northeastern Chukchi Sea in August 2007, 2008, and 2009, and in September 2009. Catch and species composition differed by gear type and between sample periods, including the two in 2009. A total of 16 039 fish representing 18 species were captured in 24 beach seine hauls, and 3108 fish representing 24 species were captured in 48 trawl tows. Beach seine catch was dominated by capelin (83%), and trawl catch was dominated by Arctic cod (56%). Species that were good discriminators between gear types were capelin (seine) and slender eelblenny (trawl), and unidentified small sculpins were the most common taxa caught with both gear types. Capelin and Arctic cod captured by either gear type were mostly juveniles (judging by size). Variability among sampling periods in catch and species composition within gear types can likely be attributed to annual variations in environmental conditions, including differences in water temperature (range: 2˚ – 9˚C). The shallow nearshore environment of the northeastern Chukchi Sea provides important habitat for many fish species and is extremely vulnerable to disturbance. Loss of sea ice from global warming may open up formerly inaccessible areas to oil and gas exploration, vessel traffic, and commercial fishing. Thus, long-term monitoring of nearshore fish assemblages in the Alaskan Arctic is necessary for managers to make informed decisions in this fragile environment.

Key words: Arctic, Alaska, Chukchi Sea, nearshore, Arctic cod, capelin, beach seine, bottom trawl

RÉSUMÉ. L’écosystème de l’Arctique change rapidement, mais pourtant, il existe très peu d’information sur les assemblages de poissons du sublittoral du nord-est de la mer des Tchouktches. Afin de combler ce besoin en information, nous avons échantillonné des assemblages de poissons du sublittoral à l’aide d’une senne de plage et d’un petit chalut de fond à six stations du nord-est de la mer des Tchouktches en août 2007, 2008 et 2009, puis en septembre 2009. La composition des prises et des espèces différait en fonction du type d’équipement et des périodes d’échantillonnage, notamment entre les deux périodes de 2009. En tout, 16 039 poissons représentant 18 espèces ont été capturés dans 24 coups de filet de senne de plage, et 3 108 poissons représentant 24 espèces ont été capturés dans 48 traits de chalut. Les prises de senne de plage étaient principalement constituées de capelans (83 %), tandis que la morue polaire (56 %) dominait les prises de chalut. Les espèces qui faisaient une bonne discrimination entre les types d’équipement étaient le capelan (senne) et la lompénie de Fabricius (chalut), et les petits chabots non identifiés étaient les taxons les plus courants à avoir été attrapés avec les deux types d’équipement. Les capelans et les morues polaires capturés par l’un ou l’autre des types d’équipement étaient surtout juvéniles (d’après leur taille). La variabilité de la composition des prises et des espèces entre les périodes d’échantillonnage est vraisemblablement attribuable à la variation annuelle des conditions environnementales, dont les différences de température de l’eau (écart entre 2˚ et 9˚ C). Le milieu sublittoral peu profond du nord-est de la mer des Tchouktches est un habitat important pour de nombreuses espèces de poissons et est extrêmement vulnérable aux perturbations. La perte de glace de mer attribuable au réchauffement planétaire risque d’ouvrir des zones anciennement inaccessibles à l’exploration pétrolière et gazière, à la circulation d’embarcations et à la pêche commerciale. Par conséquent, la surveillance à long terme des assemblages de poissons du sublittoral de la partie alaskienne de l’Arctique s’impose pour que les gestionnaires puissent prendre des décisions éclairées dans cet environnement fragile.

Mots clés : Arctique, Alaska, mer des Tchouktches, sublittoral, morue polaire, capelan, senne de plage, chalut de fond

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INTRODUCTION

The Arctic is an ecologically fragile area experiencing rapid changes in climate (warming) and loss of sea ice (Moline et al., 2008). In September 2012, sea ice covering the Arctic fell to its lowest extent since satellite records began in 1979 (National Snow and Ice Data Center, 2012). Loss of sea ice through climate change threatens marine life and habitat and has the potential to open formerly inaccessible areas to oil and gas exploration, increased vessel traffic, and development of fisheries. Nearshore fish habitat is also being affected because changes in sea ice have caused erosion of beaches adjacent to some Arctic communities (Lynch and Brunner, 2007). Ecosystem-wide changes already occurring in the Arctic include changes in the distribution and abundance of some fishes (Genner et al., 2004; Rijnsdorp et al., 2009; Grebmeier et al., 2010). Because of the warming climate and the likelihood of increased human activity (particularly oil and gas exploration) in the northeastern Chukchi Sea of Alaska, more information is needed on nearshore fish assemblages for resource managers to make informed decisions.

Nearshore marine waters of Alaska support a diverse and abundant array of fishes (Johnson et al., 2012). Common fishes in nearshore waters of the Beaufort and Chukchi Seas include Arctic cisco (*Coregonus autumnalis*), Arctic cod (*Boreogadus saida*), capelin (*Mallotus villosus*), least cisco (*Coregonus sardinella*), and Pacific sand lance (*Ammodytes hexapterus*) (Craig, 1984; Fechhelm et al., 1984; George et al., 2009; Johnson et al., 2010). Many of these species are important in subsistence fisheries or as prey for other fishes, seabirds, and marine mammals (George et al., 2009; Johnson et al., 2012). Nearshore waters of the Beaufort and Chukchi Seas provide foraging habitat for Arctic cisco and least cisco (Craig, 1984) and spawning habitat for capelin (Walters, 1955; George et al., 2009).

Most information on nearshore fishes in the Alaskan Arctic is from the Beaufort Sea, where the discovery of oil in Prudhoe Bay in 1968 – 69 prompted a series of studies (Craig and Haldorson, 1981; Craig et al., 1982, 1985; Haldorson and Craig, 1984; Moulton and Tarbox, 1987; Thorsteinson et al., 1990; Cannon et al., 1991; Jarvela and Thorsteinson, 1999; Fechhelm et al., 2003). However, the nearshore environment of the Beaufort Sea differs from that of the northeastern Chukchi Sea because the Beaufort Sea has a lagoon-barrier island environment, influenced considerably by freshwater from large river systems (Craig, 1984), whereas the northeastern Chukchi nearshore is a "marine" environment without the influence of large rivers. The brackish lagoons in the Beaufort Sea are dominated by anadromous species such as whitefishes (e.g., Arctic cisco and least cisco) (Craig, 1984), whereas the marine nearshore environment on the seaward side of the barrier islands is more like the northeastern Chukchi Sea and is dominated by Arctic cod, capelin, and fourhorn sculpin (*Myoxocephalus quadricornis*) (Griffiths et al., 1977; Craig et al., 1985; Jarvela and Thorsteinson, 1999).

