CHAPTER 4

WATER MASSES AND TRANSPORT OF YOUNG-OF-THE-YEAR FISH INTO THE NORTHEASTERN CHUKCHI SEA[1]

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Abstract.—It is hypothesized that some fish species in the northeastern Chukchi Sea are maintained through transport from more southern areas. We examine this hypothesis and report on the abundance and distribution of young-of-the-year Arctic cod and Bering flounder in relation to water masses. Ichthyoplankton were sampled with a variety of mid-water gears during 1989-1991. Arctic cod dominated the catches and occurred throughout the northeastern Chukchi Sea with higher concentrations at northern stations during all three years. They rarely occurred at southern stations when Bering Shelf Water (BSW) was present. Larval Arctic cod (› 6.3 mmSL) were caught mid-July in 1991 indicating reproduction extends into late July. Bering flounder occurred primarily in areas dominated by the Alaska Coastal Water (ACW) as far north as 71° N. They did not occur when Resident Chukchi Sea Water was present. We conclude that populations of Bering flounder in the northeastern Chukchi Sea are maintained by the transport of larvae in the ACW. While these fish and others may be routinely advected into the northeastern Chukchi Sea by Alaska Coastal Water, Resident Chukchi Water may be a critical factor in delimiting their northern distribution.

INTRODUCTION

Many species of fish from the north Pacific Ocean and Bering Sea have their northern range bordering the Chukchi Sea, e.g., starry flounder (*Platichthys stellatus*), Pacific halibut (*Hippoglossus stenolepis*), and Pacific cod (*Gadus macrocephalus*). Others, however, commonly occur in the region and are considered Arctic, e.g., Arctic cod (*Boreogadus saida*) (Alverson and Wilimovsky 1966; Allen and Smith 1988). Three species of Gadidae occur in the northeastern Chukchi Sea. Arctic cod is the dominant species (Pruter and Alverson 1962; Alverson and Wilimovsky 1966; Gillispie *et al.* Chapter 7) and has a circumpolar distribution. They are found near the ice edge, migrate, and spawn under the ice (Ponomarenko 1968) and are a key link in the transport of energy from lower to higher trophic levels (Craig *et al.* 1982). Additionally, Arctic cod is an important prey for eleven species of marine mammals, twenty species of marine birds, and four species of fish (Lowry and Frost 1981). Six species of adult flatfish commonly

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occur in the Chukchi Sea of which Bering flounder is dominant (Pruter and Alverson 1962; Smith *et al.* Chapter 6). Bering flounder range from Tatar Strait in the west to the Chukchi Sea through the Bering Sea to the Aleutian Is. (Andriyashev 1937; Pruter and Alverson 1962). Pruter and Alverson (1962) hypothesized that species like the Bering flounder might be maintained by import from the northern Bering Sea to the Chukchi Sea. To investigate this possibility we sampled planktonic young-of-the-year fishes in the late summer or fall of 1989-1991. From these samplings we describe the relationship of Bering flounder (*Hippoglossoides robustus*) to the physical oceanographic conditions in the northeastern Chukchi Sea and compare this distribution to that of Arctic cod.

The passive movement of planktonic oceanic fish larvae and post-larvae is affected by currents (Sinclair 1988). Distributions of Atlantic cod, *Gadus morhau* (Elizarov 1965), herring, *Clupea harengus* (Jakobsson 1969), and capelin, *Mallotus villosus* (Stergiou 1991) have been associated with changes in the distribution of water masses in the North Atlantic. Arctic populations of saffron cod, *Eleginus gracilis*, are known to vary in distribution and abundance with differing current regimes (Vasil'kov *et al.*1981). The relationship of ice cover, as well as other physical factors affected by atmospheric forcing, affects the distribution of walleye pollock, *Theragra chalcogramma* (Vasil'kov and Glebova 1984).

The currents in the northeastern Chukchi Sea are dominated by flow from the Bering Sea, which is caused by the Arctic Ocean being approximately 0.5 m lower than the Pacific Ocean (Stigebrandt 1984). Secondarily, the direction and strength of the wind, especially in summer, influences the rate of northerly flow and periodically imposes southerly flow over the shelf (Coachman and Shigaev 1992). The result is that three water masses predominate in the northeastern Chukchi Sea, the Alaska Coastal Water (ACW), Resident Chukchi Water (RCW), and Bering Shelf Water (BSW). Their distribution is influenced by the wind, and modified by the freezing and melting of seasonal sea ice (Weingartner, Chapter 2). The flow of currents northward introduces nutrients, phytoplankton and zooplankton into the Chukchi (Walsh *et al.* 1989).

MATERIALS AND METHODS

A bongo net, Isaac-Kidd midwater trawl (IKMT), and a beam trawl were used to sample young-of-the-year (YOY) fish during late summer and autumn of 1989-1991. The bongo net was 60 cm in diameter with 1.0 mm mesh netting, and a 0.5 mm meshed codend, and sampled 0.28 m^2 of water. The IKMT had a 1.8 m head bar and a net having 5.0 mm mesh, a 1.0 mm mesh codend, and sampled approximately 2.65 m^2 of water. Both nets were fitted with a calibrated flow meter suspended in the mouth of the nets. In 1989 the IKMT was deployed from the *Alpha Helix*. In 1990 and 1991 the IKMT and bongo net were deployed from a 33.5 m trawler. In 1991 a 2.24 m^2 square beam trawl was also used, the net's mesh of which graded in size from 6.5 mm to 4.0 mm with a 1.0 mm lining in the cod end. It was deployed from the *Oshoro Maru* (University of Hokkaido). Also in 1991, as a pilot program the bongo net and IKMT were deployed from a 9 m skiff operating from an anchored barge. All nets were pulled at a speed of approximately 2 kts and deployed in double oblique tows from surface to near bottom.

All collections were preserved in 5% sea water-formalin solution and returned to the laboratory. Fish were separated from the plankton samples, identified to the lowest taxonomic level possible following Matarese *et al.* (1989), and preserved in 80% ethanol. Standard lengths (SL) were measured on all undamaged fish to the nearest 0.1 mm; no shrinkage corrections were applied. The densities for each station were calculated as the mean of two replicate tows and reported as number/1000 m^3. Total number of fish captured is reported for the beam trawl collections due to the absence of a flow meter.

General station locations were chosen to increase the probability of sampling different water masses. Latitude and longitude were determined with a Global Positioning System. At the end of each sampling, vertical profiles of salinity, temperature, and depth were obtained with a Seabird SBE 19 conductivity-temperature-depth instrument. These data were used to classify each station as to one of four water masses present on the northeastern Chukchi Sea's shelf following the scheme of Coachman and Shigaev (1992) and Weingartner (Chapter 2). Two water masses, Alaska Coastal Water (ACW) and Bering Shelf Water (BSW), originate in the Bering Sea. The ACW flows northward from the Bering Sea along the coast of Alaska and is influenced by freshwater input, primarily the Yukon River (Weingartner, Chapter 2). It is characterized by relatively warm temperatures of 2 - 6° C and salinity less than 31.5 psu. BSW is colder (0 - 3°C) and more saline (> 32.5 psu) than ACW and also flows northward to the west of ACW. Resident Chukchi Water (RCW) is a combination of Arctic Ocean Water and water from the melting and freezing of sea-ice. RCW is characterized by low temperatures (<1°C) and high salinity (32 - 33 psu).

Wind stress curl at 67.5° N 167.5° W for 1981 - 1991 was obtained from Figure 11 in Weingartner (Chapter 2). Salmon (1992) calculates the north-south wind stress curl for the Chukchi Sea from atmospheric pressure data for 1981 - 1990.

RESULTS

Members of nine families were captured of which Cottidae, Gadidae, Pleuronectidae, Stichaeidae, Liparidae, and Agonidae were present in all years (Table 1).

Table 1.—Percent abundance of each species sampled by oblique tows with the Isaccs-Kidd mid-water trawl (IKMT), beam trawl, and a bongo net during summers of 1989, 1990, and 1991. Species indicated by a "t" were less than 2% of the total catch.

YEAR **GEAR**	**1989** **IKMT**	**1990** **Bongo**	**1990** **IKMT**	**1991** **Beam**	**1991** **Bongo**
Cottidae	2	3			
Myoxecephalus	t	t	t	6	t
M. "verucosa	t	0	t	0	0
Gymnocanthus spp.	0	0	t	2	t
G. tricuspis	3	0	t	0	0
Porocottus sp.	0	0	t	0	0
Gadidae					
Boreogadus saida	79	16	36	83	85
Eleginus gracilis	0	10	19	2	t
Theragra chalcogramma	0	t	t	3	0
Pleuronectidae					
Hippoglossoides robustus	7	23	18	t	0
Pleuronectes spp.	t	t	t	0	0

Table 1. continued

YEAR **GEAR**	**1989** **IKMT**	**1990** **Bongo**	**1990** **IKMT**	**1991** **Beam**	**1991** **Bongo**
Cottidae	2	3			
P. asper	t	t	t	0	0
P. proboscideus	t	t	t	0	0
Platyichthys stellatus	0	0	t	0	0
Lepidopsetta spp.	0	t	t	0	0
Agonidae					
Aspidophoroides olriki	t	0	t	t	0
A. bartoni	t	0	0	0	0
Agonus acipenserinus	t	0	0	t	0
Stichaeidae					
Stichaeus punctatus	t	t	7	t	10
Lumpenus "sp.	2	t	6	3	t
Liparididae					
Liparis sp.	t	t	5	t	t
Ammodytidae					
Ammodytes hexapterus	3	14	3	0	t
Bathylegidae	0	t	t	0	0
Pholididae	0	0	0	0	t
Zoracidae					
Lycodes sp.	t	t	t	0	0
Total number - fish	2068	99	581	379	76
Total number - stations	21	48	48	17	16

Zoarcidae, Bathylagidae and Pholididae occurred occasionally and were least abundant. Arctic cod dominated the pelagic larval and juvenile fish fauna in all 3 years. Species and abundance varied greatly between years with a notable reduction of pleuronectids in 1991.

During 3 - 9 September 1989, sampling was limited to 21 stations along two lines of longitude (169° and 168° W) in the northeastern Chukchi Sea (Figure 1). ACW was present at the surface throughout the study area (Figure 1). BSW was evident at the most southern station below 10 m. RCW underlay the ACW north of 70° N below 20-25 m. Seven families of fishes were caught in the IKMT of which YOY Arctic cod (79%) and Bering flounder (7%) were most common (Table 1). Arctic cod were present at all stations irrespective of water type. They were most common north of 70° N in ACW/RCW where densities at three stations ranged from 130 to 403 fish/1,000 m^3 (Figure 1). Two stations at the boundary of the ACW and ACW/RCW water masses had densities of 137 and 709 fish/1,000 m^3. South of this area the densities were much lower and ranged from 2.4 to 31 fish/1,000 m^3. YOY Arctic cod ranged from 27 - 52 mmSL. Bering flounder larvae were present at stations south of 71° N primarily in ACW or ACW and BSW. Densities reached 32 fish/1,000 m^3 at the two stations along 70° N. These fish ranged in size from 15 - 34 mmSL.

During 16 August to 16 September 1990 we sampled 48 stations throughout the northeastern Chukchi Sea (Figure 2). ACW was evident in surface waters throughout the area. Two additional water masses were present underneath the ACW; BSW occurred in the southeastern stations and RCW occurred in the northern stations (Figure 2). Thermoclines and pycnoclines were only evident where ACW overlay a colder, more saline water mass. Eight families of fishes were captured with Arctic cod, saffron cod, and Bering flounder dominating (Table 1). YOY Arctic cod made up 36% of the catch with the IKMT and were caught at all stations. Abundance exceeded 25 fish/1,000 m^3 at 3 stations north of Icy Cape (Figure 2). Size averaged 33 mmSL and ranged from 12.2 - 5.1 mmSL. The distribution of larval Arctic cod captured with the bongo net reflected that of the YOY caught with the IKMT. Their abundance, however, was much lower varying from 0.1 to 0.7 fish/1,000 m^3. Bering flounder were also captured in the IKMT but south of 71°N. At stations where they occurred, densities ranged from 1.1 to 4.6 fish/1,000 m^3. Bering flounder occurred in ACW and where ACW overlaid BSW Bering flounder larvae captured in the bongo net reflected the same distribution as figure 1 those captured in the IKMT and also occurred south of 71° north in ACW. Densities, however, were much lower which ranged from 0.1 to 0.4 fish/1000 m^3. The bongo net captured smaller fish which averaged 15 mmSL and ranged in size from 7.6 - 25.7 mmSL. The IKMT averaged 29 mmSL and ranged from 8.3 to 51.5 mmSL.

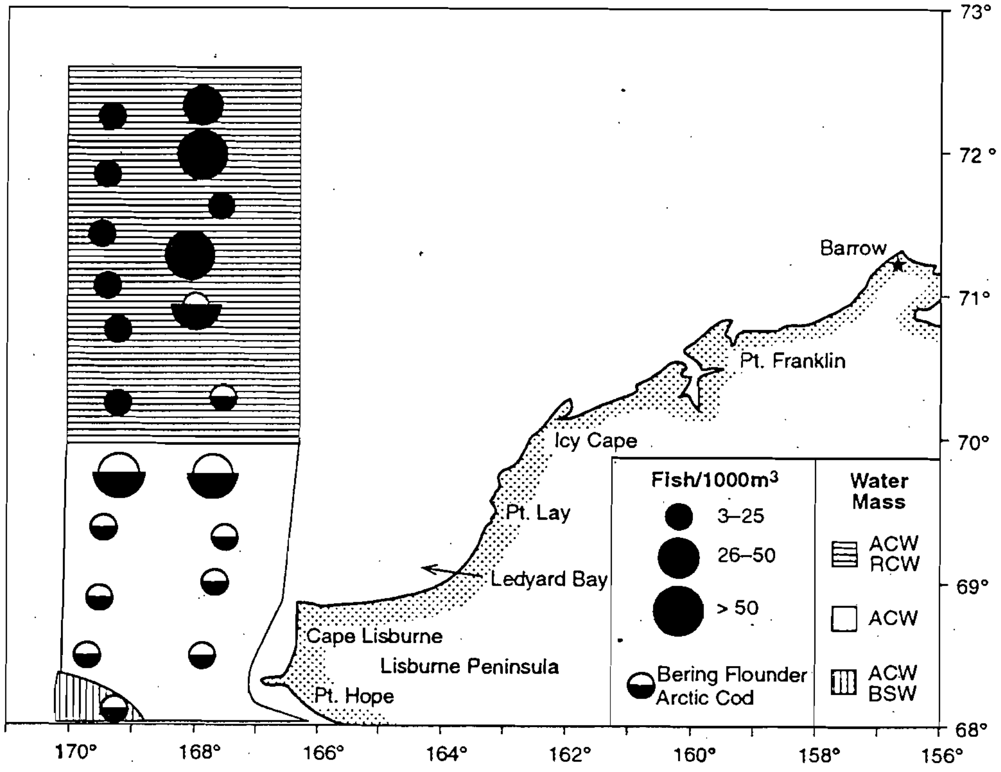

Figure 1. Abundance and distribution of Arctic cod and Bering flounder captured with the Isaccs-Kidd mid-water trawl in 1989. Densities are in fish/1,000 m^3. Water masses indicated by shading.

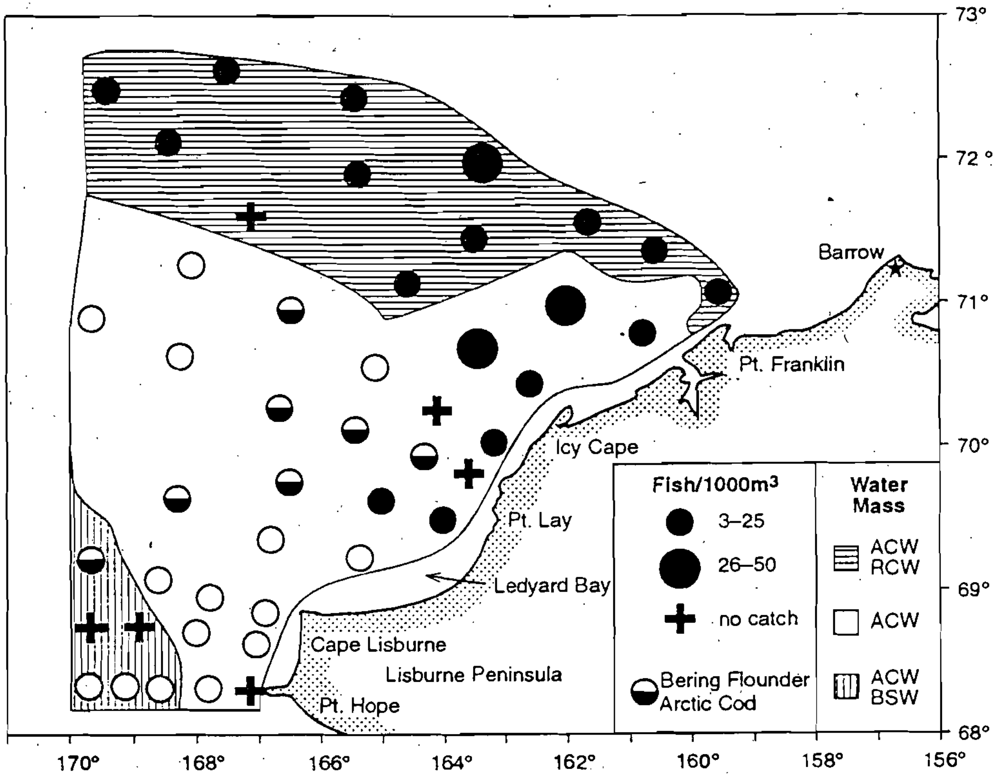

Figure 2. Abundance and distribution of Arctic cod and Bering flounder captured with the Isaccs-Kidd mid-water trawl in 1990. Densities are in fish/1,000 m^3. Water masses indicated by shading.

During 25-31 July 1991 we sampled 17 stations with the beam trawl. ACW was present south of 70°N and ACW/RCW occurred north of 69°30'N (Figure 3). Seven families of fish were caught in the beam trawl with Arctic cod (83%), *Myoxocephalus* spp. and *Stichaeus punctatus* the dominant species (Table 1). Arctic cod were caught throughout the study area, the highest numbers occurring in RCW where up to 65 fish per half hour tow. Average size was 14 mmSL and ranged between 7 - 36 mmSL. One Bering flounder was caught in ACW. Sampling with the bongo net during 2 - 25 September fish were caught at 5 of 16 stations. Again Arctic cod dominated (85%), and occurred in ACW/RCW and RCW. Sizes averaged 14 mmSL ranged between 7 - 37 mmSL. No Bering flounder were caught. Sampling near the ice edge from the skiff during 16 July, Arctic cod captured in the bongo net averaged 11.8 mmSL and ranged between 6.3 - 19.5 mmSL. In 16 August the average size was 13.1 and ranged between 8.2 and 23 mmSL.

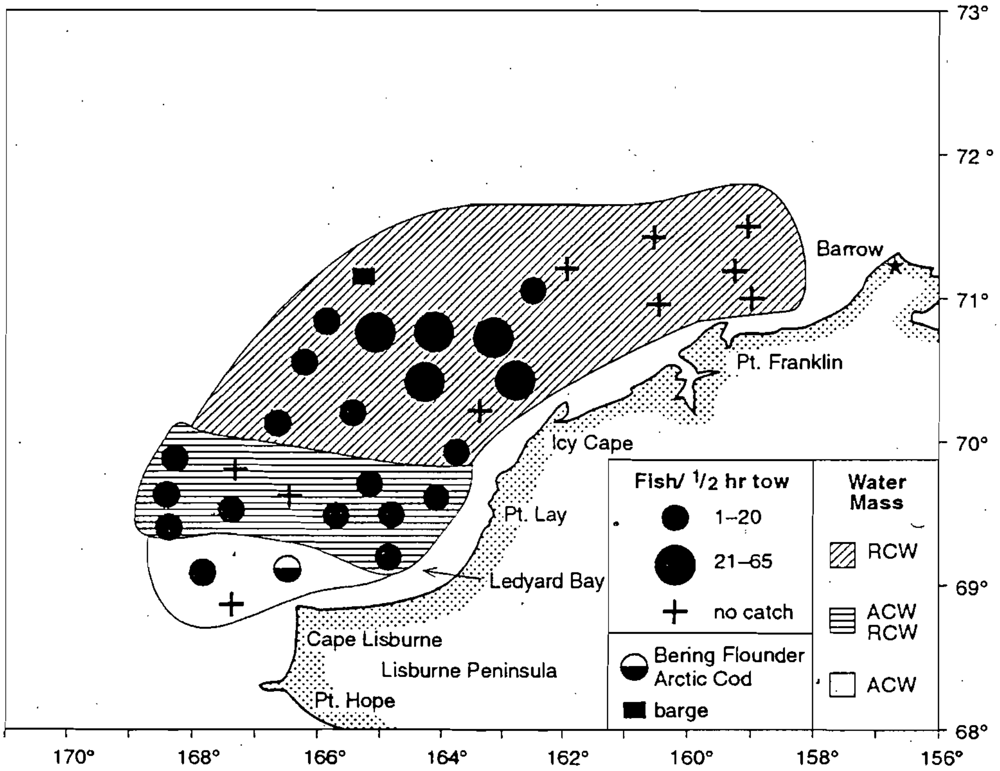

Figure 3. Abundance and distribution of Arctic cod and Bering flounder captured with the Issacs-Kidd mid-water trawl in 1991. Densities are in fish/1,000 m^3. The square is the barge location. Water masses indicated by shading.

DISCUSSION

The water of the northeast Chukchi Sea is primarily derived from two water types, BSW and ACW, flowing from the Bering Sea. RCW is a combination of Arctic Ocean water devected onto the shelf and mixing with waters formed from the freezing and melting during the previous winter (Weingartner, Chapter 2). Pruter and Alverson (1962) suggested that some of the marine fishes and invertebrates inhabiting the area maintain their populations only through continual recruitment of eggs and larvae transported northward. If so, it would be expected that the larvae of those fish with their main distribution primarily in the Bering Sea might be more associated with the ACW and the BSW in the northeast Chukchi Sea. In contract, those fish with their center of distribution in the Arctic Ocean might be more associated with the RCW.

In 1989 and 1990, the surface water mass extending throughout the study area was ACW (Figures 1 and 2). RCW occurred on the bottom from 70°N northward. In 1991, however, a different distribution was observed. ACW extended as far north as 70°N while RCW was prevalent throughout the water column northward. The distribution of YOY Bering flounder reflects the distribution of those water masses. Bering flounder were present during 1989 and

1990 in ACW and ACW/BSW but absent from ACW/RCW. In 1991 only one YOY Bering flounder was captured and it was in ACW (Figure 3). *Pleuronectes* spp. dominated by yellowfin sole (*P. asper*), and sandlance (*Ammnodytes hexapterus*), followed the same general pattern. These fish are primarily distributed in the Bering Sea and extend into the Chukchi Sea (Allen and Smith 1988). In 1989 and 1990 *Pleuronectes* spp. occurred in ACW, and sandlance was sampled from ACW and ACW/RCW but were absent in 1991 (Table 1). This suggests that YOY Bering flounder, and quire possibly yellowfin sole and sandlance, were advected into the northeastern Chukchi Sea with ACW.

Change in the distribution and abundance of organisms is coincident with the boundary between ACW and RCW which forms a semi-permanent front along the bottom between 70° and 71°N (Weingartner, Chapter 2). The distributions of adult (Smith *et al.* Chapter 6) and YOY (Figures 1 - 3) Bering flounder are close aligned with the position of RCW and the influx of ACW along the front and appears to be a boundary. In 1990 adults were most abundant in ACW south of 70°N, while few were present in RCW (Smith *et al.* Chapter 6). In 1991 abundance was very low relative to 1990 and restricted to the area south of 70°N. Additionally, Feder *et al.* (1990) identified two distinct benthic communities that change characteristics near 71°N.

YOY Arctic cod were distributed throughout the northeastern Chukchi Sea, with higher concentrations at or near stations where RCW was present. In waters off Greenland (between 69° and 72°N) a high abundance of Arctic cod was noted in the mid 1920's and absence since the mid 1930's (Rass 1968). This decline was attributed to the warmer climate which occurred at that time. These observations suggest that the distribution of arctic cod might change as a result of climatic shifts.

Climatic conditions in the northeastern Chukchi Sea were similar in 1989 and 1990. Winds during July-November were northward, resulting in an eastward displacement of ACW and an increased flushing of RCW from the shelf (Weingartner, Chapter 2). In contrast, during 1991 the winds were predominantly southward limiting the northern extent of ACW and pushing RCW southward.

In summary, we report two significant findings. First, the smallest Arctic cod caught (6.3 mmSL) in mid-July 1991 were the size of newly hatched larvae (5.5 mmSL; Rass 1968). Previous studies state that Arctic cod hatch no later than February in these waters (Matarese 1989). Our data suggests that the time of hatching may extend to mid-July.

Second, our data supports Pruter and Alverson's (1992) hypothesis. To further test this we reexamined an earlier study. In September and October of 1970 a team of scientists conducted a survey of the southeastern Chukchi sea (Websec-70 1972). Using the data reported by Quast (1972) and the temperature and salinity profiles of Ingham and Rutland (1972) reported in this study, we reconstructed the water masses present and YOY distribution. The ACW was present nearshore and to 71°N (Figure 4) while RCW was not present south of 69°30'N. Arctic cod were present at all stations but Bering flounder occurred only at stations south of 69°30'N and were associated with ACW. Water mass characteristics, and distribution of pelagic juvenile fish species indicate that the conditions of 1970 were similar to those in 1989 and 1990.

We conclude that populations of Bering flounder in the northeastern Chukchi Sea are maintained by the transport of larvae in the ACW and the northern limit of Bering flounder is undoubtedly connected to the presence of RCW. Hence, while these fish and others may be routinely advected into the northeastern Chukchi Sea by Alaska Coastal Water, Resident Chukchi Water may be a critical factor in delimiting their northern distribution.

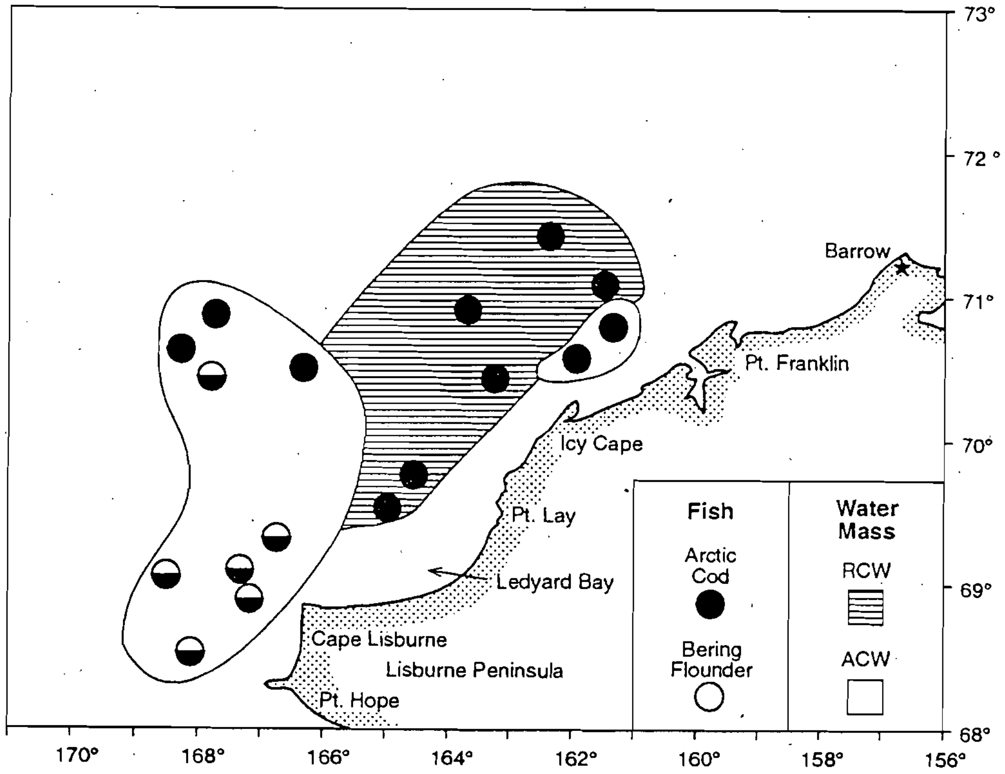

Figure 4. Distribution of Arctic cod and Bering flounder captured with the Isaccs-Kidd mid-water trawl in 1970. Water masses indicated by shading. Based on data from Quast (1972), and Ingham and Rutland (1972).

We conclude that populations of bering flounder in the northeastern Chukchi Sea are maintained by the transport of larvae in the ACW and the northern limit of Bering flounder is undoubtedly connected to the presence of RCW. Hence, while these fish and others may be routinely advected into the northeastern Chukchi Sea by Alaska Coastal Water, Resident Chukchi Water may be a critical factor in delimiting their northern distribution.

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CHAPTER 5

BIOLOGY OF THE ARCTIC STAGHORN SCULPIN, *GYMNOCANTHUS TRICUSPIS,* FROM THE NORTHEASTERN CHUKCHI SEA[1]

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Abstract.—Distribution, abundance, age structure, growth and reproduction were examined for the Arctic staghorn sculpin captured by otter trawl in the northeastern Chukchi Sea, Alaska. High biomass and numbers generally occurred inshore and south of Icy Cape (70°15'N). Mean biomass for 1990 and 1991 were 8.4 and 4.7 kg/km^2, respectively. Highest biomass and abundance values obtained for a station were 67 kg/km^2 and 8050 individuals/km^2, respectively. Both biomass and abundance were variable between years, trawl stations and replicate hauls of a single station. Mean biomass and abundance were significantly higher in 1990 than in 1991.

The oldest female observed was 9 years old; the oldest male was 8. The age structure changed dramatically from 1990 to 1991. In 1990, 42% of the population was $\geq$ 4 years old but in 1991 only 9% was $\geq$ 4 years old. The 1987 year class was virtually missing. After 3 years of age, females grew faster and reached larger size than males.

Both sexes increased gonad indices over the sampling period, achieving mean values of about 6% for males and about 15% for females by late September. The species is dimorphic with respect to pelvic fin length. Considering gonad indices, length of pelvic fins and presence of ova, it appears that males begin to reach maturity at 60-70 mm standard length while first maturity in females occurs at to about 90 mm.

The Arctic staghorn sculpin exhibited interannual variability in distribution, abundance and age structure. This variability suggests that the species is existing in an unpredictable and dynamic habitat that may result in recruitment failures, perhaps mass mortalities and/or dispersal of individuals.

INTRODUCTION

The Arctic staghorn sculpin is a circumpolar member of the family Cottidae inhabiting continental shelves of the Arctic and subarctic oceans (Andryiashev 1954). In the subarctic, it is found in the north Atlantic south to the Gulf of St. Lawrence (Leim and Scott 1966), the Chukchi Sea and the Bering Sea to the Gulf of Anadyr and Nataliya Bay (610°N) (Andryiashev 1954). It is common in the Chukchi and Beaufort Seas (Frost and Lowry 1983) and was one of

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the most abundant fish species caught by benthic trawl in the three years of this study. The purpose of this study was to expand our knowledge of the fish species, ecological interactions of these fishes and oceanographic constraints upon them.

MATERIALS AND METHODS

Fish were captured with a NMFS 83-112 survey otter trawl towed at approximately 2 kts. The trawl had a 25.2 m headrope and a 34.1 m footrope set back 7.1 cm from a tickler chain. The cod end was 90 mm stretched mesh into which a liner of 33 mm stretched mesh was inserted. Each trawl station consisted of two 30 min hauls. Width of the net opening was determined electronically with a Scanmar system incorporating sensor-transmitters attached to the outer wings of the net opening. Area sampled (m^2) was determined by multiplying the width of the net opening by the distance trawled. Distance trawled was determined from the ship's position (latitude and longitude as determined with a Global Positioning System) at the start and end of each haul. Trawl station locations listed in Table 1 are the end locations of the first haul at that station. Biomass (kg/km^2 trawled) and abundance (number of $fish/km^2$ trawled) were calculated by averaging the two 30 min hauls at each station. Mean biomass and abundance values for the two years were compared with a Mann-Whitney U test (Zar 1984).

Table 1.—Station locations sampled in 1990 and 1991 in the northeast Chukchi Sea. Included are depth (m), bottom temperature (°C), bottom salinity (psu), abundance (number/km^2), and biomass (kg/km^2) of Arctic staghorn sculpin.

Station	Date	Latitud		Longitude		Depth	Bottom	Bottom	Abundanc	Biomass
#	d/m/y	°	'N	°	'W	m	°C	Salinity (psu)	$\#/km^2$	kg/km^2
1	16081990	71	55	168	48	50.4	-1.24	33.31	35.1	1.6
2	17081990	71	33	167	45	46.8			0	0
3	17081990	71	29	167	02	46.8			36.7	1.1
4	17081990	71	09	165	54	41.4			282	4.5
5	18081990	70	48	164	11	45	-0.19	32.21	77.8	2.8
6	21081990	68	23	166	51	18	12.65	29.69	216	3.8
7	21081990	68	28	167	16	45	7.09	30.84	2560	40.1
8	21081990	68	29	168	03	54	2.54	32.59	2240	25.7
9	22081990	68	33	168	45	54	2.11	32.41	1690	37.3
10	22081990	68	39	168	47	52.2	2.09	32.44	756	14.1
11	22081990	68	46	168	42	52.2	2.72	32.06	526	6.7
12	22081990	68	51	167	56	48.6	2.55	32.26	1060	10.8
13	23081990	68	52	167	27	45	5.04	31.71	688	4.6
14	23081990	68	52	166	28	41.4	10.85	29.64	1320	13.4
15	23081990	68	68	166	20	36	10.49	29.78	19.8	0.4
16	24081990	69	69	167	39	46.8	2.75	32.2	155	2.5
17	24081990	69	11	168	22	48.6	3.19	32	371	4.4
18	24081990	69	12	168	50	50.4	2.21	32.33	402	5.4
19	30081990	69	07	164	54	21.6	10.7	29.45	8040	66.6

Table 1. continued

Station	Date	Latitud		Longitude		Depth	Bottom	Bottom	Abundanc	Biomass
#	d/m/y	°	'N	°	'W	m	°C	Salinity (psu)	#/km^2	kg/km^2
20	30081990	69	17	165	41	30.6	8.92	30.34	708	8.9
21	30081990	69	26	166	31	37.8	7.09	32.27	392	5.9
22	31081990	69	38	167	18	45	5.83	31.77	531	4.2
23	06091990	70	22	162	43	30.6	3.5	31.11	379	5.4
24	06091990	70	32	163	21	39.6	2.59	31.74	400	2.2
25	07091990	70	49	160	28	52.2	-0.58	32.58	0	0
26	07091990	70	56	160	53	52.2			0	0
27	07091990	71	09	161	55	46.8	-1.02	32.82	0	0
28	08091990	71	34	163	39	43.2	-1.07	32.99	0	0
29	08091990	71	59	165	22	41.4	1.12	32.26	0	0
30	08091990	72	03	166	48	45	0.81	32.39	12.9	0.6
31	09091990	71	34	164	56	39.6	0.61	32.25	20.5	0.5
32	09091990	71	05	163	20	43.2	0.16	32.27	0	0
33	09091990	70	52	161	39	39.6	2.19	31.68	113.5	7
34	09091990	70	32	161	23	27	3.95	30.95	1250	3.9
35	10091990	69	58	163	15	19.8	5.69	30.35	2070	26.3
36	10091990	69	59	163	32	23.4	5.84	30.33	729	5.4
37	10091990	70	26	164	42	43.2	4.25	31.66	0	0
38	11091990	70	45	165	48	41.4	4.37	31.6	143	3
39	11091990	71	04	167	25	39.6	2.08	32.19	0	0
40	11091990	70	49	168	40	39.6			21.9	1
41	13091990	70	31	167	38	46.6			110	0.9
42	13091990	70	13	166	06	45	5.68	31.84	152	1.1
43	14091990	70	04	164	55	39.6	6.47	31.26	155	1.5
44	14091990	69	48	164	04	28.8	6.91	29.62	1010	7.4
45	14091990	69	39	163	18	14.4			733	13.3
46	14091990	69	33	164	00	48.6	7.52	29.7	3990	42
47	15091990	69	37	164	40	27	7.08	30	879	15.8
48	16091990	69	42	166	11	41.4	6.49	31.44	91	1
90-16	14091991	69	00	167	25	47	1.48	31.82	0	0
90-21	16091991	69	23	166	28	39	4.24	30.99	0	0
90-22OH	16091991	69	38	167	41	47	-0.38	32.66	110	2.5
91-28	17091991	69	46	167	03	47	-1.28	33.18	106	2.4
91-22OH	17091991	69	40	168	31	51	0.39	32.44	283	2.4
91-29	18091991	69	53	167	59	48	0.16	32.44	133	2.1
91-27	18091991	70	01	168	48	40	0.17	32.66	0	0
90-27	19091991	71	12	161	54	46	-1.65	33.3	0	0
90-31	19091991	71	36	160	12	51	-1.72	33.48		
91-32	20091991	71	37	159	02	51	-1.73	33.51	32.6	0.7
91-33	20091991	71	14	158	40	115	-1.59	33.37	0	0
91-34	20091991	71	06	158	38	52	-1.38	33.32	464	7.1
90-23	21091991	70	21	162	53	30	-1.34	33.33	1800	27.5

Table 1. continued

Station	**Date**	**Latitud**		**Longitude**		**Depth**	**Bottom**	**Bottom**	**Abundanc**	**Biomass**
#	**d/m/y**	**°**	**'N**	**°**	**'W**	**m**	**°C**	**Salinity (psu)**	**#/km^2**	**kg/km^2**
91-35	21091991	71	59	159	23	27	-1.47	32.27	0	0
90-36	22091991	70	01	163	27	38	-1.14	32.21	969	13.2
90-43	22091991	69	57	164	53	33	-1.21	33.08	243	1
90-06	23091991	68	26	166	38	18	7.09	29.48	2720	15.9

A total of 255 (1990) and 315 (1991) individual fish were returned to the laboratory for examination. We measured total and standard lengths (mm), total fish weight (g), stomach content weight (g), gonad weight (g) and pelvic fin length (mm). The value for fish weight used in subsequent calculations and ratios was determined by subtracting stomach content weight from total fish weight. Gonosomatic index equaled gonad weight/fish weight x100. We removed and preserved otoliths, ovaries and stomach contents. Analysis of stomach contents is reported by Coyle *et al.* (Chapter 8). Mean lengths and other indices were compared with a t-test; slopes of regressions were compared with another t-statistic (Zar 1984).

Two different techniques were used to evaluate age, surface aging and break and burn. In the surface technique, the annulus on the otolith viewed with transmitted light was defined as the translucent zone. In fishes four years old or younger, this zone could be traced entirely around the otolith. In older fish the zone was incomplete but most easily visible on the rostrum (anterior end). The annulus observed in burnt otolith sections was defined as the dark zone. The surface pattern of annuli on otoliths of 374 fish was read using a dissecting microscope. The ages determined from both techniques were compared for 178 fish and only two did not agree; both differed by one year. Otoliths were measured along their longest axis with an ocular micrometer calibrated with stage micrometer.

Fecundity estimates were determined volumetrically for six of the most mature females. Eggs were separated from ovarian tissue by gently rolling the ovary between thumb and index finger and then carefully rinsing away the extraneous ovarian tissue. The volume of ova was measured in a graduated cylinder; a subsample of 0.5 ml was removed and counted. From this subsample 100 ova were randomly selected and measured along their longest axis.

RESULTS

Distribution and Abundance.—Arctic staghorn sculpin were present at 39 of 48 stations sampled in 1990, however none were collected north of 700°15'N (Icy Cape). Where present, Arctic staghorn sculpin occurred in numbers ranging from 13 to 8050 individuals/km^2 (Figure 1a), and biomass varied from 0.45 to 66.6 kg/km^2 (Figure 1b). Generally, high biomass and numbers occurred inshore and south of Icy Cape. Considerable variability in abundance was observed among stations and also between hauls at the same station. For instance, at several stations one of the two hauls yielded no Arctic staghorn sculpin while the other did. Mean abundance for all 48 stations was 716 ± 1345 individuals/km^2; mean biomass for all 48 stations was 8.4 ± 13.5 kg/km^2.

In 1991 Arctic staghorn sculpin were present at 10 of 17 stations, ranging from 32 to 2,720 individuals/km^2 (Figure 1c) and from 0.7 to 27.5 kg/km^2 (Figure 1d). Again, highest abundances and biomasses were from inshore stations south of Icy Cape. Mean abundance for the 16 stations for which we have data was 429 ± 776 individuals/km^2; mean biomass was 4.7 ± 7.8 kg/km^2. Comparison of abundance and biomass values for the two sample years indicated significantly higher values for 1990 ($p < 0.001$).

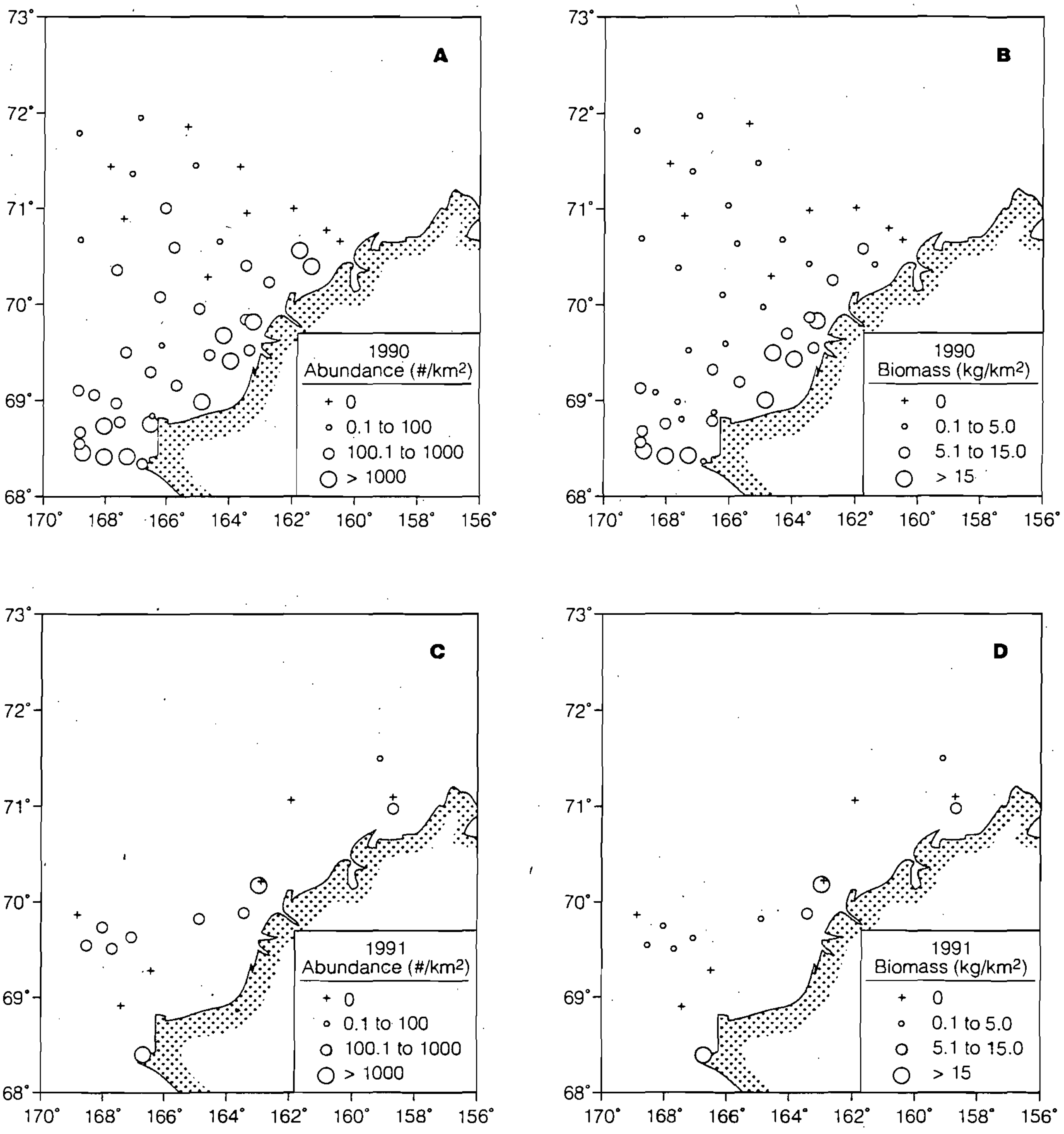

Figure 1. Abundance (numbers of individuals/km^2) and biomass (kg/km^2) of Arctic staghorn sculpin in the northeastern Chukchi Sea. (A) abundance in 1990; (B) biomass in 1990: (C) abundance in 1991; (D) biomass 1991.

Length and Weight Relationships.—Total length was a linear function of standard length for 1990 fish ($r^2 = 0.98$; Table 2). Similarly, otolith length was a linear function of standard length ($r^2 = 0.92$; Table 2).

Table 2.—Functional relationships developed from measurements of Arctic staghorn sculpin in this study.

Y	X	Equation	r^2	n
Total Length (mm)	Standard Length (mm)	$y = 1.14x + 2.64$	0.98	274
Otolith Length (mm)	Standard Length (mm)	$y = 0.043x + 0.444$	0.92	102
Weight (g)	Standard Length (mm)	$y = 5.73 \cdot 10^{-6} x^{3.29}$	0.98	274
Mean Length of Females (mm)	Age (y)	$y = 140 (1 - e^{-0.383[x - 0.165]})$		235
Number of Eggs per Gram	Body Weight (g)	$y = -2.02x + 215$	0.85	6
Gonad Weight of August Females (g)	Body Weight (g)	$y = 0.109x - 1.09$	0.87	27
Gonad Weight of August Males (g)	Body Weight (g)	$y = 0.023x - 0.017$	0.37	15
Gonad Weight of September Females (g)	Body Weight (g)	$y = 0.145x - 0.281$	0.91	50
Gonad Weight of September Males (g)	Body Weight (g)	$y = 0.0553x - 0.091$	0.84	40
Pelvic Fin Length of Females (mm)	Standard Length (mm)	$y = 0.224x - 4.92$	0.82	40
Pelvic Fin Length of Males (mm)	Standard Length (mm)	$y = 0.265x - 5.15$	0.68	39

Rearranging the linear equation allows prediction of fish length (x) based on otolith length (y). A standard length-weight regression calculated for all fish sampled in 1990 conformed to a power curve ($r^2 = 0.98$; Table 2).

Age Structure.—Maximum longevity among the 374 individuals examined from 1990 and 1991 was 9 years for females and 8 years for males. For 1990 the oldest females and males were 8 years old. In 1991 the oldest female was 9 years; the oldest males were only 3 years old.

Overall, the age structure of the population in the northeastern Chukchi Sea differed markedly in 1990 and 1991 (Figure 2; Table 3). In 1990 41.6% of the population consisted of fish ≥ 4 years old; 4.4% were ≥ 6 years old. In contrast, in 1991 only 8.9% of the population was ≥ 4 years old; only 1.4% was 6 years old. Of 148 individuals aged from 1991 only three were 4 year old fish. Among the 216 individuals aged from 1990 only five were 3 years old. Of 148 individuals aged from 1991 only three were 4 years old fish.

Table 3.—Mean length (mm) at age of Arctic staghorn sculpin in southern and northern regions of the study area in 1990 and 1991.

		Age										Mean		
	Area	0	1	2	3	4	5	6	7	8	9	Size	Age	N
						1990								
	Southern	—	—	76±10.8	80	107±10.8	119±8.7	122±9.3	140	118	—	108.1	4.18	
Female		0	0	4	4	1	32	6	5	1	1	0		50
	Northern	33	47±5.2	61±5.7	82±2.9	104±10.1	112±5.2	0	131±13.4	136±0.7	—	81.0	2.94	
		1	32	10	2	39	7	0	2	2	0			95
	Southern	—	54±8.5	67±3.8	80±7.1	92±7.9	92±0.0	101.0	—	—	—	77.2	2.86	
Male		0	7	14	3	15	2	1	0	0	0			42
	Northern	—	45±1.5	65±10.8	0	85±1.1	94±5.7	—	—	100	—	65.8	2.36	
		0	9	23	0	6	2	0	0	1	0			41
						1991								
	Southern	—	—	64±4.8	82±8.9	—	—	—	—	—	—	68.0	2.22	
Female		0	0	39	11	0	0	0	0	0	0			50
	Northern	—	—	57±5	72±11.1	100±7.0	115±7.2	—	—	—	133±0.7	84.8	3.66	
		0	0	9	11	3	8	0	0	0	2			33
	Southern	—	—	62±4.5	77±4.2	—	—	—	—	—	—	63.3	2.06	
Male		0	0	47	3	0	0	0	0	0	0			50
	Northern	—	—	60±4.9	69±3.7	—	—	—	—	—	—	63.8	2.46	
		0	0	7	6	0	0	0	0	0	0			13
														374

Mean lengths at age were calculated for fishes from the northern and southern parts of the study area for 1990. The only significant difference observed was in age 2 females; southern fish were larger ($t = 5.27$; $p < 0.001$). Comparing mean length at age of age classes in the southern part of the study area from 1990 and 1991 (Table 3) showed significantly larger fish ($p < 0.001$) in 1990 in both age 2 females ($t = 4.91$) and age 2 males ($t = 4.22$). No such difference was found in length at age for any age class in the northern part of the study area. Comparing growth rates of the two sexes (both areas and both years combined) we found that males and females grow at the same rate in the first three years. By the end of the fourth year, however, females were significantly larger (Table 4). Von Bertalanffy growth curves were calculated and fitted to the combined mean length at age data (Figure 3; Table 2).

Reproductive Biology.—Fecundity, based on egg counts of only six females, ranged from 3030 to 5414 eggs in fish ranging from 112 to 134 mm standard length (25.6 to 57.4 g body weight). Fecundity as a function of body weight resulted in a linear equation exhibiting a poor fit of the data ($F = 4.5$; $r^2 = 0.53$). These fecundity values equate to 154 to 91 eggs/g of carcass weight (total weight-stomach contents weight-gonad weight), respectively. When number of eggs/g is plotted against body weight a linear regression with negative slope results (Table 2).

Table 4.—Mean standard length (mm) at age for Arctic staghorn sculpin from the northeast Chukchi sea, 1990 and 1991 data combined. Values are mean length in mm ± one standard error. Numbers in parentheses are sample sizes for the different age classes.

Age	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
M		49±1.8 (16)	64±0.8 (91)	74±1.8 (12)	88±1.6 (24)	93±1.7 (4)	101 (1)		100 (1)	
F	33	48±0.9 (1)	63±0.8 (33)	78±2.0 (62)	105±1.2 (26)	115±1.6 (78)	122±4.2 (21)	134±6.3 (5)	130±6.2 (3)	134±0.5 (2)

When gonosomatic index was examined in relation to standard length for all 1990 Arctic staghorn sculpin there was wide variation in gonad development for a particular size interval of fish. Gonad indices for males ranged from 0 to about 7%. The range for females was 0 to19%. Body weight-gonad weight relationships were developed for both sexes at 1990 Stations 10 and 35 to try to assess whether collection date was a possible influence on gonosomatic variation. At Station 10, sampled on 22 August, there were significant relationships for both males and females (Table 2). Gonad-body weight relationships at Station 35, sampled 10 September, are presented in Table 2. The slopes of female relationships from the two sample dates were significantly different ($t = 5.32$; $p < 0.001$); and so were the slopes of male relationships ($t = 6.97$; $p < 0.001$). Males and females of this species are divergent not only in growth rate and longevity but also in pelvic fin development (Figure 4). Males have proportionally longer pelvic fins and in mature fish, these fins are banded in coloration. Plotting pelvic fin length versus standard length for each sex yielded linear regressions (Table 2). These regressions differ significantly in slope ($t = 5.94$; $p < 0.001$). The regression lines begin to diverge at about 60 mm SL and are quite distinct at lengths above 70 mm SL. This suggests that sexual maturity in males occurs at lengths from about 60 to 70 mm SL. The data relating gonad index to SL indicates that some males as small as 60-70 mm have gonads as large as 6-7% of the body weight, among the maximum values obtained in this study.

DISCUSSION

Distribution and Abundance.—Distribution of Arctic staghorn sculpin over the study area was not uniform. Replicate trawl hauls at the same location did not necessarily agree on the abundance or even the presence of this species. We were unable to discern bottom type directly at trawl stations and, therefore, could not correlate abundance or presence with bottom type. However, Andriyashev (1954) reported this species burrowed in sandy or sandy-muddy bottoms, was often present on pebbly bottoms and was rarely encountered on mud or clay bottoms. Plotting the 1990 station locations at which Arctic staghorn sculpin was absent on the map of sediment classes for the northeast Chukchi Sea (Feder *et al.* 1989; Figure 3) revealed that three of the stations were over mud bottom, five over gravelly mud and one over gravelly sand. This suggests that much of the variation in abundance of this species may be explicable based on the

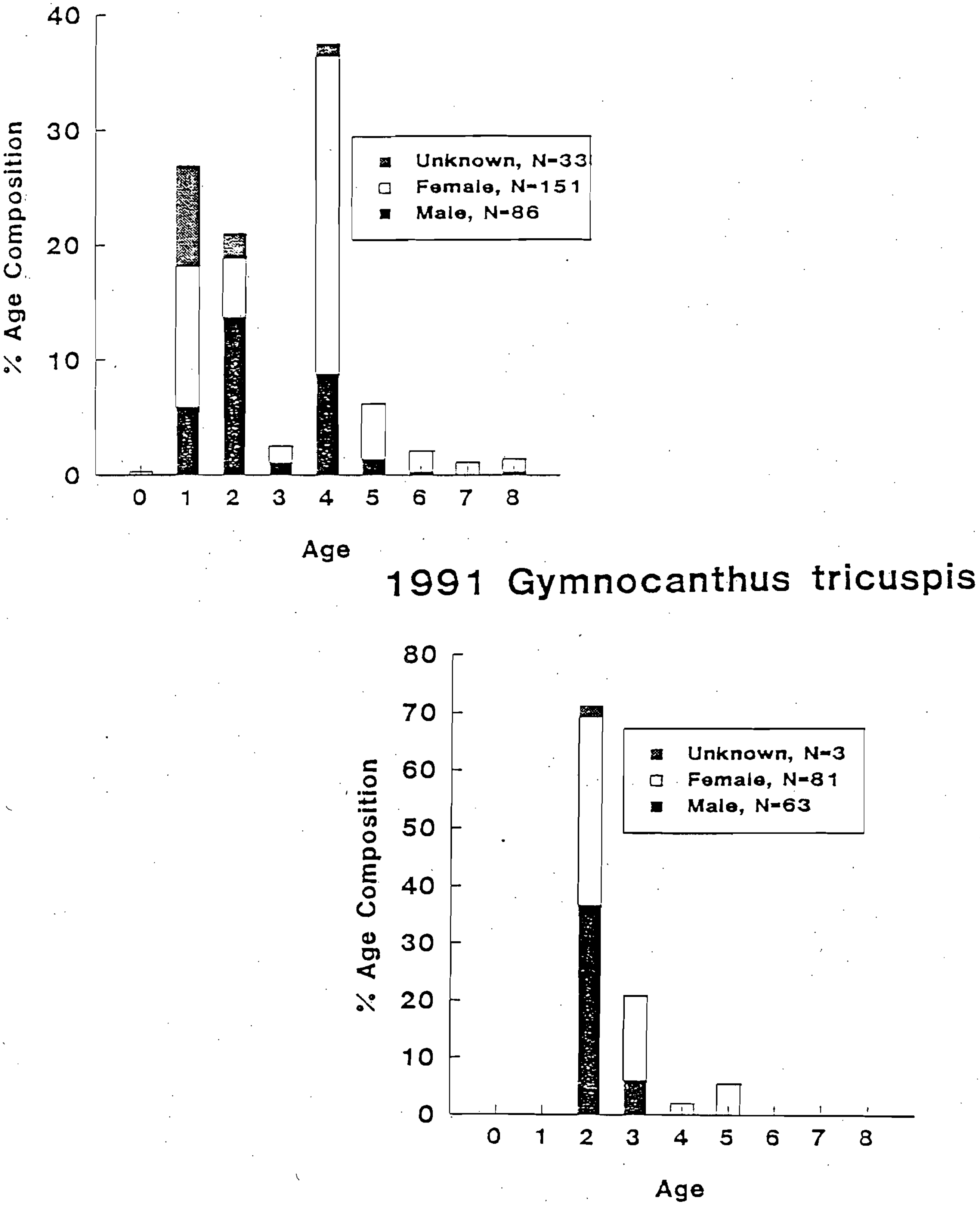

Figure 2. Population age structure of Arctic staghorn sculpin in the northeast Chukchi Sea: upper panel, all 1990 data combined; lower panel, all 1991 data combined.

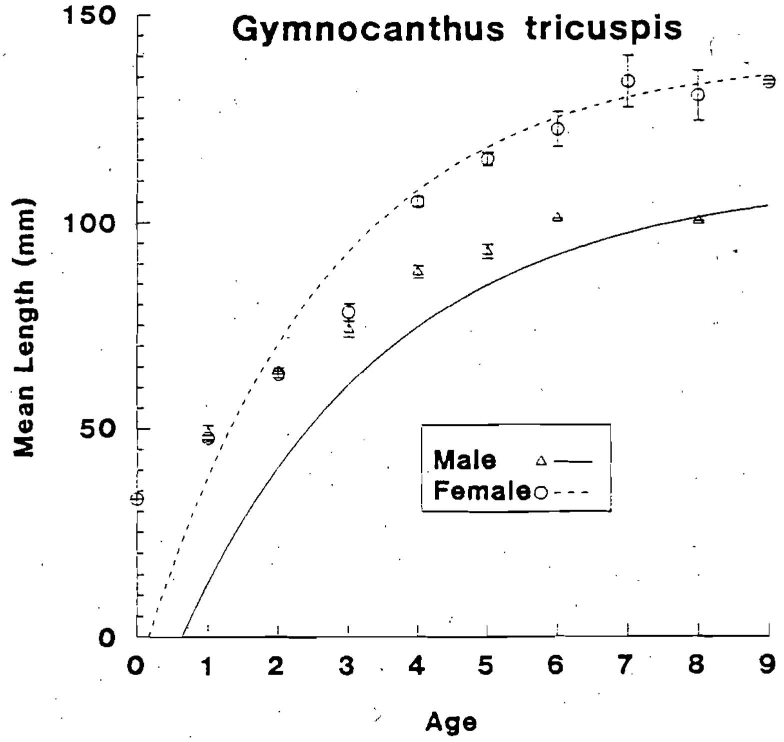

Figure 3. Mean length at age and von Bertalanffy equations for male and female Arctic staghorn sculpin from the northeast Chukchi Sea (1990 and 1991 length at age combined). The equation for females is: $y = 140 (1 - e^{-0.38[x - 0.165]})$; the equation for males is: $y = 110 (1 - e^{-0.338[x - 0.161]})$.

broad scale and local distribution of sediment types in the Chukchi Sea. Over its entire geographic range, Arctic staghorn sculpin tolerates considerable temperature (-1.7 to +12.5°C) and salinity (16-35 psu) ranges but is primarily a species inhabiting temperatures of below or close to 0°C and salinities of 32-35 psu (Andriyashev 1954).

Our mean biomass values can be compared to those of Wolotira *et al.* (1977) since they also used the 83-112 trawl with the same codend liner, towed at approximately the same speeds. They reported biomasses of 3.5 kg/km^2 in the southeast Chukchi, 2.9 kg/km^2 in Kotzebue Sound and 8.2 kg/km^2 in the northern Bering Sea north of St. Lawrence Island. Our biomasses of 8.4 and 4.7 kg/km^2 for the northeastern Chukchi Sea for 1990 and 1991, respectively, are similar in magnitude.

Age and Length Relationships.—Arctic staghorn sculpin, with a maximum age of 9 years, appears to be shorter-lived than its congeners. Tokranov (1988) found maximum ages of *G. pistilliger* and *G. galeatus* from the coast of Kamchatka to be 11 and 13 years for males and females, respectively. Three year old fish were very scarce in 1990 and 4 year old fish were scarce in 1991 suggesting that the 1987 class had very poor recruitment success. Because the stations from which fish were aged ranged from the extreme southern boundary of the study area to far to the northeast, this possible recruitment failure was widespread and could have resulted from a large-scale perturbation in the environment. Further, the marked difference in age distributions of Arctic staghorn sculpin in the two sample years suggests that variation in the physical environment may result in recruitment failures or mass mortality in this species.

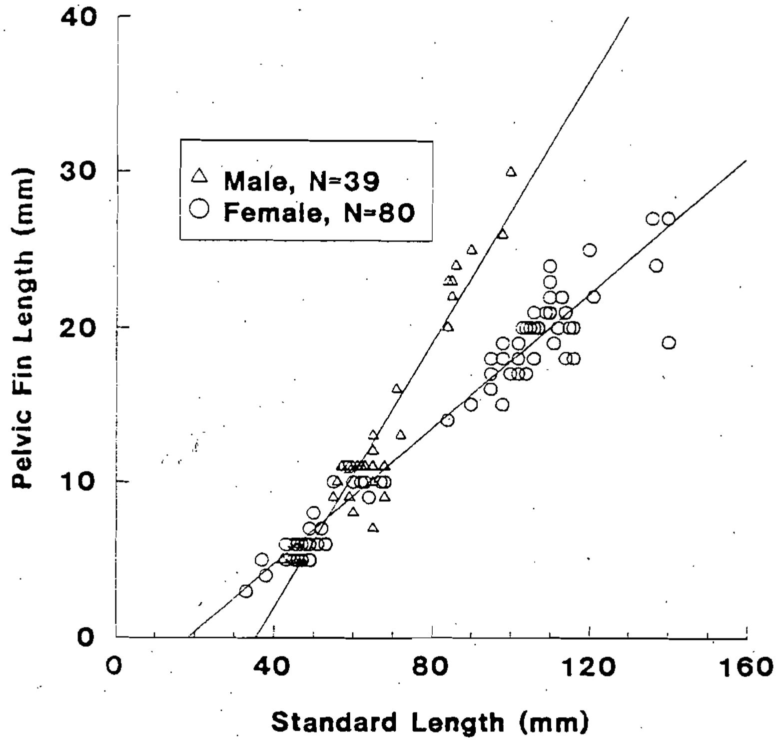

Figure 4. Pelvic fin length as a function of standard length in Arctic staghorn sculpin from the northeast Chukchi Sea.

Males and females grow at similar rates for the first three years. Beyond 3 years, females grow faster and, ultimately, much larger. Mean length at age in males plateaus at about 110 mm SL; females at about 140 mm SL. Data for Arctic staghorn sculpin from the Laptev Sea (Andriyashev 1954) supports the disparity in growth rates of the different sexes we report beyond 3 years. Adjusting Andriyashev's (1954) total lengths to standard lengths produces mean length at age data almost identical to those reported in Table 4, above.

The largest specimens of Arctic staghorn sculpin, 300 mm TL, came from the western coast of Greenland (Andriyashev 1954). The population off Greenland must find conditions for growth much more favorable than populations in the Chukchi and Laptev Seas.

Reproductive Biology.—The scatter of gonosomatic indices exhibited in our specimens probably resulted from pooling fish caught over a one month period during which gonadal development was occurring rapidly. This possibility is supported by the significant differences in slopes of both female and male gonad weight to body weight regressions. These slopes represent gonad indices. Another factor that may contribute to the wide variance in pooled indices is that not all individuals spawn yearly.

In comparison to those from station 10, the ovaries of females at Station 35 appeared to be more mature and contained well developed ova. Based on the slopes of these regressions, one could infer that gonad weight increased from about 2% to 5% of body weight in males and from about 11% to 15% of body weight in females during the month of August. We conclude that the sampling date (10/9/90) at Station 35 was nearer the spawning period for this population.

Based on gonad indices and sexual dimorphism in the pelvic fin of Arctic staghorn sculpin (Figure 4) it appears that males become sexually mature at lengths of 60-70 mm SL, corresponding to ages 2 and 3. Andryiashev (1954) indicated that sexual maturity is attained, apparently, toward the fourth year of life. Dimorphism in pelvic fin length in Arctic staghorn sculpin was also reported by Backus (1957). However, based on data in Backus (1957; Figure 2) no clear divergence of male and female pelvic fin lengths appears until standard lengths of about 120 mm.

Our female gonosomatic indices suggest that the onset of maturity (as indicated by GSI values of 10% or higher) occurs at lengths of about 90 mm SL, corresponding to ages 3 and 4 (Table 2). These values agree with Andryiashev (1954) and are similar to those reported by Tokranov (1981) for *G. detrisus* in Kamchatka waters. Tokranov (1981) reported first maturity at ages 3 and 4 and lengths of 18-22 cm. All males were mature in their fifth year (22-24 cm); all females in their sixth year (24-26 cm).

G. detrisus spawns in December and January in Kamchatka waters when ovary weights amount to 17-24% of body weight. The September ovary indices exhibited by Arctic staghorn sculpin (15% of body weight) are approaching the spawning values for *G. detrisus*. Further, Andryiashev (1954) reported female Arctic staghorn sculpin from the Kara and White Seas with ripe eggs in the second half of September. Absolute fecundities in this study (3,030-5,414) are similar to those reported for Arctic staghorn sculpin by Andryiashev (1954) (2,060 to 3,512 for females of 117 to 158 mm) but lower than the 6,100-72,000/female reported for *G. detrisus* (Tokranov 1981). The lower fecundity values are undoubtedly due to the size difference between Arctic staghorn sculpin and *G. detrisus*. Relative fecundity in Arctic staghorn sculpin ranged from 91-154 eggs/g (this study); *G. detrisus* produces 40-225 eggs/g (Tokranov 1981).

Food Webs.—The Arctic staghorn sculpin was found as prey in Arctic cod and Bering flounder in this research project (Coyle *et al.* Chapter 8). It also is prey to Atlantic cod in eastern Arctic Canada (Dunbar and Hildebrand 1952) and to an eelpout, *Lycodes turneri*, at Point Barrow (Walters 1955). Based on the occurrence of pelagic larvae of this species in spring and early summer (Pertseva, cited in Andriyashev 1954), *G. tricuspis* is susceptible to planktotrophic predators during this season. Young of the year recruit to the benthic habitat in late summer (Andriyashev 1954) and, at that time, become available as prey to benthophages.

Sculpins, perhaps including Arctic staghorn sculpin, are an occasional prey of ringed seals in the Chukchi Sea (Lowry *et al.* 1980). Bearded seals also prey on sculpins incidentally but primarily feed on benthic crustaceans and clams (Lowry and Frost 1981) including some of the same genera as are found in the diet of Arctic staghorn sculpin. Gray whales and, to a lesser extent, bowhead whales feed on benthic amphipods in the Chukchi Sea (Frost and Lowry 1981) and, therefore, share a food resource with the Arctic staghorn sculpin.

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CHAPTER 6

BIOLOGY OF THE BERING FLOUNDER, *HIPPOGLOSSOIDES ROBUSTUS*, FROM THE NORTHEASTERN CHUKCHI SEA[1]

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Abstract—Biomass, abundance, distribution, growth and age structure were determined for Bering flounder, *Hippoglossoides robustus*, collected by benthic trawl in 1990 and 1991. Both biomass and abundance were dramatically different in the two years of this study. Mean biomass declined significantly from 17.2 kg/km^2 in 1990 to 0.79 kg/km^2 in 1991. Our data plus historical information on species abundance and age distribution in the Chukchi Sea suggest that this species is subjected to an unstable physical environment that may cause either mass mortalities, recruitment failures or both. This possibility is consistent with the difference in growth rates from the 1950's and the 1980's and is consistent with recent data on interannual variability in wind and current directions and larval abundance.

Examination of length-weight and age-length relationships indicated that females, beyond the third year, grew faster and larger than males. L_∞ values for males and females were 211 mm and 241 mm (TL), respectively. Maximum age in this study was 11 years.

INTRODUCTION

This paper is part of a fisheries and oceanographic study of the northeastern Chukchi Sea. The purpose of this study was to expand our knowledge of the fish species, ecological interactions of these fishes and oceanographic constraints upon them. The Bering flounder, *Hippoglossoides robustus*, was the most common flatfish captured in benthic trawls in the study area during 1990 and 1991. In this paper we report on the distribution, abundance, length-weight and age relationships and make other inferences about the life history of this species.

The Bering flounder differs from its close relative the flathead sole, *Hippoglossoides elassodon*, in several anatomical characteristics. In addition to having a more markedly curved lateral line and a wider interorbital space, the Bering flounder has lower dorsal and anal fin ray counts (D 67-79; A 51-60) than the flathead sole (D 76-86; A 60-69) (Shmidt 1950, Andriyashev 1954). The geographic ranges of these two species overlap considerably. The flathead sole occurs from northern California, through the Gulf of Alaska, across the Bering Sea and southward to Japan (Hart 1973). The Bering flounder is much more restricted in its distribution, occurring from Tatar Strait to the Chukchi Sea and extending through the Bering Sea to the Aleutian

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Islands (Quast and Hall 1972). In the area of overlap it is unclear whether interbreeding occurs or to what extent niche specialization has led to reduced competition between these two very similar forms.

The Bering flounder falls prey to Arctic cod (Coyle *et al.* Chapter 8) and to several marine mammals including white whales (Frost and Lowry 1981) and bearded seals (Lowry and Frost 1981). Pruter and Alverson (1962) found the Bering flounder to be the most abundant flatfish in the southeast Chukchi Sea, most frequently occurring at depths $\geq$ 44 m. Moiseev (1953) found that the Bering flounder occurs in greater abundance at subzero temperatures than at temperatures above $0^{o}C$. Although present in the Chukchi Sea in August of 1959, the Bering flounder occurred at extremely low population densities (Pruter and Alverson 1962).

MATERIALS AND METHODS

Fish were captured from 16 August through 16 September, 1990 and from 14 September through 23 September, 1991. A NMFS 83-112 survey otter trawl was towed at approximately 2 kts. The net had a 24.2 m headrope, 34.1 m footrope set back 7.1 cm from a tickler chain. The cod end was 90 mm stretched mesh into which a liner of 33 mm stretched mesh was inserted. Each trawl station consisted of two 30 min hauls. Area sampled (m^2) was calculated by multiplying the width of the net opening by the distance trawled. In 1990 the opening of the net was verified by use of a Scanmar mensuration unit attached to the wings of the net. Distance trawled was determined from the ship's position (latitude and longitude) at the start and end of each haul. Trawl station locations listed in Table 1 are the end locations of the first haul at that station. Biomass (kg/km^2 trawled) and abundance (number of fish/km^2) were calculated by averaging the two 30 min hauls at each station (Table 1). Mean biomass and abundance values for the two years were compared with a Mann-Whitney U test (Zar 1984).

Table 1.—Trawl station locations, depths, bottom temperatures, abundances and biomasses of Bering flounder for the 1990 and 1991 sample periods.

Station #	**Date d/m/y**	**Latitude °**	**'N**	**Longitude °**	**'W**	**Depth m**	**Bottom °C**	**Bottom Salinity (psu)**	**Abundance #/km^2**	**Biomass kg/km^2**
1	16081990	71	55	168	48	50.4	-1.24	33.31	35.1	1.1
2	17081990	71	33	167	45	46.8			67.5	2.6
3	17081990	71	29	167	02	46.8			208.	3.9
4	17081990	71	09	165	54	41.4			36.8	0.6
5	18081990	70	48	164	11	45	-0.19	32.21	15.6	0.7
6	21081990	68	23	166	51	18	12.65	29.69	0.	0.
7	21081990	68	68	167	16	45	7.09	30.84	793.	27.7
8	21081990	68	29	168	03	54	2.54	32.59	2010.	66.7
9	22081990	68	33	168	45	54	2.11	32.41	6430.	223.8
10	22081990	68	39	168	47	52.2	2.09	32.44	3280.	126.9
11	22081990	68	46	168	42	52.2	2.72	32.06	1690.	66.7
12	22081990	68	51	167	56	48.6	2.55	32.26	953.	36.8
13	23081990	68	52	167	27	45	5.04	31.71	1100.	43.5
14	23081990	68	52	166	28	41.4	10.85	29.64	147.	6.7

Table 1. continued

Station	**Date**	**Latitude**		**Longitude**		**Depth**	**Bottom**	**Bottom**	**Abundance**	**Biomass**
#	**d/m/y**	**°**	**'N**	**°**	**'W**	**m**	**°C**	**Salinity (psu)**	**#/km^2**	**kg/km^2**
15	23081990	68	58	166	20	36	10.49	29.78	19.8	1.3
16	24081990	69	06	167	39	46.8	2.75	32.21	1100.	42.9
17	24081990	69	11	168	22	48.6	3.19		2330.	70.7
18	24081990	69	12	168	50	50.4	2.21	32.33	1820.	66.1
19	30081990	69	07	164	54	21.6	10.7	29.45	37.7	1.8
20	30081990	69	17	165	41	30.6	8.92	30.34	48.9	2.2
21	30081990	69	26	166	31	37.8	7.09	31.27	235.	9.5
22	31081990	69	38	167	18	45	5.83	31.77	254.	6.3
23	06091990	70	22	162	43	30.6	3.5	31.11	0.	0.
24	06091990	70	32	163	21	39.6	2.59	31.74	0.	0.
25	07091990	70	49	160	28	52.2	-0.58	32.58	0.	0.
26	07091990	70	56	160	53	52.2			0.	0.
27	07091990	71	09	161	55	46.8	-1.02	32.82	0.	0.
28	08091990	71	34	163	39	43.2	-1.07	32.99	0.	0.
29	08091990	71	59	165	22	41.4	1.12	32.26	0.	0.
30	08091990	72	03	166	48	45	0.81	32.39	13.	0.6
31	09091990	71	34	164	56	39.6	0.61	32.25	0.	0.
32	09091990	71	05	163	20	43.2	0.16	32.27	0.	0.
33	09091990	70	42	161	39	39.6	2.19	31.68	0.	0.
34	09091990	70	32	161	23	27	3.95	30.95	0.	0.
35	10091990	69	58	163	15	19.8	5.69	30.35	0.	0.
36	10091990	69	59	163	32	23.4	5.84	30.33	0.	0.
37	10091990	70	26	164	42	43.2	4.25	31.66	0.	0.
38	11091990	70	45	165	48	41.4	4.37	31.64	44.3	0.5
39	11091990	71	04	167	25	39.6	2.08	32.19	11.9	0.5
40	11091990	70	49	168	40	39.6			11.	1.
41	13091990	70	31	167	38	46.6			60.	0.9
42	13091990	70	13	166	06	45	5.68	31.84	58.7	1.1
43	14091990	70	04	164	55	39.6	6.47	31.26	66.5	2.
44	14091990	69	48	164	04	28.8	6.91	29.62	21.8	1.
45	14091990	69	39	163	18	14.4		32.60	32.6	0.7
46	14091990	69	33	164	00	48.6	7.52	29.71	11.	0.5
47	15091990	69	37	164	40	27	7.08		0.	0.
48	16091990	69	42	166	11	41.4	6.49	31.44	182.	7.7
90-16	14091991	69	00	167	25	47	1.48	31.82	0.	0.
90-21	16091991	69	23	166	28	39	4.24	30.99	0.	0.
90-22OH	16091991	69	38	167	41	47	-0.38		12.3	0.6
91-28	17091991	69	46	167	03	47	-1.28	33.18	11.9	0.5
91-22OH	17091991	69	40	168	31	51	0.39	50.39	70.8	1.6
91-29	18091991	69	53	167	59	48	0.16	32.44	0.	0.
91-27	18091991	70	01	168	48	40	0.17	32.66	99.9	4.6
90-27	19091991	71	12	161	54	46	-1.65	33.30	0.	0.
90-31	19091991	71	36	160	12	51	-1.72	33.48		
91-32	20091991	71	37	159	02	51	-1.73	33.51	32.6	0.7

Table 1. continued

Station #	Date d/m/y	Latitude °	'N	Longitude °	'W	Depth m	Bottom °C	Bottom Salinity (psu)	Abundance #/km^2	Biomass kg/km^2
91-33	20091991	71	14	158	40	115.	-1.59	33.37	0.	0.
91-34	20091991	71	06	158	38	52	-1.38	33.32	0.	0.
90-23	21091991	70	21	162	53	30	-1.34	33.33	0.	0.
91-35	21091991	71	59	159	23	27	-1.47	33.27	0.	0.
90-36	22091991	70	01	163	27	38	-1.14	33.21	33.4	0.1
90-43	22091991	69	57	164	53	33	-1.21	33.08	88.6	0.3
90-06	23091991	68	26	166	38	18	7.09	29.48	23.5	4.3

A total of 232 individual fish were returned to the laboratory and examined. Initial laboratory data collection included measurement of fish total and standard lengths (mm), fish weight (g), stomach content weight (g), gonad weight (g) and the preservation of otoliths, stomach contents and ovaries. The value for fish weight used in subsequent calculations and ratios was determined by subtracting stomach content weight from total weight. Gonosomatic index equaled gonad weight/fish weight x100.

The annulus on the otolith viewed with transmitted light was defined as the thin, translucent zone. In fishes four years old or younger, this zone could be traced entirely around the otolith. In older fish the zone was incomplete but most easily visible on the rostrum (anterior end). The annulus observed in burnt sections of otoliths was defined as the dark zone. The surface pattern of annuli on otoliths of 125 fish was read using a dissecting microscope. Otoliths were measured with an ocular micrometer calibrated with a stage micrometer.

RESULTS

Distribution and Abundance in Study Area—Bering flounder occurred at 32 of 48 stations sampled in 1990 and eight of 16 stations sampled in 1991 (Figure 1). Nineteen of the 24 stations at which the Bering flounder was missing were north of 70°N. The northernmost point in distribution in this study was above 72°N (1990 Station 30) and the easternmost point was 159°W (1991 Station 90-32). Where present, Bering flounder abundance ranged from 11 to 6436 individuals/km^2 (Table 1). Biomass ranged from 0.1 to 223 kg/km^2 (Table 1). The 1990 data (Figures 1a and 1b) show that, generally, highest biomass and numbers of Bering flounder occurred in the southernmost part of the study area (south of 69°30'N and west of 167°W).

Considerable variability in abundance was observed among stations and also between hauls at the same station. For instance, at several stations one of the two hauls yielded no Bering flounder while the other did. Replicate hauls at the same station differed up to fifteen fold in biomass (1990 Station 21) and up to threefold (1990 Station 14) in abundance. Our mean abundance estimates for all stations sampled in 1990 and 1991 (995 and 429 individuals/km^2, respectively) differed significantly ($U = 785$; $p < 0.001$). Similarly, 1990 and 1991 mean biomass estimates (17.2 and 0.79 kg/km^2, respectively) also differed significantly ($U = 825$; $p < 0.001$). Eight stations were sampled in both field seasons. Mean abundance and biomass at these stations in 1990 (207 individuals/km^2; 7.6 kg/km^2, respectively) were significantly higher ($U = 85$; $p < 0.001$) than the estimates for 1991 (19.7/km^2; 0.66 kg/km^2, respectively). This reduced abundance and biomass in 1991 was associated with significantly lower temperatures in 1991. Comparing the eight stations common to both years we found mean bottom temperatures of 5.4 and 0.9°C, respectively ($U = 54$; $p < 0.05$).

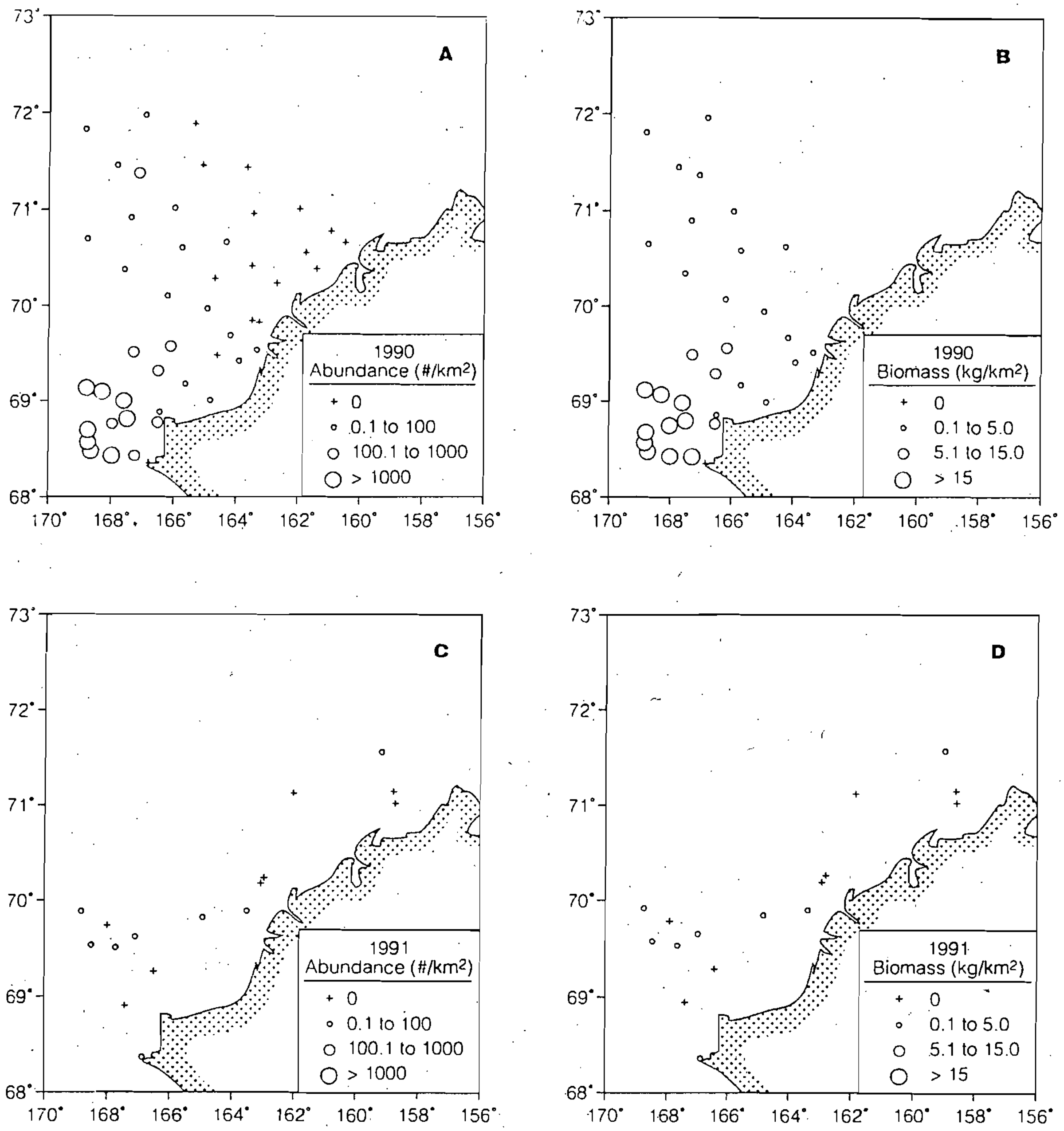

Figure 1. Abundance (numbers of individuals/km^2) and biomass (kg/km^2) of Bering flounder in the northeastern Chukchi Sea. (A) abundance in 1990; (B) biomass in 1990; (C) abundance in 1991; (D) biomass in 1991.