Most fish surveys in the Chukchi Sea have taken place in deeper, offshore waters using trawls. These include surveys in the southwestern region (Alverson and Wilimovsky, 1966; Wolotira et al., 1977; Norcross et al., 2010) and the northeastern region (Quast, 1974; Lowry and Frost, 1981; Frost and Lowry, 1983; Barber et al., 1997; Gillispie et al., 1997; Wyllie-Echeverria et al., 1997; Norcross et al., 2011; Priest et al., 2011). Little is known about the use of shallow nearshore waters (within 1 km from shore); in the only known nearshore study in the northeastern Chukchi Sea, fish were sampled with fyke nets and gillnets from Peard Bay to Point Hope in the summer of 1983 (Fechhelm et al., 1984). To the best of our knowledge, our fish sampling is the first in nearshore waters in the vicinity of Barrow, Alaska, and only the second nearshore study in the northeastern Chukchi Sea.

The nearshore of the northeastern Chukchi Sea is influenced largely by sea ice and wind. Sea ice, which is present for six months of the year, is a key factor in the ecology of the Chukchi Sea, since the location of sea ice can affect phytoplankton blooms and larval fish distribution (Barber et al., 1994). Wind is an important factor in the advance and retreat of sea ice (Muench et al., 1991; Barber et al., 1994), and onshore winds can delay ice breakup or push floating ice into the nearshore (Barber et al., 1994). Generally, a northeasterly current in the nearshore Chukchi Sea, transported north from the Bering Sea, forms the Alaska current; local variations are driven by winds (Barber et al., 1994), which blow from the northeast 40 – 60% of the time (Stegall and Xhang, 2012).

Our objective was to establish a baseline to help detect possible changes in fish distribution, abundance, and species composition caused by anthropogenic impacts and climatic change. We sampled with a beach seine and a small bottom trawl in the shallow nearshore waters of the northeastern Chukchi Sea near Barrow, Alaska, in August 2007 to 2009 and in September 2009. For the purposes of this paper, we define shallow nearshore as those marine waters extending from the shoreline offshore to a depth of about 8 m (up to 1 km offshore).

METHODS

Fish Capture

We sampled fish at six stations in the northeastern Chukchi Sea near Barrow, Alaska, from 2007 to 2009. Stations were approximately 5 to 9 km apart, ranging from Point Barrow about 40 km westward (Fig. 1). Stations were sampled once each year in mid-August and once in September 2009. At each station, one beach seine haul and two bottom trawls were made during each sampling period. Visual observations indicated that all beach seine sites were low gradient beaches composed of sand and gravel, whereas substrate collected inside trawls indicated that trawl sites were composed primarily of mud. Surface water

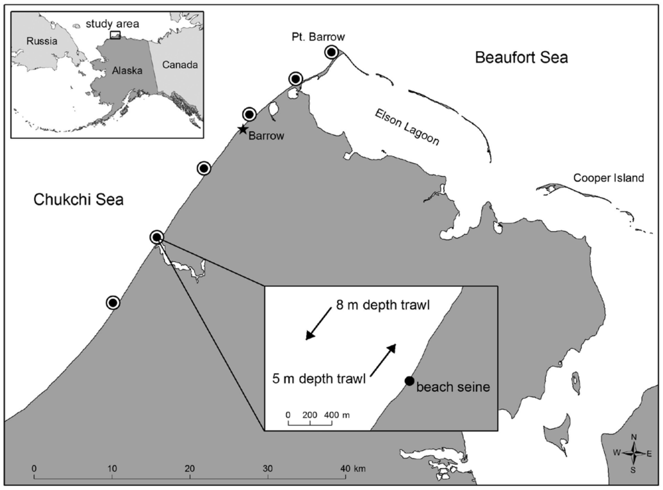

FIG. 1. Six stations in the northeastern Chukchi Sea, Alaska, sampled with a beach seine and a bottom trawl in August of 2007–09 and in September 2009.

temperature and salinity were measured at all seine and trawl sites during each site visit. We measured temperature and salinity (practical salinity units, PSU) at a depth of approximately 10 cm, using a thermometer and hand-held refractometer. At the 8 m trawl sites in August 2009, we also measured temperature and depth with a CTD (conductivity, temperature, depth) water sampler.

At each beach seine site (< 5 m deep, < 20 m from shore), fish were captured with a 37 m long variable-mesh beach seine that tapers from 5 m deep at the center to 1 m deep at the ends. Outer panels are each 10 m of 32 mm stretch mesh, intermediate panels are each 4 m of 6 mm square mesh, and the bunt is 9 m of 3.2 mm square mesh. We set the seine as a round haul by holding one end on the beach, backing around in a skiff with the other end to the beach about 18 m from the start, and pulling the seine onto shore. The seine has a lead line and a float line so that the bottom contacts the substrate and the top floats on the surface. Net characteristics and methods of setting the seine are the same that we have used throughout Alaska since 1998 (National Marine Fisheries Service, 2012).

Offshore of each beach seine site, fish were captured with a small bottom trawl at two depths: 5 m (about 0.25 km offshore) and 8 m (about 1 km offshore) (Fig. 1). The mouth of the trawl is 2.6 m wide and 1.2 m deep and is attached to a 6.3 m long bridle of 1.3 cm braided line. The trawl is 5.2 m in total length and has two weighted doors (33 cm × 61 cm); inside the outer skirt of 29 mm stretch mesh is a cod-end 1.7 m long made of 3.2 mm stretch mesh. The trawl was towed from a skiff at about 2.5 knots. The scope of the tow line (1.6 cm polypropylene) was 15 m for the 5 m tows and 24 m for the 8 m tows. Tows were parallel to shore and the direction of tow alternated from station to station (e.g., north to south at first station, south to north at next station) (Fig. 1). Duration of each tow was 5 minutes and mean distance towed was about 366 m.

After retrieval of either net, the entire catch was sorted, identified to species, and counted, and a subsample (up to 50 fish) of most taxa was measured to the nearest millimeter fork length (FL) or total length (TL), depending on the species. Fish were anesthetized in a mixture of 1 part carbonated water to 2 parts seawater for identification and measurement. Smaller individuals (< 40 mm length) that could not be identified to species in the field were identified to family (e.g., Cottidae). Length frequency distributions and age-length data from other Arctic studies were used to estimate ages of Arctic cod and capelin; Arctic cod less than 60 mm FL and capelin less than 82 mm FL were assumed to be young-of-the-year (YOY) (Welch et al., 1993; Jarvela and Thorsteinson, 1999).

Data Analysis

Catch data are expressed in absolute numbers (total catch per seine haul or trawl haul) and as catch-per-unit-effort (CPUE): number of fish per seine haul or trawl tow. Differences in mean total catch among sampling periods and between gear types were tested with a nonparametric Kruskal-Wallis test and differences in species (number of fish species captured) were tested with ANOVA. Differences in total catch (log transformed) among sites for each gear type were tested with ANOVA, and a Tukey's correction was used for individual comparisons between sites (Minitab, 2006). The relationship of total fish catch and water temperature was tested with regression analysis by gear type; catch data were log transformed (Minitab, 2006). Frequency of occurrence (FO) was calculated for all species—FO represents the number of seine hauls in which a species was captured divided by the total number of seine hauls multiplied by 100. We used the Mann-Whitney Rank Sum test (Minitab, 2006) to examine for differences in lengths of fish between gear types. Differences in water temperature and salinity among sampling periods were tested with a permutation test (Efron and Tibshirani, 1993). For seine and trawl catches, unidentified small flatfish (Pleuronectidae), gadids (Gadidae), pricklebacks (Stichaeidae), and sculpins (Cottidae) were counted in the total catch, but were not considered separate species for species richness calculations because at least one identifiable species from these taxa was captured; unidentified small snailfish and unidentified small poacher were considered separate species because no identifiable species from the families Liparidae and Agonidae were captured.

To test for differences in species composition between gear types, we conducted an analysis of similarity (ANOSIM) using a Bray-Curtis similarity matrix among all catch samples (Clarke and Green, 1988). Two trawl sites that had zero catches in August 2009 were not included in species composition analyses. Data were transformed to square roots prior to analyses in order to balance the influence of both uncommon and abundant species. Because trawl catch and species composition did not differ significantly (one-way ANOVA, $p = 0.57$; ANOSIM: $R = 0.027$, $p = 0.18$) by depth, we combined catch data for both depths at each trawl station. To determine which species contributed most to

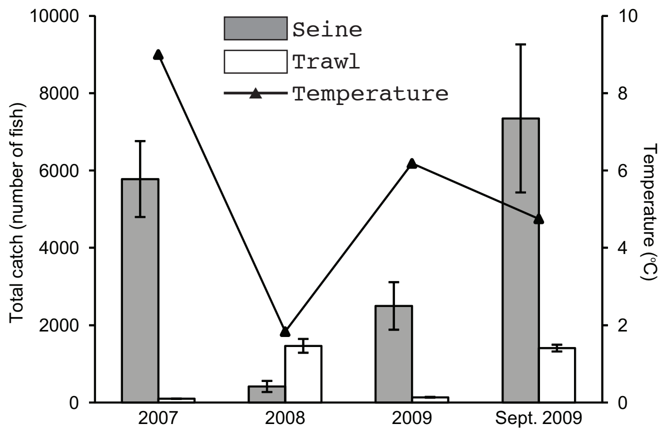

FIG. 2. Total fish catch by beach seine and bottom trawl and mean surface water temperature by sampling period in the northeastern Chukchi Sea, in August of 2007–09 and in September 2009. Error bars represent the standard deviation of fish catch of six beach seine hauls or 12 bottom trawls.

the similarity and differences between gear types, we used SIMPER, a similarity percentages analysis (Clarke, 1993).

RESULTS

The shallow nearshore of the northeastern Chukchi Sea is characterized by a diverse assemblage of fishes dominated by capelin and Arctic cod. The total capture from all sampling periods was 19 147 fish representing 29 species: 16 039 fish representing 18 species from 24 seine hauls, and 3108 fish representing 24 species from 48 trawl tows. Overall, capelin was the most abundant species in seine catches (83% of total seine catch), and capelin, Pacific sand lance, and saffron cod (*Eleginus gracilis*) accounted for 96% of the total seine catch. Arctic cod dominated trawl catches (56% of total catch), and Arctic cod, slender eelblenny (*Lumpenus fabricii*), and unidentified small sculpins accounted for 87% of the total trawl catch. In seine catches, FO of capelin ranged from 33% to 100%, and in trawl catches, FO of Arctic cod ranged from 8% to 100%. Median CPUE was 183 fish for seine catches and 16 fish for trawl catches. The mean total catch was similar among seine sites ($p > 0.05$), but differed among trawl sites: catch at two of the trawl sites differed from the rest of the trawl sites ($p < 0.05$). The mean total catch differed significantly among sampling periods for both seine ($p < 0.05$) and trawl ($p < 0.001$) catches (Fig. 2). In pairwise comparisons (Kruskal-Wallis test), mean total trawl catches were significantly smaller in August 2007 (8 fish) than in August 2008 (122 fish, $p = 0.009$) or September 2009 (117 fish, $p < 0.001$) and significantly greater in September 2009 (117 fish) than in August 2009 (11 fish, $p < 0.001$).

Species richness was significantly greater ($p < 0.05$) for trawl catches (24 species) than for seine catches (18 species). Species richness was similar ($p > 0.05$; range 8 – 10 species) among sample periods (Table 1) for seine catches. For trawl catches, species richness differed significantly ($p < 0.001$; range 10 – 18 species) among sample periods (Table 2). The greatest number of species caught by trawl corresponded to sample periods with the greatest catches (Table 2; 17 species in August 2008; 18 species in September 2009). Species that were captured only by seine were Arctic cisco and threespine stickleback (*Gasterosteus aculeatus*), whereas species captured only by trawl were longhead dab (*Limanda proboscidea*), rainbow smelt (*Osmerus mordax*), whitespotted greenling (*Hexagrammos stelleri*), and marbled eelpout (*Lycodes raridens*). Two species that were captured only in September were saffron cod (seine) and rainbow smelt (trawl).

Species composition varied among sample periods for each gear type and between gear types. Overall, species composition for seine catches differed significantly between August 2007 and August 2008, between August 2008 and September 2009, and between August 2009 and September 2009 (ANOSIM: $R = 0.343$, $p < 0.01$; Fig. 3). For trawl catches, species composition differed significantly (ANOSIM: $R = 0.443$, $p < 0.03$) among all sampling periods (Fig. 4). Pairwise comparisons showed significant differences in species composition between seine and trawl catches (ANOSIM: $R = 0.572$, $p < 0.01$; Fig. 5). The assemblage of fish from seining had an overall within-group Bray-Curtis similarity of 38.7% and consisted mainly of capelin, unidentified small sculpins, unidentified small pricklebacks, and saffron cod, which together accounted for 90% of the cumulative within-group similarity (Fig. 5). The assemblage of fish from trawling had an overall within-group similarity of 39.5% and consisted mainly of slender eelblenny, unidentified small sculpins, Arctic cod, longhead dab, Arctic staghorn sculpin (*Gymnocanthus tricuspis*), unidentified small poachers (Agonidae), and saffron cod, which together accounted for 85% of the cumulative within-group similarity (Fig. 5). Species that were good discriminators between gear types were capelin, unidentified small sculpins, and slender eelblenny, which together accounted for 53% of between-group dissimilarity.