Otolith, Length and Weight Relationships—Both total length and otolith lengths were linear functions of standard length in Bering flounder (Table 2). Rearranging the equation representing otolith length versus fish standard length allows the prediction of fish length (x) based on otolith length (y): $x = (y - 0.383)/0.026$. Weight was found to be a power function of fish standard length (Table 2).

Age and Growth—Maximum longevity among the 125 individuals examined in this study was 11 years for females and 8 years for males (Figure 2). About 75% of the population consisted of fish $\geq$ 5 years old.

Table 2.—Functional relationships developed from measurements of Bering flounder in this study. Coefficients of determination (r^2) and sample sizes for each relationship are included.

Y	**X**	**Equation**	r^2	**n**
Total Length (mm)	Standard Length (mm)	$y = 1.15x + 4.24$	0.99	126
Otolith Length (mm)	Standard Length (mm)	$y = 0.026x + 0.383$	0.92	135
Weight (g)	Standard Length (mm)	$y = 4.89 \cdot 10^{-6}\ x^{3.25}$	0.99	135
Mean Length of Females (mm)	Age (y)	$y = 206\ (1 - e^{-0.215[x - 0.009]})$		67
Mean Length of Males (mm)	Age (y)	$y = 180\ (1 - e^{-0.230[x - 0.185]})$		58
Gonosomatic index of Females (% body wt.)	Standard Length (mm)	$y = 2.37 \cdot 10^{-7}\ x^{3.20}$	0.84	69

Mean lengths at age were calculated for fishes from the study area. These mean lengths suggest that in the first three years males and females grow at the same rate. By the end of the fourth year, however, females appear to be significantly larger (Table 3).

Table 3.—Mean length (mm) at age of male and female Bering flounder from 1990.

Age	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
males	48 (1)	77±2.9 (4)	95±2.9 (10)	106±2.0 (6)	122±3.1 (30)	122±4.4 (4)	-	157±6.5 (3)
females	-	80±3.0 (3)	98±2.6 (6)	116 (1)	135±2.0 (29)	143±3.1 (11)	154 (1)	175±3.4 (16)

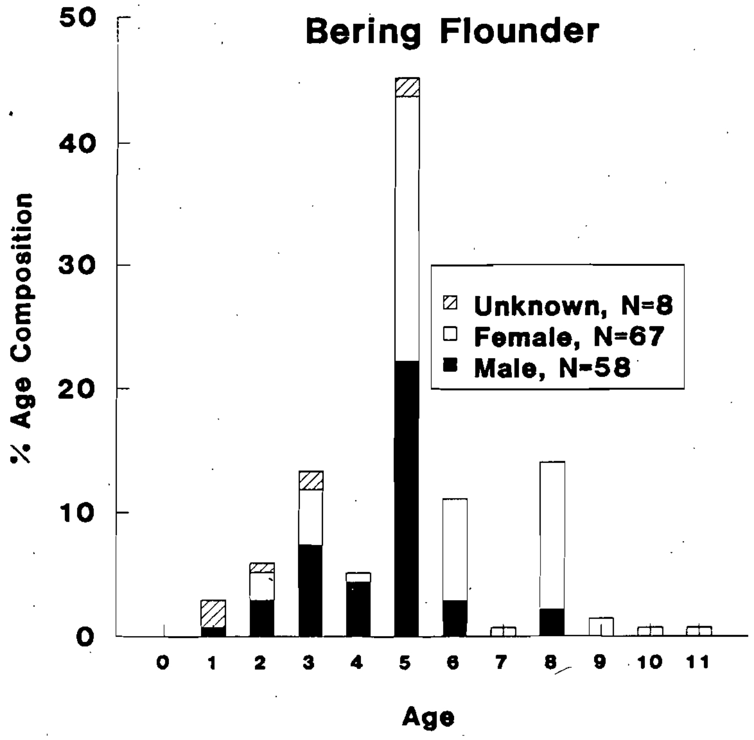

Figure 2. Population age structure of Bering flounder in the northeast Chukchi Sea: all 1990 data combined; n = 133.

Von Bertalanffy growth parameters were calculated from the mean length at age data (Figure 3). The L_0 for females was 241 mm TL (206 mm SL); $t_0 = 0.009$. L_0 for males was 211 mm TL (180 mm SL); $t_0 = - 0.185$.

Reproductive Biology—Gonosomatic index was plotted as a function of standard length for males and females collected in 1990. For males, the result was a scatter of points with wide variation in gonad development for a particular size interval of fish. Gonad indices for males ranged from 0 to about 2%. Female gonosomatic indices could be fit with a power curve (Table 2). Female gonads ranged from near zero to about 7% of body weight.

DISCUSSION

Distribution and Abundance—Distribution of Bering flounder over the study area was not uniform. Replicate trawl hauls at the same location did not necessarily agree on the abundance or even the presence of this species. We were unable to discern bottom type directly at trawl stations and, therefore, could not correlate abundance or presence of this species with bottom type. Plotting the 1990 station locations at which Bering flounder were absent on the map of sediment classes for the northeast Chukchi Sea (Feder *et al.* 1989; Figure 3) revealed that the bottom type at eight of 16 stations was mixed mud and gravel, two were gravel, four combined gravel and sand and the remaining two were muddy sand. Conversely, this species occurred at stations where the following sediment types were recorded previously: muddy gravel; gravely sand; gravely mud; mud; sandy mud; muddy sand. Thus, the only sediment type excluded from stations where this species was captured was gravel. Other than this apparent avoidance of gravel, sediment type in the study area does not seem to have an obvious influence on the spatial distribution of Bering flounder. In this study, the Bering flounder occurred over a salinity rangeof 29.4 to 33.5 ‰ and was missing at stations exhibiting a salinity range of 29.7 to 33.4 psu suggesting that this salinity range had little or no effect on distribution.

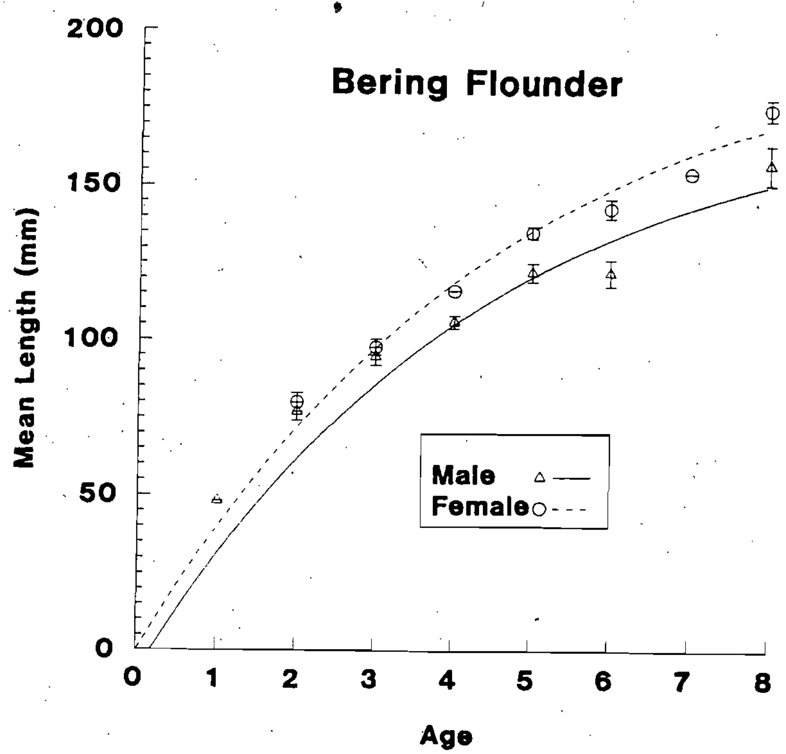

Figure 3. Mean length (SL) at age for male and female Bering flounder from the northeast Chukchi Sea. The von Bertalanffy equation for males is: $L_t = 180\ (1\text{-}e^{-0.230[t+0.185]})$; the corresponding equation for females is: $L_t = 206\ (1\text{-}e^{-0.215[t-0.009]})$. Fish were sampled in 1990.

Although present in the Chukchi Sea (southern part of our study area) in August of 1959, the Bering flounder occurred at extremely low population densities; Pruter and Alverson (1962) caught a total of 289 individuals (<23 kg total) in 59 hauls of 30 min duration each. The highest catch rate Pruter and Alverson reported for Bering flounder was 30 individuals in a 30 min tow using an "eastern otter trawl." In contrast, our 1990 station 9 yielded 587 Bering flounder (20.4 kg) in two 30 min hauls.

Comparisons of 1990 and 1991 biomass and abundance values suggest considerable interannual variation in these parameters. Additional evidence to support this contention may be found by comparing our values with those of Wolotira *et al.* (1977). Using the same 83-112 benthic trawl and the same liner, Wolotira *et al.* (1977) reported a biomass of 4.1 kg/km^2 for Bering flounder in the southeast Chukchi Sea, 2.4 kg/km^2 in Kotzebue Sound and 0.59 kg/km^2 in the northern Bering Sea. In Wolotira's study the starry flounder (*Platichthys stellatus*) was found in far higher biomasses than Bering flounder in both the southeast Chukchi Sea and in Kotzebue Sound. Additional evidence of temporal variability in distribution and abundance of Bering flounder is Andriyashev's (1954) contention that Bering flounder did not occur in the Chukchi Sea before 1933. Taken together, these observations on abundance suggest that the Bering flounder may experience periodic population increases and also periodic mass mortalities due to either direct mortality, recruitment failure or both. Data on age distribution (below) and larval abundance (Wyllie-Echeverria *et al.* Chapter 4) are consistent with this scenario of population fluctuation.

Age, Growth and Population Structure—Our data on length and weight (Table 3, Figure 3) indicate that maximum size in Bering flounder in 1990 approached 200 mm SL and 150 g weight. These sizes correspond to the older fish in the study, ages 9-11. L_∞ values of 211 mm TL (180 mm SL) and 241 mm TL (206 mm SL) were calculated for males and females, respectively, based on mean length at age (Figure 3). Andriyashev (1954) reported the length of the largest specimen from the Chukchi Sea at 150 mm total length. In Pruter and Alverson's (1962) collections, Bering flounder ranged from 140-260 mm, averaging 199 mm total length. They calculated the Bertalanffy parameters for females: $L_\infty = 320$ mm, $k = 0.10$, $t_0 = -0.41$ years. These divergent L_∞ values suggest that conditions for growth in this species were markedly different in the 1930's and 1950's. The small length at age and low biomasses in the 1930's and 1950's led Alverson and Wilimovsky (1966) to conclude that the physical climate of the Chukchi Sea limited population size and depressed normal growth patterns in the Bering flounder.

In our sampling all age classes from 1 to 11 were represented, with age 5 dominating (Figure 3); 75% were ≥ 5 years old. In contrast, the ages of 89 Bering flounder determined by Pruter and Alverson (1962) ranged from 6 to 13 years with 7, 8 and 9 year olds comprising 90% of the population. Thus there is evidence for dramatic shifts in population age structure over time as well as variability in abundance (Figure 1).

Based on the lack of juvenile fishes in their samples, Pruter and Alverson (1962) suggested that this species may not successfully reproduce in the Chukchi Sea. Drift might well carry the larvae to conditions even harsher than those experienced by the adult spawners. Alternatively, the Chukchi Sea population may rely on the drift of pelagic larvae northward on the prevailing surface currents from more southerly locations to maintain population levels. Wyllie-Echeverria *et al.* (Chapter 4) presented evidence that recruitment of Bering flounder larvae to the study area varies interannually. Larvae were relatively abundant in the southern part of the study area in 1990 but entirely missing in 1991. Weingartner (Chapter 2) described temporal variability in the northward flow of Alaska Coastal Water (ACW) from the southern Chukchi Sea caused by changes in wind directions. In 1990 winds were consistently northeastward, increasing the northward flow of the ACW and the advection of larvae from the south. In contrast, 1991 was characterized by more southerly winds which would decrease or reverse the typical northward flow of the ACW. This reversal would prevent the recruitment of Bering flounder larvae to the northeastern Chukchi Sea.

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CHAPTER 7

DISTRIBUTION, ABUNDANCE, AND GROWTH OF ARCTIC COD (*BOREOGADUS SAIDA*) IN THE CHUKCHI SEA[1]

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Abstract. — Distribution, abundance, and growth of Arctic cod from the northeast Chukchi Sea were examined. Arctic cod was the most frequently caught fish by benthic trawl in 1990 and 1991. In 1990, highest abundance and biomass occurred in the southern portion of the study area in Bering shelf water (BSW) followed by Alaska coastal water (ACW) and resident Chukchi water (RCW). In 1991 none of the stations sampled occurred in BSW. Stations with higher abundance and biomass still occurred in the southern part of the study area in RCW.

Environmental conditions in 1990 were more favorable to Arctic cod than 1991. Differences in age distribution recruitment between the two years suggests 1991 was a harsher year. In addition, fish younger than 4 years old were larger in 1990 (1990 age 1 were 122 mm, age 2 129 mm, age 3 173 mm, in 1991 age 1 were 91 mm, age 2 147 mm, age 3 147 mm). Water mass may also influence growth. Older (≥ 3 years) fish at an offshore station in BSW were larger than those at an inshore station in ACW.

INTRODUCTION

Arctic cod, *Boreogadus saida*, is one of the most abundant and widely distributed circumpolar fishes in the Arctic. Along the Alaskan coast, they can be found from the northern Bering Sea through the Chukchi Sea and east to the Canadian border. In the Bering Sea they were found as far south as 60° latitude by Frost and Lowry (1981a), with the more commonly reported southern limit just south of Norton Sound (Pereyra *et al.* 1977, Lowry and Frost 1981). Arctic cod have been found in the Chukchi Sea (Alverson and Wilimovsky 1966, Wolotira *et al.* 1977), however, prior to this study little information was available regarding Arctic cod in the northeastern Chukchi Sea (Walters 1955, Frost and Lowry 1983, Fechhelm *et al.* 1985). Along the northern Alaska coast, most studies have been conducted in the Beaufort Sea and Prudhoe Bay (Cannon *et al.* 1991). Kleinenberg *et al.* (1969) reported finding Arctic cod as far north as 88° north latitude off the Russian coast. Andriyashev (1954) observed Arctic cod near the north pole and hypothesized that they would also occur under the polar ice cap.

In general, Arctic cod abundance and biomass is higher in Arctic waters than in the more southerly Bering Sea (Wolotira *et al.* 1977). Lowry and Frost (1981) hypothesized that fish moved northward every spring and summer with the receding ice edge from the northern Bering Sea and southward in the fall with the advancing ice edge. This annual pattern is consistent with

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their known tolerances for temperatures ranging from -1.8° C (Andiriyashev 1954, Alverson and Wilimovsky 1966) to 6° C (Craig *et al.* 1982). However, Arctic cod have been found inhabiting waters of up to 13.5° C (Craig *et al.* 1982).

Arctic cod contribute significantly to the diets of marine mammals (Frost and Lowry 1980; Lowry *et al.* 1980b; Bradstreet 1982; Finley and Evans 1983) and seabirds (Springer *et al.* 1987). In many areas it is the only abundant food source for these animals and appears to be an important link from lower to upper trophic levels (Bradstreet and Cross 1982). Ringed seal (*Phoca hispida*) abundance has been related to Arctic cod populations and densities by Chapskii (1940). It has been proposed that the primary prey for bulukha whales (Kleinenberg *et al.* 1969) during their summer stay in the Chukchi Sea is Arctic cod. Kleinenberg *et al.* (1969) also related bulukha whale migrations to movement of Arctic cod. Other marine mammals which consume Arctic cod include sei whales [*Balaenoptera borealis* (Tomilin 1957)], killer whales [*Orcinus orca* (Lowry *et al.* 1980b)], ribbon seals [*Phoca fasciata* (Frost and Lowry 1980)], and fin whales [*Balaenoptera physalus* (Klumov 1963)]. Arctic cod was an important prey item for nesting seabirds on Saint Lawrence Island, and on the eastern Chukchi and western Beaufort seashores (Springer and Byrd 1988).

Weingartner's (Chapter 2) review of the hydrography of the northeast Chukchi Sea identifies the water masses and their characteristics and origins. Three primary water masses, Alaska coastal water (ACW), Bering shelf water (BSW), and resident Chukchi water (RCW), are found in the Chukchi Sea. Both BSW and ACW flow north from the Bering Sea. The BSW is a mixture of Bering Sea and Gulf of Anadyr waters with temperatures ranging from 0 to 3° C and salinity 32.5 to 33 practical salinity units (psu). The ACW is formed in coastal areas and mixed with fresher water from Kotzebue Sound. Temperatures of ACW range from 2 to 13° C and salinities are less than 32.2 (psu). The RCW, found offshore in the northern Chukchi Sea, is derived from the upper layers of the Arctic Ocean or shelf water left from the previous winter (Weingartner Chapter 2). The RCW has a temperature less than 1° C and salinity ranges from 32 to 33 psu.

Two other factors which affect the Chukchi Sea are ice cover and melting ice. Ice formation begins in September and October (Lowry *et al.* 1980b) and covers the Chukchi Sea from about November to July (Aagaard 1988). Freezing sea water results in the formation of a highly saline brine which can contribute to the highly saline water of RCW (Weingartner Chapter 2). Ice cover, especially land fast ice, reduces the impact of wind driven surface currents (Aagaard 1988). Melting ice contributes to the fresh water input and may produce an additional water mass (Weingartner Chapter 2). In addition, the ice edge does not melt at a uniform rate, resulting in meltwater embayments (Paquette and Bourke 1981) where upwelling may occur (Hakkinen 1986).

The purpose of this study was to expand our knowledge of Arctic cod abundance, distribution, and age in the northeast Chukchi Sea. We attempt to assess these aspects of Arctic cod biology within the context of biological and physical oceanographic features of the Chukchi Sea.

MATERIAL AND METHODS

Stations in the northeast Chukchi Sea were sampled for fish from August 16 to September 16, 1990 and September 14 to September 23, 1991. A total of 48 stations were sampled in 1990 and 17 stations in 1991. Sampling was done using a NMFS 83-112 survey otter trawl. The net had a 25.2 m headrope, a 34.1 m foot rope set back 7.1 cm from a tickler chain. the cod end was 90 mm stretched mesh with a 33 mm stretched mesh liner inserted in it. Two 30 minute hauls at a trawling speed of approximately 2 knots were taken from each sampling station. The area sampled (m^2) was calculated by multiplying the width of the net opening (measured electronically by a NMFS Scanmar) by the distance trawled. the distance was determined from the ship's position (latitude and longitude) at the beginning and end of each haul. Station locations in table 1 are the end locations of the first haul at the station. Biomass (kg/km^2 trawled) and abundance (number of fish/km^2 trawled) were determined as the average of the two hauls from each station. A subset of captured fish were frozen prior to transport to the lab; 287 individuals were examined from 1990 and 60 from 1991. In addition to biological sampling, CTD information was collected with a Seabird SBE 19.

Fish were measured (total and fork length) to the nearest mm and weighed to the nearest 0.1 g. The fish weight used in all calculations was the total body weight minus the stomach content weight. Otoliths were removed for aging and stored in 50% glycerin.

The annulus on otoliths viewed with transmitted light was defined as the translucent zone, whereas the annulus in burnt sections of otoliths was defined as the dark zone. Age was determined by counting the number of annuli. Otoliths were measured with a calibrated ocular micrometer.

Statistical analyses included t-tests for differences in means (Freund 1979) and F statistics (Neter *et al.* 1990) for slopes and elevations . A Mann-Whitney U test was conducted to detect differences between years in biomass and abundance (Zar 1984). To determine differences in biomass and abundance between water masses with each year, a non-parametic multiple comparison was conducted. When only 2 water masses were present, then a Mann-Whitney U test was conducted.

RESULTS

In 1990 bottom temperature ranged from 12.7° C nearshore by Point Hope decreasing offshore and northward to as low as -1.2° C (maps of temperature and salinity can be found in Weingartner 1994). Salinity was lowest, 29.7 psu, nearshore between Point Hope and Point Lay. It increased both offshore and northward to 33.3 psu. In 1991 bottom temperature ranged from 7° C nearshore by Point Hope decreasing offshore and northward to as low as -1.7° C. Salinity was lowest nearshore at Point Hope and increased offshore and northward to as high as 33.5 psu. In 1990 the sea ice edge was positioned at approximately 74° North while in 1991 it was around 71° 30' North.

Distribution and Abundance.—Arctic cod was the most abundant of the fishes caught in this study; 76% of the total fish catch in 1990, 66% in 1991. In 1990 Arctic cod were present at all 48 stations sampled and ranged in numbers from 10 to 120,000 fish/km^2 (Table 1, Figure 1a). They tended to be most abundant in the southern part of the sampling area off Point Hope, Alaska. Of the 6 stations where abundance was $\geq$50,000 fish/km^2, four occurred in BSW and two in ACW. The BSW had the highest average abundance (59,700 fish/km^2) followed by ACW with 13,400 fish/km^2 and RCW with 8,340 fish/km^2. The BSW abundance was significantly different from ACW ($p < 0.005$) and RCW abundances ($p < 0.001$). There was no significant difference between ACW and RCW abundances ($p > 0.50$).

Arctic cod biomass from 1990 comprised 61% of the total fish biomass. Biomass ranged from 0.45 to 1830 kg/km^2 (Table 1, Figure 1b). Of the nine stations where biomass was $\geq$400 kg/km^2, five where in BSW, two in ACW, and two in RCW. The BSW had the highest average biomass at 864 kg/km^2 followed by RCW at 196 kg/km^2 and ACW at 188 kg/km^2. The BSW biomass was significantly different from RCW ($p < 0.002$) and ACW ($p < 0.010$). There was no significant difference between ACW and RCW biomasses ($p > 0.500$).

Table 1.—Station locations sampled in 1990 and 1991 in the northeast Chukchi Sea. Included are depth (m), bottom temperature (°C), bottom salinity (psu), abundance (number/ km^2), and biomass (kg/km^2) of Arctic cod.

Station #	**Date d/m/y**	**Latitude °**	**'N**	**Longitude °**	**'W**	**Depth m**	**Bottom °C**	**Bottom Salinity (psu)**	**Abundanc #/km^2**	**Biomass kg/km^2**
1	16081990	71	55	168	48	50.4	-1.24	33.31	9090	132
2	17081990	71	33	167	45	46.8			10200	286
3	17081990	71	29	167	02	46.8			39500	1120
4	17081990	71	09	165	54	41.4			17600	382
5	18081990	70	48	164	11	45	-0.19	32.21	5670	94.0
6	21081990	68	23	166	51	18	12.65	29.69	56700	923
7	21081990	68	28	167	16	45	7.09	30.84	2620	27.7
8	21081990	68	29	168	03	54	2.54	32.59	24400	337
9	22081990	68	33	168	45	54	2.11	32.41	120000	1830
10	22081990	68	39	168	47	52.2	2.09	32.44	89700	1710
11	22081990	68	46	168	42	52.2	2.72	32.06	41400	767
12	22081990	68	51	167	56	48.6	2.55	32.26	57000	435
13	23081990	68	52	167	27	45	5.04	31.71	15100	141
14	23081990	68	52	166	28	41.4	10.85	29.64	886	28.5
15	23081990	68	58	166	20	36	10.49	29.78	9.9	0.45
16	24081990	69	06	167	39	46.8	2.75	32.2	22000	213
17	24081990	69	11	168	22	48.6	3.19	32	25900	262
18	24081990	69	12	168	50	50.4	2.21	32.33	97200	1360
19	30081990	69	07	164	54	21.6	10.7	29.45	5660	56.4
20	30081990	69	17	165	41	30.6	8.92	30.34	72300	1110
21	30081990	69	26	166	31	37.8	7.09	32.27	31200	331
22	31081990	69	38	167	18	45	5.83	31.77	22200	142
23	06091990	70	22	162	43	30.6	3.5	31.11	1820	18.6
24	06091990	70	32	163	21	39.6	2.59	31.74	4620	112
25	07091990	70	49	160	28	52.2	0.58	32.58	4970	100
26	07091990	70	56	160	53	52.2			220	7.75
27	07091990	71	09	161	55	46.8	1.02	32.82	2110	19.4
28	08091990	71	34	163	39	43.2	1.07	32.99	264	3.33
29	08091990	71	59	165	22	41.4	1.12	32.26	885	1.52
30	08091990	72	03	166	48	45	0.81	32.39	1270	5.87
31	09091990	71	34	164	56	39.6	0.61	32.25	246	2.33
32	09091990	71	05	163	20	43.2	0.16	32.27	1280	25.6
33	09091990	70	52	161	39	39.6	2.19	31.68	2520	20.2
34	09091990	70	32	161	23	27	3.95	30.95	1430	4.84
35	10091990	69	58	163	15	19.8	5.69	30.35	2880	57.5
36	10091990	69	59	163	32	23.4	5.84	30.33	18700	185
37	10091990	70	26	164	42	43.2	4.25	31.66	6700	86.8
38	11091990	70	45	165	48	41.4	4.37	31.6	18100	355
39	11091990	71	04	167	25	39.6	2.08	32.19	35700	793
40	11091990	70	49	168	40	39.6			747	18.4
41	13091990	70	31	167	38	46.6			1060	47.7

Table 1. continued

Station	Date	Latitude		Longitude		Depth	Bottom	Bottom	Abundanc	Biomass
#	d/m/y	°	'N	°	'W	m	°C	Salinity (psu)	#/km^2	kg/km^2
42	13091990	70	13	166	06	45	5.68	31.84	7140	172
43	14091990	70	04	164	55	39.6	6.47	31.26	13300	247
44	14091990	69	48	164	04	28.8	6.91	29.62	12800	222
45	14091990	69	39	163	18	14.4			1730	20.0
46	14091990	69	33	164	00	48.6	7.52	29.7	12200	71.6
47	15091990	69	37	164	40	27	7.08	30	7740	124
48	16091990	69	42	166	11	41.4	6.49	31.44	11400	167
90-16	14091991	69	00	167	25	47	1.48	31.82	2270	33.8
90-21	16091991	69	23	166	28	39	4.24	30.99	394	10.8
90-22OH	16091991	69	38	167	41	47	-0.38	32.66	8160	114
91-28	17091991	69	46	167	03	47	-1.28	33.18	8920	90.8
91-22OH	17091991	69	40	168	31	51	0.39	32.44	14000	113
91-29	18091991	69	53	167	59	48	0.16	32.44	11600	121
91-27	18091991	70	01	168	48	40	0.17	32.66	4740	44.9
90-27	19091991	71	12	161	54	46	-1.65	33.3	2130	17.9
90-31	19091991	71	36	160	12	51	-1.72	33.48		
91-32	20091991	71	37	159	02	51	-1.73	33.51	3900	42.2
91-33	20091991	71	14	158	40	115	-1.59	33.37	0.00	0.0
91-34	20091991	71	06	158	38	52	-1.38	33.32	3920	42.8
90-23	21091991	70	21	162	53	30	-1.34	33.33	2090	11.8
91-35	21091991	71	59	159	23	27	-1.47	32.27	968	24.9
90-36	22091991	70	01	163	27	38	-1.14	32.21	2140	16.4
90-43	22091991	69	57	164	53	33	-1.21	33.08	5110	50.8
90-06	23091991	68	26	166	38	18	7.09	29.48	15700	220

In 1991 Arctic cod were present at 16 of the 17 stations. Their abundance ranged from 394 to 15,700 fish/km^2 (Table 1, Figure 1c). As in 1990, they tended to be most abundant off Point Hope. However, fish were generally present in fewer numbers at each station in the sampling area; there were no stations in which abundance was $\geq$50,000 fish/km^2. The RCW had the highest average abundance of 6110 fish/km^2 while ACW had an average of 5200 fish/km^2. The BSW was not present at any of the stations sampled. The difference in abundance between ACW and RCW was not significant ($p \leq 0.946$). Arctic cod biomass comprised 47% of the total fish biomass. Biomass ranged from 0 to 220 kg/km^2 (Table 1, Figure 1d). Unlike 1990, none of the stations had a biomass $\geq$400 kg/km^2. The ACW had an average biomass of 88.4 kg/km^2 and RCW had an average of 53.1 kg/km^2. The difference in biomass between the two water masses was not significant ($p \leq 0.946$).

The average biomass for the northeast Chukchi Sea was 304 kg/km^2 in 1990 and 60 kg/km^2 in 1991. The difference in biomass between years was significant ($p \leq 0.001$). The average abundance for the area was 19,540 fish/km^2 in 1990 and 5370 fish/km^2 in 1991. The difference in abundance between years was significant ($p \leq 0.001$).

Length - Weight Relationships.—Fork length (FL) was a linear function of total length (TL), $FL = 2.223 + 0.952\ TL$; $r^2 = 0.998$. Otolith length (OL) as a function of fork length was $OL = -0.143 + 0.041\ FL$; $r^2 = 0.953$ for 1990 fish and $OL = 0.390 + 0.040\ FL$, $r^2 = 0.876$ for 1991 fish (Figure 2). The equations for otolith length and fork length were significantly different between the two years ($p < 0.001$).

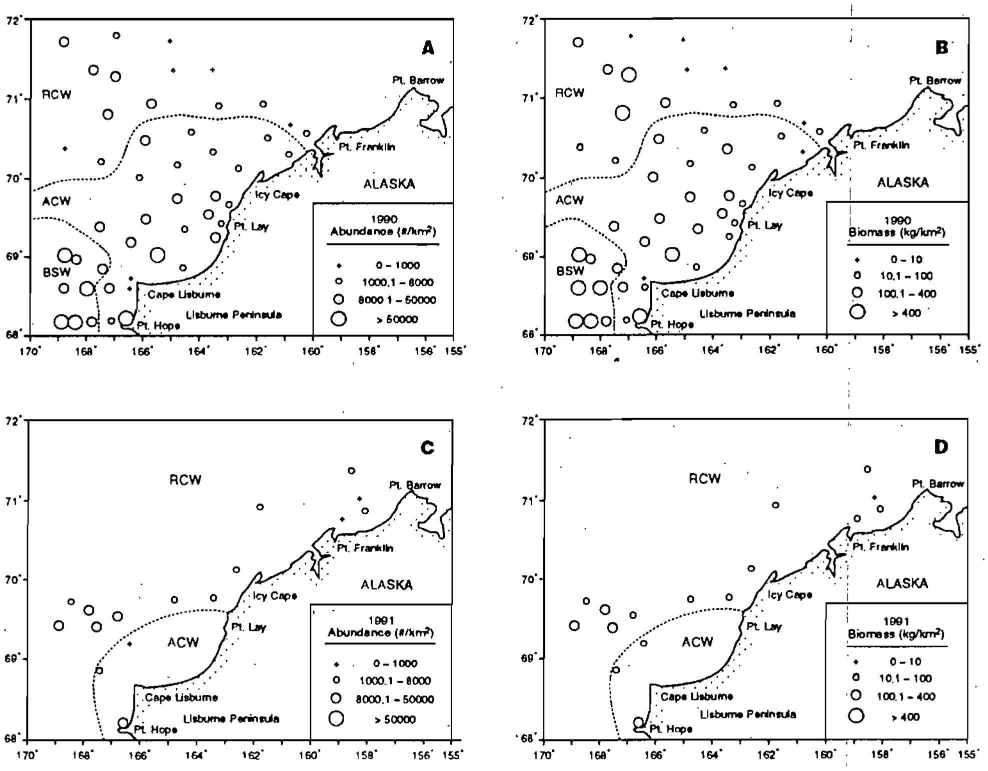

Figure 1. Abundance (fish/km^2) and biomass (kg/km^2) of Arctic cod from the northeastern Chukchi Sea; (A) abundance in 1990, (B) biomass in 1990, (C) abundance in 1991, (D) biomass in 1991.

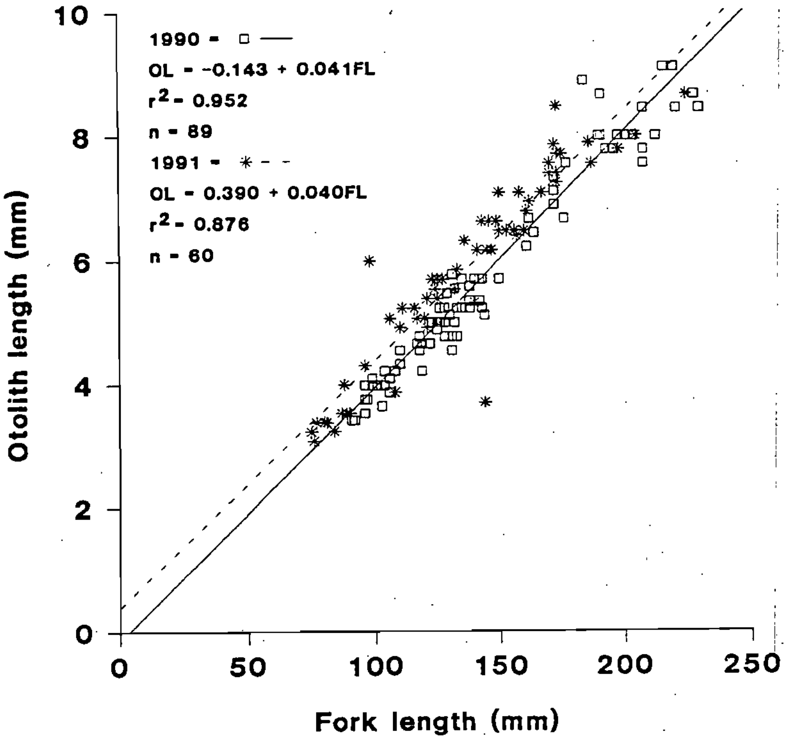

Figure 2. Otolith length (mm) as a function of fork length (mm) for Arctic cod from 1990 and 1991

Weight (W) was a curvilinear function of FL; $W = (4.989*10^{-6}) * FL^{3.072}$; $r^2 = 0.990$ for 1990 fish and $W = (9.233*10^{-6}) * FL^{2.948}$, $r^2 = 0.995$ for 1991 fish. These two regression equations were not significantly different ($p=0.536$) therefore the data were pooled. The equation from the pooled data was $W = (5.398 * 10^{-6}) * FL^{3.056}$; $r^2 = 0.991$ (Figure 3).

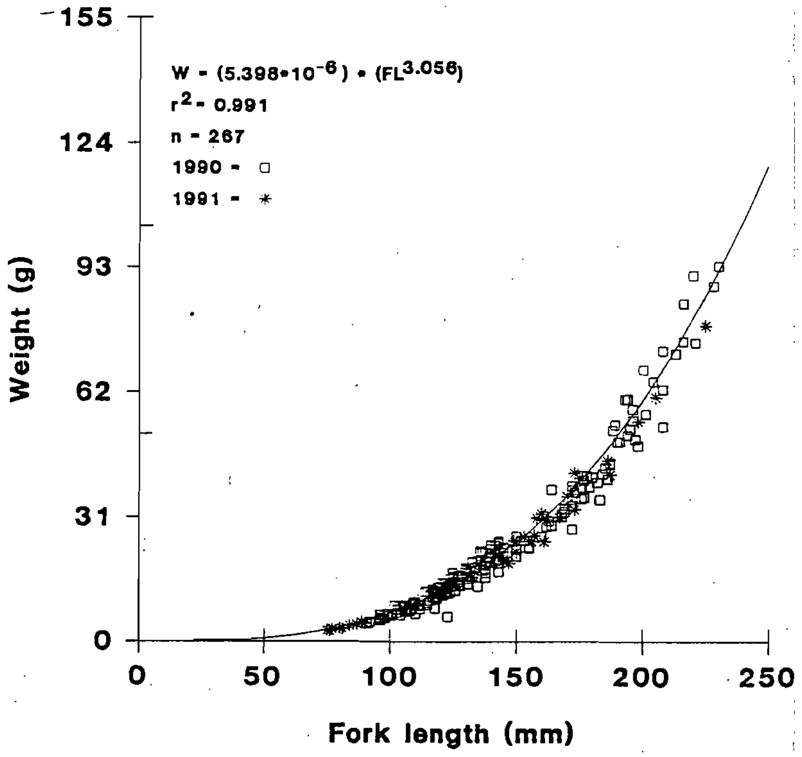

Figure 3. Weight (g) as a function of fork length (mm) for Arctic cod. Data were pooled for the two years of the study.

Age.—Of the fish examined from 1990 the maximum age recorded was one 8 year old female with a FL = 228 mm. In 1991 the oldest fish was a 5 year old male with a FL = 187 mm. There were no age 7 fish for either year and no age 6 fish in 1991. In 1990 61% of the total sample were age 1 fish, while in 1991 only 32% were age 1 (Figure 4). In 1990 78% were less than 3 years old, while in 1991 70% were less than 3. Females and males were equally represented in age-classes 1 and 2 while fish older than 2 years were primarily females (70%) (Table 2).

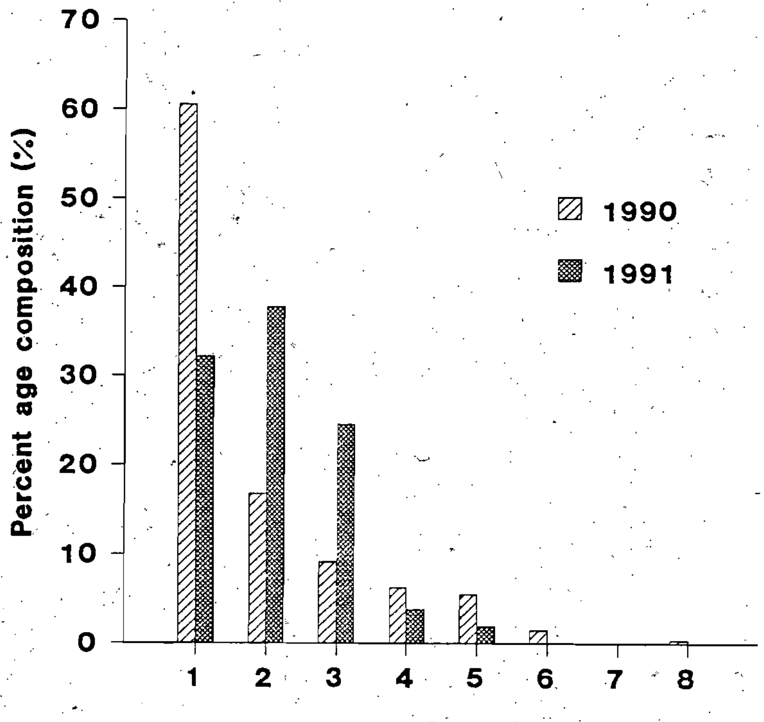

Figure 4. Percent age composition for Arctic cod from both 1990 and 1991 sampling periods.

Table 2.—Sex ratios of Arctic cod from 1990 and 1991 sampling periods.

	1990		1991	
Age	**n**	**% Females**	**n**	**% Females**
1	149	54	15	47
2	41	37	20	55
3	23	70	13	92
4	16	69	2	100
5	14	57	1	0
6	3	33		
8	1	100		

The average fork length at age (Table 3) was significantly larger in 1990 than 1991 for age groups 1 ($p<0.001$), 2 ($p=0.008$), and 3 ($p=0.007$). There was no significant difference between years for the 4 year olds ($p=0.979$) and insufficient data were available for comparing age groups greater than 4 years.

Fish captured in the northern part of the study area (station 31) did not have significantly different fork lengths from those captured in the southern part (station 7) for both fish < 3 years old ($p = 0.465$) and fish ≥ 3 years ($p = 0.944$). However, when inshore fish (station 7) were compared with offshore fish (station 10), offshore fish ≥ 3 years were significantly larger ($p < 0.001$). Fish < 3 years did not differ significantly ($p = 0.246$) in size between the two areas.

Table 3.—Comparison of mean and range of fork length (mm) at age for Arctic cod from the northeast Chukchi Sea.

	This study (1990)			**This study (1991)**			**Frost & (1983)**		**Craig *et al.* (1982)**		
Age	**n**	**$\bar{x}$**	**range**	**n**	**$\bar{x}$**	**range**	**$\bar{x}$**	**range**	**n**	**$\bar{x}$**	**range**
1	127	122	91-161	15	91	75-120	72	45-117	225	84	54-110
2	30	129	99-193	20	147	111-173	116	97-144	137	128	88-177
3	25	173	98-221	13	147	121-198	141	129-160	94	159	120-196
4	17	199	184-220	2	199	172-225	171	161-180	19	180	129-203
5	15	189	160-230	1	187	187			9	209	153-250
6	1	216	216						4	240	198-247
8	1	228	228								

DISCUSSION

Abundance and Distribution.—Studies relating Arctic cod to physical parameters have been done only in the inshore environment. No relationships have been determined for offshore habitats. Moulton and Tarbox (1987) found Arctic cod in the inshore Beaufort Sea were more concentrated along the transition of cold (<- 1° C), high salinity (28-32 psu) marine bottom water and warm (2 - 9° C, low salinity (6 - 27 psu) coastal surface water. Our data (not restricted to inshore) did not follow a similar trend as the highest concentrations of Arctic cod were in the southern offshore part of the study area by Point Hope in 2 to 3° C (bottom temperatures) BSW. The -1° bottom isotherm was farther north off of Point Franklin (Weingartner Chapter 2). As the BSW is known to have a higher abundance of zooplankton compared to ACW and RCW (Springer *et al.* 1989), Arctic cod may be more attracted to it for food. Moulton and Tarbox (1987) reported high concentrations of copepods and mysids in the transition layer as well as Arctic char and Arctic cisco.

Wolotira *et al.* (1977) conducted a study in the Southeast Chukchi Sea in 1976 utilizing the same net type as ours. Arctic cod biomass in their northernmost stratum, occupied by ACW (determined by examining their temperature and salinity data), was 12.3 kg/km^2. This was considerably lower than that found in the northeast Chukchi Sea where the average biomass was 25 times more in 1990 and 5 times more in 1991. Average biomass for ACW was 15 times more in 1990 and 7 times more in 1991. The differences between these two studies, separated by 13 years, may be the result of extreme interannual differences in oceanographic conditions.