Most capelin and Arctic cod captured by either gear type were juveniles (Tables 3 and 4; Fig. 6). Nearly all (96%) capelin were YOY (< 82 mm FL), whereas only 37% of Arctic cod were YOY (< 60 mm FL). For capelin, mean FL was significantly greater ($p < 0.05$) in trawl catches (84 mm) than in seine catches (60 mm). For Arctic cod, mean FL was significantly greater ($p < 0.001$) in trawl catches (91 mm) than in seine catches (39 mm); 31% of Arctic cod were YOY in trawl catches, whereas 97% of Arctic cod were YOY in seine catches.

Water temperature and salinity varied among sampling periods. Water temperature differed significantly ($p < 0.001$) among all sampling periods (Fig. 2). The highest mean temperature was 9.0˚C in 2007 and the lowest mean temperature was 1.8˚C in 2008. Mean salinity ranged from 32 PSU in August 2007 to 30 PSU in September 2009. Salinity in 2007 was significantly greater ($p < 0.05$) than all other sample periods, and salinity in August 2009 was significantly greater ($p < 0.05$) than in September 2009. Water

TABLE 1. Beach seine catch statistics: Catch-per-unit-effort (CPUE, seine haul), standard deviation (SD), and percent frequency of occurrence (FO) of fish captured with a beach seine at six stations in the northeastern Chukchi Sea near Barrow, Alaska, in August of 2007–09 and in September 2009. Six seine hauls, one at each station, were made in each sampling period. Taxa are listed in decreasing order of abundance in the total catch. Blank spaces represent the absence of a taxon.

		2007			2008			2009			September 2009		
Common name	Scientific name	CPUE	SD	FO	CPUE	SD	FO	CPUE	SD	FO	CPUE	SD	FO
Capelin	*Mallotus villosus*	944.5	979.4	83	11.5	27.7	33	121.0	157.3	83	1123.7	1942.4	100
Pacific sand lance	*Ammodytes hexapterus*	13.2	17.3	83	0.2	0.4	17	259.5	635.6	17	2.0	2.0	83
Saffron cod	*Eleginus gracilis*										77.8	95.8	83
Unidentified sculpin	Cottidae	2.5	2.4	83	8.8	16.4	100	23.2	23.7	100	5.7	8.8	67
Unidentified cod	Gadidae				38.0	87.8	50	0.7	0.8	50			
Unidentified prickleback	Stichaeidae	1.3	2.3	50	9.3	11.6	83	7.3	11.1	67			
Arctic cod	*Boreogadus saida*	0.5	0.8	33							11.5	16.1	67
Slender eelblenny	*Lumpenus fabricii*				0.2	0.4	17	1.5	3.7	17	3.0	4.6	67
Unidentified snailfish	Liparidae							1.0	1.5	50	0.2	0.4	17
Arctic staghorn sculpin	*Gymnocanthus tricuspis*				0.5	0.5	50	0.3	0.8	17			
Arctic sculpin	*Myoxocephalus scorpioides*	0.7	1.6	17									
Fish larvae	Division Teleostei							0.7	1.6	17			
Arctic cisco	*Coregonus autumnalis*										0.5	1.2	17
Unidentified poacher	Agonidae							0.5	0.8	33			
Shorthorn sculpin	*Myoxocephalus scorpius*	0.2	0.4	17				0.3	0.8	17			
Arctic flounder	*Pleuronectes glacialis*							0.2	0.4	17			
Threespine stickleback	*Gasterosteus aculeatus*				0.5	1.2	17						
Alaska plaice	*Pleuronectes quadrituberculatus*							0.2	0.4	17			
Fourhorn sculpin	*Myoxocephalus quadricornis*										0.2	0.4	17
Fourline snakeblenny	*Eumesogrammus praecisus*	0.2	0.4	17									
Unidentified flatfish	Pleuronectidae	0.2	0.4	17									
Pink salmon (adult)	*Oncorhynchus gorbuscha*				0.2	0.4	17						
Total catch		5779			415			2498			7347		
Number of species		8			8			12			8		
Median CPUE		814			10			225			441		

temperature and salinity in August 2009 were consistent from the surface to the bottom at all 8 m trawl sites.

Fish catch and species richness for all sampling periods were correlated with water temperature. Total seine catch was positively correlated with mean water temperature ($r^2 = 19.9$, $p < 0.05$), whereas total trawl catch was negatively correlated with water temperature ($r^2 = -10.5$, $p < 0.05$) (Fig. 2). The total seine catch was highest in 2007 (5779 fish) when water temperature was highest (9.0˚C), and the lowest total seine catch in August 2008 (415 fish), when water temperature was lowest (1.8˚C). For trawl tows, mean catch was greatest in 2008 (1464 fish), when water temperature was lowest; mean catch was lowest in 2007 (98 fish) when water temperature was highest. Species richness for trawl sites was negatively correlated with water temperature among sampling periods ($r^2 = -33.0$, $p < 0.001$), but was similar among seine sites ($r^2 = 1.0$, $p = 0.66$).

DISCUSSION

The nearshore environment of the northeastern Chukchi Sea provides important habitat during the ice-free season for many fish species, including capelin and Arctic cod. Capelin and Arctic cod are important in subsistence fisheries (George et al., 2009) and as prey for other fishes, marine mammals, and seabirds (Watts and Draper, 1986; Bogstad and Gjøsæter, 2001; Cherel et al., 2001). Use of the nearshore Chukchi Sea by fish, particularly by capelin and Arctic cod, demonstrates the importance of understanding and protecting this habitat from anthropogenic impacts such as oil and gas exploration. The effects of global climate change on the nearshore are unknown, but could include changes in fish distribution and abundance (Genner et al., 2004). Increased exposure to larger and more frequent waves from changes in sea ice could cause beach erosion, damaging capelin and Pacific sand lance spawning habitat. However, subtidal spawning habitat for capelin could increase.

Our results are similar to those of Fechhelm et al. (1984) from a 1983 study in the nearshore marine waters near Kasegaluk Lagoon in the northeastern Chukchi Sea. The two dominant species from their fyke net catches, Arctic cod and capelin, were also the two dominant species in our beach seine and trawl catches. The age of capelin captured, however, differed between studies; Fechhelm et al. (1984) captured only mature or spawned-out adults, whereas we captured predominately juveniles. Additionally, Fechhelm et al. (1984) sampled with a gill net, and one of their most abundant species caught with this gear type, Pacific herring, was not caught in our study. Beach seining results in the nearshore of the southeastern Chukchi Sea were different from results for the northeastern Chukchi Sea. Alverson and Wilimovsky (1966) reported that Arctic char (*Salvelinus alpinus*) and Dolly Varden char (*S. malma*) were the most abundant species captured by seine.

Like the coastal waters of the eastern Beaufort Sea, the nearshore northeastern Chukchi Sea appears to be

TABLE 2. Bottom trawl catch statistics: Catch-per-unit-effort (CPUE, tow) with standard deviation (SD) and percent frequency of occurrence (FO) of each fish species captured with a bottom trawl at six stations in the northeastern Chukchi Sea, near Barrow, Alaska, in August of 2007–09 and in September 2009. Two tows (5 and 8 m depth) were made at each station; n = 12 for each sampling period. Catches were similar at both depths (ANOVA; $p = 0.57$), so data were combined. Taxa are listed in decreasing order of abundance in the total catch. Blank spaces represent the absence of a taxon.

		2007			2008			2009			September 2009		
Common name	Scientific name	CPUE	SD	FO	CPUE	SD	FO	CPUE	SD	FO	CPUE	SD	FO
Arctic cod	*Boreogadus saida*	0.6	1.9	33	71.9	267.0	50	0.3	1.6	8	73.4	131.6	100
Slender eelblenny	*Lumpenus fabricii*	0.9	2.2	50	20.2	51.3	92	4.3	7.8	67	11.3	7.9	92
Unidentified sculpin	Cottidae	3.5	3.0	83	8.2	17.6	67	3.0	7.7	58	7.5	14.2	92
Arctic staghorn sculpin	*Gymnocanthus tricuspis*				6.8	21.6	67	0.6	1.6	33	6.2	4.6	100
Saffron cod	*Eleginus gracilis*				0.3	1.2	25	0.3	0.8	17	7.5	13.4	92
Longhead dab	*Limanda proboscidea*	1.4	2.4	67	1.7	5.0	50	0.3	0.8	17	2.8	4.3	58
Unidentified poacher	Agonidae				2.8	4.0	67						
Unidentified flatfish	Pleuronectidae	0.1	0.4	8	1.3	5.2	25	0.5	1.6	33	1.7	3.4	50
Atlantic poacher	*Leptagonus decagonus*	0.1	0.4	8	1.7	4.4	17						
Unidentified snailfish	Liparidae				1.9	3.8	42	0.4	1.2	33	0.8	3.2	25
Shorthorn sculpin	*Myoxocephalus scorpius*	0.1	0.4	8	1.7	4.4	50	0.2	0.5	17	0.5	0.9	33
Unidentified cod	Gadidae				0.6	2.0	25	0.9	4.0	17	0.4	2.0	8
Capelin	*Mallotus villosus*	0.2	0.5	17	0.9	4.5	17	0.2	0.5	17	0.6	1.6	25
Yellowfin sole	*Limanda aspera*	0.1	0.4	8	0.8	1.6	33				0.9	1.2	50
Fourhorn sculpin	*Myoxocephalus quadricornis*				0.7	2.0	33				1.0	2.1	33
Walleye pollock	*Theragra chalcogramma*							0.2	0.8	8	1.1	3.0	25
Pacific sand lance	*Ammodytes hexapterus*	0.3	0.8	25	0.1	0.4	8	0.1	0.5	8	0.3	0.6	25
Arctic sculpin	*Myoxocephalus scorpioides*	0.6	0.9	42									
Unidentified prickleback	Stichaeidae	0.3	1.2	17	0.3	0.8	17						
Rainbow smelt	*Osmerus mordax*										0.6	2.9	17
Veteran poacher	*Podothecus veternus*							0.1	0.4	8	0.5	1.1	33
Whitespotted greenling	*Hexagrammos stelleri*										0.3	0.6	25
Arctic flounder	*Pleuronectes glacialis*							0.2	0.8	17	0.2	0.8	17
Variegated snailfish	*Liparus gibbus*				0.2	0.4	17						
Marbled eelpout	*Lycodes raridens*				0.1	0.4	8				0.1	0.1	8
Fourline snakeblenny	*Eumesogrammus praecisus*				0.1	0.4	8						
Pacific cod	*Gadus macrocephalus*										0.1	0.1	8
Plain sculpin	*Myoxocephalus jaok*							0.1	0.4	8			
Tubenose poacher	*Pallasina barbata*				0.1	0.4	8						
Total catch		98			1464			137			1407		
Number of species		10			17			15			18		
Median CPUE		7			27			11			105		

important habitat for age-0 capelin and spawning habitat for adult capelin during the ice-free season. Capelin are known to spawn in the Chukchi Sea along beaches near Barrow, Alaska (Walters, 1955; George et al., 2009), and in the eastern Beaufort Sea in Prudhoe Bay (Bendock, 1979), but juveniles appear to be generally more abundant in the nearshore Chukchi Sea than in the Beaufort Sea (Craig and McCart, 1976; Craig, 1984). Although capelin have been captured in most nearshore surveys in the Beaufort and Chukchi Seas, they are uncommon in offshore surveys in the northeastern Chukchi Sea (Quast, 1974; Lowry and Frost, 1981; Frost and Lowry, 1983; Barber et al., 1997; Gillispie et al., 1997; Wyllie-Echeverria et al., 1997; Norcross et al., 2011; Gallaway and Norcross, 2011), the southeastern Chukchi Sea (Alverson and Wilimovsky, 1966; Wolotira et al., 1977), and in the western Beaufort Sea (Frost and Lowry, 1983; Jarvela and Thorsteinson, 1999; Rand and Logerwell, 2011). Differences in capelin catches between the nearshore and offshore may indicate bias in sampling gear or a seasonal movement by capelin that could make them unavailable to offshore sampling. Offshore trawls may not be efficient at capturing capelin or older juveniles, and adult capelin may disperse into deeper water as ice forms in fall and then return to shallower nearshore waters to rear or spawn when sea ice retreats in summer, therefore avoiding offshore sampling efforts. The greater capelin catches from our beach seining compared to our trawling could indicate either a habitat preference or gear type bias, similar to what could be happening during offshore trawling. The number of capelin that we caught, together with reported adult spawning on Chukchi Sea beaches, indicates that there is at least a moderate population of capelin in the northeastern Chukchi Sea.