Interannual differences in Arctic cod abundance and biomass were evident between 1990 and 1991. In addition, time of year may have influenced the abundance and biomass particularly if Lowry and Frost's (1981) hypothesis of annual migration is correct. Wolotira *et al.* (1977) conducted their study during September to October while ours was in August and September.

Environmental Conditions Influencing Fish Growth.—Environmental conditions determine the growth and survival of fishes. Warmer years in the Chukchi Sea tend to be more favorable to the growth and abundance of some fish than cold years (Springer *et al.* 1984). Arctic cod may fall into this category as evidence by the differences in length of 1, 2, and 3 year old fish between 1990 and 1991. In 1990 the sea ice edge in our study area was farther north than in 1991. The prevailing wind direction in 1990 was from the south, whereas in 1991 the dominant wind direction was from the north. These conditions resulted in 1990 being warmer than 1991 and presumably more conducive to growth and survival. In addition, Weingartner (Chapter 2) linked warm surface temperatures with increased northward flow from the northern Bering Sea which may bring a greater abundance of pelagic prey than would otherwise be resident in the Chukchi Sea. This situation is reflected in the recruitment of Arctic cod to the age-1 year class. In 1990 the percentage of age-1 fish in the samples was nearly twice that of 1991. Our mean length at age data (Table 3) also support the contention that 1990 was more favorable for growth than 1991.

Mean fork length-at-age in this study was greater than reported in previous studies (Craig *et al.* 1982; Frost and Lowry 1983). This suggests that growth conditions in the study area were better during the years preceding this study than in the years preceding the previous studies. In addition, the significant difference in length at age of fish < 4 years old in this study indicates that 1990 was better for growth than 1991. The difference in mean length at age for older fish between offshore and inshore may be related to water masses. The BSW has higher concentrations of dissolved nutrients and chlorophyll than ACW (Walsh *et al.* 1989) and is a major source of zooplankton for the Chukchi Sea (Springer *et al.* 1989). As station 10 was located in BSW, there may have been a higher concentration of prey items contributing to greater growth than at station 7 which was located in ACW.

Age.—Of the northern gadids, Arctic cod appear to have the shortest life span. Walleye pollock (*Theragra chalcogramma*) live to 28 years (McFarlane and Beamish 1990), Atlantic cod (*Gadus morhua*) to 16 years (Fleming 1960), Pacific cod (*Gadus macrocephalus*) to 12 years (Craig *et al.* 1982), Greenland cod (*Gadus ogac*) to 11 years (Mikhail and Welch 1989), and saffron cod (*Eleginus gracilis*) live to 9 years (Wolotira *et al.* 1977). The maximum observed age of Arctic cod in previous studies was 7 years (Bradstreet *et al.* 1986). Our study suggests that Arctic cod may live to eight years. Only one fish was determined to be this age and the possibility of observer errors in aging individual otoliths may have been present. However, two readers independently read the otolith, and both agreed to the assessment of age 8. Even with this unusually old individual, Arctic cod exhibit the shortest longevity of northern gadids studied.

Arctic cod spawning has been reported to occur under the ice from late November to early February (Craig *et al.* 1982) and in some instances as late as March (Rass 1968). Aronovich *et al.* (1975) found the incubation period of the eggs could be prolonged by extended subzero winter water temperatures. An extended spawning and temperature-dependant development could lengthen the time period in which larval fish appear. Wyllie-Echeverria *et al.* (Chapter 4) observed newly hatched larvae as late as mid-July. These events, either singularly or together, may result in a wide range of lengths at age which would explain the large variability in lengths at age found in this and other studies. Another source of variability was collection date. Arctic cod in 1990 were collected nearly a month later than those in 1991.

Life History Strategy.—Species employing *r* selection reproductive strategies generally occur in environments that are unstable or unpredictable with the possibility of high mortality rates. In these environments an investment of resources in producing as many offspring as early in the life cycle as possible would be an advantage (Adams 1980). Craig *et al.* (1982) concluded that Arctic cod exhibited *r* strategy traits: small body size, relatively short life span, early maturity, rapid growth, and large numbers of offspring. Our data supports the *r* selected life strategy traits of relatively short life span and small size.

Due to the unpredictable population size of *r* selected species, Arctic cod may exert a regulatory effect on its predators (Craig *et al.* 1982). In years where environmental conditions were not conducive to population growth of Arctic cod there would subsequently be fewer fish (or lower biomass) available for consumption by marine mammals and seabirds, possibly resulting in lower reproductive success of these predators.

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CHAPTER 8

FOOD HABITS OF FOUR DEMERSAL CHUKCHI SEA FISHES[1]

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Abstract.—Four common Chukchi Sea fishes, taken during August-September, 1990-1991, were examined for food habits. The species studied were Arctic cod, *Boreogadus saida*, Arctic staghorn sculpin, *Gymnocanthus tricuspis*, Bering flounder, *Hippolglossoides robustus*, and saffron cod, *Eleginus gracilis*. All four species occurred in abundance in the northeast Chukchi Sea. Schoener dietary overlap indices on the same species from different stations indicated considerable differences in the diets between stations. Therefore, examination of interspecific dietary overlap was limited to those stations where two or more species were analyzed from the same tows. Highest dietary overlap occurred between Arctic and saffron cod, and negligible overlap occurred between the above two species and the staghorn sculpin near Point Hope. Arctic cod preyed primarily on planktonic and epibenthic organisms, saffron cod consumed epibenthic and benthic fauna, the staghorn sculpin consumed polychaetes and mollusks, and Bering flounder took fish and crustaceans. The diets of these fishes were not substantially different from those reported for closely related species studied elsewhere. Differences in the diets between stations are probably at least partially related to the distributions of water masses originating elsewhere, in the northern Bering Sea and Arctic Ocean.

INTRODUCTION

Fish are a major link in the Arctic food chain between herbivores and apex consumers. Arctic cod (*Boreogadus saida*) is one of the most abundant fish in the Arctic (Lonne and Gullksen, 1989; Borkin *et al.* 1987) and is an important food for a variety of marine mammals and birds (Lonne and Gullksen, 1989; Frost and Lowry, 1984). Saffron cod (*Eleginus gracilis*), Bering flounder (*Hippoglossoides robustus*) and staghorn sculpins (*Gymnocanthus tricuspis*) are also consumed by marine mammals in the Chukchi Sea (Lowry *et al.* 1980b). Information on the diets of these fishes in the Chukchi Sea is therefore central to understanding trophic relationships between primary and apex consumers in the Arctic food web. This paper presents information on the diets of the above four fish in the eastern Chukchi Sea north of Point Hope.

METHODS

The fish samples were collected in August-September, 1990 and 1991, as outlined in Smith *et al.* (Chapter 5). Station locations where fish for stomach analysis were collected are

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shown in Figure 1. The fish for stomach analysis were identified, weighed to the nearest g, total length was measured to the nearest mm, and the stomachs removed. Material in the stomachs was identified to the lowest taxonomic category possible and wet weights of each taxon obtained to the nearest mg on a Kahn electrobalance.

The index of relative importance as defined by Brodeur and Pearcy (1990) was calculated for the taxa at each station:

$$iri = f(\%n_i + \%w_i)$$

where f is the frequency of occurrence, $\%n_i$ is the percent number of prey item i in the stomachs and $\%w_i$ is the percent weight of prey item i in the stomachs.

The Shannon-Weiner measure of niche breadth (dietary evenness) was computed for each taxa (Brodeur and Pearcy, 1990). It is essentially a measure of diversity expressed by the formula:

$$H' = -\Sigma p_i \mathrm{Log}(p_i)$$

where H' is the diversity index, p_i is the proportion by weight or number of prey item i in the stomachs. Dietary evenness is the ratio of the diversity in the stomachs to the maximum possible diversity:

$$H'max = \log(r)$$
$$J = H'/H'max$$

where J is the evenness, H'max is the maximum possible diversity and r is the total number of taxa.

Niche overlap was computed using the Schoener (1968) index as discussed in Linton *et al.* (1981):

$$Ro = 1 - 0.5(\Sigma|p_{ij} - p_{ik}|)$$

where Ro is the overlap index, p_{ij} is the proportion by weight of prey item i in predator j and p_{ik} is the proportion by weight of prey item i in predator k.

RESULTS

The average length of fish at each station ranged from 76 to 160 mm, and weight ranged from 9 to 53 g (Table 1).

Fish for stomach analysis were selected to include the entire size range of specimens collected by the trawls. If the trawls contained high numbers of small specimens, the average size of individuals in the subsample for stomach analysis was significantly greater than that of the whole sample. The average length of Arctic cod in the whole sample at Stations 7 and 91-32 was 110.2 mm and 106 mm respectively, the average length of staghorn sculpin was 84.5 mm, 75.6 mm, 65.5 mm, and 78.8 mm at Stations 10, 35, 90-06, and 90-36, respectively, and the

Figure 1 (Chapter 8)

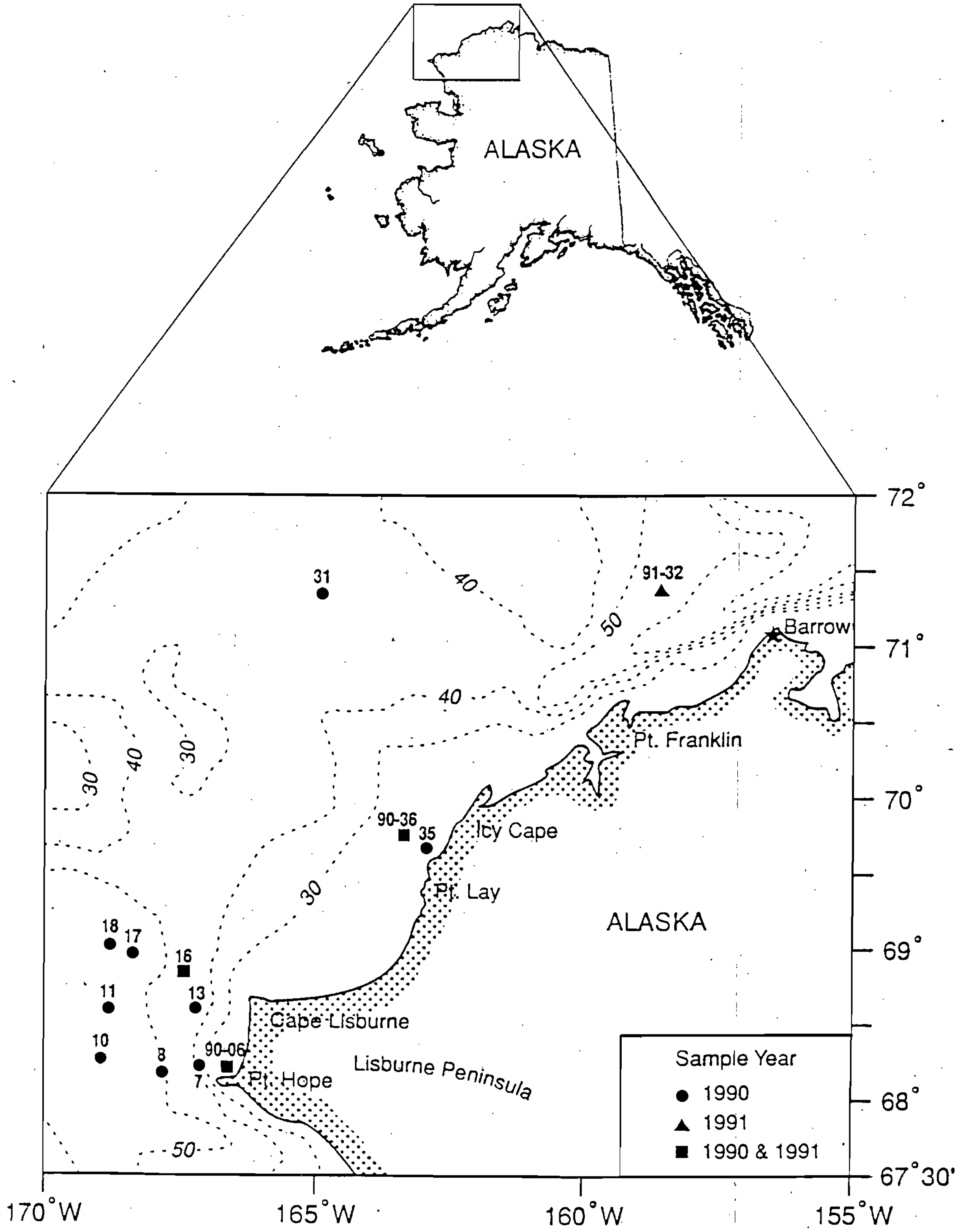


Figure 1. Station locations in the northeast Chukchi Sea from which fish were collected for stomach analysis. Dashed lines are depth contours in meter.

average length of saffron cod at station 90-06 was 130.7 mm. There were no significant differences in the average length of Bering flounder taken in the tows and selected for stomach analysis. The majority of fish had been feeding prior to capture.

Table 1.—The average length and weight, and the number of fish with full and empty stomachs in the subsamples of four demersal fish taken at various stations in the northeast Chukchi Sea.

	Station Number	**Average Length (mm)**	**Average Weight (g)**	**Number With Food**	**Number Empty**
Arctic Cod	13	125.3	20.0	20	0
	18	159.9	39.5	19	4
	31	116.7	16.9	21	1
	7	124.4	20.9	24	2
	90-06	143.8	29.4	30	2
	91-32	142.1	26.2	9	0
Arctic staghorn sculpin	8	99.1	17.5	18	0
	10	103.0	26.2	25	1
	11	86.6	17.4	20	0
	17	84.8	15.3	20	0
	18	102.2	22.3	9	0
	35	107.2	28.3	25	7
	90-06	76.1	8.9	25	2
	90-36	94.5	24.2	24	0
Bering flounder	8	118.6	35.2	49	23
	11	139.7	52.6	22	2
	16	128.9	41.8	38	14
	17	126.5	35.5	29	0
	18	128.2	39.1	19	1
Saffron cod	90-06	152.9	47.0	24	0

Schoener's (1968) test for species overlap was applied to single species to assess the effect of different locations on the diets. The overlap values varied from 0.005 to 0.598 (Tables 2 - 4) with highest values tending to occur at stations in close proximity to one another. Such variations in overlap indices for a single species from different stations indicates that these fish are generalists, capable of exploiting a broad spectrum of prey, depending on prey availability at particular locations. Since the overlap indices in Tables 2 through 4 are so different and vary markedly from 1, overlap measures to compare different species can be applied only in those cases where the species were taken at the same stations. Thus, interspecific overlap was examined only between Arctic cod, staghorn sculpin and saffron cod at Station 90-06 and between Bering flounder and staghorn sculpin at Stations 8, 11, and 17. There was insufficient material on staghorn sculpin from Station 18 to produce meaningful overlap values. Overlap between Bering flounder and staghorn sculpin at Stations 8, 11, and 17 was 0.05, 0.02, and 0.13, respectively. Overlap between Arctic cod and saffron cod was 0.425; overlap between Arctic cod and staghorn sculpin and between saffron cod and staghorn sculpin was 0.024. Overlap is considered significant at values is excess of 0.6 (Brodeur and Pearcy, 1990). Thus, even between such similar species as saffron cod and Arctic cod, overlap at the same station was insignificant.

Table 2.—Matrix of dietary overlap indices for Bering flounder from various stations in the northeast Chukchi Sea during 1990.

	Station				
Station	**8**	**11**	**16**	**17**	**18**
8	1.000	0.280	0.547	0.547	0.458
11		1.000	0.157	0.169	0.158
16			1.000	0.483	0.480
17				1.000	0.360
18					1.000

Table 3.—Matrix of dietary overlap indices (Schoener, 1968) for Arctic staghorn sculpin from various stations in the northeast Chukchi Sea during 1990 and 1991.

	Station						
Station	**8**	**10**	**11**	**17**	**35**	**90-06**	**90-36**
8	1.000	0.333	0.242	0.293	0.028	0.117	0.007
10		1.000	0.217	0.220	0.052	0.085	0.021
11			1.000	0.297	0.026	0.194	0.033
17				1.000	0.070	0.305	0.041
35					1.000	0.302	0.186
90-06						1.000	0.011
90-36							1.000

Table 4.—Matrix of dietary overlap indices for Arctic cod from various stations in the northeast Chukchi sea during 1990 and 1991.

	Station					
Station	**91-32**	**90-06**	**13**	**18**	**31**	**7**
91-31	1.000	0.035	0.003	0.138	0.065	0.096
90-06		1.000	0.010	0.034	0.027	0.034
13			1.000	0.264	0.005	0.496
18				1.000	0.253	0.305
31					1.000	0.181
7						1.000

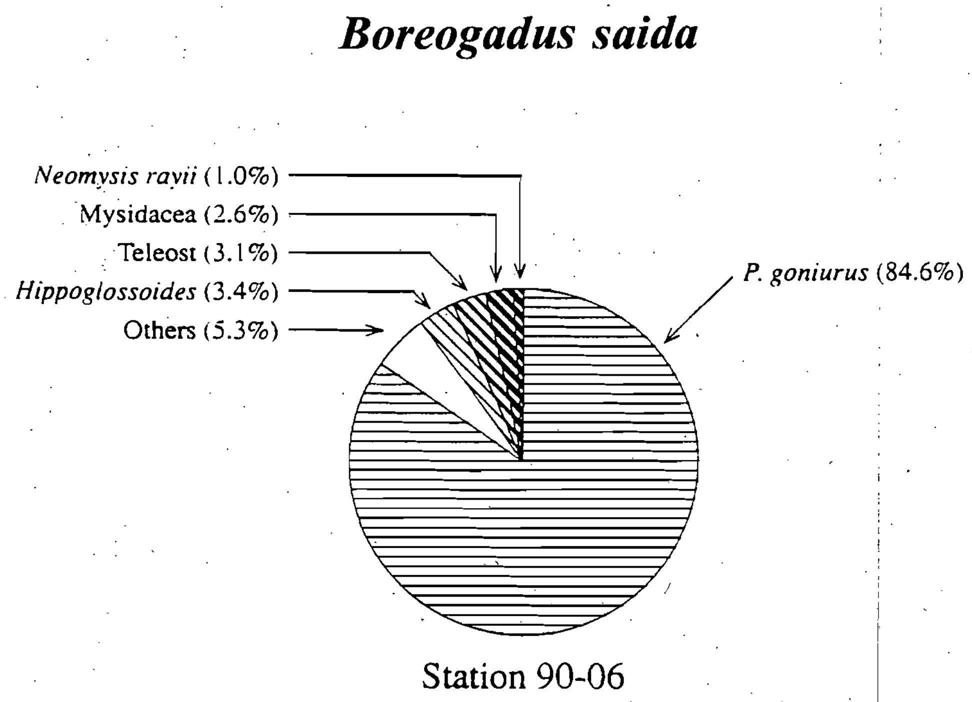
Relative importance indices indicate that *Pandalus goniurus* was a substantial component of the diets of both saffron cod and Arctic cod (Figure 2). However, saffron cod were taking a substantial number of crangonid shrimps and benthic amphipods while Arctic cod were taking epibenthic mysids and fishes. In general, a substantial portion of the Arctic cod diet consisted of pelagic organisms. *Calanus* sp. was a dominant component of the diet at Stations 7, 13 and 18 and the pelagic amphipod *Parathemisto libellula* was dominant at Station 91-32 (Figure 3).

The infaunal cumacean genera *Eudorella* and *Leucon* were important in the diet at Stations 7 and 13; almost all of the cumaceans consisted of pelagic stage adult males. The unknown food category (Stations 13 and 18) consisted of tissue, possibly belonging to larvaceans or pteropods. Decapod zoeae were important to the diets of Arctic cod at Stations 31 and 7. The "Other" category consisted of many taxa which were either taken infrequently, or were too small to contribute substantially to the diet. In Arctic cod they included benthic amphipods (*Protomedeia* spp., *Rhachotropis oculata*, *Anonyx* spp., *Boeckosimus* sp. and *Maera* sp.), pelagic amphipods (*Hyperia* sp. and *Hyperoche medusarus*), mysids (*Mysis oculata* and *Pseudomma truncatum*) and fishes (*Pungitius* sp., Pleuronectidae). The "Other" category in the saffron cod diet included polychaetes (Polynoidae, *Nephtys* sp.) and infaunal stages of cumaceans (*Diastylis* spp.). Thus, while both cod species consumed epibenthic taxa, the saffron cod tended to take more benthic prey and the Arctic cod more pelagic prey.

Staghorn sculpin at Station 90-06 were consuming primarily polychaetes and gastropods (Figure 4). The gastropods were not identified; identifiable polychaetes consisted of Flabelligeridae, Ampharetidae and *Pectinaria* sp. The "Other" category consisted of benthic amphipods (*Ericthonius* sp., *Ischyrocerus* sp.), a cumacean (*Diastylis bidentata*), an isopod and some bivalves. Staghorn sculpin at Station 90-36 were consuming primarily euphausiids (*Thysanoessa raschii*), a shrimp (*E. gaimardi*) and a benthic amphipod. This is the only station where they consumed primarily Crustacea. At the remaining two stations, Station 10 and 35, the diet included primarily polychaetes (*Nephtys* sp., Opheliidae, Flabelligeridae) and *Echiurus echiurus*.

The Bering flounder selected for stomach analysis were all collected at stations near Point Hope. Therefore, our data on the relative importance of prey taxa reflects prey availability over a small portion of the total study area. Bering flounder were consuming mainly fish; the most important identifiable fish was *Lumpenus* sp. (Figure 5). Other teleost families included zoarcids, agonids, cottids and gadids. Benthic and epibenthic crustaceans comprised most of the rest of the diet. The infaunal amphipod *Byblis* was important at Station 8. The infaunal crangonid *Argis lar* and epibenthic hippolytids (*Spironticaris* sp., *Eualus gaimardi*) were the dominant shrimp in the diet, and pagurid crabs were important at Station 16.

The Shannon-Weiner statistic is a measure of dietary evenness. In the absence of data on prey populations, the Shannon Weiner statistic is sometimes considered a measure of niche breadth (Brodeur and Pearcy, 1990). The values for Bering flounder and *Gymnocanthus* were higher than for saffron and Arctic cod because the former were consuming fewer species in more similar amounts by number and weight than the latter (Table 5).



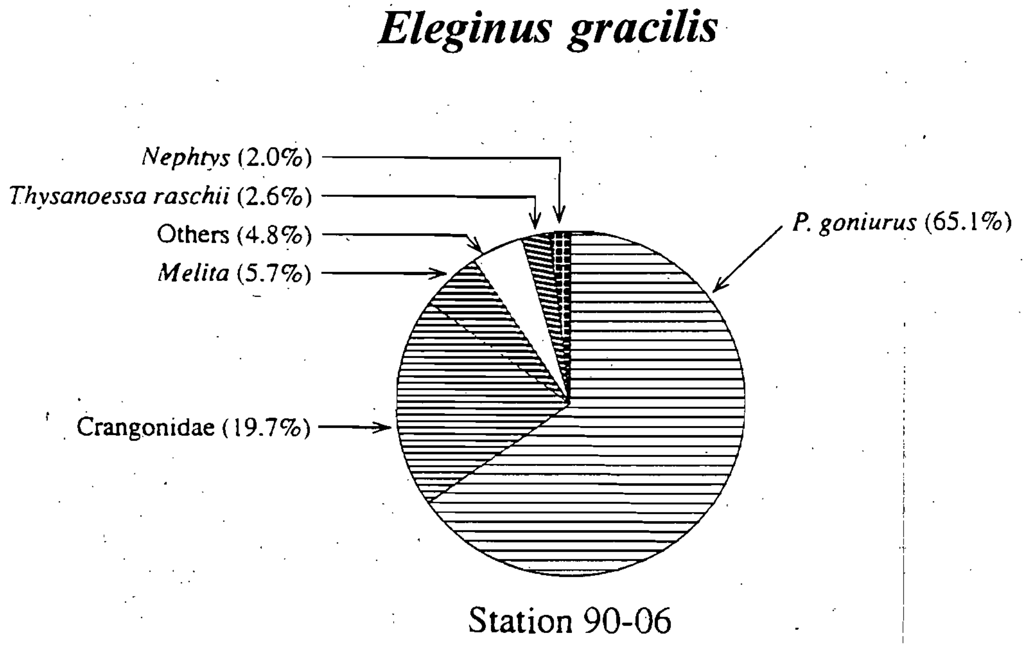


Figure 2. Index of relative importance of major taxa in the diet of Arctic cod (upper) and saffron cod (lower) from Station 90-06 in the northeast Chukchi Sea collected during 1991.

Boreogadus saida

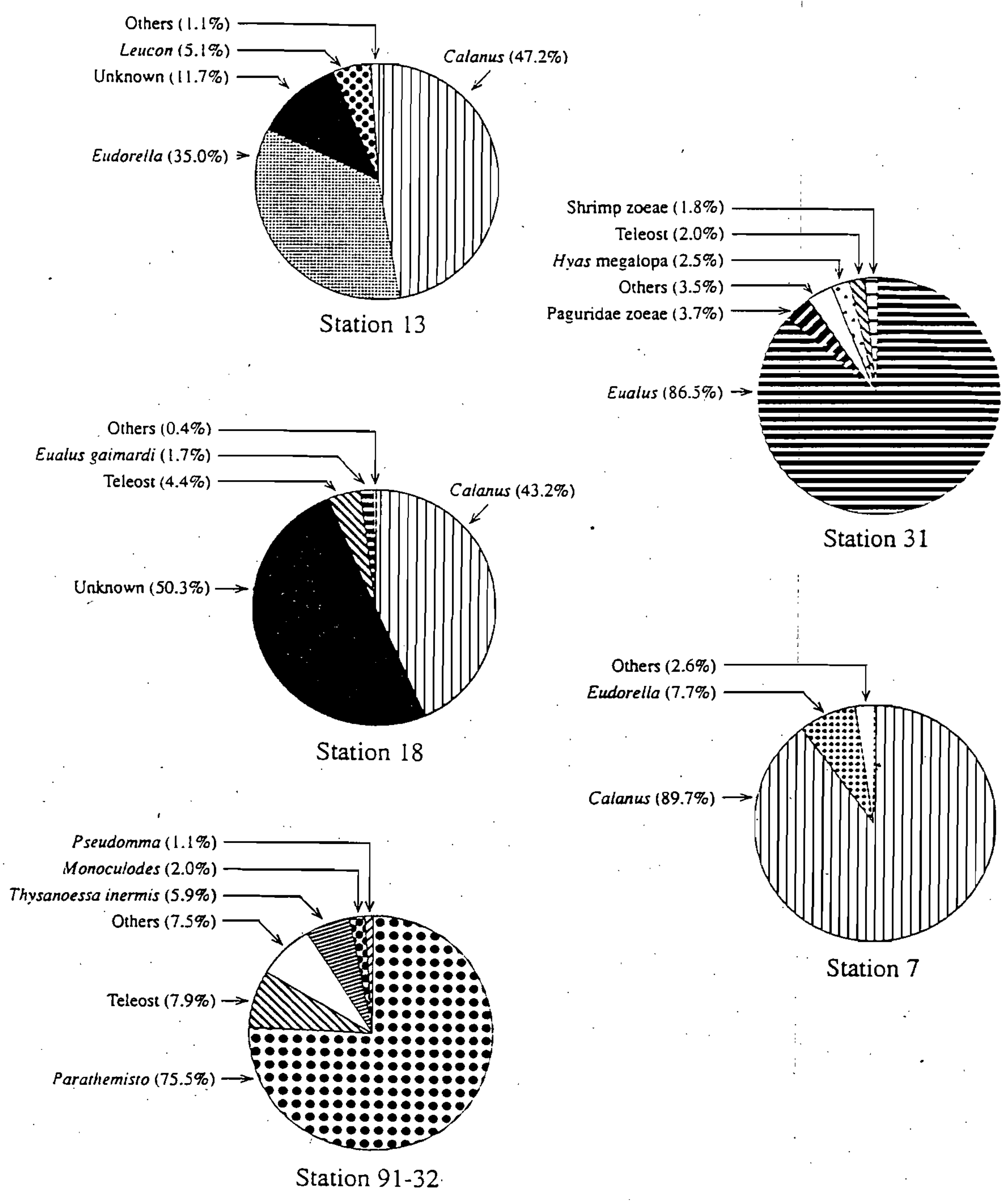


Figure 3. Index of relative importance of major taxa in the diet of Arctic cod collected from four stations in the northeast Chukchi Sea during 1990 and 1991.

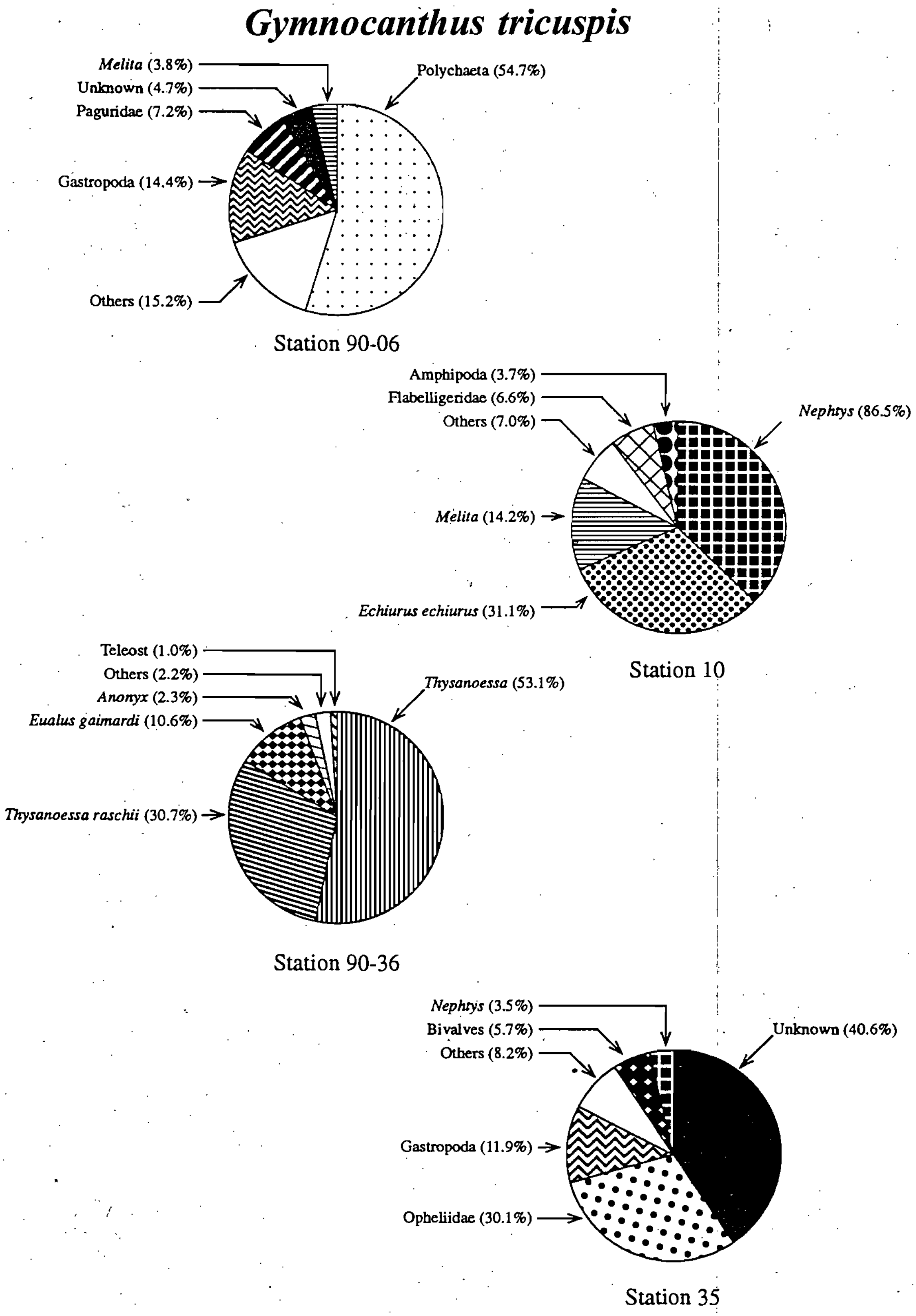


Figure 4. Index of relative importance of major taxa in the diet of Arctic staghorn sculpin collected from four stations in the northeast Chukchi Sea during 1990.

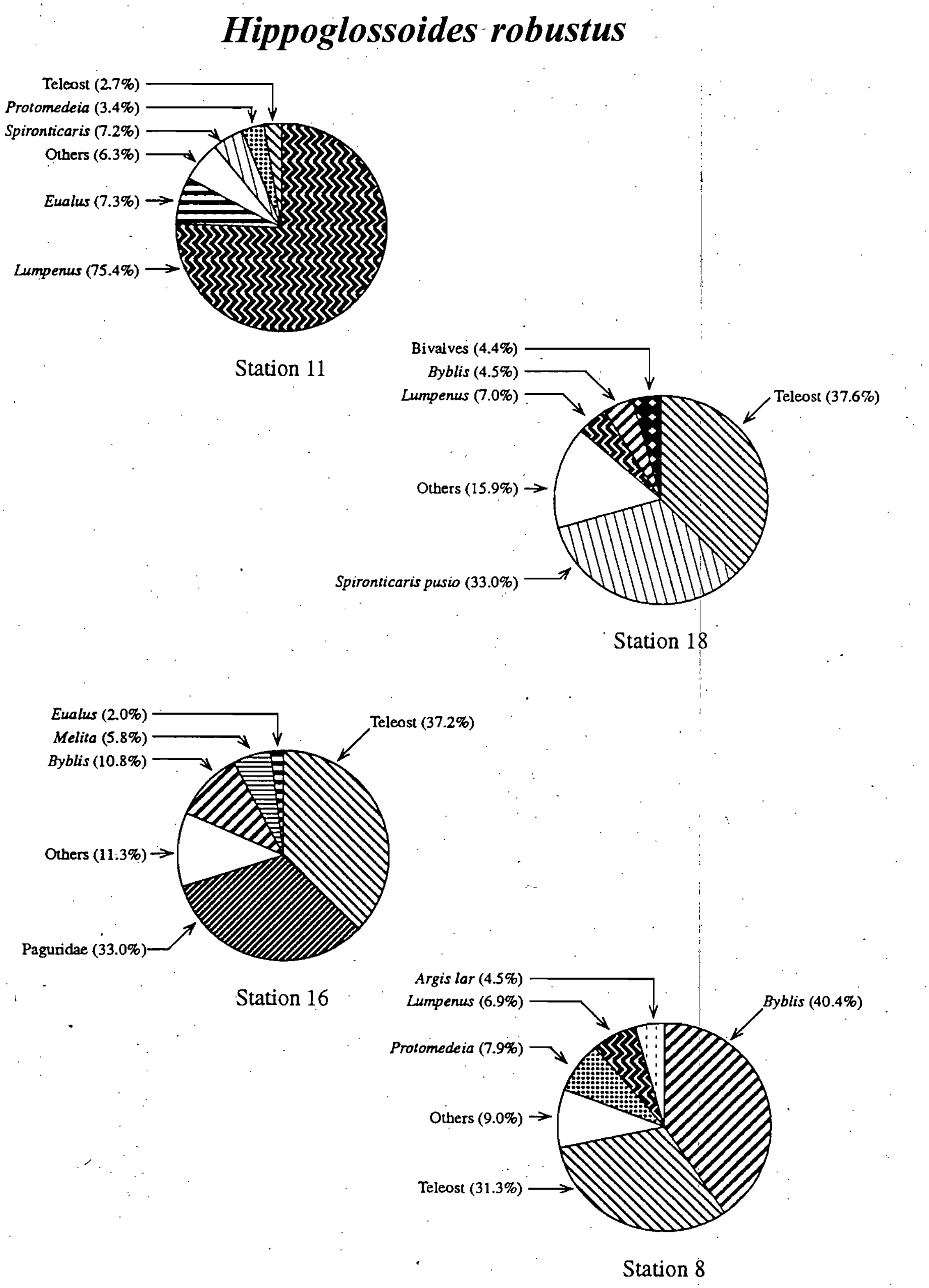


Figure 5. Index of relative importance of major taxa in the diet of Bering flounder collected from five stations in the northeast Chukchi Sea during 1990 and 1991.

Table 5.— Shannon-Weiner evenness statistic for diets of four predator species from the northeast Chukchi Sea.

Predator Taxon	**N**	**Total no. prey taxa in diet**	**Evenness by weight**	**Evenness by number**
Bering flounder	157	18	0.61	0.76
Arctic staghorn sculpin	166	21	0.71	0.29
Arctic cod	123	32	0.02	0.16
Saffron cod	24	15	0.02	0.02

DISCUSSION

In general, the diets of the fish studied here do not differ substantially from those reported elsewhere. Arctic cod consume primarily epontic amphipods and plankton during the ice-covered period, thus obtaining much of their energy through primary consumers feeding on ice algae blooms (Lonne and Gulksen, 1989). During summer they feed primarily on plankton in the Beaufort and northern Chukchi Seas and on epibenthic shrimp and gammaridean amphipods in the northern Bering Sea (Lowry and Frost, 1981). The diet of Arctic staghorn sculpin in our study area is similar to that of *Gymnocanthus pistilliger*, near the Kamchatka Peninsula which feeds primarily on polychaetes and *Echiurus* (Tokranov, 1985). *Hippoglossoides platessoides* feed primarily on mollusks, fish, crustaceans and polychaetes (Macdonald and Green, 1986), however, ophioroids can be a dominant prey item in Arctic regions where alternative prey is in low abundance or absent (Berestovskiy, 1989). Flathead sole less than 25 cm in length from the eastern Bering Sea feed primarily on small crustaceans such as mysids, gammaridean amphipods and crangonid shrimp (Livingston *et al.* 1986).

Previous research in the northern Bering and southern Chukchi Sea has demonstrated the profound influence of different water masses and their associated properties on carbon production rates and the composition of both benthic and planktonic communities (Walsh *et al.* 1989; Greibmeier *et al.* 1988; Springer *et. al.*, 1989; Naumenko and Dzhangil'din, 1987). The organic carbon and plankton advected northward with the major water masses from the northern Bering Sea (Coachman *et al.* 1975) influence species distribution, abundance and biomass, thus impacting the diets of fish, perhaps as far north as Point Franklin. Thus, an understanding of the factors influencing the diets of Arctic cod, Bering flounder and Arctic staghorn sculpin in the Chukchi Sea requires an understanding of processes occurring in the Chirikov Basin, a region of the northern Bering Sea bounded by Siberia and Alaska, St. Lawrence Is., and the Bering Strait.

Water in the Chirikov Basin is divided into three water masses, the Anadyr, Bering Shelf and Alaska Coastal water (Coachman *et al.* 1975). The characteristics and distribution of these water masses are described by Weingartner (Chapter 2). Intense summer phytoplankton blooms are often observed in the western and central Chirikov Basin, where upwelling and mixing of Anadyr and Bering Shelf water result in elevated nutrient levels in the photic zone (Hansell *et al.* 1989). The advection of carbon originating from blooms in the Chirikov Basin through the Bering Strait appears to result in elevated chlorophyll, zooplankton and benthic stocks in the southern Chukchi Sea (Greibmeier *et al.* 1988; Springer *et al.* 1989; Naumenko and Dzhangil'din, 1987). The frontal system between Bering Shelf and Alaska Coastal water can be followed northward toward Cape Lisburne (Weingartner, Chapter 2) and is particularly apparent when examining the horizontal distribution of isohaline and isothermal contours in the bottom water off Point Hope and Cape Lisburne. Presumably, zooplankton, particulate organic carbon and the remaining nutrients are advected northward along with Coastal and Bering Shelf water, thus impacting feeding conditions for fish north of Point Hope.

The impact of northward transport of food is suggested by the diets of Arctic cod near Cape Lisburne and Point Hope. Calanus were a dominant taxa in Arctic cod stomachs at Stations 7, 13, and 18. Highest concentrations of Calanus marshallae in the southern Chukchi Sea have been associated with the frontal region near the 32.4 psu isohaline contour (Springer *et. al.*, 1989). These copepods were probably being concentrated in the frontal region and transported northward past Point Hope and Cape Lisburne, where they were consumed by cod. Calanus were absent from Arctic cod stomachs at Station 90-06, which is east of the frontal zone in Alaska Coastal water, where Calanus are in low concentrations or absent. The presence of saffron cod, a neritic species, at Station 90-06 is another indication that Alaska Coastal water is influencing community composition there.

The frontal region near Point Hope and Cape Lisburne (Weingartner, Chapter 2) apparently also impacts the benthic community. Cluster and principal coordinate analysis on abundance data revealed two distinct benthic communities, a coastal and an offshore group, in the Point Hope - Cape Lisburne region (Feder *et al.* 1989). The offshore group occurred in the frontal region near Point Hope and Cape Lisburne and includes Stations 7, 8, 10, 11, 13, 16 and 18 in our study (Figure 1). The offshore community was dominated by benthic suspension feeders, in particular the amphipod Byblis gaimardi and juvenile specimens of the barnacle Balanus crenulatus (Feder *et al.* 1989). Such organisms tend to be most abundant in places such as frontal regions where elevated primary production results in a high flux of organic carbon to benthic consumers (Grebmeier *et al.* 1988). Byblis was an important prey organism in Bering flounder stomachs at Stations 16 and 18, and dominant at Station 8. Some of the fish consumed by Bering flounder may also have been feeding on Byblis or Balanus. Since we have no information on the distribution and abundance of shrimp in the study area, little can be said concerning water column processes which may be affecting their importance in diets of Bering flounder. Benthic biomass in the offshore group was dominated by polychaetes and Echiurus echiurus (Feder *et al.* 1989), the dominant prey items in Arctic staghorn sculpin at Station 10.

The potential effects of water masses or the source of carbon in the diets of fish north of Cape Lisburne is problematic since stomach analysis was done on fish from only four stations and almost nothing is known of the abundance and distribution of epifaunal invertebrates. Arctic staghorn sculpin at Stations 90-36 and 35, near Icy Cape, were feeding primarily on *T. raschii*, Opheliidae, gastropods and bivalves. Parathemisto libellula, dominating Arctic cod diets at Station 91-35, may be a resident population in Chukchi Sea water or they may have been advected south with Arctic water. The frontal system in the Pt. Franklin area (Weingartner, Chapter 2) may be a fairly persistent feature separating water masses originating in the northern Bering and southern Chukchi Seas from Resident Chukchi or Arctic water masses. If the above is true, substantially different epibenthic and planktonic communities would be expected on either side of the frontal zone and such differences would undoubtedly be reflected in the diets of fish inhabiting the different water masses.

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CHAPTER 9

FISHES AND FISH ASSEMBLAGES OF THE NORTHEASTERN CHUKCHI SEA, ALASKA

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Abstract.—Distribution, abundance, and the structure and stability of bottom fish assemblages in the northeastern Chukchi Sea, Alaska, and their relationship to general oceanographic features were determined. Fishes were collected with an otter trawl at 48 stations in 1990. In 1991 eight of these stations were resampled and 8 additional stations were occupied. Cluster analysis was used to determine fish assemblages. Stepwise multiple discriminant analysis and principal coordinate analyses were used to relate assemblages to oceanographic features. A total of 66 species in 14 families were identified. Gadids made up 83% and 69% of the abundance in 1990 and 1991, respectively. An additional 15% in 1990 and 28% in 1991 were made up of cottids, pleuronectids, and zoarcids. The number of species, species diversity (H), and evenness (V') formed a general pattern of being greater inshore than offshore and greater in the southern area than in the northern area. There were significant differences in ranks of species, species diversity, and evenness at three of eight stations sampled both years. Cluster and discriminant analyses of the 1990 data yielded three along-shore and three off-shore associations. The northern off-shore association had the fewest species, lowest diversity and evenness, and least abundance whereas the two southern associations had the highest. Discriminant and principal coordinate analyses suggest bottom salinity and percent gravel are primary factors influencing association arrangement.

INTRODUCTION

There have been many studies on the distribution and abundance of demersal fishes inhabiting the temperate and tropical seas, primarily in connection with commercially important species. Rarely have the fishes been studied beyond the compilation of species lists for given areas (Colvocoresses and Musick 1984). Survey data has been used, however, to examine the relationships between environmental factors and species distributions, or in more limited cases, to examine the relationships between environmental factors and fish associations. From these studies a number of environmental factors have been identified as important, temperature, salinity, sediment type, being the primary factors. When sampling transected the continental shelf and slope changes in fish species and associations have been primarily related to depth. For example, Overholtz and Tyler (1985) examined the species catches of surveys conducted at different depths in the Georges Bank area of the northwestern Atlantic and found six species associations which were consistent over a number of years. Off Vancouver Island Fargo and Tyler (1991) sampled at depths of 18-240 m and found four species assemblages related to depth. Merrett *et al.* (1991)

sampled depths of 2,230 - 4,787 m in the eastern North Atantic and found that the number of species decreased with depth and different species dominated the catches at different depths.

Jahn and Backus (1976) used salinity and temperature characteristics to define water masses in the Atlantic and related Slope Water, Gulf Stream, northern and southern Sargasso Sea waters and related mesopelagic fishes to these water masses. They concluded that the Slope Water and Gulf Stream faunas were distinct and different from the other two water masses. In another study of the area McKelvie (1985) also found fish associations but concluded they were not distinct from one another, rather there was a gradation between the various faunas. Mahon and Smith (1989) also found that salinity and temperature were important factors in determining fish associations on the Nova Scotian shelf but also determined that depth, and three characteristics of sediment were important factors in determining associations. They concluded, however, that the associations were more related to depth than to other attributes and there were no clear boundaries between the associations.

Some studies indicate sediment type is an important factor determining fish associations whereas others indicate sediment interacts with depth to determine fish associations. Scott (1982) found the distributions of a number of groundfish species on the shelf of Nova Scotia to be related to bottom sediment type, some species were highly specific to sand and gravel while others were broadly related to mud and silt. These relationships were complicated, however, because of the interrelationship between depth and sediment type. Day and Pearcy (1968) sampled depths of 40 - 1,829 m in the northwest Pacific off Oregon and found four demersal fish associations distributed by depth with little overlap; each was characterized by two or three abundant species. They also found that sediment type varied from 100% sand on the upper shelf to a silt clay on the lower slope and that the average sediment type was different for each species association. Species-groups and sediment type, however, did not exactly coincide; two sediment types were found in the depth range of several groups of species. Off the coast of Oregon at depths ranging from 70 to 102 m Pearcy (1978) found both a shallow and deep demersal assemblage. He found, however, an interaction between depth and sediment type where there was a clear separation of the effects of depth but not with sediment type. Pearcy (1978) concluded depth was the primary factor with sediment type of secondary importance in determining the distribution of associations.

Few studies have been conducted in arctic areas and little reported about distribution and species composition of demersal fishes inhabiting these waters. An exception is the northeastern Chukchi Sea where three trawl surveys have occurred (Alverson and Wilimovsky 1966; Frost and Lowry 1983; Fechhelm *et al.* 1985). These studies, however, were spatially limited and not adequately comprehensive to examine the number of species present in the northeast Chukchi Sea, their abundance, distribution, factors influencing distribution, or the existence of species associations. These exploratory studies, however, were important first steps in determining factors influencing the distribution and abundance of fishes in arctic waters.

The purpose of this study was to determine the distribution and abundance of demersal fishes, species assemblages and the relationship of these assemblages to oceanographic features in the northeastern Chukchi Sea, Alaska. Because of differences in the hydrographic and sediment structure, and the presence of invertebrate associations (Feder *et al.* 1990; Feder *et al.* Chapter 10) we hypothesized that there would be onshore-offshore and north-south differences in abundance and biomass, and the associations would be related to water mass characteristics.

THE STUDY AREA

The physical features of northeast Chukchi Sea have been well described by Weingartner (Chapter 2) and Feder *et al.* (Chapter 10) and we only summarize those aspects pertinent to the two hypotheses previously presented. The northeast Chukchi Shelf is relatively shallow and gradually increases to depths of 30 to 50 m offshore over most of the area (Figure 1). The bottom sediments are poorly sorted with a trend of relatively coarse sediments on the inner shelf between Pt. Hope and Pt. Barrow with muds containing various proportions of gravel and sand offshore (Sharma 1979; Naidu 1987). Sediments in the more northerly offshore region contain a higher percentage of water and lower percentage of gravel than the more southern offshore area (Feder *et al.* 1990).

There are a several water masses in the Chukchi Sea during the open water season (Weingartner, Chapter 2). In the study area, however, there are primarily two, the Alaska Coastal Water (ACW) and the Resident Chukchi Water (RCW). The ACW is nearshore and characterized by relatively warm, low salinity water. It is a mixture of Bering Shelf Water (BSW) and freshwater from river discharge along western Alaska, primarily the Yukon River. The RCW is characterized by relatively cold, high salinity water and is seaward of the ACW. It is either advected onshore from the upper layers of the Arctic Ocean and/or is remnant ACW and BSW from the previous winter. The ACW and RCW masses are separated by a bottom front which is generally between the 25 m and 40 m isobaths which intersects the coast between Icy Cape and Pt. Franklin (Johnson 1989; Feder *et al.* 1990; Weingartner Chapter 2).

Feder *et al.* (Chapter 10) examined the distribution of infaunal and epifaunal mollusks of the study area. They found that infaunal molluscan abundance and biomass were greater north of the front. Additionally, they identified six infaunal associations, three associated with more inshore waters and three offshore. Abundance and biomass of the epifaunal molluscs tended to be greater inshore than offshore. There was also an inshore-offshore epifaunal mollusc assemblage pattern but the pattern was not as clear as that formed by the infaunal molluscs.

METHODS AND MATERIALS

The sampling area was located in the area northeast of Pt. Hope (north of approximately 68° 20'N latitude), east of the international boundary (168° 58'W longitude) and limited in northward extent by weather and sea ice conditions. Forty eight stations were occupied along 11 transects perpendicular to shore between 16 August and 16 September, 1990. Nearshore stations were established nearer one another than further offshore to increase the probability of having two stations inshore of the historical position of the bottom front. Between 16 and 23 September, 1991, 16 stations were occupied of which eight had been sampled in 1990 to estimate interannual variability (Figure 1; station locations, depths, temperatures, and salinities are given in Smith *et al.*, Chapter 5). Weather conditions dictated the general areas in which sampling could be conducted and stations were numbered to reflect the sampling sequence.

Each station location was determined using a Global Positioning System. Fish were sampled from a chartered fishing vessel equipped with a National Marine Fisheries Service standard 83 - 112 survey otter trawl which had a 25.2 m head rope, a 34.1 m footrope equipped with a tickler chain, and a codend of 8.9 cm stretched mesh into which a 3.2 cm stretched mesh liner was inserted. To estimate variability in the catch at each station two half hour long trawls were conducted. Because of weather conditions and torn nets, however, only one trawl was made

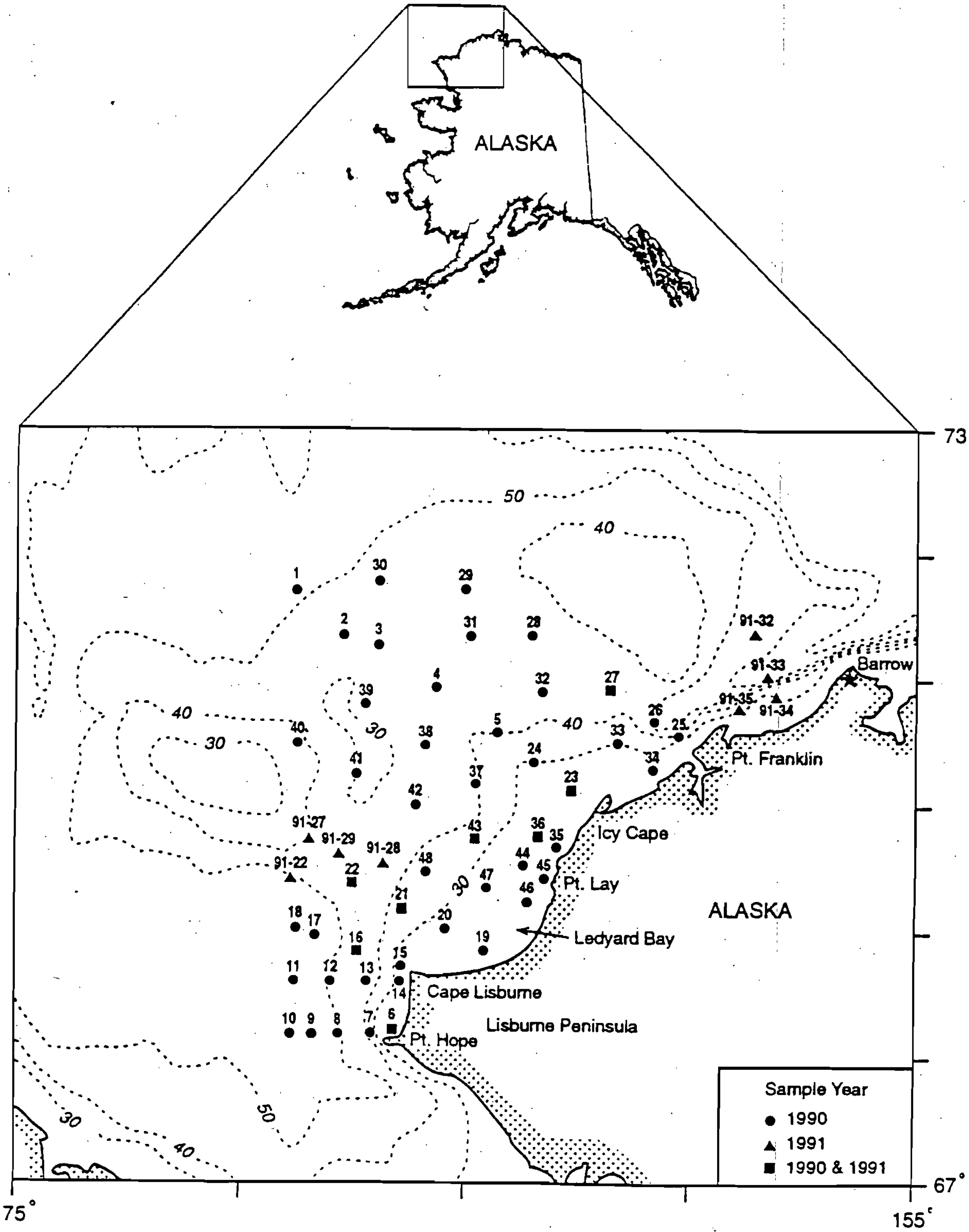


Figure 1. General location of stations sampled for demersal fishes in the northeastern Chukchi Sea, Alaska, during August and September 1990 and 1991. Specific locations for stations are given in Smith *et al.* (Chapter 5).

at station 31 in 1990 and stations 16, 91-33, 91-34, and 91-35 in 1991. Fish abundance (fish/km^2) and biomass (g/km^2) were determined by the area swept method; we noted the boat's location when the net reached bottom and when the trawl left the bottom upon retrieval. Additionally, the width of the trawl's wings and height of the headrope above the footrope were determined with a Scanmar electronic mensuration unit. Upon the trawl's retrieval the entire catch was weighed in the net with an electronic load cell (4,536 kg capacity), fish were sorted to the lowest taxonomic category possible, counted, placed in baskets, and weighed with a mechanical platform scale (81.6 kg capacity).

To investigate diversity, we used the number of species for richness (S) and calculated Shannon's index (H) (Pielou 1977) using abundance and total unique species of both trawls combined at each station. Shannon's index was calculated as:

$$\mathbf{H} = \frac{n \log n - \sum_{i=1}^{k} f_i \log f_i}{n}$$

where n = total number of fish, f_i = number of individuals in species *i*, and k = the number of species (Zar 1984). "Evenness" was estimated following Pielou with the equation

$$\mathbf{V'} = \frac{\mathbf{H}}{\ln \mathbf{S}}$$

where V' = measure of evenness, H = Shannon's diversity index, and S = the number of species present.

Determination of fish associations and their relationship to physical oceanographic conditions was established in a two staged process. The first stage used cluster analysis of species abundance followed by discriminant function and principal coordinate analyses using environmental data. Cluster analysis was used to determine fish associations. Following the recommendation of Clifford and Stevenson (1975), the most commonly occurring species (21, each of which made up >0.1% of the abundance) were chosen based on a preliminary examination of abundance data; they made up 99.6% of the total abundance and 98% of the biomass. Abundance was usually the mean of two trawls except for a few stations in which only one trawl was made. Prior to calculating similarity indices, abundance (X) was transformed (ln[X+1]) to normalize the data (Clifford and Stevenson 1975). The similarity indices were calculated as 1 - D where D is the Bray-Curtis dissimilarity index (Clifford and Stephenson 1975) adapted from Lance and Williams (1967). The algorithm for D is

$$\mathbf{D} = \frac{\sum_{i=1} |(X_{1j} - X_{2j})|}{\sum_{i=1}^{n} (X_{1j} + X_{2j})}$$

where *n* = number of individuals in species *i* and *j* = number of stations. Similarity takes on values from zero to one where one indicates identical species composition between two stations. Following Clifford and Stevenson (1975) a range of similarity indices was used to determine major groupings and a preliminary inspection of the data suggested groupings could be distinguished with indices of 50 - 60% and these were used as our reference for examining the dendograms.

Multiple discriminant function analysis (DFA) and principal coordinate analysis (PCA) were used to evaluate the relationship between fish associations and the environmental parameters. The PCA was used to validate the results of the DFA and to determine if other variables could be influencing our groupings. First a linear stepwise multiple discriminant analysis was performed using both BMDP and SPSS. To control for multicollinearity we eliminated one of any pair of variables with -0.8 > r > 0.8. Mud, bottom temperature, epifaunal biomass, and invertebrate infaunal biomass were highly correlated with gravel, bottom temperature, epifaunal abundance, and infaunal invertebrate abundance, respectively, and were therefore not included in the analyses. Three subsets of the data were used to evaluate the relationship between oceanographic conditions and fish associations based on abundance. The variables composing the first data set, depth, bottom salinity and temperature, were determined at each station with a Seabird SBE 19 internally recording conductivity-temperature-depth recorder following trawling. Due to a malfunction, however, salinity and temperature could not be recovered for 7 of the 48 stations sampled in 1990. The variables in the second data set consisted of sediment type (arc sine transformed percent of mud, sand, and gravel), which was assigned to each station from those stations sampled nearest to each of ours by Feder *et al.* (1989). The third data set contained infaunal and epifaunal mollusc biomass and abundance, from Feder *et al.* (Chapter 10) and again the data from those stations nearest ours were assigned to each of our stations. Data on sediment type, biomass, and abundance of invertebrates were provided by Dr. H. M. Feder, Institute of Marine Science, University of Alaska Fairbanks.

Three approaches were taken to examine the congruity between years for the eight stations sampled both years. First, species ranks at each site sampled both years were compared using the Wilcoxon signed ranks test (Siegel and Castellan 1988). Our hypothesis was that if there were nonsignificant differences between years, then interannual variability was minimal. If significant ($p \leq 0.05$) differences existed between years at the stations then interannual variability grossly affected taxon structure. Second, species richness and diversity were compared between years for those stations occupied in both 1990 and 1991. Lastly, the dates from those stations resampled in 1991 were combined with the 1990 data set and fish associations redetermined as previous described. If there is congruity between years, those stations sampled in both years should classify together.

RESULTS

Abundance and Biomass.—A combined total of 66 species were in 14 families found for 1990 and 1991 (Table 1). In 1990 two species of gadids made up 82% of the abundance and 69% of the biomass. Members of the cottid, pleuronectid, and zoarcid families made up an additional 15% of total abundance in 1990 and 28% in 1991. The fishes displayed four patterns of abundance in 1990: (1) Arctic cod (*Boreogadus saida*), the most dominant species, made up 76.1% of total fish abundance and 61.3% of total biomass; (2) four moderately abundant species (*Myoxocephalus verrucosus*, *Eleginus gracilis*, *Gymnocanthus tricuspis*, and *Hippoglossoides robustus*) collectively made up 12.3% of abundance and 15.8% of biomass (Table 1); (3) 16 species which occurred occasionally made up 5.9% of the abundance and 13.7% of the biomass; and (4) 35 species which were rare made up only 0.5% of the abundance and 1.8% of the biomass in 1990 (Table 1). The fish in the first two categories made up over 88.4% and 77.1% of the total abundance and biomass, respectively.

Table 1.—Species abundance (fish/km^2), biomass (g/km^2) and the percent (%) of each fish species collected in the northeastern Chukchi Sea during 1990 and 1991. The top 21 species are labeled 1 to 21.

	1990				1991			
Species	Abundance	(%)	Biomass	(%)	Abundance	(%)	Biomass	(%)
COTTIDAE (SCULPIN)								
# *Icelus spatula*	x	(*)	12	(*)	0	(0.00)	0	(0.00)
# *I. SPINIGER*	x	(*)	10	(*)	0	(0.00)	0	(0.00)
Cottidae sp.	0	(0.00)	0	(0.00)	5	(0.05)	272	(0.20)
21 *Artediellus* sp.	26	(0.10)	280	(0.06)	0	(0.00)	0	(0.00)
A. pacificus	2	(0.01)	47	(0.01)	0	(0.00)	0	(0.00)
7 *A. scaber*	141	(0.55)	583	(0.12)	197	(2.28)	704	(0.51)
Blepsias bilobus	1	(*)	169	(0.03)	0	(0.00)	0	(0.00)
Enophrys diceraus	5	(0.02)	188	(0.04)	130	(1.50)	1106	(0.81)
4 *Gymnocanthus tricuspis*	783	(3.06)	9070	(1.84)	494	(5.71)	5228	(3.81)
20 *Hemilepidotus papilio*	28	(0.11)	571	(0.12)	9	(0.11)	414	(0.30)
Megalocotus platycephalus	15	(0.06)	944	(0.19)	10	(0.12)	944	(0.72)
# *Microcottus sellaris*	x	(*)	12	(*)	0	(0.00)	0	(0.00)
3 *Myoxocephalus* sp.	1573	(6.15)	49167	(9.99)	90	(1.05)	1295	(0.94)
M. polyacanthocephal	1	(.01)	167	(0.03)	0	(0.00)	0	(0.00)
M. quadricornis	6	(0.02)	442	(0.09)	0	(0.00)	0	(0.00)
6 *M. verrucosus*	238	(0.93)	12604	(2.56)	1033	(11.95)	35017	(25.51)
Myoxocephalus sp. 2	0	(0.00)	0	(0.00)	108	(1.25)	4550	(3.31)
Myoxocephalus sp. 1	0	(0.00)	0	(0.00)	2	(0.02)	318	(0.23)
# *Nautichthys pribilovius*	x	(*)	12	(*)	4	(0.05)	15	(0.01)
# *Triglops forficata*	x	(*)	20	(*)	0	(0.00)	0	(0.00)
T. pingeli	137	(0.54)	1698	(0.35)	131	(1.52)	1294	(0.94)
		(11.56)		(15.46)		(25.61)		(37.29)
PLEURONECTIDAE (FLOUNDERS)								
5 *Hippoglossoides robustus*	486	(1.90)	17406	(3.54)	25	(0.29)	940	(0.68)
Pleuronectes aspera	20	(0.08)	746	(0.15)	101	(1.17)	1505	(1.10)
P. proboscidea	5	(0.02)	181	(0.04)	0	(0.00)	0	(0.00)
# *P. sakhalinensis*	x	(*)	12	(*)	0	(0.00)	0	(0.00)
P. quadrituberculatus	18	(0.07)	2467	(0.50)	16	(0.19)	2016	(1.47)
Platichthys stellatus	2	(0.01)	1365	(0.28)	0	(0.00)	0	(0.00)
Reinhardtius hippoglossoides	2	(0.01)	85	(0.02)	0	(0.00)	0	(0.00)
# *Hippoglossus stenolepis*	x	(*)	256	(0.05)	0	(0.00)	0	(0.00)
		(2.11)		(4.59)		(1.65)		(3.25)
ZOARCIDAE (EELPOUTS)								
11 *Lycodes palearis*	133	(0.52)	4802	(0.98)	24	(0.27)	536	(0.39)
14 *L. polaris*	83	(0.33)	7780	(1.58)	0	(0.00)	0	(0.00)
15 *L. raridens*	67	(0.26)	8078	(1.64)	71	(0.82)	5241	(3.82)
L. turneri	8	(0.03)	580	(0.12)	0	(0.00)	0	(0.00)
L. rossi	4	(0.02)	137	(0.03)	0	(0.00)	0	(0.00)
Lycodes sp. Y	0	(0.00)	0	(0.00)	8	(0.09)	92	(0.07)
lycodes sp. X	0	(0.00)	0	(0.00)	8	(0.09)	92	(0.07)
Lycodes sp.	0	(0.00)	0	(0.00)	4	(0.04)	112	(0.08)
# *Gymnelus hemifasciatus*	x	(*)	12	(*)	0	(0.00)	0	(0.00)
G. viriis	1	(*)	30	(0.01)	30	(0.35)	72	(0.05)
		(1.16)		(4.37)		(1.66)		(4.48)
PSYCHROLUTIDAE								
Eurymen gyrinus	x	(*)	31	(0.01)	1	(0.01)	17	(0.01)

Table 1. continued

	1990				1991			
Species	**Abundance**	**(%)**	**Biomass**	**(%)**	**Abundance**	**(%)**	**Biomass**	**(%)**
AGONIDAE (POACHERS)								
# *Aspidophoroides bartoni*	1	(*)	24	(*)	0	(0.00)	0	(0.00)
A. olriki	2	(0.01)	85	(0.02)	0	(0.00)	0	(0.00)
16 *Podothecus acipenserinus*	57	(0.22)	1077	(0.22)	24	(0.28)	147	(0.11)
# *Occella dodecaedron*	x	(*)	11	(*)	0	(0.00)	0	(0.00)
Pallasina barbata	0	(0.00)	0	(0.00)	2	(0.02)	9	(0.01)
STICHAEIDAE (PRICKLEBACK)								
Chirolophis snyderi	0	(0.00)	0	(0.00)	1	(0.01)	57	(0.04)
13 *Lumpenus fabrichii*	90	(0.35)	1122	(0.23)	52	(0.61)	102	(0.07)
# *L. medius*	1	(*)	38	(0.01)	0	(0.00)	0	(0.00)
Stichaeus sp.	0	(0.00)	0	(0.00)	2	(0.02)	48	(0.03)
S. punctatus	2	(0.01)	107	(0.02)	1	(0.01)	28	(0.02)
Eumesogrammus praecisus	1	(0.01)	61	(0.01)	3	(0.04)	151	(0.11)
GADIDAE (COD)								
1 *Boreogadus saida*	19456	(76.06)	301878	(61.34)	5728	(66.27)	63913	(46.56)
2 *Eleginus gracilis*	1642	(6.42)	38769	(7.88)	255	(2.95)	7150	(5.21)
17 *Gadus macrocephalus*	44	(0.17)	1869	(0.38)	0	(0.00)	0	(0.00)
8 *Theragra chalcogramma*	138	(0.54)	1883	(0.38)	0	(0.00)	0	(0.00)
		(83.19)		(69.98)		(69.22)		(51.77)
CYCLOPTARIDAE (LUMPSUCKERS)								
# *Eumicrotremus andriashevi*	x	(*)	11	(*)	31	(0.34)	753	(0.55)
E. orbis	4	(0.02)	116	(0.02)	2	(0.02)	112	(0.08)
LIPARIDAE (SNAILFISH)								
Liparis sp.	1	(*)	34	(0.01)	4	(0.05)	373	(0.27)
L. tunicatus	10	(0.04)	373	(0.08)	0	(0.00)	0	(0.00)
18 *L. gibbus*	44	(0.17)	442	(0.90)	17	(0.20)	2408	(1.75)
OSMERIDAE (SMELTS)								
19 *Osmerus mordax*	32	(0.13)	1903	(0.39)	13	(0.15)	129	(0.09)
10^*Mallotus villosus*	133	(0.52)	710	(0.14)	1	(0.01)	6	(*)
HEXAGRAMIDAE (GREENLINGS)								
Hexagrammos stelleri	4	(0.01)	151	(0.03)	0	(0.00)	0	(0.00)
CLUPEIDAE (HERRING)								
12 *Clupea harengus pallasi*	126	(0.49)	17469	(3.55)	1	(0.01)	57	(0.04)
AMMODYTIDAE (SANDLANCES)								
Ammodytes hexapterus	0	(0.00)	0	(0.00)	5	(0.06)	10	(0.01)
ANARHICHADIDAE (WOLFFISH)								
# *Anarhichas orientalis*	1	(*)	61	(0.01)	0	(0.00)	0	(0.00)

x - Less than 0.49
* - Less than 0.01%
\# - Found at only 1 station in 1990
^ - Found at only 1 station in 1991

These trends are generally reflected in the 1991 data. For example, the two gadids made up 69% of total abundance and 52% of total biomass (Table 1). There are, however, some notable exceptions. In 1990 Bering flounder made up 2% of the abundance and nearly 4% of the biomass but in 1991 this species was nearly absent, making up 0.3% of the abundance and

0.7% of the biomass. In contrast, *M. verrucosus* during 1990 made up 0.9% of abundance and 2.6% of biomass, but in 1991 this species made up 12% of abundance and 26% of the biomass (Table 1).

There was a tendency for abundance and biomass of all species combined to be greatest in the southern part of the study area, intermediate off the Pt. Lay area, and lowest in the northern part of the study area (Figure 2). In 1990 the greatest abundance occurred at station 19 (118,800 fish/km^2) and greatest biomass at station 20 (1,591 kg/km^2) in Ledyard Bay (Figure 2). The lowest abundance (16 fish/km^2 at station 26) and biomass (2.1 kg/km^2 at station 29) both occurred off Pt. Franklin. Of the 17 stations sampled from Ledyard Bay and southward seven had abundances greater than 50,000 fish/km^2 but no station north of the area had an abundance this large. In contrast, of those stations with an abundance of less than 10,000 fish/km^2, 14 of 17 stations were off Icy Cape and northward, 6 of 14 stations off the Pt. Lay area, and only one south of Ledyard Bay. Biomass also reflected this general trend (Figure 2).

In 1991 abundance and biomass estimates were low over the entire study area with no trend of higher abundance or biomass in the southern area (Figure 2). Additionally, biomass and abundance estimates differed widely from those found at the eight stations previously sampled in 1990, three (stations 16, 21, and 22) of which differed significantly ($P<0.05$) between the two years (Table 2). Species in common between years at these three stations varied from 6.7% to 42.1% and for those that were present in both years sampled, abundance varied substantially. For example, at station 22, Arctic cod was 2.4 times as abundant in 1990 as in 1991 but Bering flounder was 23 times as abundant in 1991 as in 1990. Similar observations can be made for those stations in which there were no significant differences. For example, the number of species in common varied from 20% to 60%. Differences in the catch between years at these stations also varied extensively and at station 6, which had the largest number of species both years, Arctic cod was four times as abundant in 1990 as in 1991 (Table 2). The opposite was true for *Enophrys diceraus* which was 32 times more abundant in 1991 than in 1990.

Table 2.—Estimated abundance (fish/km^2) of demersal fishes collected at stations sampled in the northeastern Chukchi Sea during both 1990 and 1991. Species sequence is based on the overall abundance of 1990 (Table 1).

	Station 6		**Station 16**		**Station 21**		**Station 22**	
Species	**1990**	**1991**	**1990**	**1991**	**1990**	**1991**	**1990**	**1991**
B. saida	56373.8	14183.5	22386.5	2273.4	32184.6	196.8	20475.3	8527.7
G. tricuspis	324.8	0.0	0.0	27.1	630.5	0.0	0.0	568.8
M. verrucosus	0.0	3793.9	265.4	0.0	54.8	0.0	0.0	0.0
E. diceraus	59.4	1932.8	11.6	0.0	0.0	0.0	0.0	0.0
Myoxocephalus sp.	0.0	0.0	712.2	0.0	599.4	0.0	608.9	0.0
L. aspcsa	40008	1520.2	0.0	0.0	0.0	0.0	0.0	0.0
H. robustus	0.0	37.5	1113.5	0.0	229.7	0.0	254.8	10.8
L. raridens	0.0	102.4	0.0	54.1	0.0	0.0	1061.0	0.0
Myoxocephalus sp.2	0.0	1621.1	0.0	0.0	0.0	0.0	0.0	0.0
L. palearis	0.0	37.5	492.1	162.4	199.8	0.0	416.1	0.0

Table 2. continued

	Station 6		Station 16		Station 21		Station 22	
Species	**1990**	**1991**	**1990**	**1991**	**1990**	**1991**	**1990**	**1991**
L. fabricii	22.1	651.8	147.3	0.0	129.8	0.0	128.0	0.0
T. pingeli	0.0	519.1	0.0	0.0	27.4	0.0	0.0	0.0
C. harengus	221.8	18.8	10.7	0.0	804.1	0.0	26.0	0.0
G. macrocephalus	830.6	0.0	102.7	0.0	0.0	0.0	62.5	0.0
NUMBER OF OTHER SPECIES	2853.2	1474.2	226.7	0.0	321.6	0.0	551.6	135.6
TOTAL	61293	28939	25625	2516	35568	393	24075	9367
Wilcoxon Z		0.58 0		- 2.95 9		- 3.41 1		- 2.85 9
P Value		0.56 2		0.00 3		0.00 1		0.00 4
Number of Species	19	24	15	4	15	1	17	8
Number of Species in Common Both Years		13		3		1		8
Total Number of Species Both Years Combined		32		17		15		19
% Common		40.6%		17.6%		6.7%		42.1%
SW Diversity	0.47	1.83	0.62	0.40	0.52	---	0.74	0.40

Table 2. continued

	Station 23		Station 43		Station 36		Station 27	
Species	**1990**	**1991**	**1990**	**1991**	**1990**	**1991**	**1990**	**1991**
B. saida	3180.0	2379.4	13684.7	5090.2	19104.8	2139.4	3017.3	2180.3
G. tricuspis	1163.1	1016.2	170.6	189.8	246.7	702.2	0.0	0.0
M. verrucosus	0.0	0.0	0.0	11.0	574.3	0.0	0.0	0.0
E. diceraus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Myoxocephalus sp.	6.0	55.9	0.0	11.0	0.0	0.0	0.0	0.0
L. aspcsa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
H. robustus	0.0	0.0	66.8	88.2	0.0	33.4	0.0	0.0
L. raridens	0.0	0.0	550.5	22.0	0.0	0.0	0.0	34.6
Myoxocephalus sp.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
L. pealearis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
L. fabricii	0.0	0.0	43.0	111.0	0.0	11.1	0.0	0.0
T. pingeli	57.8	111.8	375.4	22.2	49.1	11.1	0.0	0.0
C. harengus	0.0	0.0	34.1	0.0	0.0	0.0	0.0	0.0
G. macrocephalus	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NUMBER OF OTHER SPECIES	28.9	86.3	178.0	88.2	49.0	100.3	0.0	251.1
TOTAL	5219	5690	15263	5877	20751	3966	3017	2465

Table 2. continued

Species	Station 23 1990	Station 23 1991	Station 43 1990	Station 43 1991	Station 36 1990	Station 36 1991	Station 27 1990	Station 27 1991
Wilcoxon Z		0.765		-0.806		0.031		0.677
P Value		0.444		0.420		0.975		0.498
Number of Species	7	9	14	13	8	10	1	5
Number of Species in Common Both Years		6		9		4		1
Total Number of Species Both Years Combined		10		18		14		5
% Common		60%		50%		28.6%		20%
SW Diversity	1.01	1.25	0.53	0.54	0.38	1.18	---	0.37

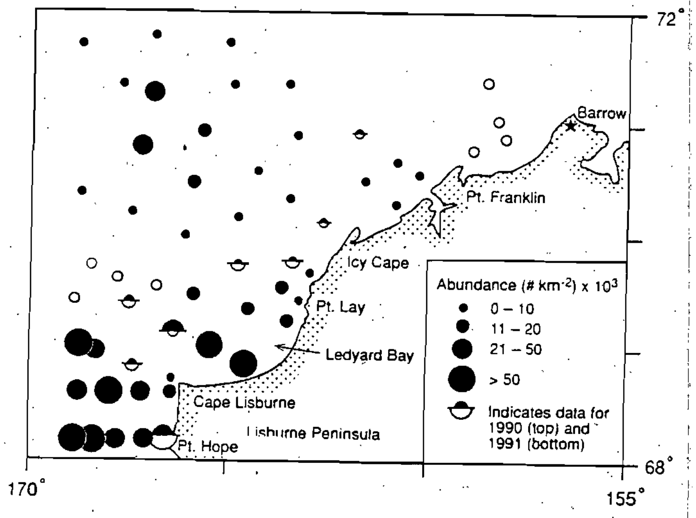
Species Richness, Diversity, and Assemblage Structure.—Families contributing the most species were Cottidae (21), Zoarcidae (10), Pleuronectidae (8), Stichaeidae (6), and Agonidae (5) (Table 1). The remaining families contributed only 16 additional species. Nearly 45% of the species were represented by a single specimen, while 55% were represented by >10 individuals.

Species richness was greatest south of Icy Cape and lowest in the north. The most species per station (19) were recorded at stations 6 (Pt. Hope), 45 (Pt. Lay), and 48 (Ledyard Bay) in 1990 and at station 6 (23 species) in 1991 (Figure 3). The fewest species (2 and 3) occurred at four stations in the most northern area (stations 28 through 32). There was a tendency for these stations south of Icy Cape to have 11 or more species with those stations north to have 10 or less; the majority of the latter had fewer than 8 species. There was interannual variability in the number of species found at a station (Table 2). Species ranks were significantly (P<0.05) different at three stations just northeast of Cape Lisburne between 1990 and 1991. At these stations there were between 15 and 17 species in 1990 but in 1991 the number varied from 1 to 8 species (Table 2). In the north there was one species found at station 21 in 1990 but five in 1991.

For species diversity there was a trend of higher diversity inshore than offshore and in the southern part of the study area than the northern (Figure 3). Those stations with a species diversity of >0.90 occurred south of a line from northeast of Pt. Franklin south-westward. The greatest species diversity (1.99) occurred at station 45 off Pt. Lay with two stations off Cape Lisburne (15 and 14) nearly as large (1.56 and 1.87, respectively). Nearly all stations with a diversity of >1.0 occurred along shore from Pt. Franklin to Pt. Hope. The smallest species diversity occurred at station 39 (0.02) west of Pt. Franklin. Stations 3 and 29 just north of station 39 also had very low (0.07) diversity indices. Like species richness, there was considerable interannual differences in species diversity. The greatest interannual difference occurred at station 6 followed closely by station 36 (Table 2). Evenness followed the same pattern as species diversity indices (Figure 3).

Cluster analysis of fishes collected in 1990 formed six associations at a similarity level of 0.5 - 0.6, three near shore and three offshore, with one station (15) not classifiable (Figure 4).

Two clusters formed an association (I) off the Lisburne Peninsula. A second association (II) was formed by one cluster which bisected the northern offshore association (VI). Interestingly association II was more closely related to association I off Lisburne Peninsula than the association it bisected. The northern offshore association (VI) consisted of two relatively distant clusters while the northern inshore association (III) consisted of two closely related clusters, one of which was made up of two stations. The central offshore association (IV) was formed by two clusters. Finally, there was the central onshore association (V) in Ledyard Bay which consisted of four closely related and two distantly related stations. Cluster analysis was also repeated without Arctic cod, the most abundant species, and similar results were obtained.



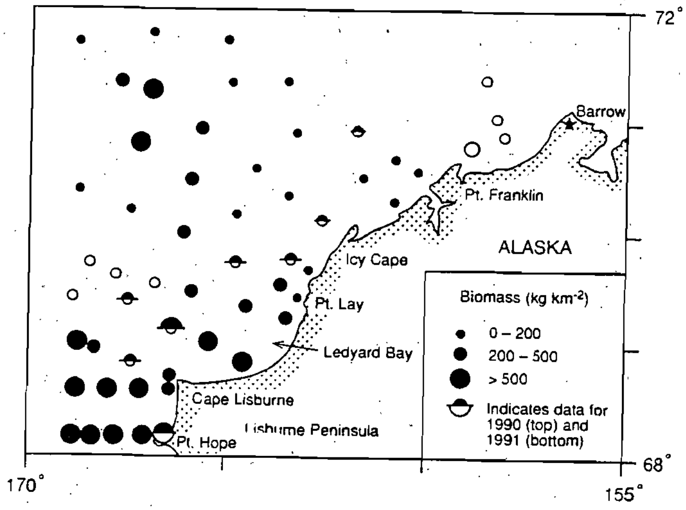


Figure 2. Relative abundance (fish/km^2) and biomass (kg/km^2) estimates of benthic fishes at 48 and 16 stations sampled during 1990 and 1991, respectively, in the northeastern Chukchi Sea, Alaska.

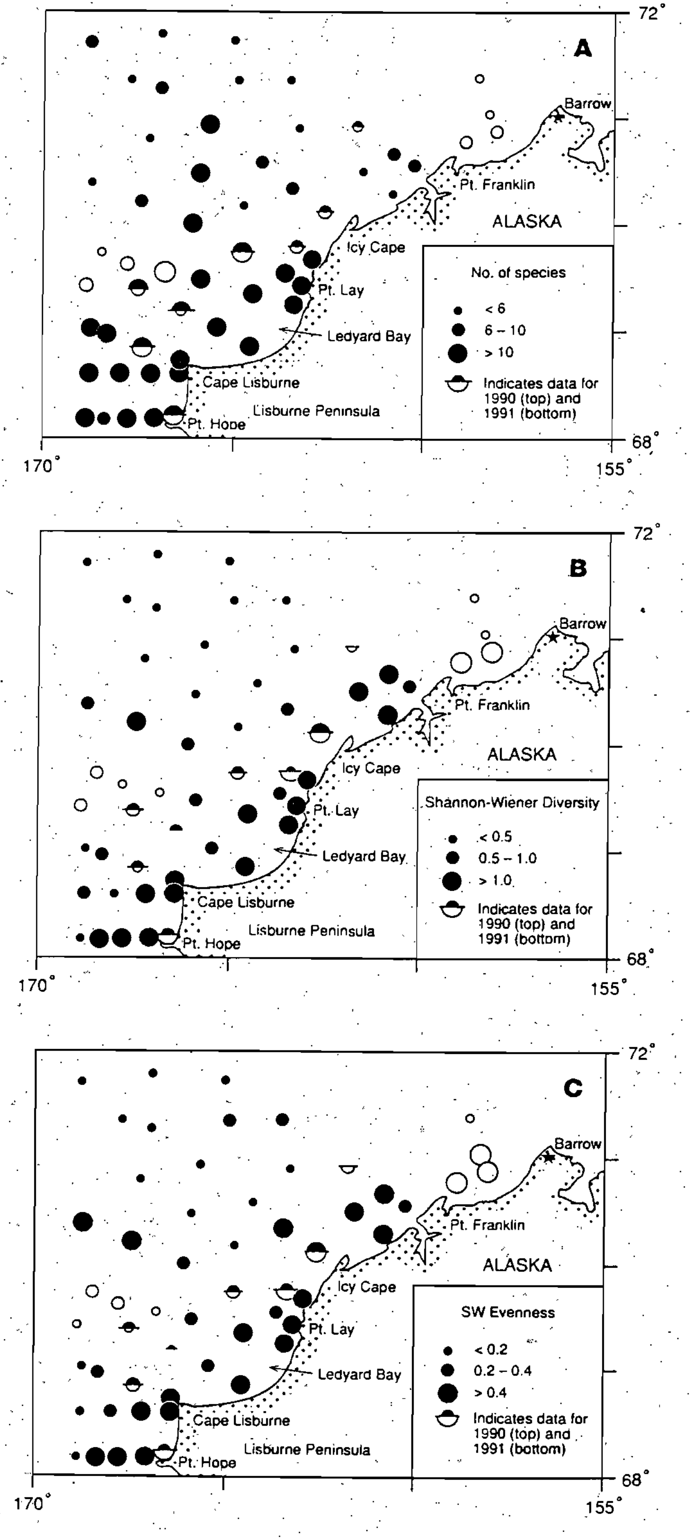


Figure 3. Relative richness (number of species), species diversity (Shannon index), and evenness of behthic fishes at 48 and 16 stations sampled during 1990 and 1991, respectively, in the northeastern Chukchi Sea, Alaska.