Abundance of Arctic cod and capelin in nearshore waters of the Arctic appears to be related to hydrographic characteristics, movements in water mass, and ultimately to the timing of sea ice retreat (Fechhelm et al., 1984; Moulton and Tarbox, 1987; Barber et al., 1994; Jarvela and Thorsteinson, 1999). When sea ice remained in the nearshore off Barrow late in 2008 (ice breakup July 21; Petrich et al., 2012) and water temperature was cold, we had the largest catches of Arctic cod and the lowest catches of capelin of any August sampling period. Conversely, in 2007, when sea ice retreated from the nearshore early (ice breakup

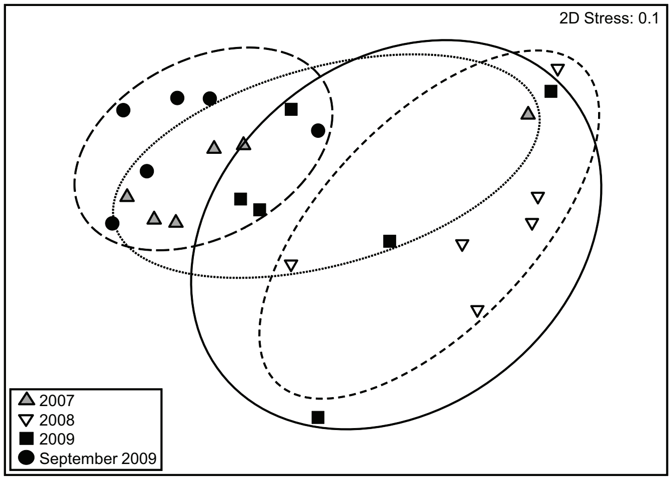

FIG. 3. Non-metric multidimensional scaling ordination of fish assemblages based on abundance of fish captured with a beach seine at six stations in the northeastern Chukchi Sea, August 2007–09 and September 2009.

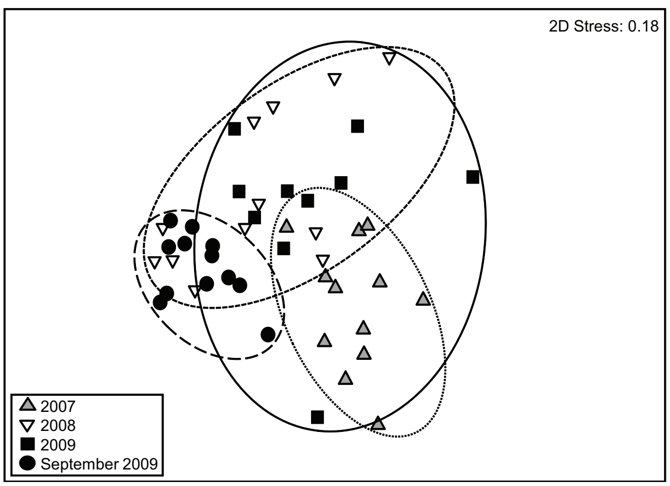

FIG. 4. Non-metric multidimensional scaling ordination of fish assemblages based on abundance of fish captured with a bottom trawl at six stations in the northeastern Chukchi Sea, in August of 2007–09 and in September 2009. Two bottom trawls (5 m and 8 m deep) were made at each station.

June 13; Petrich et al., 2012) and water temperature was warmer, we had the largest catches of capelin and the lowest catches of Arctic cod in any sampling period. Air temperatures and wind direction also varied between 2007 and 2008. Air temperatures were warmer in July and August in 2007 (mean = 6.7˚C, 7.2˚C) than in 2008 (mean = 4.4˚C, 3.3˚C), and the number of days in July and August on which the wind direction had a westerly (onshore) component was smaller in 2007 (4, 4) than in 2008 (10, 11) (National Weather Service, 2012). In the Beaufort Sea, wind direction plays an important role in the epipelagic fish community (Jarvela and Thorsteinson, 1999). Changes in sea ice patterns could affect distribution and survival of plankton and thus affect fish that prey on them (Barber et al., 1994). Several times in July and August 2008, floating sea ice was pushed into nearshore areas near Barrow (Sea Ice Group at the Geophysical Institute, 2012). Multi-year sampling in the nearshore Chukchi Sea is necessary considering the

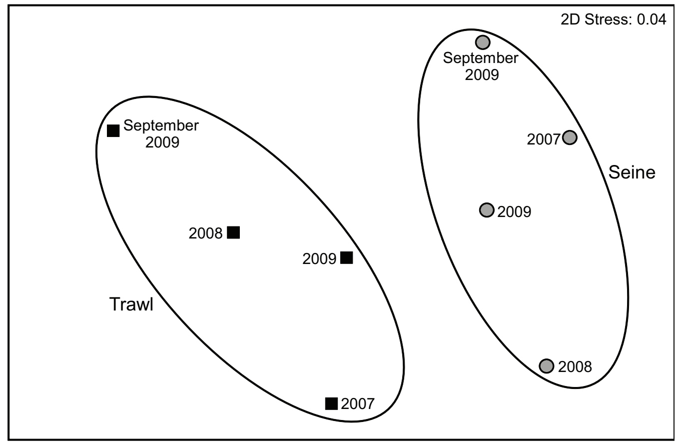

FIG. 5. Non-metric multidimensional scaling ordination of fish assemblages based on abundance of fish captured with a beach seine and a bottom trawl at six stations in the northeastern Chukchi Sea, in August of 2007–09 and in September 2009.

prevalence of annual variations in water, wind, and ice conditions.

During short Arctic summers, some species may exhibit seasonal patterns in distribution. For example, our trawl catch of Arctic cod was low in August 2009 (CPUE < 1 fish) but very high (CPUE = 73 fish) in September 2009. Similarly, we captured saffron cod by seine and rainbow smelt by trawl only in September. Seasonal movements of Arctic cod and rainbow smelt between offshore and nearshore waters of the Arctic have been reported by others (Craig and Haldorson, 1981; Craig et al., 1982; Haldorson and Craig, 1984; George et al., 2009). In the nearshore northeastern Chukchi Sea, winter catches were small and consisted almost exclusively of Arctic cod, whereas in summer at another location in the northeastern Chukchi Sea, catches were larger and more diverse than in winter (Fechhelm et al., 1984).

The species richness reported in our study is similar to that in other nearshore areas in the northeastern Chukchi and Beaufort Seas and the offshore Beaufort Sea, but generally less than in offshore areas of the northeastern Chukchi Sea. For example, in the nearshore, Fechhelm et al. (1984) identified 14 species captured with fyke and gillnets in the northeastern Chukchi Sea, and Griffiths et al. (1977), Bendock (1979), Schmidt et al. (1983), Craig and Haldorson (1981), Jarvela and Thorsteinson (1999), and Johnson et al. (2010) reported from 12 to 22 species in the nearshore Beaufort Sea compared to the 18 species that we identified in seine catches. In historic offshore studies in the northeastern Chukchi Sea, the number of species ranged from 14 (Frost and Lowry, 1983) to 66 (Barber et al., 1997), compared to the 24 species we captured by trawl. Frost and Lowry (1983) trawled only 10 stations in a relatively small area, whereas Barber et al. (1997) trawled 64 stations, covering a large area over a two-year period. In more recent mid-water and bottom trawl surveys in the northeastern Chukchi Sea, number of species has ranged from 29 to 39 (Norcross et al., 2011; Priest et al., 2011; Gallaway and

TABLE 3. Beach seine catch statistics: Total catch, number measured (n), mean fork or total length (mm), and length range of each fish species captured with a beach seine in the northeastern Chukchi Sea near Barrow, Alaska, in August of 2007–09 and in September 2009. One seine haul was made at each station. Blank spaces represent the absence of a taxon.