Even though the six fish assemblages and the unclassified station were composed of different species and abundances, the associations all had a common feature, in each Arctic cod made up over 90% of the abundance (Table 3). The most distinctive assemblage was VI from the northern area which had the fewest species, lowest abundance, and least diversity and evenness. This compares to either associations I or V which had much higher values for all of these measures. The top five species characterizing this association, in order of abundance were Arctic cod, *L. raridens*, *M. verrucosus*, *G. tricuspis*, and *C. harengus pallasi*. Association I had the most species, the top five of which were Arctic cod, *Myoxocephalus* sp., *H. robustus*, *G. tricuspis*, and *L. palearis*.

Table 3.—Estimated mean abundance (fish/km^2), number of species, Shannon diversity, and evenness found in the six fish associations for the 21 most abundant species determined from the cluster analysis using the Bray-Curtis similarity index.

	Group					
Species	**1**	**2**	**3**	**4**	**5**	**6**
Boreogadus saida	43733	16419	5280	8172	16096	6100
Eleginus gracilis	684	2	170	19	10956	0
Myoxocephalus sp.	3391	49	44	2	4492	0
Gymnocanthus tricuspis	1005	87	889	156	2618	7
Hippoglossoides robustus	1599	72	0	61	15	3
Myoxocephalus verrucosus	178	0	429	177	773	9
Artediellus scaber	20	0	0	11	1061	4
Theragra chalcogramma	69	0	0	26	861	0
Triglops pingeli	70	3	120	59	722	0
Mallotus villosus	437	0	0	40	0	0
Lycodes palearis	453	0	0	7	0	0
Clupea harengus pallasi	195	0	0	139	323	0
Lumpenus fabricii	235	18	2	14	141	0
Lycodes polaris	260	64	2	0	6	0
L. raridens	76	7	4	284	13	5
Podothecus acipens	60	0	18	5	280	0
Gadus macrocephalus	21	0	1	6	273	0
Liparis gibbus	129	2	0	15	29	0
Osmerus mordax	0	0	0	0	258	0
Hemilepidotus papilio	89	0	0	13	0	0
Artediellus sp.	80	0	0	0	20	0
NUMBER OF SPECIES	20	10	11	18	18	6
SHANNON DIVERSITY	0.35	0.05	0.37	0.25	0.72	0.02
EVENNESS	0.27	0.05	0.35	0.20	0.57	0.02

The objective of the discriminant analysis was to determine the extent the cluster analysis groupings using Bray-Curtis similarity matrix, based on abundance, could be differentiated using environmental variables. Bottom salinity and percent gravel were the key factors which separated assemblage groups, the first axis accounting for 72% and the second axis 28% of the variation (Table 4). Bottom salinity showed the strongest association with axis 1 whereas percent gravel was strongest in axis 2. The different associations outlined in the cluster analysis are readily apparent on the plot of the two ordination axes (Figure 5). The lines superimposed on Figure 5 enclose stations of similar environmental conditions. There is relatively little overlap of groups III and V, the former characterized by low salinity and high gravel whereas the latter is intermediate in salinity and gravel (Figure 5). Stations 14 and 15 classified together, having the lowest salinity and percent gravel of the groups. There is overlap at the peripheries of groups I and VI suggesting a gradation in environmental conditions. Group VI is more saline but consists of a wide range of percent gravel.

Our data clustered into six groups and one unclassified station. Based on the first two of seven probabilities (Mahalanobis D-square) of association in the discriminant analysis, 33 of 41 (80.5 %) station classifications using bottom salinity and percent gravel agreed with our cluster analysis groupings based on abundance of each species. To emphasize the different classification of the eight stations and overlap between associations, the ordination is replotted (Figure 5, lower panel) but stations are coded with symbols used in the cluster analysis. The superimposed lines again enclose stations of similar hydrographic conditions.

Table 4.—Discriminate function analysis of environmental factors with Chukchi Sea fish abundance as the class criterion.

	STANDARDIZED DISCRIMINANT FUNCTION COEFFICIENTS	
Dependent	**1st Axis**	**2nd Axis**
Bottom Salinity	0.94189	0.48469
Percent of Gravel	-0.14688	1.04905
Percent Variance	71.81	28.19
Eigenvalue	1.887	0.741

Principal component analysis, which includes all environmental data, qualitatively supports the discriminant analysis but also suggests other variables are important determinants of fish associations (Table 5). In the first dimension, which accounts for 31.8% of the variance among stations, high loadings occur for bottom salinity, depth, and gravel. An additional 27.8% of the variation is accounted for by the second dimension in which epifaunal and infaunal abundances, and gravel have high loadings. The third dimension, which accounts for an additional 15.6% of variation, has high loadings on gravel and sand.

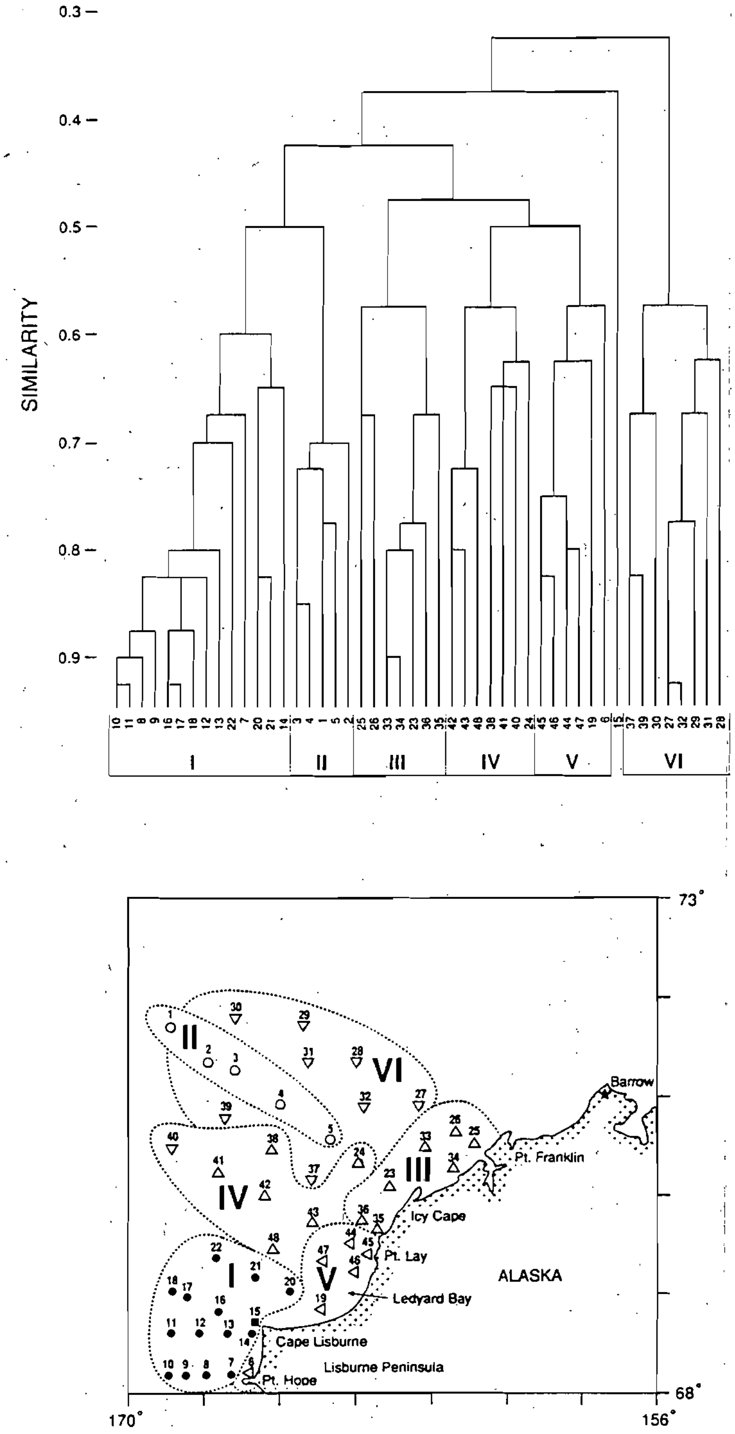


Figure 4. Similarity dendogram and demersal fish associations for fishes captured in the northeastern Chukchi Sea, Alaska, during 1990. The decision criteria for determining association was a similarity index of 0.5 - 0.6.

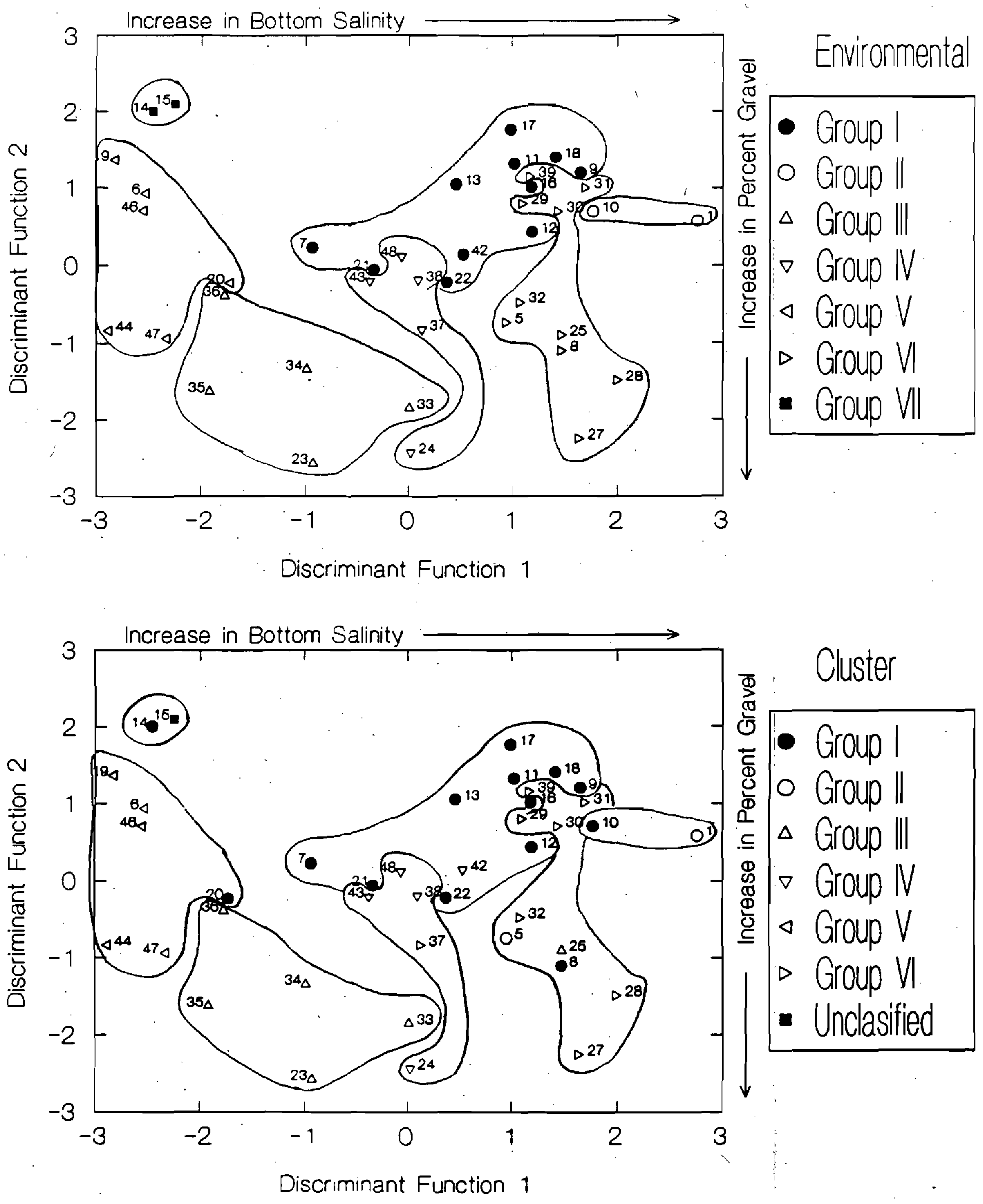


Figure 5. Station groupings formed in the discriminant function analysis based on environmental data. To demonstrate the differences in classification of eight stations, station associations of the upper panel are replotted in the lower panel with symbols used for the associations determined in the cluster analysis of Figure 4.

Table 5.—Results of the principal component analysis using both environmental factors, and infaunal and epifaunal abundance.

Variable	**PC1**	**PC2**	**PC3**
Sand	0.563	-0.451	-0.643
Gravel	0.663	-0.421	0.771
Depth	-0.796	0.398	-0.238
Bottom salinity	-0.882	0.118	0.105
Epifaunal abundance	0.461	0.861	0.060
Infaunal abundance	0.318	0.880	0.040
Cumulative variance	0.371	0.649	0.805
Eigenvalue	2.596	1.951	1.095

DISCUSSION

Based on sediment distribution, hydrography, and infaunal and epifaunal molluscs of the area, we hypothesized that there would be differences in abundance and biomass of fishes occupying the different water masses in the northeastern Chukchi Sea and that fish communities would relate to infaunal and eipfaunal invertebrate communities previously identified. We found that abundance and biomass of fishes are generally arranged in an onshore-offshore and north-south configuration. Further, species richness decreased from south to north. The distribution of fish associations was also related qualitatively to the infaunal and epifaunal mollusc associations found by Feder *et al.* (Chapter 10), i.e., the several nearshore and offshore fish associations were similarly distributed as the mollusc associations..

The total of 66 species, 56 in 1990 and an additional 10 species in 1991, collected in this study is considerably more than has been collected in previous studies in the area. The total number of species varied from only one (Arctic cod) at station 27 to 19 species at stations 6, 45, and 48 in 1990. In 1991 only one (Arctic cod) was found at station 21 with 24 species occurring at station 6. A common feature between the other studies and ours was the dominance of Arctic cod. In a trawl survey west of Pt. Barrow and western Beaufort Sea, Frost and Lowry (1983) found 19 species, with Arctic cod, Canadian eelpout (*Lycodes polaris*), twohorn sculpin (*Icelus bicornus*), and hamecon being the most common taxa. Fechhelm *et al.* (1985) surveyed primarily the along-shore waters of the area with several offshore stations sampled and captured 29 species with a trend of lower catch/unit effort (CPUE) from south to north and greater offshore than onshore. Fechhelm *et al.* found that, in addition to Arctic cod, the other most common species were capelin and Arctic flounder (*Liopsetta glacialis*). The number of species we collected, however, is somewhat similar to that collected by Alverson and Wilimovsky (1966) in the southeastern Chukchi Sea whose sampling extended as far north as Cape Lisburne. Alverson and Wilimovsky (1966) identified 52 species of which Arctic cod, capelin (*Mallotus villosus*), and Bering flounder were most common. They also commented that there was no "definite" pattern in abundance of the top 10 species.

The number of species we found (66) in the northeastern Chukchi Sea is comparable to other areas. Day and Pearcy (1968) found 67 species representing 21 families offshore of central Oregon in depths of 40 to 1,829 m. In contrast, Pearcy (1978) sampled seven stations off Oregon found between 19 and 35 species at depths of 74 to 195 m. Fargo and Tyler (1991) report more than 50 species of groundfish in Hecate Strait, British Columbia. Oviatt and Nixon (1973) found 99 species in Narragansett Bay, 10 of which accounted for 91% of the catch. Merrett *et al.* (1991) found 43 species in 15 families at depths of 2,230 to 4,787 m in the eastern North Atlantic. In contrast to numbers of species, species diversity indices seem to be somewhat lower than that reported for other areas and more in the range observed in areas stressed by anthropogenic sources. Diversity indices in our study varied from 0.20 (station 18 but was zero at other stations previously mentioned where only Arctic cod were found) to 1.87 (station 14 off Cape Lisburne) and 1.99 (station 45 off Pt. Lay). Percy (1978) found diversity (H_e) ranging from 0.7 to 2.47. Oviatt and Nixon (1973) found that species diversity indices varied from about 1.5 in January to 3.0 in September. In a polluted estuary of the Port of Boston Haedrich and Haedrich (1974) calculated indices which varied from 0.33 in August to 1.03 in March. Bechtel and Copeland (1970) investigated diversity in relation to pollutants in Galveston Bay, found indices to vary from 0.89 in February to 1.59 in July with some sites as low as 0.022 - 0.091. Because of the differences in effort and area covered, however, it should be cautioned that these comparisons of species numbers and diversity are qualitative.

At first inspection it appears that abundance and biomass is comparable to that found in more southern areas (Table 6). For example, in 1990 abundance ranged from 366 fish/km^2 (station 26) to 131,000 fish/km^2 (station 9) and biomass ranged from 2 kg/km^2 (station 29) to 2,228 kg/km^2 (station 9). Arctic cod, however, made up the majority of abundance and biomass in the study area and the proportion varied extensively. Abundance of Arctic cod made up a low of 0.23% and biomass 0.18% at station 15 off Cape Lisburne to a high of 100% at station 27 northwest of Pt. Franklin. Thus, even though total abundance and biomass seems comparable to other studies (Table 6), it consists primarily of Arctic cod and abundance and biomass of the remaining species is very low.

Table 6.—Standing crop, abundance (fish/km^2) and biomass (kg/km^2) for fishes from other representative studies.

Area	**Abundance**	**Biomass**	**Authors**
Norton Sound Nearshore	-----	320	Wolotira *et al.*, 77
Norton Sound Offshore	-----	159	Wolotira *et al.*, 77
Bering Sea Nearshore	-----	639	Wolotira *et al.*, 77
Bering sea Offshore	-----	351	Wolotira *et al.*, 77
Narragansett Bay	8,400	9,000-30,000	Nixon & Oviatt 73
Continental Oregon	14,000-40,000	900- 2,200	Pearcy 78
Coral Reef	-----	58,000	Bardach 59
Kelp Forest	-----	33,000-37,000	Quast 68
Embayment	-----	335,000	Nixon & Oviatt 73
Chukchi Sea	366-13,100	2.1- 2,229	Current Study

There is a qualitative similarity in the distribution of fish abundance, biomass, and associations to the epifaunal molluscs (Feder *et al.* Chapter 10). Feder *et al.* found abundance and biomass of epifaunal molluscs highest at stations along the coast with very high values adjacent to Pt. Hope and north of Cape Lisburne. High infaunal abundance and biomass, however, occurred north of and adjacent to the bottom front associated with the Alaska Coastal Current and along the coast north of Icy Cape and adjacent to or north of Cape Lisburne. Feder *et al.* also described six infaunal and five epifaunal assemblages. Significant to the current study, we found several nearshore and offshore fish assemblages which were configured somewhat similarly to the epifaunal mollusc assemblages found by Feder *et al* (Chapter 10).

The qualitative similarities between our study and that of Feder *et al.* (Chapter 10) suggests that there are common variables influencing the distribution of organisms inhabiting the area. In our study the results of the multivariate analyses using environmental data yielded similar patterns of classification; 80% of the stations were classified similarly in the discriminant analysis on salinity and percent gravel as they had been classified in the cluster analysis. Moreover, the principal component analysis accounted for 75% of the variation in station classification with heavy loadings on bottom salinity and percent gravel. The principal component analysis also suggests other variables are important, besides heavy loadings on bottom salinity and gravel, there were heavy loadings on depth, and infauna and epifaunal abundance. Other studies have found relationships between sediment type (Scott 1982), salinity and temperature (Jahn and Backus 1976; Mahon and Smith 1989), depth (Day and Pearcy 1968; Fargo and Tyler 1991), and organic matter (Oviatt and Nixon 1973). The influences of these factors are difficult to discern, undoubtedly due to their varying in concert and interactions between them. As an example, Fargo and Tyler (1991) found associations related to depth and sediment type where sediment type was different for each species association. Species-associations and sediment type, however, did not exactly coincide; two sediment types were found in the same depth range of species-associations. They suggested that faunal similarities were maintained in regions of sediment transition and factors other than sediment type governed distribution of associations. Similarly Pearcy (1978) found a clear separation of the effects of depth but not sediment for two associations, one shallow and one deep. There was, however, an interaction between depth and sediment type where the shallow assemblage showed a high similarity between stations of different sediment types. Although Pearcy did not find a significant relationship between sediment type and total abundance, he did find a significant relationship with particular flatfish species. For example, higher catches of the slender sole (*Lyopsetta exilis*) were found on clay/silt sediments and low catches on sandy sediments. In contrast the Pacific sandab (*Citharichthys sordidus*) showed the opposite relationship. Although depth has been found to be a factor influencing fish associations, in our case it seems surprising that it entered the principal component analysis; the depth profile of the study area is characterized as gradual and shallow except for off Pt. Franklin (Figure 1).

If the associations we identified were a constant feature of the area and unaffected by the variation in hydrography, we would expect to find no significant (statistical) differences between years in species ranks at stations sampled both years. Additionally, those stations resampled in 1991 would also classify in the same association when included with the 1990 data. Three of the 8 stations sampled both years were significantly (Table 2) different between years in species rankings. These three stations also classified with other associations when the data from those stations resampled in 1991 are combined with the 1990 and similarities are recalculated. At those stations which were not significantly different between years there still were considerable differences in abundance between years (Table 2). For example, there were an estimated 61,000 fish/km^2 at station 6 in 1990 but only 29,000 fish/km^2 in 1991.

The age structure of Arctic staghorn sculpin and Bering flounder, and interannual differences in the Alaska Coastal Current (ACC) suggest there is considerable instability in the hydrography of the northeastern Chukchi Sea. Whether our observed assemblages and their location are permanent features of the area is unclear. Smith *et al.* (Chapter 5) found that 42% of the Arctic staghorn sculpin sampled in 1990 consisted of fish older than four years. In 1991 the number of fish in these age categories represented only 9% of the total. For Bering flounder in 1990 Smith *et al.* (Chapter 6) found that ages ranged from 1 to 11 with age class 5 dominating. This differs considerably with Pruter and Alverson (1962) who found ages ranging from 6 to 13 with ages 7 through 9 making up 90% of the total number of fish. Finally, the strong coherence between wind directions and direction of the ACC (Weingartner, Chapter 3) causes periodic southerly reversals of the ACC (Johnson 1989; Weingartner Chapter 3) which can be prolonged. This in turn causes considerable variation in the flow into the Chukchi Sea and potential transport of adult and larval fishes into the area. This could cause, in part, a lack of coherence in fish associations between years.

Although considerable instability in the areal distribution and abundance of fish species and therefore associations is suggested, this may not lead to different associations and their locations. Overholtz and Tyler (1985) concluded that, even though some assemblages changed dramatically in species richness and relative abundance, the spatial integrity of each complex remained constant over time. Similarly there were seasonal changes in species associations on the Scotian Shelf but they were relatively constant over nine years within seasons (Mahon and Smith 1989). Colvocoresses and Musick (1984) examined nine years of trawl data from the Middle Atlantic Bight. The distributional patterns were largely structured by temperature on the inner- and mid-shelf and by depth on the outer shelf and shelf break. They also found there was sedimentary and topographical uniformity of the inner- and mid-shelf with no strong species group-sedimentary relationships. Temporally, as with Mahon and Smith (1989), they found good geographic definition in both autumn and spring groups with overlap between groups. The groups which made up the communities differed between seasons but simultaneously had much in common. Colvocoresses and Musick also found relationships between groups and depth, and shifts in the groups with changes in temperature. For example, the geographic extent of the associations varied between years depending on the southward extent of the cooler 8° C water. They concluded that the fish behave as a group in response to environmental variation.

The fish associations found in this study were depicted as having clear assemblage boundaries, each of which has a characteristic assemblage of species and proportions of each species, that are related to sediment type and hydrographic features. Although other characteristics may be determinants, as indicated by the principal coordinate analysis, the associations should undoubtedly be thought of as gradual shifts in species and proportions over transitional areas of these features as evident in the ordination plots (Figure 5). This is similar to the mesopelagic fishes of McKelvie (1985) who concluded that the associations were best interpreted as a gradation between faunas. The area could be viewed as a transition zone between the fish communities of northern Bering Sea and the southern Chukchi Sea, and the Arctic Ocean in which fishes of the northeastern Chukchi Sea are a mixture of the two fish communities. In this view the presence of the different species, their abundance and biomass vary, shifting somewhat offshore/onshore or northerly/southerly, with the shifts in the hydrographic structure of the area.

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CHAPTER 10

DISTRIBUTION OF MOLLUSKS IN THE NORTHEASTERN CHUKCHI SEA[1]

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Abstract.—Infaunal and epifaunal mollusks of the northeastern Chukchi Sea were sampled, and one hundred and thirty-nine molluscan taxa identified. The pattern of spatial distribution of molluscan species was determined by cluster analysis which resulted in six infaunal and five epifaunal station groups. Species characterizing various faunal groups are defined. Stepwise multiple discriminant analysis was applied to correlate benthic biological associations with environmental variables. Delineation of infaunal groups was mainly due to percentage of sand and bottom salinity while epifaunal groups were separated by percent gravel and bottom temperature. An increase in abundance and biomass of infaunal mollusks occurred adjacent to, and north and northwest of an identified bottom front between the Bering Shelf and Resident Chukchi Water, and Alaska Coastal Water. Epifaunal molluscan abundance and biomass were highest near the coast. Mollusks, especially smaller species and the juvenile stages of larger species, represent a food resource for bottom-feeding predators in the study area.

Key words: Chukchi Sea, mollusk, benthic, infauna, epifauna, bottom front, bottom - feeding predators, cluster analysis, discriminant analysis.

INTRODUCTION

Limited quantitative information is available for marine mollusks of the Chukchi Sea north of 68° 21' latitude and east of 170° 00' west longitude (Figures 1 and 2). However, an investigation of the infauna of this region by Feder *et al.* (1990) indicated that this group is an important one comprising approximately 20% of the abundance, 36% of the wet weight, and 40% of the carbon biomass of infauna collected. Studies by Stoker (1978, 1981) in the northeastern Chukchi Sea examined distribution, abundance, and biomass data for mollusks in conjunction with other infaunal organisms. Both Stoker (1978) and Feder *et al.* (1990) include interpretations of total infaunal distributions based on environmental parameters. The abundance and distribution of bivalves in the western Chukchi Sea are discussed in Filatova (1957). The distributional ecology of bivalves in the adjacent western Beaufort Sea is presented in Carey *et*

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[1] In press with Arctic for publication.

al. (1984). Qualitative reports on molluscan fauna in the general area are included in MacGinitie (1955) for the Point Barrow region, Ingham *et al.* (1972) and Mann (1977) in the eastern Chukchi Sea, and Frost and Lowry (1983) in the western Beaufort Sea. Supplemental information on the composition and general distribution of selected mollusks in these northern latitudes is also available from feeding investigations on walrus and bearded seals (Johnson *et al.* 1966; Fay, 1982; Lowry et *al.* 1980a, b). Additionally, a number of studies include information for molluscan fauna in the southeastern Chukchi Sea. Sparks and Pereyra (1966) present data from 1959 on the composition and relative abundance of mollusks south of Point Hope, although they include some data from stations north of Cape Lisburne. A trawl survey conducted in 1976 provides quantitative data on the epifauna, inclusive of mollusks and demersal fishes, in the area between Bering Strait and Point Hope (Wolotira *et al.* 1977; Feder and Jewett, 1978; and Jewett and Feder, 1981). Qualitative and quantitative sampling for epifauna and demersal fishes was conducted in 1982 in shallow waters (<15 m) in the Kivalina region, south of Point Hope (Blaylock and Erikson, 1983; Blaylock and Houghton, 1983). Information on infauna, inclusive of mollusks, is included in multi-year studies in the northern Bering and southern Chukchi Seas by Feder *et al.* (1985), Grebmeier (1987, 1992), Grebmeier *et al.* (1988, 1989), and Feder *et al.* (1990a,b).

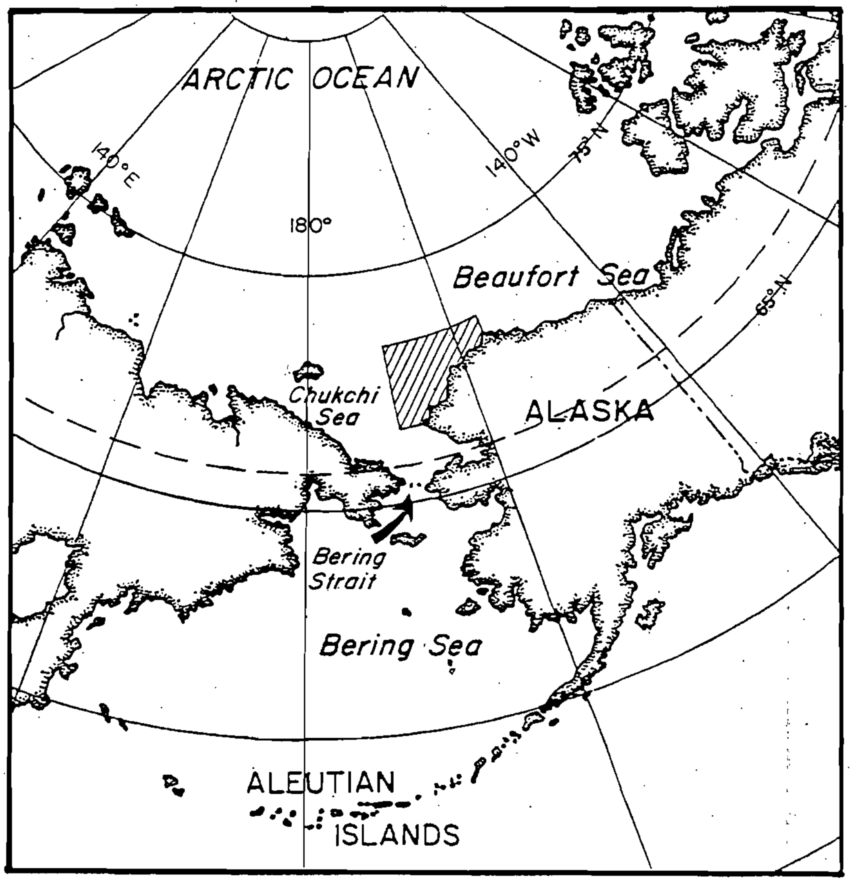

Figure 1. Location of the study area (cross hatched).

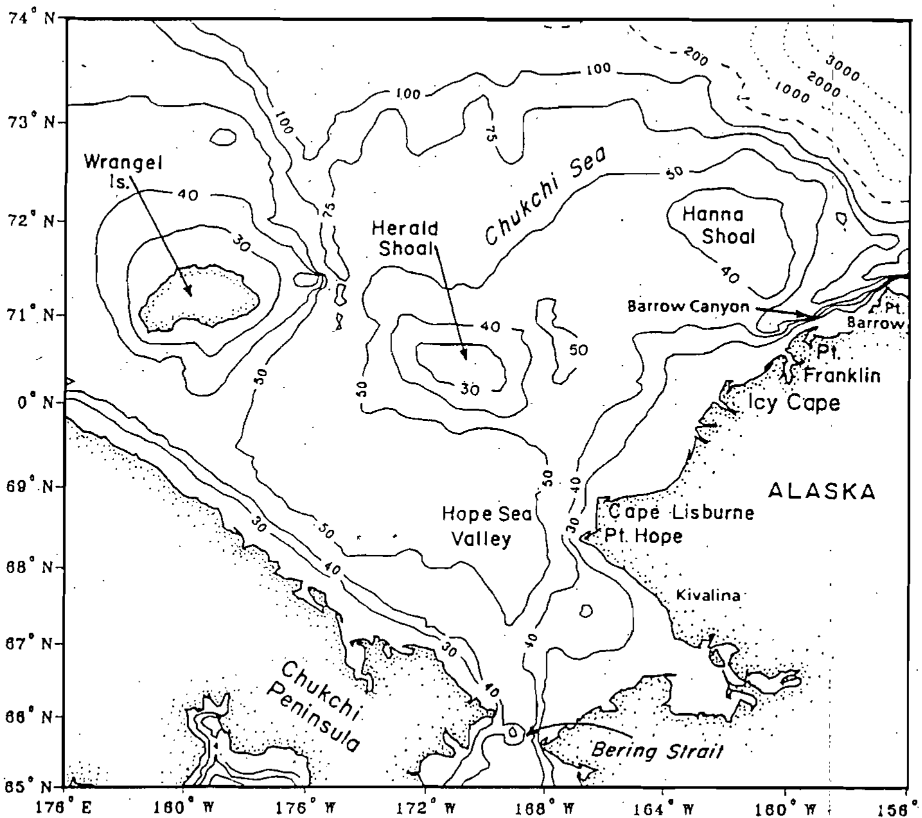

Figure 2. Bathymetry of the Chukchi Sea.

Taxonomic literature on mollusks of the northeastern Chukchi Sea is scattered among many sources. Because most mollusks within the study area are widely distributed in arctic and boreal seas, taxonomic descriptions are primarily included in publications relating to areas adjacent to the Chukchi Sea. MacGinitie (1959) describes the molluscan fauna near Point Barrow; Macpherson (1971) summarizes the gastropods, chitons, and scaphopods from the Canadian Archipelago; Bernard (1979) and Lubinsky (1980) provide useful descriptions of the bivalve fauna of the western Beaufort Sea and the eastern Canadian arctic, respectively. Mollusks from adjacent Japanese waters (including the Okhotsk and western Bering seas) are described in Okutani *et al.* (1988, 1989), and reference to these and other mollusks is also found in Pavloskii (1955). Foster (1981) and Baxter (1987) summarize the composition and distribution of molluscan fauna throughout Alaskan waters.

In this paper we consider the infaunal and epifaunal mollusks of the northeastern Chukchi Sea, and relate their abundance and biomass values to environmental parameters, and consider the importance of mollusks as food for benthic predators in the study area.

THE STUDY AREA

The northeastern Chukchi Sea is relatively shallow, with depths ranging between 30 and

60 m over most of the region (Figure 2). In general, bottom depth varies smoothly, although there are several important bathymetric features which influence both the flow and distribution of water masses. These features include (1) Barrow Canyon which strikes northeastward across the continental shelf and slope west of Point Barrow, (2) Hope Sea Valley, a broad, 55 m deep depression which trends northwestward from Point Hope, (3) Hanna Shoal to the west of Barrow Canyon, and (4) Herald Shoal in the center of the Chukchi Basin. The two shoals have minimum depths of about 25 m.

Circulation features and water-mass properties of the Chukchi Sea are discussed by Coachman *et al.* (1975), Walsh *et al.* (1989), Johnson (1989), and Weingartner (Chapter 2). Chukchi Sea waters reflect a combination of both advective and *in situ* processes with the most important of these being the northward advection of waters through Bering Strait. This flow bifurcates offshore of the Lisburne Peninsula. One branch transports Bering Shelf Water (BSW) northwestward through the Hope Sea Valley but also northward along the eastern flank of Herald Shoal. This water mass is characterized by low temperatures (-1° to 2°C), high salinity (>32.5/psu) and relatively high nutrient and particulate organic carbon (POC) concentrations (Grebmeier *et al.* 1988; Walsh *et al.* 1989). In summer and fall, part of the northeastward flowing branch forms the Alaska Coastal Current (ACC) and consists primarily of Alaska Coastal Water (ACW). This water mass, which is heavily influenced by coastal freshwater discharge from the Yukon River and numerous smaller drainages along the western coast of Alaska, consists of relatively warm (>2°C) and dilute (<31.8/psu) water, with a high sediment load but low concentrations of nutrients and POC (Grebmeier *et al.* 1988). The Alaska Coastal Current flows inshore of and parallel to the 30 and 40 m isobaths and exits the Chukchi Sea through Barrow Canyon. A third water mass, Resident Chukchi Water (RCW), is either advected onshore from the upper layers of the Arctic Ocean and/or is ACW and BSW remnant from the previous winter when its salinity was increased and temperature decreased due to freezing processes. As noted by Johnson (1989) and Weingartner (Chapter 2), a bottom-intersecting front paralleling the 30 and 40 m isobaths is typically observed in summer and fall months. The front extends northward from the Lisburne Peninsula to about 71°N and then bends eastward toward Icy Cape and Pt. Franklin. ACW lies inshore of this front while BSW, RCW, and mixtures of these water masses lie offshore and to the north of the front (Johnson, 1989). Because ACW is less dense than BSW or RCW, ACW may also be observed at the surface and offshore of the bottom front. Year-long current meter records from 1991/92 and a fall 1992 hydrographic survey identified a persistent northward flow of BSW along the east flank of Herald Shoal (Weingartner, unpublished). Coachman and Shigaev (1992) and Whitledge *et al.* (1992) speculate that a fraction of the water flowing north along the Lisburne Peninsula is ultimately derived from the vicinity of Wrangel Island in the northwest Chukchi Sea. This high-salinity, nutrient-rich water is advected into the southeastern Chukchi Sea along the Siberian coast by the Siberian Coastal Current. They suggest that nutrients within this current supplement those derived from the Bering Sea to enhance annual primary production in the southcentral Chukchi Sea and contribute POC to the northeastern shelf (Grebmeier *et al.* 1988; Walsh *et al.* 1989). Occasionally, wind-induced reversal of the normal northeastern water flow along the coast is accompanied by upwelling (Wiseman and Rouse, 1980: Johnson, 1989). As discussed later, all the above observations have important effects on the distribution, abundance, and biomass of mollusks in the northeastern Chukchi Sea.

In the northeastern Chukchi Sea, the inner shelf between Point Hope and Point Barrow is carpeted by relatively coarse sediments. Further seaward are muds containing various proportions of gravel and sand (Naidu, 1987). Sediments of the more northerly offshore region have a higher percentage of water and lower percentage of gravel than the southern offshore area (Feder *et al.* 1990a). All sediments are very-poorly to extremely-poorly sorted. The central portion of the northeastern Chukchi Sea receives the major proportion of clayey sediments of Yukon River origin. Sediment is displaced from the Bering Sea via the net northward flow of water masses presumably as a nepheloid layer (McManus and Smyth, 1970). Sea ice covers the Chukchi Sea from November through June and can affect the benthos by ice gouging (Grantz *et al.* 1982; Carey, 1991). Polynyas can occur from Cape Lisburne to Point Barrow, generally extending seaward from just beyond the landfast ice (Stringer and Groves, 1991).

MATERIALS AND METHODS

Infaunal mollusks, and conductivity, temperature and depth (CTD) data, were collected in August-September 1986 at 37 stations in the study area (Figure 3a). Five replicate samples using a 0.1 m^2 van Veen grab were taken at each station. Epifaunal mollusks and associated physical oceanographic data were collected in August 1990 at 48 stations at similar depths to the 1986 collection, as part of a fish survey in the northeastern Chukchi Sea (Figure 3b; Smith *et al.* unpublished). Epifauna was obtained using a NMFS 83-112 otter trawl. The net had a 90 mm mesh cod end and a 32 mm stretched liner. Effective opening width of the net was 17.0 m. Two 30-minute tows were taken at each station. Sediment data are from Naidu (1987) and Feder *et al.* (1990a).

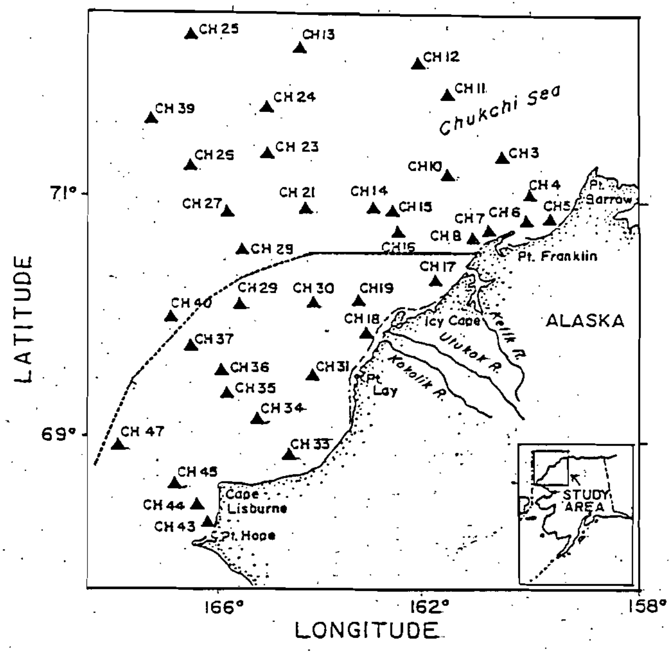

Figure 3a. Location of the infaunal sampling stations occupied in the northeastern Chukchi Sea by Feder *et al.* (1990a). Dashed line represents a bottom frontal zone that separates Bering Shelf and Resident Chukchi Water, offshore and to the north, from Alaska Coastal Water, inshore of the front.

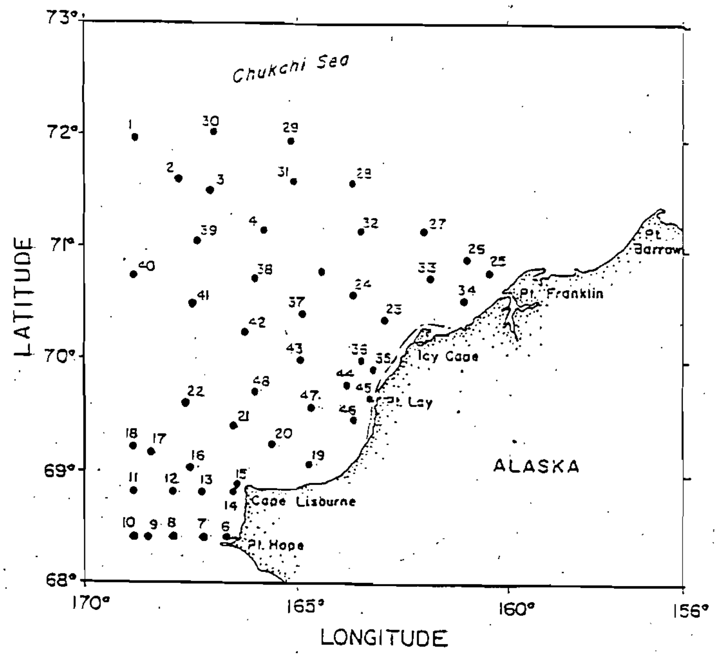

Figure 3b. Location map showing epifaunal sampling stations occupied in the northeastern Chukchi Sea in 1990 by Smith *et al.* (unpublished).

Specimens were identified to species or lowest possible taxon. Voucher specimens are deposited in the University of Alaska Museum Aquatic Collection, Accessions 1993-3 (specimens collected in 1986) and 1992-16 (specimens collected in 1991). Photographs of nine species, which are common in the study area, but have not been well illustrated in the literature, are included in this paper.

The 1986 infaunal collection of Feder *et al.* (1990a) extended farther north than the epifaunal sampling of 1990 (Smith *et al.*Chapter 5). Infaunal and epifaunal samples were collected by different gear types. Each infaunal sample represented a localized area while epifaunal data were derived from samples taken over a variable distance. Consequently, it was necessary to establish new station numbers for the epifaunal studies in August 1990. Thus, it was not technically possible to pool and analyze all molluscan data. Infauna and epifauna are treated separately here with some integrations of data included in the discussion.

Data used in the classification of stations consisted of taxon abundance values (infauna: ind/m^2; epifauna: ind/km^2). One species, (*Neptunea heros*) was eliminated in the epifaunal multivariate analysis because its high abundance and ubiquitous occurrence overwhelmed the variations among other species considered dominant. In order to normalize data, a log transformation (*ln* [X+1]) was applied prior to cluster analysis. The Czekanowski similarity coefficient was used for clustering (Bray and Curtis, 1957; Boesch, 1977). Top-ranked taxa in each station group and percent fidelity of these taxa to stations in each station group are presented. Stepwise multiple discriminant analysis (Davies, 1971), using the BMDP7M and SPSS Discriminant programs, was applied to biological data to correlate station group separation by cluster analysis with environmental variables. Such an analysis has been used elsewhere to test a biological model (e.g., station groups), with environmental parameters (Flint, 1981; Shin, 1982; Weston, 1988). Environmental variables used were sediment variables [particle size parameters, organic carbon (C), nitrogen (N), and C/N values], and bottom temperature and salinity. The percentage values for sediment grain-size distribution were arcsine transformed. Wet-weight values of infauna were converted to carbon by applying conversion values of Stoker (1978) determined for taxa in the same region. Only wet-weight values were used for the epifaunal analyses. Standard discriminant function coefficients are presented. These coefficients indicate the relative contribution of the variables in calculating the discriminant scores on each function, and are commonly used as measures of the relative importance of the variables in discriminating among groups (Green, 1971; Green and Vascotto, 1978). Infaunal stations were segregated into a northern and a southern group by the frontal zone identified by Johnson (1989), Feder *et al.* (1990a), and Weingartner (Chapter 2) and the differences between mean abundance and carbon biomass values for each group tested statistically. Statistical analysis of these data consisted of *t*-tests utilizing SYSTAT (Wilkinson, 1990). Prior to analysis, a square root transformation was applied to the data (Sokal and Rolf, 1969; Zar, 1974).

RESULTS

General.—Approximately 75 and 62 mollusk taxa were identified from the grab and the trawl samples, respectively. These taxa included 52 bivalves, 83 gastropods, three polyplacophorans, and one cephalopod. One hundred and thirty nine molluscan taxa were identified. All taxa are listed in Appendix I, along with comments on taxonomy.

Infauna.—Abundance values for the 37 stations sampled in 1986 ranged from 16 to 880 ind.m^{-2} with a mean of 248 ind/m^2. Biomass ranged from 0.007 to 15.02 gC/m^2 with a mean of 3.04 g C/m^2. Highest abundance and biomass values generally occurred north of and adjacent to the bottom front identified by Johnson (1989), Feder *et al.* (1990a) and Weingartner (Chapter 2) (Figures 4a,b). Some high values were also recorded adjacent to Point Hope and north of Cape Lisburne. At stations north and west of the bottom front, mean infaunal molluscan carbon biomass ($\bar{X}$=3.97; S.D.=3.48) was significantly higher (P=0.01) than at the southern stations ($\bar{X}$=1.72; S.D.=1.53).

Protobranch bivalves dominated infaunal abundance and biomass, and were widely distributed. *Nucula tenuis* was present at 29 stations, primarily where muddy substrate prevailed. Other protobranch species, *Nuculana radiata, Yoldia hyperborea*, *Y. scissurata*, and *Y. myalis*, were more localized in their distribution. Three species of heterodont bivalves (*Astarte montagui, A. borealis*, and *Cyclocardia ovata*) also had high abundance and biomass values but more patchy distributions. The heterodont bivalve *Macoma calcarea* was widely distributed (present at 24 stations), but mainly dominated infaunal abundance and biomass within the muddy, northern offshore region and stations just north of Cape Lisburne. The heterodont bivalves *Astarte montagui, A. borealis* and *C. ovata* were more common in gravelly substrates, while *Thyasira gouldi* (present at 25 stations), was most abundant off Point Hope at Station 44.

Although a few gastropod taxa were relatively common, compared to bivalves, they were far less abundant. The relationship between small gastropod species collected in the study area and sediment parameters is not known. The opisthobranch gastropods *Cylichna alba* and *Retusa obtusa* were present at 19 and 11 stations, respectively. Common prosobranch gastropods included *Tachyrhynchus erosus* and the trochids, *Solariella varicosa* and *S. obscura.* Turridae, mostly unidentified species of *Oenopota*, were occasionally common.

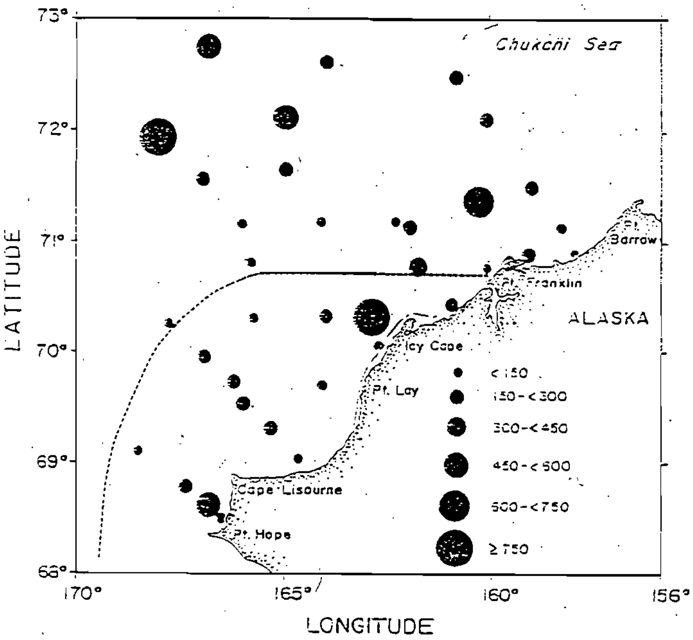

Figure 4a. Abundance (ind/m^2) of infaunal mollusks in the northeastern Chukchi Sea. Dashed line represents a bottom frontal zone that separates Bering Shelf and Resident Chukchi Water, offshore and to the north, from Alaska Coastal Water, inshore of the front.

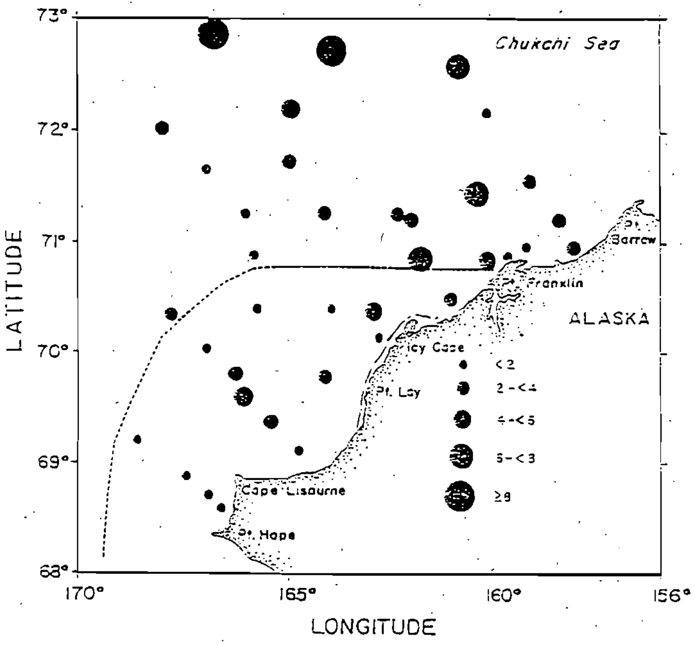

Figure 4b. Carbon biomass (gC/m^2) of infaunal mollusks in the northeastern Chukchi Sea. Dashed line represents a bottom frontal zone that separates Bering Shelf and Resident Chukchi Water, offshore and to the north, from Alaska Coastal Water, inshore of the front.

From the recurrence of stations in the cluster analysis of abundance data (Figure 5), six station groups were determined (Figures 5 and 6). One station adjacent to Point Hope, Station 43, and one station north of Cape Lisburne, Station 33, were not classified based on the distinct faunal composition of each of these stations (Table 1). The dominant fauna (present in 50% or more of stations in a station group) characterizing each station group and the percent occurrence of dominant taxa at stations comprising the groups are included in Table 1. Abundance varied from 42 ind/m^2 within inshore Group VI to 388 ind/m^2 in northern offshore Group I; carbon biomass varied from 0.9 gC/m^2 within inshore Group IV to 5.4 gC/m^2 in Group I (Table 2). The highest abundance and carbon biomass occurred within offshore Station Group I. The largest numbers of *N. tenuis* and *M. calcarea* were found within Group I; abundance of both of these species was considerably less at Groups II and III, the other offshore groups. Group III comprised a mixture of taxa characteristic of inshore and offshore stations, and had the second highest carbon biomass value for station groups. Group IV, extending northwest of Cape Lisburne, was distinguished by large numbers of the bivalve *Thyasira gouldi* with most other taxa in low abundance. Group VI, a sandy-gravelly inshore site just south of Icy Cape, had one of the lowest number of taxa and lowest abundance of mollusks, as well as total infauna (Feder *et al.* 1990a); also, the lowest carbon biomass of infaunal mollusks occurred within this station group. This station group was the only one at which the protobranch bivalve *Y. scissurata* occurred. Substrate at inshore Group V, north of Group VI, comprised a higher percentage of gravel, and had the highest number of taxa of all groups.

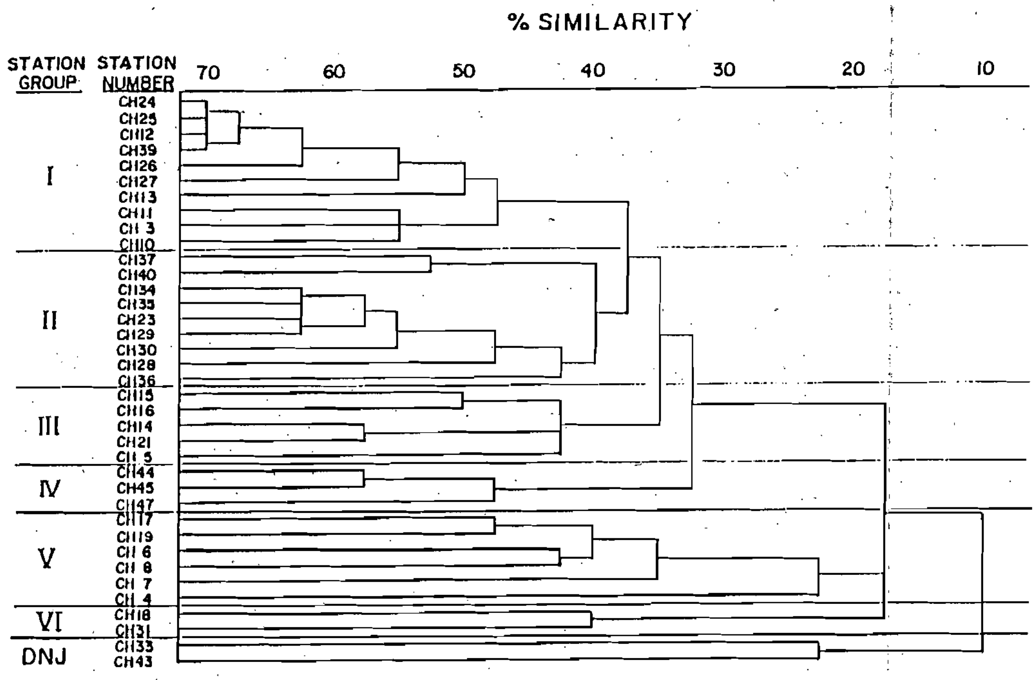

Figure 5. Dendogram showing grouping of stations based on a cluster analysis of infaunal molluscan abundance data. DNJ=Did not join any group.

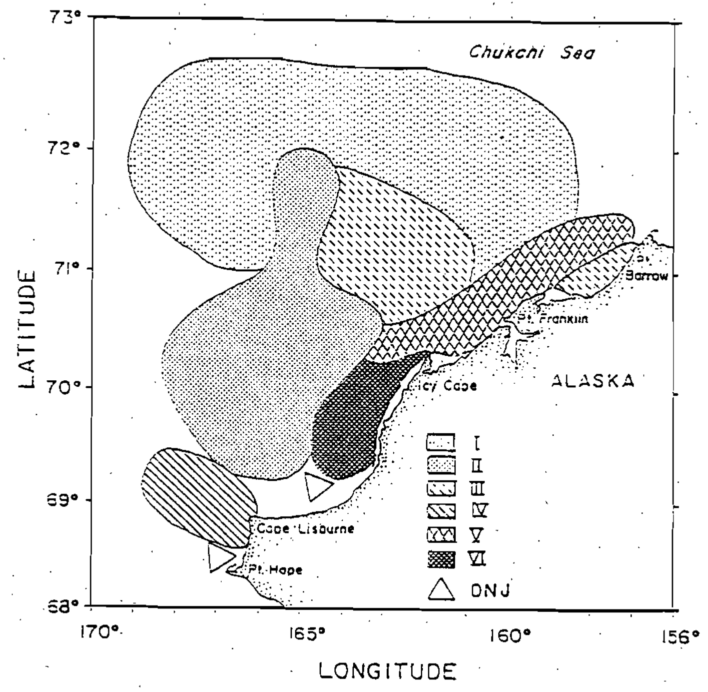

Figure 6. Infaunal molluscan assemblages in the northeastern Chukchi Sea based on cluster analysis.

Table 1.—Infaunal molluscan abundance dominants within six stations groups and two stations not classified. Taxa occurred at 50% or more of the stations within a station group. DNJ= Did not join a station group.

Station Group	Stations in Group	Taxa	Abundance (ind/m^2)	% Occurrence in Group[1]
I	3 10 11	*Nucula tenuis*	196	100
	12 13 24	*Macoma calcarea*	88	100
	25 26 27	*Thyasira gouldi*	17	90
	39	*Yoldia hyperborea*	14	80
		Nuculana radiata	14	50
		Retusa obtusa	11	90
		Mysells sp.	8	60
		Cylichna alba	8	70
II	23 28 29	*Nucula tenuis*	98	100
	30 34 35	*Thyasira gouldi*	14	89
	36 37 40	*Macoma calcarea*	6	56
		Tachyrhynchus erosus	5	89
		Solariella varicosa	4	78
		Cylichna alba	4	56
III	5 14 15	*Nucula tenius*	70	100

Table 1. continued

Station Group	Stations in Group	Taxa	Abundance (ind/m^2)	% Occurrence in Group[1]
III cont.	16 21	*Astarte montagui*	16	100
		Cyclocardia ovata	10	100
		Astarte borealis	9	80
		Solariella obscura	6	100
		Cylichna alba	5	80
		Oenopota sp.	5	100
		Propebela sp.	5	60
IV	44 45 47	*Thyasira gouldi*	105	67
		Nucula tenius	65	100
		Nuculana radiata	57	100
		Retusa obtusa	8	67
		Tachyrhynchus erosus	3	67
		Polinices pallidus	3	100
V	4 6 7 8 17 19	*Cyclocardia ovata*	123	83
		Astarte montagui	29	100
		Liocyma viride	25	83
		Yoldia myalis	14	50
		Mysella sp.	13	83
		Ainopsida serricata	8	50
		Musculus spp.	7	100
		Hiatella arctica	5	50
		Polinices pallidus	4	100
VI	18 31	*Yoldia scissurata*	12	100
		Thyasira gouldi	5	50
		Macoma calcarea	4	100
		Clinocardium ciliatum	4	100
		Liocyma viride	3	50
		Liocyma fluctuosa	2	50
		Natica clausa	2	50
		Tellina lutea	2	50
		Cylichna alba	2	100
DNJ	33	*Musculus* spp.	26	
		Cylichna alba	4	
		Nucula tenuis	2	
		Yoldia myalis	2	
		Oenopota spp.	2	
DNJ	43	*Musculus* spp.	10	
		Hiatella arctica	6	

Table 1. continued

Station Group	Stations in Group	Taxa	Abundance (ind/m^2)	% Occurrence in Group[1]
DNJ cont.		(no other molluscan taxa were present)		

[1]The value for each taxon in the column of % Occurrence in Group is based on the number of stations at which the particular taxon occurs.

Table 2.—Number of taxa, abundance, and biomass of infaunal taxa, by station group.

Station Group	Number of Taxa	Abundance (ind/m^2)	Wet Weight Biomass (g/m^2)	Carbon Biomass (gC/m^2)
I	44	388	147	5.4
II	35	168	51	1.8
III	46	201	134	3.5
IV	13	260	20	0.9
V	50	300	70	2.9
VI	15	42	43	0.28

Table 3 shows the results of multiple discriminant analysis of the environmental conditions relative to infaunal station groups determined by multivariate analysis. The discriminant functions (DF) 1 and 2 contribute nearly 85% of the total separation among the groups ($P \leq 0.001$), and 76% of the stations were classified correctly according to station group. Only these functions are considered further in the interpretation. After the final step in the discriminant analysis, F statistics between pairs of station groups showed significant differences ($P \leq 0.003$) in all comparisons except one (Group I vs Group III). Nevertheless, the comparison between the latter two groups was marginally significant ($P=0.06$). The low negative value along the DF 1 is due to percent sand (Figure 7). The high positive value along DF 2 is the result of bottom salinity (Figure 7). The centroid of Group VI is well separated from the other groups along the axis of DF 1. Also, the centroids of Groups II, IV, and V are separated from Groups I and III along DF 1. The centroid of Group IV is well separated from the other groups along the axis of DF 2. Also, the centroids of Groups I, III, and V are separated from Groups II and IV along the axis of DF 2. The separation of inshore Group VI from the other groups is due to the higher percentage of sand at the Group VI stations. Alternatively, offshore Groups I, II and III, and southern inshore Group IV off Cape Lisburne are distinguished by the lower percentage of sand (i.e., presence of more mud) within stations of these groups. The low bottom salinity for Group IV differentiates it from the other station groups. The highest salinity occurs at stations of northern offshore Groups I and III, and northern inshore Group V, which separates them from the other groups.

Table 3.—Results of the discriminant analysis of the environmental conditions among the six infaunal station groups. *Significance at P ≤ 0.001.

Discriminant Function	1	2	3
Percent separation	48.73	35.95	15.31
Cumulative percent separation	48.73	84.69	100.00
Test of significance Chi-squared value	87.88*	49.99*	18.11
Degrees of freedom	15	8	3

Variables and Standardized Discriminant Function Coefficient			
Percent sand	-0.82	0.29	-0.53
Salinity	0.26	1.00	-0.18
OC/N	-0.26	0.49	0.89

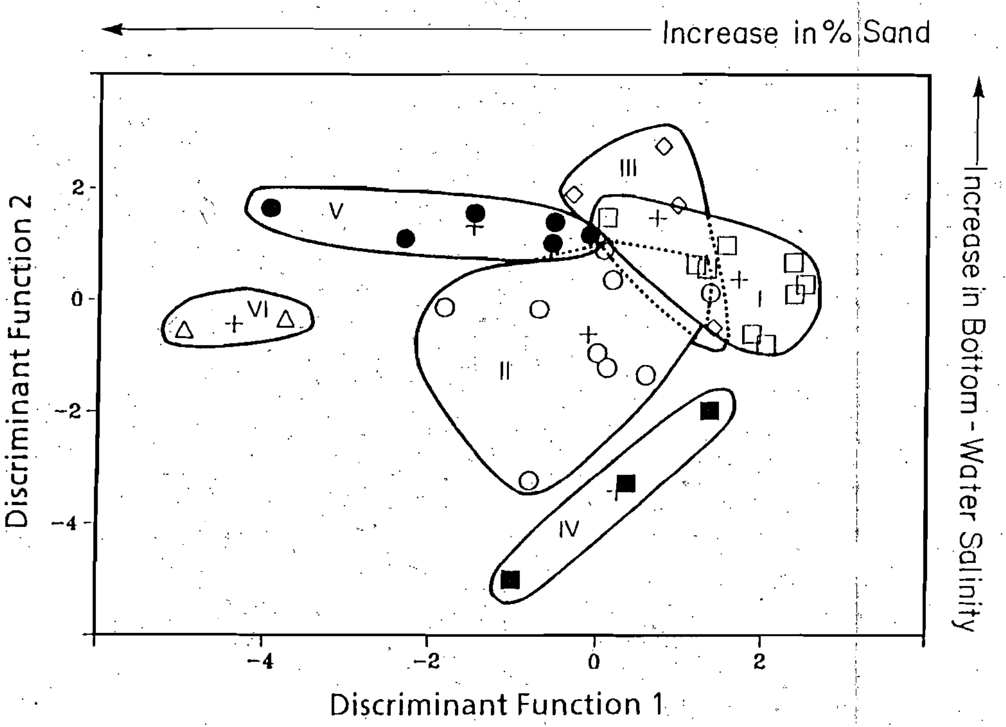

Figure 7. Station and station group plot from stepwise multiple discriminant analysis of molluscan infauna utilizing environmental variables. + = the centroids of the station groups. Sediment values used in the analysis based on dry weights.

Epifauna.—Abundance values from the 48 stations sampled in 1990 varied from 170 to 71,817 ind/km^2 with a mean of 4,227 ind/km^2. Wet-weight biomass ranged from 0.29 to 47.28 kg/km^2 with a mean of 6.42 kg/km^2. Abundance and biomass were highest at stations nearest the coast, with particularly high values west and north of Cape Lisburne and near Point Franklin (Figures 8a and 8b).

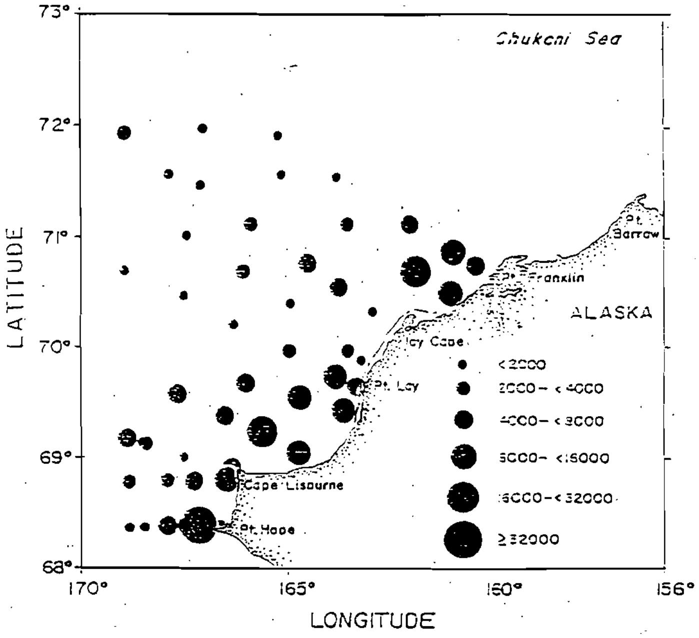

Figure 8a. Abundance (ind/m^2) of epifaunal mollusks in the northeastern Chukchi Sea.

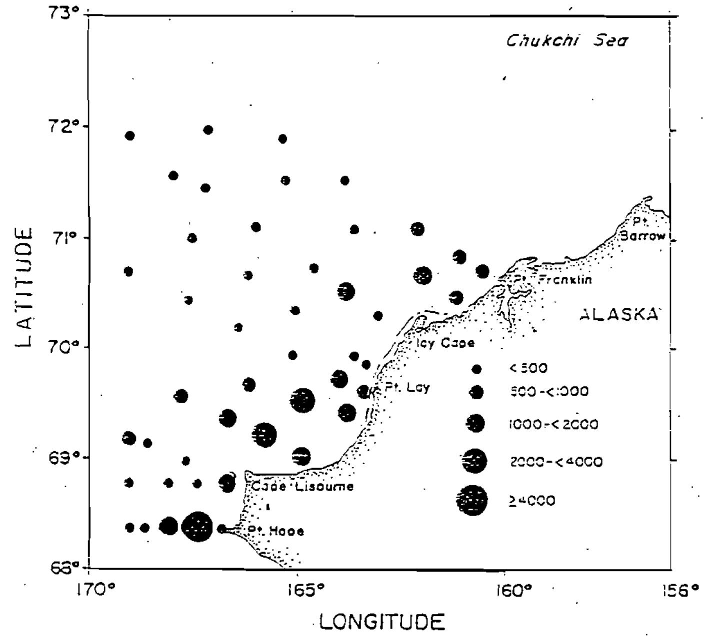

Figure 8b. Biomass (kg/km^2) of epifaunal mollusks in the northeastern Chukchi Sea.

Gastropods made up the greatest portion of the molluscan epifauna in abundance and biomass. The gastropod *Neptunea heros* (Figure 9a) occurred at all stations, and was typically the most abundant mollusk present. Two other species of *Neptunea*, *N. ventricosa* (Figure 9b), and *N. borealis* (Figure 9c), were nearly as common, occurring at 35 and 45 of the stations, respectively. Other common neptunids included *Volutopsius deformis*, *V. stefanssoni* (Figure 10a), *V. fragilis* (Figure 10b), *Beringius stimpsoni* (Figure 11a), and *Plicifusus kroyeri*. Also generally common were buccinids [*Buccinum angulosum*, *B. polare*, *B. scalariforme*, *B. solenum* and *B. tenellum* (Figure 11b, c)] and naticids (*Polinices pallidus* and *Natica clausa*). The internal-shelled prosobranch *Onchidiopsis* had a wide distribution, but whether one or more species was present is uncertain.

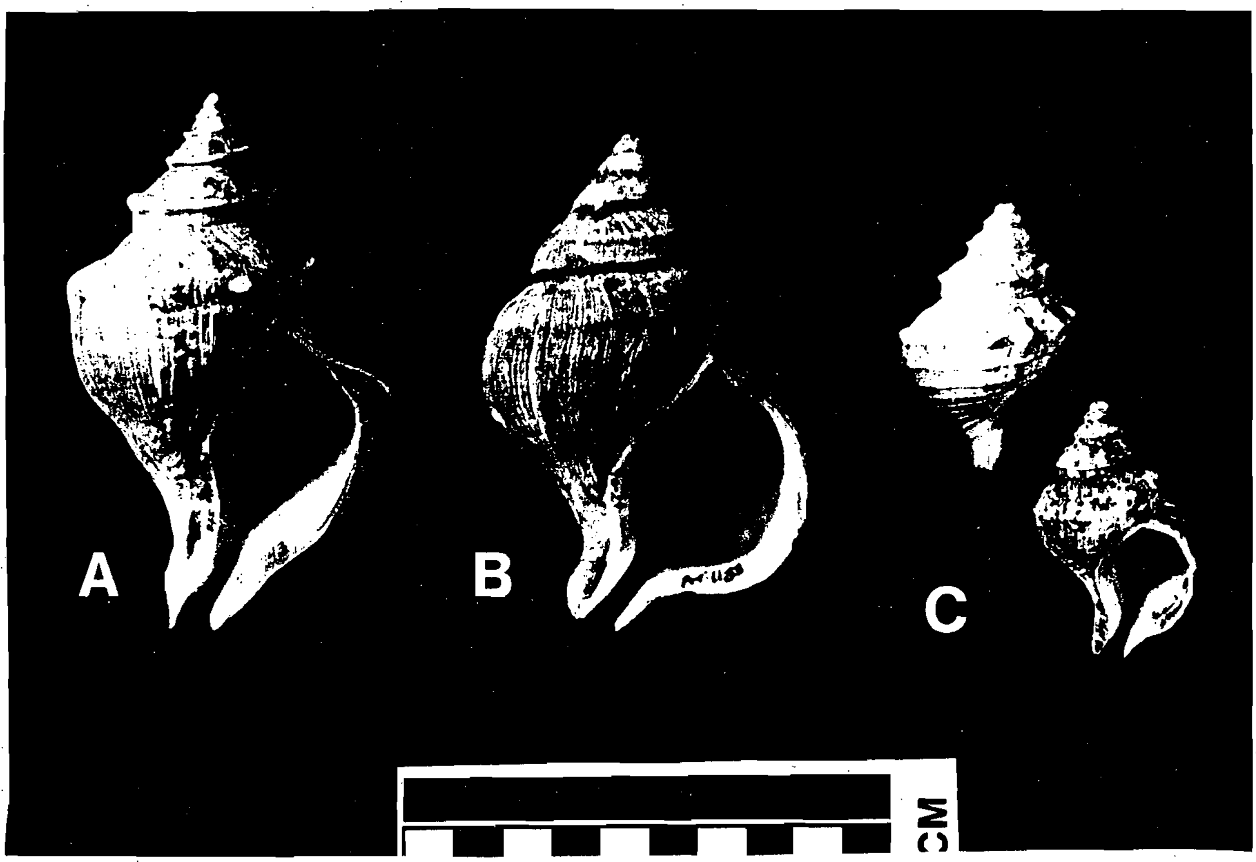

Figure 9a. *Neptunea heros,* 9b. *Neptunea ventricosa,* and 9c. *Neptunea borealis.*

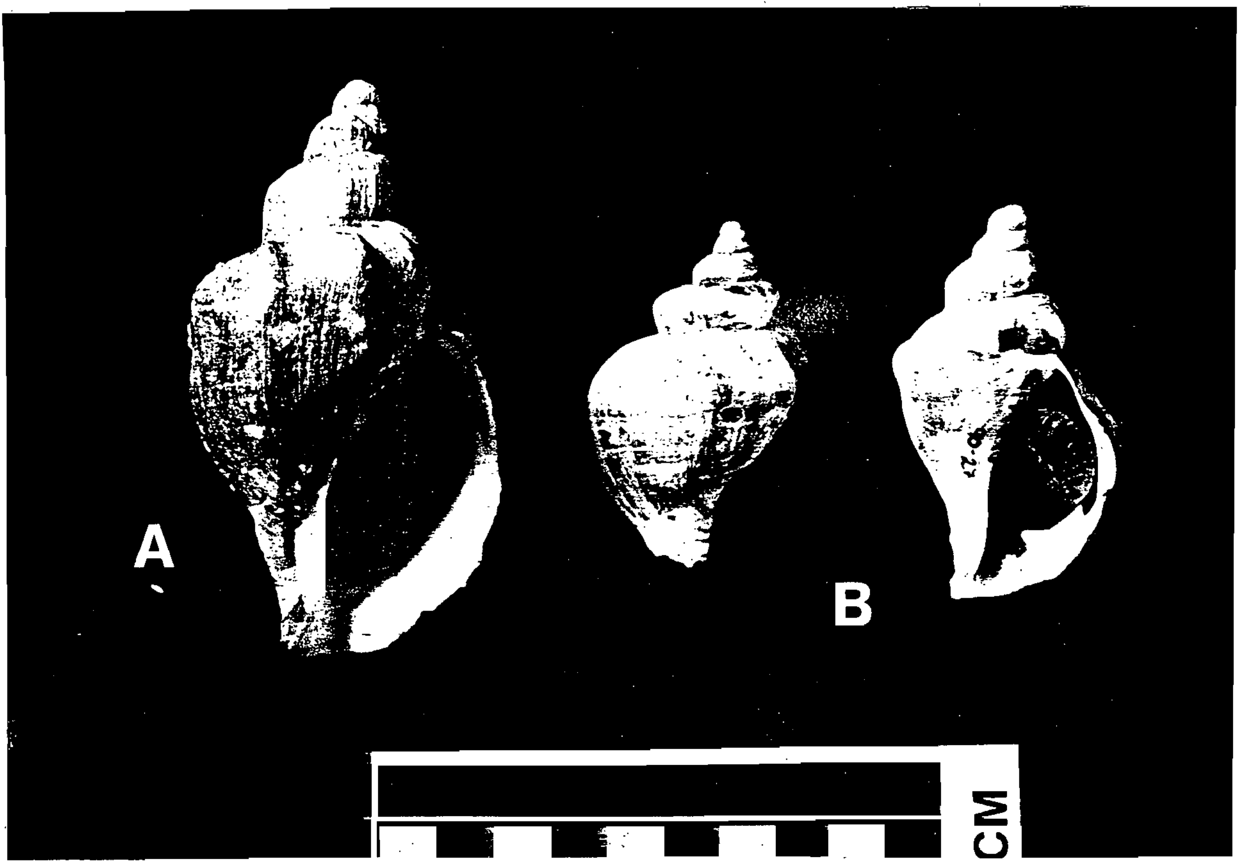

Figure 10a. *Volutopsius stefanssoni,* and 10b. *Volutopsius fragilis.*

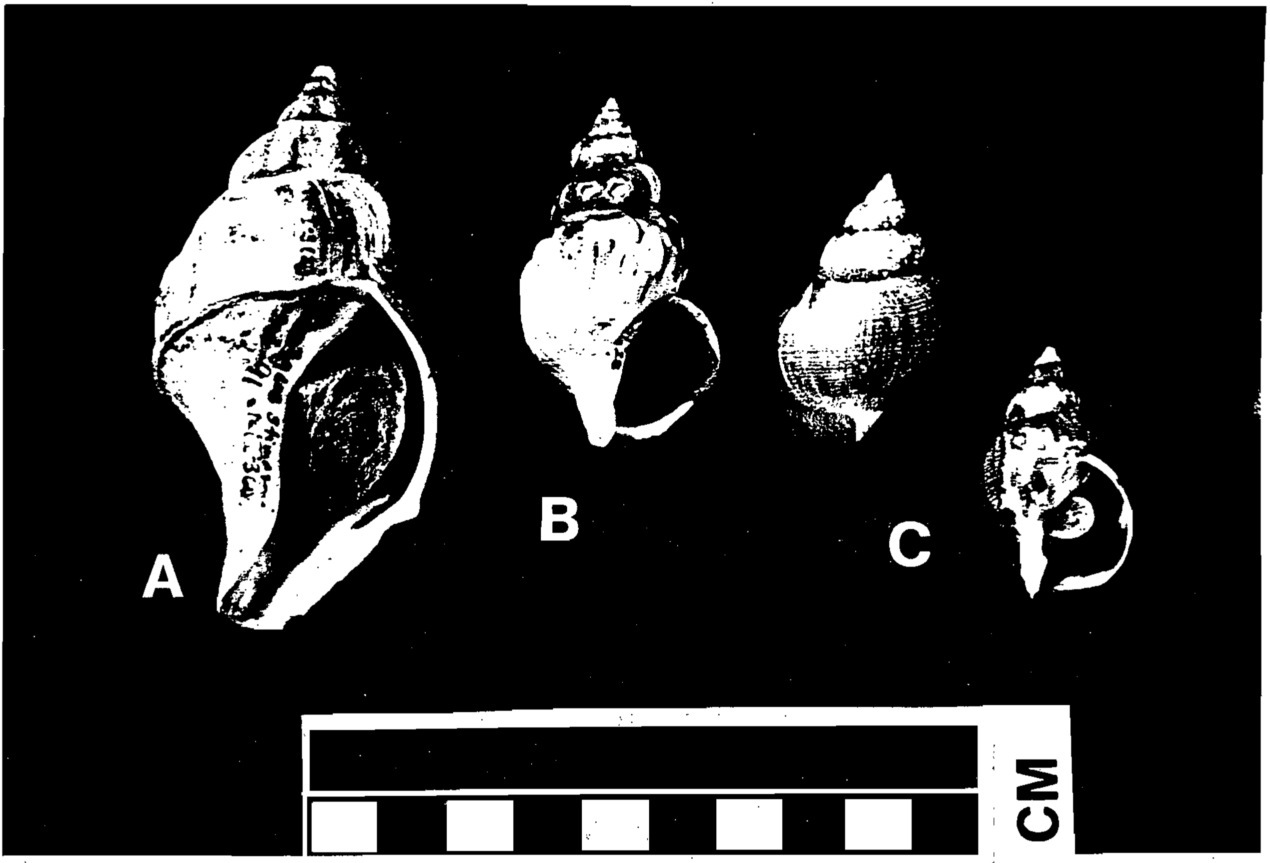

Figure 11a. *Beringius stimpsoni,* 11b. *Buccinum solenum,* and 11c. *Buccinum tenellum.*

The most abundant bivalve was the scallop *Chlamys behringiana* which occurred at 12 stations, with especially high numbers observed (24,000 ind/km^2) at Station 7 off Point Hope (Figure 12). The scallop was also common at Stations 19 and 22 north of Cape Lisburne and Stations 25, 26, 27 and 33 adjacent to Point Franklin. The cardiid bivalves *Serripes groenlandicus* and *Clinocardium ciliatum* were abundant at 22 and 13 stations, respectively.

The chiton *Amicula vestita* was found at 17 stations, with the greatest abundance just north of Cape Lisburne. An octopus, tentatively identified as *Octopus leioderma*, occurred at 12 stations and, although never abundant, was common offshore (Figure 13a). Four relatively common gastropods (*Colus spitzbergensis*, *Beringius beringi*, *Buccinum glaciale*, and *Trichotropis bicarinata*) were present in the nearshore areas (see Figure 13b for example).

Five species (*Beringius stimpsoni*, *C. magna*, *C. behringiana*, *Cyclocardia crassidens*, and *Astarte montagui*) had disjunct distributions, with individuals occurring at stations off Cape Lisburne and at northern stations (see Figures. 13c,d for examples).