Taxon	2007				2008				2009				September 2009			
			Length				Length				Length				Length	
	Catch	n	Mean	Range	Catch	n	Mean	Range	Catch	n	Mean	Range	Catch	n	Mean	Range
Capelin	5667	228	66.5	47–140	69	24	52.3	37–139	726	169	48.4	29–65	6742	241	63.6	40–90
Pacific sand lance	79	79	73.1	53–102	1	1	124.0		1557	49	65.3	53–78	12	8	87.8	62–110
Saffron cod													467	119	37.2	26–50
Unidentified sculpin	15	10	24.3	19–32	53	31	28.0	21–37	139	42	20.5	11–35	34	26	35.0	26–42
Unidentified cod					228	23	27.8	20–39	4	4	34.0	29–39				
Unidentified prickleback	8	8	32.6	25–52	56	38	44.1	34–54	44	20	31.4	21–43				
Arctic cod	3	3	38.7	29–45									69	57	48.5	33–66
Slender eelblenny					1	1	72.0		9	8	43.0	37–47	18	17	48.9	44–65
Unidentified snailfish									6	6	21.7	17–26	1	1	38.0	
Arctic staghorn sculpin					3	3	33.0	30–38	2	2	54.5	53–56				
Arctic sculpin	4	4	82.5	70–115												
Fish larvae									4	4	28.3	12–38				
Arctic cisco													3	3	83.0	79–86
Unidentified poacher									3	3	22.0	21–23				
Shorthorn sculpin	1	1	87.0						2	2	48.0	45–51				
Arctic flounder									1	1	46.0					
Threespine stickleback					3	3	81.3	77–85								
Alaska plaice									1	1	120.0					
Fourhorn sculpin													1	1	80.0	
Fourline snakeblenny	1	1	29.0													
Unidentified flatfish	1	1	54.0													
Pink salmon (adult)					1	0										

Norcross, 2011), greater than the 24 species we captured by trawl. In offshore surveys in the western Beaufort Sea, Frost and Lowry (1983) caught 17 species and Rand and Logerwell (2011) caught 30 fish species in offshore bottom trawls, which is similar to our trawling results.

Overall species composition in our study is similar to other nearshore and offshore surveys in Arctic waters of Alaska. Capelin (pelagic species) dominated our total seine catch (83%), whereas Arctic cod (semi-demersal) dominated our total trawl catch (56%). We captured many demersal taxa (e.g., flatfishes, poachers, pricklebacks, and sculpins), mostly in small numbers; some exceptions were slender eelblenny and sculpins, the second and third most abundant taxa. Similarly, Arctic cod dominated most nearshore and offshore catches in the northeastern Chukchi Sea, and demersal species comprised most of the remainder of catches—eelpouts, pricklebacks, and sculpins were the next most abundant taxa (Frost and Lowry, 1983; Fechhelm et al., 1984; Barber et al., 1997; Norcross et al., 2011; Priest et al., 2011). A notable difference in survey results was that saffron cod was the second most abundant species caught by Barber et al. (1997) and the third most abundant species in our seine catches, but was rare in other northeastern Chukchi Sea surveys. Our catches of eelpouts (< 1% of trawl catch) were much smaller than catches in offshore Chukchi Sea surveys. In the offshore western Beaufort Sea, Rand and Logerwell (2011) reported that Arctic cod dominated their catches and that walleye pollock (*Theragra chalcogramma*), Canadian eelpout (*Lycodes polaris*), and ribbed sculpin (*Triglops pingelii*) were their second, third, and fourth most abundant species. We did not catch Canadian

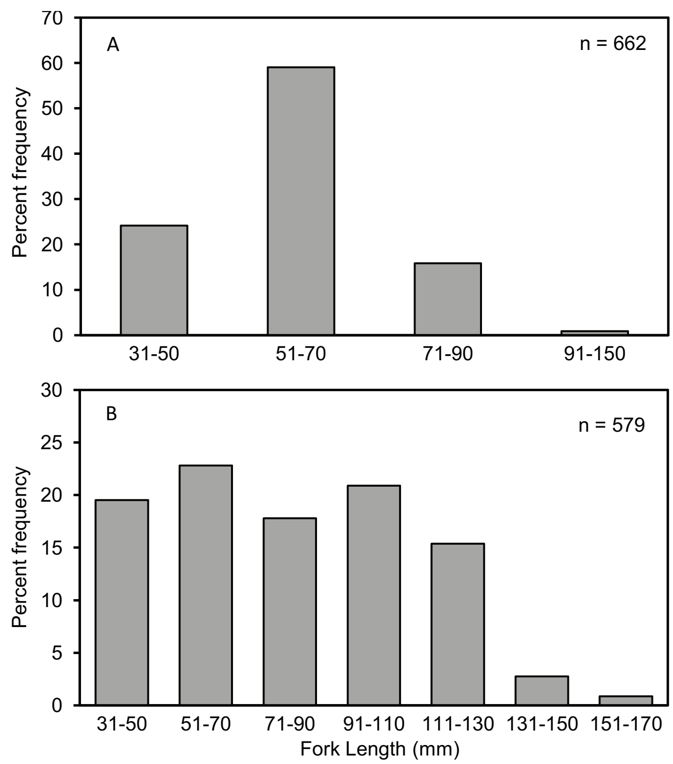

FIG. 6. Length frequency distribution of (A) capelin captured with a beach seine and (B) Arctic cod captured with a bottom trawl in the northeastern Chukchi Sea, Alaska, in August of 2007–09 and in September 2009.

eelpout or ribbed sculpin and only a small number of walleye pollock. For demersal fishes in our nearshore trawl catches, slender eelblenny was the second most abundant

TABLE 4. Bottom trawl catch statistics: Total catch, number measured (n), mean fork or total length (mm), and length range of fish captured with a bottom trawl in the northeastern Chukchi Sea near Barrow, Alaska, in August of 2007–09 and in September 2009. Two tows (5 and 8 m depth) were made at each station; catches were similar at both depths (ANOVA; $p = 0.57$) so data were combined. Blank spaces represent the absence of a taxon.

Taxon	2007				2008				2009				September 2009			
		Length				Length				Length				Length		
	Catch	n	Mean	Range	Catch	n	Mean	Range	Catch	n	Mean	Range	Catch	n	Mean	Range
Arctic cod	7	7	78.9	52–102	863	171	91.6	62–156	4	4	101.3	95–107	881	397	77.0	33–171
Slender eelblenny	11	11	86.9	60–105	242	119	71.9	52–100	51	42	76.1	59–94	135	72	80.9	55–112
Unidentified sculpin	42	34	26.9	20–35	98	73	30.3	19–39	36	25	24.6	12–55	90	37	41.6	24–76
Arctic staghorn sculpin					82	43	51.7	33–110	7	7	60.4	52–81	74	52	66.2	50–110
Saffron cod					4	4	78.8	66–95	3	3	70.7	68–73	90	81	68.7	32–213
Longhead dab	17	17	62.9	32–102	20	20	63.6	43–81	3	3	64.3	55–74	33	31	65.7	39–101
Unidentified poacher					33	31	28.7	25–33								
Unidentified flatfish	1	1	61.0		15	15	48.1	41–53	6	6	40.0	25–60	20	18	38.2	26–52
Atlantic poacher	1	1	23.0		20	20	27.6	24–34								
Unidentified snailfish					23	23	59.3	20–76	5	3	26.3	22–30	9	9	51.4	25–111
Shorthorn sculpin	1	1	79.0		20	20	80.3	60–102	2	2	91.0	61–121	6	6	95.7	69–121
Unidentified cod					7	7	38.9	30–45	11	3	25.0		5	5	45.0	42–50
Capelin	2	2	78.0	67–89	11	10	75.1	44–132	2	2	85.0	38–132	7	7	98.0	57–145
Yellowfin sole	1	1	105.0		9	9	109.4	75–144					11	11	109.7	55–154
Fourhorn sculpin					8	8	92.4	70–121					12	12	86.6	48–128
Walleye pollock									2	2	84.0	82–86	13	13	93.1	73–132
Pacific sand lance	4	4	121.8	109–139	1	1	123.0		1	1	108.0		3	3	98.0	80–122
Arctic sculpin	7	7	68.7	55–115												
Unidentified prickleback	4	4	44.0	39–49	3	1	54.0									
Rainbow smelt													7	7	117.7	72–203
Veteran poacher									1	1	43.0		6	5	43.0	36–66
Whitespotted greenling													3	3	83.0	81–86
Arctic flounder									2	2	40.0	38–42	2	2	60.5	51–70
Variegated snailfish					2	2	47.5	27–34								
Marbled eelpout					1	1	55.0						1	1	62.0	
Fourline snakeblenny					1	1	164.0									
Pacific cod													1	1	254.0	
Plain sculpin									1	1	73.0					
Tubenose poacher					1	1	129.0									

species, whereas stout eelblenny (*Anisarchus medius*) was the most abundant eelblenny caught in the offshore Chukchi Sea (Priest et al., 2011).

Species composition in the nearshore "marine" habitat of the Beaufort Sea was similar to what we found for the nearshore northeastern Chukchi Sea, but species composition of the lagoon-barrier island environment of the Beaufort Sea differed from our results. The dominant taxa in our catches, capelin, Arctic cod, sculpins, and slender eelblenny, have all been reported as present or abundant in the nearshore marine habitat of the Beaufort Sea (Craig and McCart, 1976; Craig, 1984; Johnson et al, 2010). One notable exception was that capelin were not as abundant in the nearshore Beaufort Sea as in our catches. Species composition of Beaufort Sea lagoons is dominated by whitefish (Griffiths et al., 1977; Schmidt et al., 1983; Craig et al., 1985; Jarvela and Thorsteinson, 1999; Johnson et al., 2010), whereas, our whitefish catches consisted of only three Arctic cisco.

Different species and life stages can use the shallow nearshore at any time and be vastly different from offshore fish assemblages. For example, two of the dominant species that we captured primarily by beach seine (capelin and Pacific sand lance) were absent or captured in low numbers in bottom trawls in offshore waters in the northeastern Chukchi and the western Beaufort Seas (Fechhelm et al., 1984; Barber et al., 1997; Rand and Logerwell, 2011). One exception was that Pacific sand lance was the second most abundant fish caught by Norcross et al. (2011). Similarly, we captured rainbow smelt only by trawl and only in September.

Size distributions of capelin and Arctic cod in our nearshore sampling were similar to those of other nearshore and offshore waters of the Chukchi and Beaufort Seas. For Arctic cod in the nearshore northeastern Chukchi Sea, Fechhelm et al. (1984) reported a mode of 75 mm FL; the median FL of Arctic cod in our study was 80 mm. Priest et al. (2011) reported a mean length of 62.5 mm in the offshore northeastern Chukchi Sea and Lowry and Frost (1981) reported a mean FL of 88 mm for Arctic cod in the offshore northeastern Chukchi and Beaufort Seas. For Arctic cod in the offshore southeastern Chukchi Sea, Frost and Lowry (1983) reported a mode FL of 80 mm, Quast (1974) reported a mode TL of 44 mm, and Alverson and Wilimovsky (1966) reported a mean length of 159 mm. In the western Beaufort Sea, Johnson et al. (2010) reported a mean FL for Arctic cod of 79 mm in the nearshore and Rand and Logerwell (2011) reported a mean FL of 113 mm for Arctic cod in the offshore. In the nearshore northeastern Chukchi Sea, Fechhelm et al. (1984) captured primarily adult capelin that were part of a spawning population (mode FL = 130 mm) but did not catch any capelin offshore. For capelin in the nearshore western Beaufort Sea, Johnson et al. (2010) reported catching mostly YOY fish with a mean FL of 57 mm. Jarvela and Thorsteinson (1999) also caught mostly YOY capelin in the nearshore Beaufort Sea, with an annual mean FL ranging from 62 to 64 mm over a three-year period.

This study indicates that many fish species use the nearshore environment of the northeastern Chukchi Sea during the ice-free season, and that species composition varies with annual fluctuations in environmental conditions. Species composition can also differ between nearshore waters and deeper, offshore waters, but these two areas are generally similar—numerous marine species with a few dominant species. Although our sampling offers only a snapshot of nearshore fish assemblages in the northeastern Chukchi Sea, it is clear that nearshore habitats are important to numerous fish species, and that the shallow nearshore should be included as a component in any Arctic fisheries study. Loss of sea ice from climate change may open up formerly inaccessible areas to industrial development, increased vessel traffic, and commercial fishing, posing direct threats to nearshore habitats. Therefore, long-term monitoring of shallow-water, nearshore fish assemblages in the Arctic is important for making informed management decisions.

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