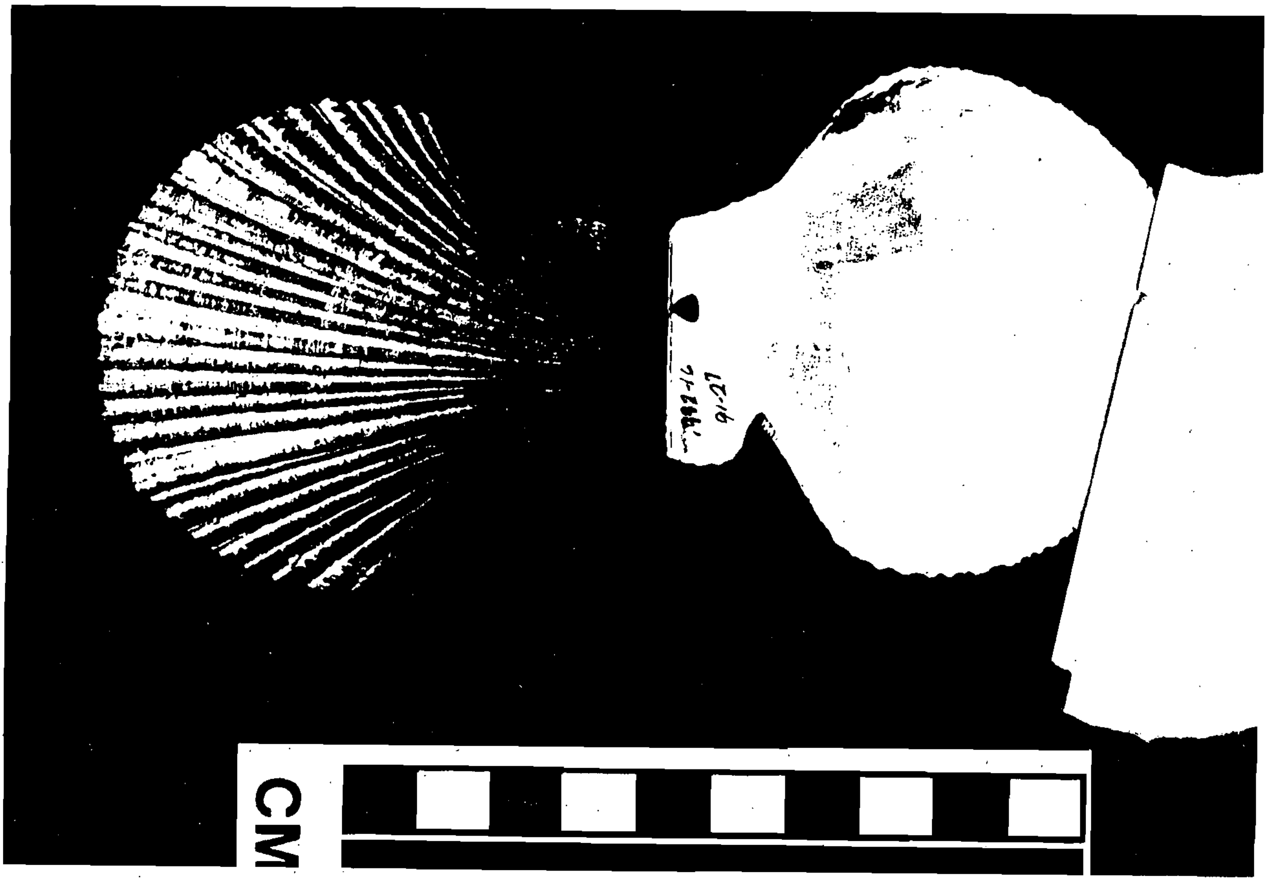

Figure 12. *Chlamys behringiana.*

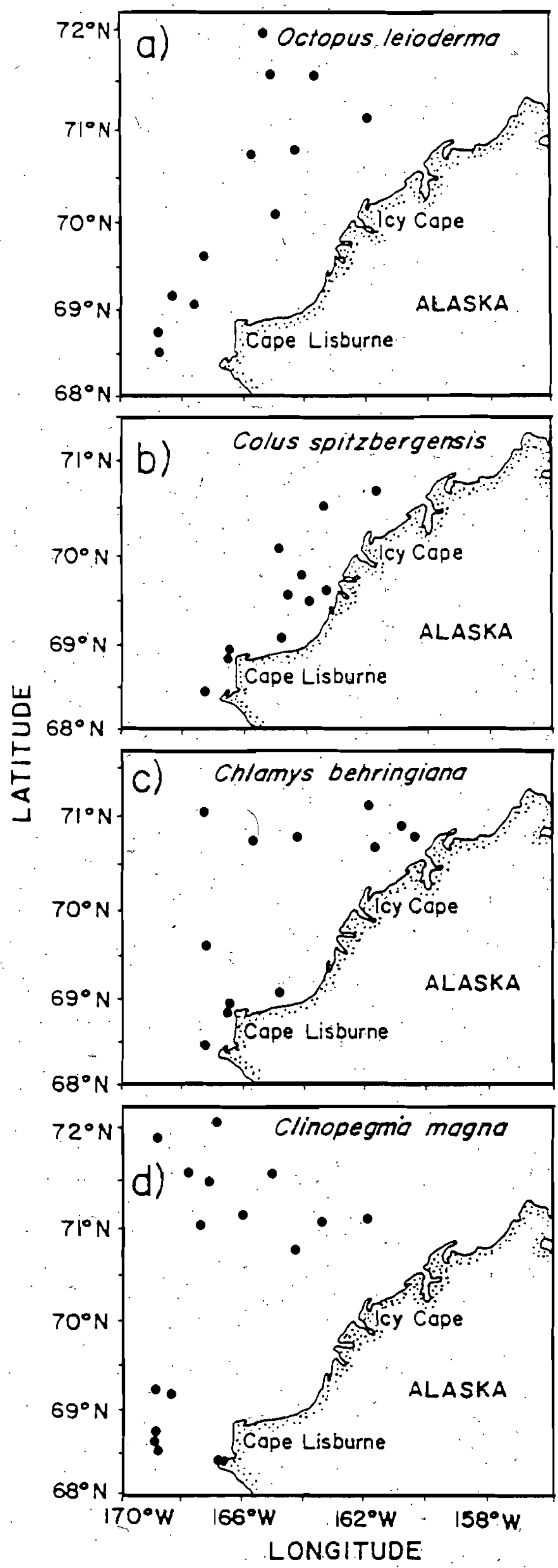

Figure 13a. Distribution of *Octopus leioderma,* 13b. Distribution of the gastropod *Colus spitzbergensis,* 13c. Distribution of the scallop *Chlamys behringiana,* and 13d. Distribution of the gastropod *Clinopegma magna.*

From the recurrence of stations in the cluster analysis of abundance data (Figure 14) five station groups were identified, with three stations not classified (Figures 14 and 15). Dominant fauna characterizing each of the station groups are found in Table 4.

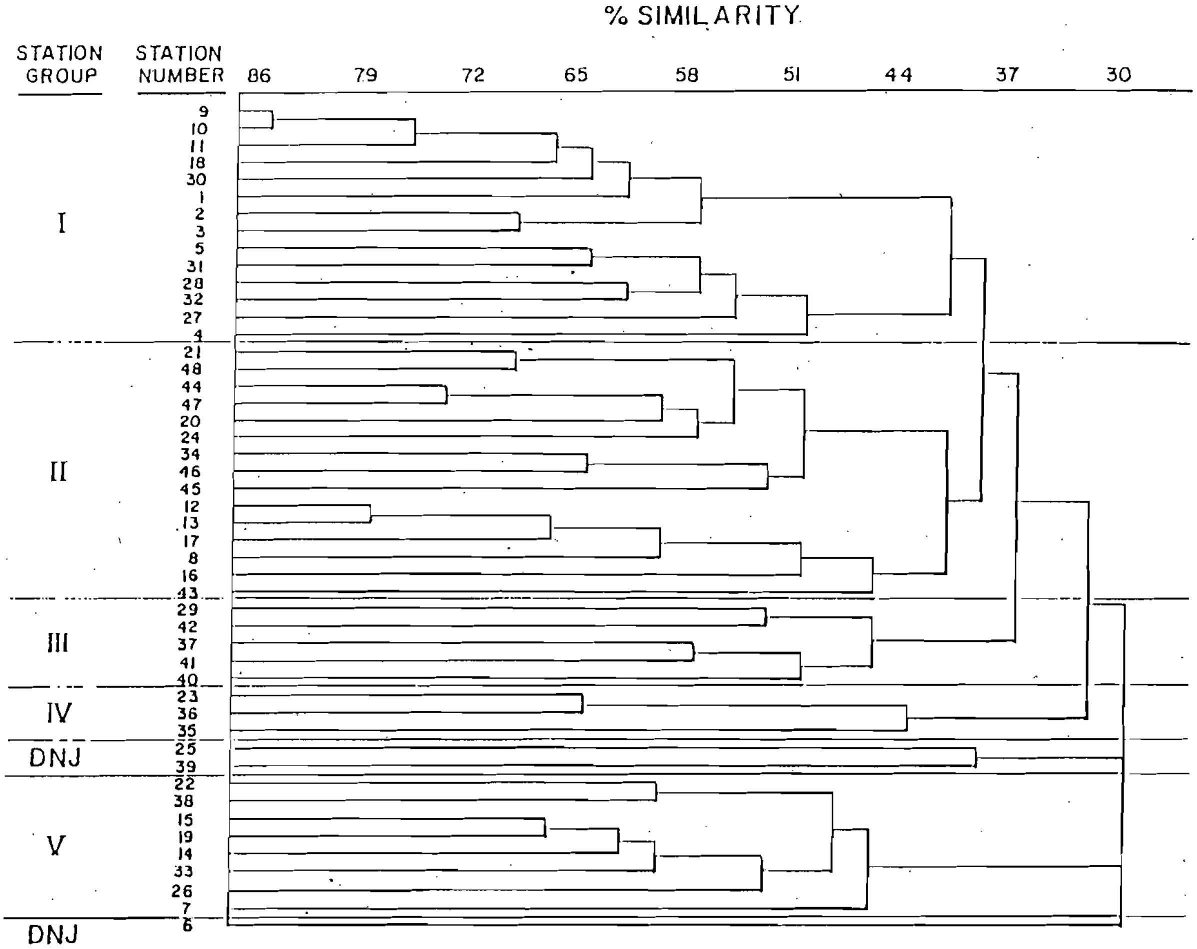

Figure 14. Dendogram showing grouping of stations based on a cluster analysis of epifaunal molluscan abundance data. DNJ = did not join any group.

Table 4.—Epifaunal molluscan abundance dominants within five station groups. Taxa occurred at 50% or more of stations within a station group. DNJ = Did not join a Group.

Station Group	Stations in Group	Taxa	Abundance (ind/km^2)	% Occurrence in Group[1]
I	2 3 4 5 9	*Neptunea heros*	1021	100
	11 18 27	*Buccinum polare*	390	100
	30 31 32	*Neptunea borealis*	236	100
		Buccinum scalariforme	128	100
		Volutopsius fragilis	126	50
		Natica aleutica	97	86
		Polinces pallidus	87	86
		Clinopegma magna	81	93
		Onchidiopsis sp.	76	100
II	8 12 13 16 17 20	*Neptunea heros*	4256	100
	21 24 34 43 44 45	*Neptunea ventricosa*	668	60
	46 47 48	*Buccinum scalariforme*	506	93
		Neptunea borealis	436	100
		Buccinum angulosum	147	93
		Onchidiopsis sp.	72	67
		Beringius beringi	54	73
		Volutopsius fragilis	33	60
		Serripes groenlandicus	31	67
III	29 37 40 42 41	*Neptunea heros*	442	100
		Neptunea borealis	72	100
		Buccinum scalariforme	71	100
		Buccinum polare	51	80
		Neptunea ventricosa	37	60
		Plicifusu kroyeri	17	60
IV	23 35 36	*Neptunea heros*	752	100
		Buccinum tenellum	98	100
		Buccinum polare	91	67
		Buccinum angulosum	85	67
		Natica clausa	57	67
		Neptunea borealis	56	100
		Polinices pallidus	28	67
		Neptunea ventricosa	28	100
		Bulbus fragilis	3	67
		Buccinum sp.	6	67
V	7 14 15 19 22 26	*Chlamys behringiana*	3971	100

Table 4. continued

Station Group	Stations in Group	Taxa	Abundance (ind/km^2)	% Occurrence in Group[1]
V cont.	33 38	*Neptunea heros*	2363	100
		Neptunea ventricosa	1814	100
		Buccinum angulosum	1471	88
		Trichotropis bicarinata	1457	63
		Amicula vestita	1168	100
		Margarites costalis	821	50
		Onchidiopsis sp.	794	100
		Plicifusus kroyeri	748	100
		Buccinum scalariforme	477	75
		Cyclocardia cassidens	419	88
		Volutopsius deformis	391	62
		Beringius stimpsoni	431	50
		Volutopsius stefansoni	341	62
		Buccinum polare	293	50
		Beringius beringi	258	88
		Boreotrophon clathratus	204	63
		Colus spitzbergensis	167	63
		Neptunea borealis	136	50
		Buccinum glaciale	127	75
		Serripes groenlandicus	61	63
		Clinocardium ciliatum	57	75
		Crepidula grandis	35	62
		Musculus discors	32	50
DNJ	25	*Neptunea heros*	3177	
		Neptunea ventricosa	498	
		Volutopsius deformis	453	
		Buccinum plectrum	199	
		Buccinum glaciale	199	
		Chalmys behringiana	199	
		Beringius beringi	54	
		Beringius stimpsoni	54	
		Buccinum polare	54	
DNJ	39	*Chlamys behringiana*	160	
		Neptunea heros	114	
		Buccinum angulosum	46	
		Plicifusus kroyeri	23	
		Neptunea ventricosa	23	
		Buccinum polare	23	
		Clinopegma magna	23	
DNJ	6	*Neptunea ventricosa*	410	

Table 4. continued

Station Group	Stations in Group	Taxa	Abundance (ind/km^2)	% Occurrence in Group[1]
DNJ cont.		*Clinocardium californiense*	155	
		Neptunea heros	114	
		Musculus discors	68	
		Serripes groenlandicus	46	
		Beringius beringi	33	
		Clinopegma magna	22	

[1] The value for each taxon in the column of % Occurrence in Group is based on the number of stations at which the particular taxon occurs.

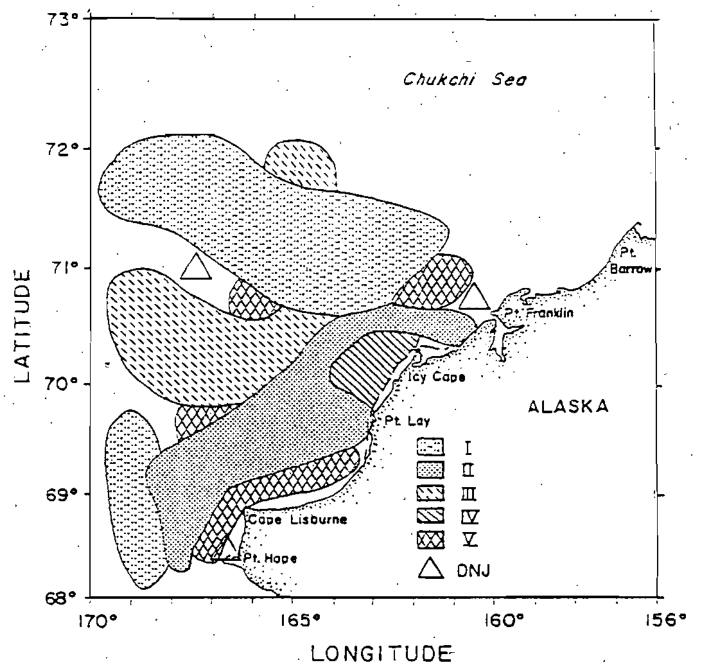

Figure 15. Epifaunal molluscan assemblages in the northeastern Chukchi Sea based on cluster analysis.

Number of taxa at station groups varied from 16 in Group IV to 65 at Group V (Table 5). Abundance ranged from 765 in Group III to 18,993 ind/km^2 in Group V (Table 5). Biomass ranged from 24 to 292 kg/km^2 at Groups IV and V, respectively. As observed for offshore infaunal station groups, the northern epifaunal offshore Group I had a larger number of taxa, and higher abundance and biomass than southern offshore epifaunal Group III. Also, as noted for the infauna, there is a distinctive epifaunal assemblage (inshore Group IV) in the sandy area between Icy Cape and Point Lay. The number of taxa, abundance, and biomass here was relatively low. Distinctive species in Group IV were *Buccinum tenellum*, *B. polare*, *B. angulosum*, and *Natica clausa*. The most diverse group, Group V, has a disjunct distribution (Figure 15). The group was dominated by large numbers of *C. behringiana*. Group II wasdistinguished by its relatively large number of taxa, and high abundance and biomass values.

Table 5.—Number of taxa, abundance, and biomass of epifaunal station groups.

Station Group	**Number of Taxa**	**Abundance (ind/km^2)**	**Wet Weight Biomass (kg/km^2)**
I	63	2770	54
II	52	6884	188
III	20	765	33
IV	16	1245	24
V	65	18993	292

Table 6 shows the results of the multiple discriminant analysis of the environmental conditions relative to epifaunal station groups identified by multivariate analysis. Discriminant Functions (DF) 1 and 2 contribute 88.8% of the total separation among the groups ($P \leq 0.001$), and only these two functions are considered further in the interpretations. Sixty-one percent of the stations and station groups were correctly classified. After the final step in the discriminant analysis, F statistics between most pairs of station groups showed significant differences ($P \leq 0.001$). Station and station group positions along these two functional axes are plotted in Figure 16 (also see station group locations in Figure 15). The low negative value along DF 1 is due to higher bottom-water temperature. The low negative value along DF 2 is due to the high percent gravel. The centroid of northern offshore Station Group I is well separated from most of the other groups along the axis of DF 1. Also, the centroid of offshore Group III is separated from inshore Groups II, IV, and V on DF 1. The centroids of inshore Group V and inshore Group IV are separated from the other groups along the axis of DF 2. The separation of offshore Groups I and III from the other stations is a result of lower bottom water temperature; both groups share similar sediment characteristics. The separation of Group V from the other groups is due to the high percentage of gravel present at stations of this group, and Group IV differs from the other groups by the low percent of gravel present (see Figures 15 and 16).

DISCUSSION

Our results show higher abundance and biomass values for infaunal mollusks adjacent to and north and northwest of the bottom front separating Bering Shelf (BSW) and Resident Chukchi Water (RCW) from Alaska Coastal Water (ACW). A north-south infaunal biomass difference in the northeastern Chukchi Sea was also noted for total infauna by Feder *et al.* (1990a) where higher biomass for the northern region was explained by lower bottom-water temperatures and higher bottom salinities in the northern region. In contrast, epifaunal mollusks have their greatest abundance and biomass within stations adjacent to the coast. Of particular interest is the observed enhancement of infauna at northern stations relative to those farther south. Oceanographic mechanisms which could lead to the observed enhancement of the infaunal benthos to the north include: (1) advection into the area by BSW with its high nutrient and POC load, (2) a flux of ungrazed phytoplankters to the bottom, (3) the recurring presence of polynyas along the coastal region north of Point Franklin (Stringer and Groves, 1991), (4) enhanced primary productivity associated with the summer-fall position of the marginal ice zone (which is typically observed in this region at this time: Grantz *et al.* 1982), and (5) enhanced primary production due to upwelling and slope/shelf exchange of nutrient-rich water found at depth along the continental slope to the north of the study area.

Table 6.—Results of the discriminant analysis of environmental factors among the five epifaunal station groups. Sediment data used are dry weight values from Naidu (1987) and oceanographic data from Feder *et al.* (1990a). *Significance at $P \leq 0.001$.

Discriminant Function	**1**	**2**	**3**
Percent Separation	58.31	30.45	11.25
Cumulative Percent Separation	59.31	88.76	100.00
Test of significance			
Chi-squared value	58.55*	27.71*	8.55
Degrees of freedom	12	6	2

Variables and Standardized Discriminant Function Coefficients			
Depth	0.43	-0.60	0.78
Bottom Temperature	-0.99	0.27	0.69
Percent Gravel	0.54	-0.86	-0.69

The northward flow of BSW along the east flank of Herald Shoal (Weingartner, Chapter 2), with its contained nutrients and POC, spreads north and eastward along the bottom, mixes with RCW, and forms a bottom-intersecting front with ACW. The annual water-column primary production north of this front is estimated to be from 50-100 gC/m^2 (Parrish, 1987). Much of the initial pulse of this water-column primary productivity probably remains ungrazed as observed for the northeastern Bering Sea (Grebmeier *et al.* 1988). The sinking of ungrazed phytoplankton, as well as POC within the BSW/RCW, would enrich the benthic environment north of the front. Additional nutrient enrichment along the front might also contribute to increases in benthic organisms at stations adjacent to that front. Fronts are characterized by high primary productivity, and it is here that high values for benthic abundance and biomass are often found (Creutzberg, 1986). An increase in benthic organisms along the frontal system in the northeastern Bering and southeastern Chukchi Seas was also noted by Grebmeier *et al.* (1988, 1989) and Feder *et al.* (1990b).

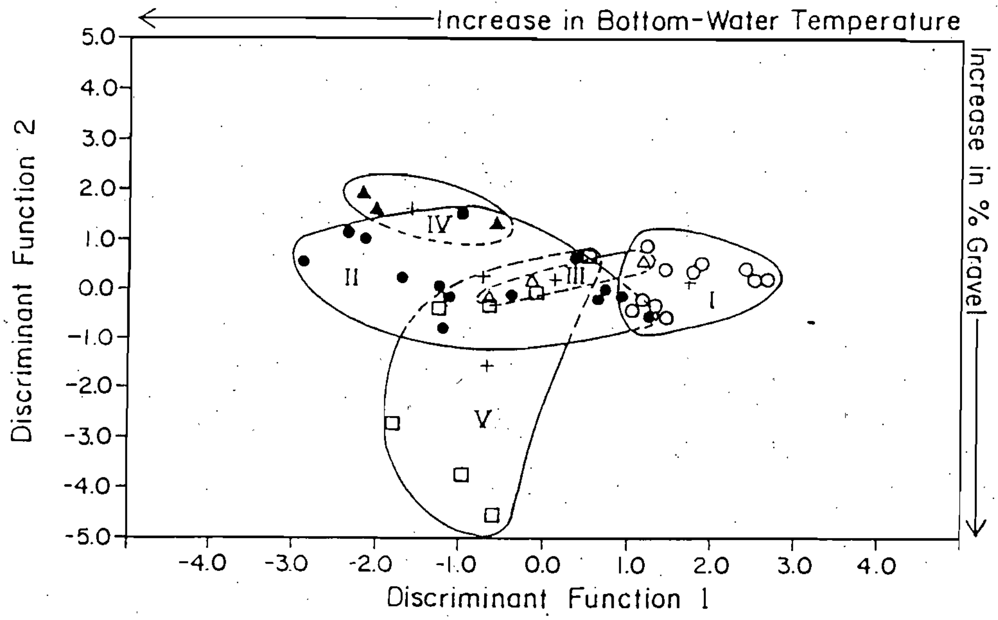

Figure 16. Station and station group plot from stepwise multiple discriminant analysis of molluscan epifauna utilizing environmental variables. + = centroids of the station groups. Sediment values used in the anlysis based on dry weights.

Open-water regions within polynyas are considered important in sustaining primary and secondary productivity in polar regions and are regularly associated with large numbers of sea birds and marine mammals (Dunbar, 1981; Stirling *et al.* 1981; Massom, 1988; Smith *et al.* 1990; Grebmeier and Barry, 1991; Deming *et al.* 1993).. The ice-water boundary at marginal ice zones is the site of the earliest spring water-column phytoplankton blooms in polar regions (Alexander and Niebauer; 1981, Johannessen *et al.* 1982; Niebauer and Alexander, 1985). It is hypothesized that polynyas influence water-column productivity due to ice-edge dynamics at the marginal ice zone, but few studies have investigated pelagic-benthic coupling processes in polynyas (Grebmeier and Barry, 1991). Concentrations of plant-derived pigments and meiomacrofauna were higher in sediments under the Northeast Water (NEW) polynya off the northeast coast of Greenland than under ice-covered regions (Deming *et al.* 1993). Also, Piepenberg (1988) describes an enhanced epifaunal abundance in the area of the NEW compared to benthos underneath the ice pack. Increased infaunal abundance and biomass north of Icy Cape, observed in our study and by Feder *et al.* (1990a), may reflect, in part, a flux to the bottom of locally produced POC within polynyas that supplements advected carbon sources. Additionally, the recurring presence of early summer feeding walrus at the ice edge off Point Franklin (Fay, 1982), adjacent to a northern polynya in the northeastern Chukchi Sea, indicates that flux of carbon to the bottom in this area is an annual event that enhances food resources for these animals.

Upwelling of nutrient-rich water along the shelf break might also stimulate primary production on the outer shelf. This upwelling is seasonally modulated and occurs most frequently from October through January when sea ice covers the region (Aagaard and Roach, 1990). Hence, upwelling could enhance water-column production insofar as it preconditions shelf waters prior to the seasonal sea-ice retreat.

The higher molluscan abundance and biomass values in the northeastern Chukchi Sea compared to the Beaufort Sea can be related, in part, to the higher primary productivity in the former region (Parrish, 1987). As mentioned above, much of the primary productivity in the northeastern Chukchi Sea probably remains ungrazed and fluxes to the bottom. However, only 1-10% of water-column production in the Beaufort Sea is estimated to reach the bottom (Carey and Ruff, 1977; Carey, 1987). Thus, carbon limitation has an important influence on benthic abundance and biomass in the Beaufort Sea.

Ice-scouring of the sea floor disrupts and modifies the sea bed over much of the ice-stressed continental shelf of the Alaskan arctic, and influences faunal abundance and biomass (Barnes and Reimnitz, 1985; Carey and Ruff, 1977; Carey, 1991; Grebmeier and Barry, 1991). Comparison of benthic infaunal biomass in the northeastern Chukchi and adjacent Beaufort Sea shelves indicates regional differences (Carey *et al.* 1974; Feder *et al.* 1990a; Grebmeier and Barry, 1991). In the Beaufort Sea, ice gouging contributes to the lowered benthic abundance and biomass in the inner shelf (Feder and Schamel, 1976; Carey and Ruff, 1977; Carey *et al.* 1984; Braun, 1985), and is also responsible for much of the mid-shelf faunal patchiness (Carey and Ruff, 1977). In contrast, benthic abundance and biomass are higher on the northeastern Chukchi inner and midshelf areas. In fact, in the vicinity of Point Franklin, there are high molluscan abundance and biomass values inshore (Figures 4 and 8). Decreased annual ice cover occurs in the northeastern Chukchi Sea as compared the Beaufort Sea (Grantz *et al.* 1982). Further, polynyas along the coastal shelf areas of the northeastern Chukchi Sea (Stringer and Groves, 1991) periodically exclude ice in winter. Ice gouging is markedly reduced here during this period. Consequently, the effects of sea ice on benthos of the Chukchi shelf are less intensive and pervasive than on the Beaufort shelf (Grantz *et al.* 1982).

The large numbers of molluscan epifauna, observed in this study adjacent to the coast north of Icy Cape, probably represent a response to the abundant infaunal food there. Additionally, increased abundance and biomass of infaunal and epifaunal mollusks at stations adjacent to and northeast of Cape Lisburne appear related to POC originating in Kotzebue Sound (Feder *et al.* 1990 a,b) and the gyre northeast of the Cape (Coachman *et al.* 1975; Johnson, 1989;) which presumably concentrates this POC.

The abundance and biomass of bivalves, the dominant component of the molluscan infauna, appear related to specific physical properties of sediments, bottom salinity, and regional availability of POC. This relationship is reflected by the relatively discrete station groups (composed mainly of bivalves) determined by cluster analysis and the station group affinities shown by discriminant analysis. The dominance of the protobranch bivalve *Nucula tenuis* at infaunal Station Groups I, II, III, and IV is attributed to the presence of muddy sediments where this species typically occurs (Levinton, 1977; Feder and Jewett, 1987; Feder *et al.* 1990a). However, there are subtle differences in the sediment nature at stations comprising these groups, as illustrated by differences in proportions of coarse grains (gravel+sand) and water (Figure 17). These sediment differences are reflected by dissimilarities in abundance of dominant species between groups. The relatively higher water content in mud at stations in northern offshore Group I results in a fluidized sediment, which facilitates access to its contained POC for the common deposit-feeding bivalves *N. tenuis* and *Macoma calcarea* present there. Close association of POC with muddy sediments is shown by numerous investigators (e.g., see Weston, 1988, for references). Sediments at stations of northern offshore infaunal Group I generally have a relatively high organic carbon and nitrogen content (Feder *et al.* 1990a). The importance of muddy, fluidized, and POC-enriched sediments as an environment for deposit-feeding organisms is further demonstrated by the variety of surface and subsurface deposit-feeding infaunal species present offshore (Feder *et al.* 1990a). Carey *et al.* (1984) observed an increase in the abundance and diversity of protobranch and other deposit-feeding bivalves in muddy sediments of shallow nearshore areas of the southwestern Beaufort Sea. Similarly, Mann (1977) found protobranchs and *Macoma* spp. in greater abundance in soft sediments. The high bottom salinity at northern offshore Groups I and III and northern inshore infaunal Group V, which separates them from inshore Groups IV and VI, indicates the presence of BSW/ RCW with its relatively high POC content in the northern portion of the study area.

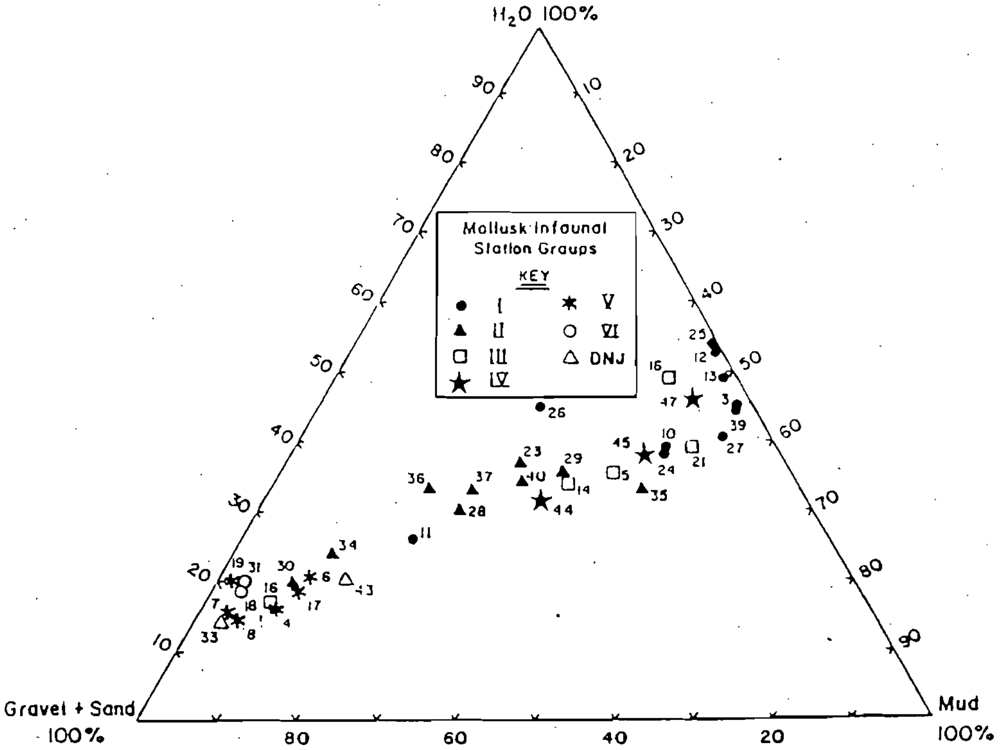

Figure 17. Ternary diagram relating infaunal molluscan stations and station groups to percent water, gravel+sand, and mud (see Figures 3a, 5, and 6).

The broad distribution of large, epifaunal gastropods, primarily the abundant *Neptunea* spp., in the study area can probably be attributed to their mobility and opportunistic feeding behavior (Golikov, 1963; Feder, 1967; Pearce and Thorson, 1967; Taylor, 1978; MacIntosh and Somerton, 1981). The mobility of molluscan epifauna is reflected by the considerable overlap of station groups in the cluster and discriminant analyses. The relatively low abundance levels of most species of epifaunal gastropods offshore may be related to lack of suitable substrate for egg-laying activities in the muddy sediments there. However, Golikov (1963) and Pearce and Thorson (1967) indicate that the large gastropod *Neptunea* mainly attaches its egg cases to shells of other *Neptunea* spp. and consequently, we do not believe that substrate type explains the distribution of this genus. In our study area, *Neptunea* spp. was common on the muddy offshore substrate.

The surface-deposit feeding clam *Thyasira gouldi* and the suspension-feeding scallop *Chlamys behringiana* occurred in large numbers off Point Hope, and to a lesser extent, the deposit-feeding clams *Nucula tenuis* and *Nuculana radiata* were important here (infaunal Group

IV and epifaunal Group V). High levels of suspended and deposited organic carbon, which furnish food for these species, were reported for this area (Feder *et al*, 1990b). South of our study area, along the coast from Kivalina to Point Hope, relatively high densities of suspension-feeding organisms (e.g., barnacles and tunicates) occur. Their presence indicates the availability of a stable source of carbon in the water column, derived from Kotzebue Sound, which ultimately contributes POC to the benthos off Point Hope (Feder *et al.* 1990b; Naidu *et al.* 1993). This POC is concentrated north of Cape Lisburne by a gyre where it sustains another large population of scallops. The scallop, as well as ampeliscid amphipods, were common northwest of Point Franklin in an area where high levels of POC occur (Feder *et al.* 1990a). 1990; Grebmeier and Barry, 1991; Deming *et al.* 1993). The ice-water boundary at marginal ice region (Moore and Ljunglad, 1984; Moore and Clarke, 1986; Phillips and Colgan, 1987; Feder *et al.* 1990a).

Inshore infaunal Group V is located in a sandy-gravelly environment dominated by suspension-feeding bivalves. The relatively intense longshore currents entrain suspended sediments and associated POC as a food source for the mollusks here (Feder *et al.* 1990a). A general increase in the proportion of suspension-feeding bivalves with coarser sediments is reported by Mann (1977) in the eastern Chukchi Sea and Carey *et al.* (1984) in the nearshore areas of the southwestern Beaufort Sea. High abundance values of molluscan epifauna, mainly *Neptunea* spp., occurred in the same general inshore area (Figure 8a), presumably attracted by the abundant infaunal food available here (Feder *et al.* 1990a).

Stations of inshore infaunal Group VI and epifaunal Group IV are occupied by low numbers of a few molluscan species. This region sustains a large, resident population of suspension-feeding sand dollars, *Echinarachnius parma* Lamarck (Feder *et al.* 1990a), which presumably excludes other infauna via their sediment reworking activities (Brenchley, 1981; Smith, 1981; Highsmith, 1982; Highsmith and Coyle, 1991). Reduced numbers of epifaunal gastropods here probably reflect the low abundance of prey species (Feder *et al.*1990a).

Mollusks, particularly when small, represent a food resource for bottom-feeding predators in the study area. Documented and potential crustacean predators on mollusks in the northeastern Chukchi Sea include pandalid and crangonid shrimps, and pagurid and majid crabs. The pandalid shrimp *Pandalus goniurus* Stimpson and the crangonid shrimps *Sclerocrangon boreas* (Phipps) and *Argis lar* (Owen), were common to abundant at some stations in the study area (Feder *et al.* 1990a; Foster, unpublished); these and related species feed on small mollusks in the Gulf of Alaska (Rice, 1980; Rice *et al.* 1980; Feder and Jewett, 1981; Feder *et al.* 1981; Feder and Jewett, 1986). Forty-one percent of the majid crab *Chionoecetes opilio* (Fabricius) examined in the southeastern Chukchi Sea were feeding on small bivalve mollusks (Feder and Jewett, 1978) and 61% of those examined in the northeastern Chukchi Sea were utilizing small bivalves (Feder *et al.* 1990a). This crab also fed on small gastropods to a lesser extent in these areas. Other large, predatory crustaceans in the study area were hermit crabs (Paguridae) and the majid crab *Hyas coarctatus* Brandt (Feder *et al.* 1990a; Foster, unpublished). In the Gulf of Alaska some species of hermit crabs and *H. lyratus* Dana feed on small mollusks (Feder *et al.* 1981).

The distribution of predatory naticid gastropods, *Natica clausa* and *Polinices pallidus*, in the northern portion of the study area overlaps that of the most dense populations of the thin-shelled bivalves *N. tenuis* and *M. calcarea*, on which they probably prey. Evidence that naticids consume infaunal bivalves, and especially *M. calcarea*, comes from observing their characteristic boreholes in shells in the study area (personal observation) and from fossil and subfossil assemblages in the Canadian Arctic (Aitken and Risk, 1988). Neptunid snails, abundant in the study area (Table 4), also utilize bivalves as one component of their diet (Pearce and Thorson, 1967; MacIntosh and Somerton, 1981), as do the Muricidae, represented in the study area by *Boreotrophon* spp.

Ophiuroids and asteroids also prey on gastropods and bivalves in the study area. A common ophiuroid in the study area, *Ophiura sarsi* Lütken, fed heavily on small mollusks, with 92% of those examined utilizing bivalves and 50% feeding on gastropods (Feder *et al.* 1990a). It is suggested by Feder (1981), based on the related *O. ophiura* Linnaeus (=*O. texturata* Lamarck), that where ophiuroids are common they can cause rapid disappearance of bivalve spat after settlement, which subsequently results in low densities of adult clams (also see Thorson, 1966). Large sea stars are abundant in the southeastern (Feder and Jewett, 1978) and northeastern Chukchi seas (Feder *et al.* 1990a; Foster, unpublished). At least nine sea-star taxa [*Asterias amurensis* Lütken, *Crossaster borealis* Fisher, *C. papposus* (Linnaeus), *Evasterias echinosoma* Fisher, *Lethasterias nanimensis* (Verrill), *Leptasterias polaris acervata* (Stimpson), *Leptasterias* spp., *Orthasterias koehleri* (de Loriol), and *Pteraster obscurus* (Perrier)] were identified from epifaunal samples collected in the northeastern Chukchi Sea in 1986 (Feder *et al.* 1990a) and 1991 (Foster, unpublished). Feeding observations on *L. polaris acervata* from the southeastern Chukchi Sea revealed that 75% of the prey types were mollusks, with gastropods more frequently taken than bivalves by two to one (Feder and Jewett, 1978). Since *L. polaris acervata* is one of the most abundant sea stars in the northeastern Chukchi Sea (Feder *et al.* 1990a; Foster, unpublished), it is probable that mollusks are important prey here as well. Other sea stars documented as predators on mollusks in the southeastern Chukchi Sea and elsewhere in Alaskan waters are *A. amurensis*, *Leptasterias* sp., *E. echinosoma* and *L. nanimensis* (Feder and Jewett, 1978, Feder and Jewett, 1981; Jewett and Feder, 1981).

Mollusks are a minor component of the diet of fishes in the study area (Coyle *et al.*, Chapter 8). Gastropods and bivalves were present, but never important, in the diet of the staghorn sculpin *Gymnocanthus tricuspis* Reinhardt. The arctic flounder *Hippoglossoides robustus* Gill and Townsend utilized bivalve mollusks for food in only a small percentage of fish examined. Mollusks are also a minor portion of the diet of the related flathead sole *H. elassodon* Jordan and Gilbert in the southeastern Bering Sea (Mineva, 1964; Mito, 1974).

Two marine mammals, the walrus *Odobenus rosmarus divergens* Illiger and the bearded seal *Erignathus barbatus* Fabricius, are the most important predators on mollusks in the study area. Bivalves are an important component of the diet of walrus (Fay, 1982). *Macoma calcarea* and other small bivalves were common in our northern offshore infaunal Group I and at stations within the same general region studied by Stoker (1981), an area where walrus feed on these mollusks (Fay, 1982; Fay, pers. comm. in Feder *et. al.*, 1990a). Neptunid and buccinid snails are occasionally reported as prey for walrus (Fay, 1982). Limited data from the northwestern and northeastern Chukchi Sea suggest that mainly smaller molluscan species are consumed by walrus (Krylov, 1971; Feder *et al.* 1990a). The bearded seal feeds on the cockle *Serripes groenlandicus*, the clam *Mactromeris (=Spisula) polynyma* Stimpson and the gastropods *Buccinum* spp. and *Polinices* spp. in the Bering Sea (Lowry *et al.* 1979; Lowry *et al.* 1980a). Snails are of minor importance (one percent of invertebrate prey volume) as food for the bearded seal in the northeastern Chukchi Sea, but the clams *S. groenlandicus* and *M. polynyma* (this species was not taken in our study) can be important dietary components for this mammal in the area (Lowry *et. al.*, 1980a).

In summary, the northeastern Chukchi Sea has an abundant and diverse molluscan fauna. Distribution, abundance and biomass can be related to several environmental factors.

Dissimilarities in abundance of particular infaunal molluscan species are primarily related to specific sediment parameters but also to bottom salinity. Epifaunal species are more abundant inshore where sandy-gravelly substrate prevails, although the large gastropods *Neptunea* spp. are common throughout the study area. Increase in biomass for infaunal mollusks north of 71°N latitude appears to be influenced by the presence of a bottom front adjacent to Point Franklin. Further, advection of POC-enriched water from the southeast Chukchi Sea to north of the front appears to support, in part, an enhanced infaunal molluscan fauna there. Although mollusks are not the dominant food utilized by invertebrate, fish, and walrus predators in the study area, they can occur in the diet of most of these organisms. However, it seems that small molluscan species and juvenile stages of large mollusks are mainly consumed by these predators. Clams, but rarely gastropods, serve as prey for the bearded seal. Mollusks, in general, are long lived in arctic seas (Thorson, 1936, 1957; Ockelmann, 1958; Golikov, 1963; Dunbar, 1968; Chia, 1970). Consequently, larger species, as adults, particularly gastropods, represent a carbon sink that mainly contribute carbon to the system via gamete production and death [see discussions in Isaacs (1976) and Feder and Jewett (1981)].

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APPENDIX I. CHAPTER 10

List of molluscan taxa. Infaunal taxa are those reported in Feder *et al.* (1990a). Taxa designated "sp." were generally too small to be determined to species. Epifaunal mollusks were identified in the field by Rae Baxter. Name changes are based, in part, on specimens collected in the same area in 1991 by N. Foster. Other suggested name changes are by N. Foster.

T=species collected by otter trawl, primarily epifauna, except *Mya* spp.

G=species collected by grab, primarily infauna.

These designations may not always be consistent with the life habits of the animals, as the grab may pick up small epifauna, and, on soft sediments, the otter trawl may dig in and collect larger infaunal species.

Gastropoda

T		*Lepeta caeca* (Müller, 1776)
T		*Margarites argentatus* (Gould, 1841)
T	G	*Margarites costalis* (Gould, 1841)
T		*Margarites giganteus* (Leche, 1878)
T		*Margarites vorticifer* (Dall, 1873)
T	G	*Solariella obscura* (Couthouy, 1838)
T	G	*Solariella varicosa* (Mighels and C. B. Adams, 1842)
	G	Trochidae, not determined
	G	*Moelleria costulata* (Møller, 1842)
	G	*Alvania* sp.
T	G	*Tachyrhynchus erosus* (Couthouy, 1838)
T	G	*Tachyrhynchus reticulatus* (Mighels and C. B. Adams, 1842)
	G	Boreoscala greenlandica (G. Perry, 1811)
T		*Asterophila japonica* Randall and Heath, 1912 [endoparasitic in sea stars (Hoberg *et al.* 1980); biomass was not calculated]
T	G	*Crepidula grandis* Middendorff, 1849
T		*Trichotropis bicarinata* (Sowerby, 1825)
T	G	*Trichotropis borealis* Broderip and Sowerby, 1829
T		*Trichotropis coronata* Gould, 1860
	G	*Trichotropis kroyeri* Philippi, 1848
	G	*Trichotropis* sp.
T		*Bulbus fragilis* (Leach, 1819)
T		*Natica aleutica* Dall, 1919 [may = *N. clausa*][1]
T	G	*Natica clausa* Broderip and Sowerby, 1829
T	G	*Polinices pallidus* (Broderip and Sowerby, 1829)
T		*Marsenina glabra* (Couthouy, 1832) [id. by N. Foster][2]
T		*Onchidiopsis* spp.
T		*Capulacmaea commoda* (Middendorff, 1851)
T		*Velutina plicatilis* (Müller, 1776)
T		*Velutina undata* (T. Brown, 1839)
T		*Velutina velutina* (Müller, 1776)

T	G	*Boreotrophon clathratus* (Linnaeus, 1758)
T		*Boreotrophon muriciformis* (Dall, 1877)
	G	*Boreotrophon beringi* Dall, 1902
T		*Boreotrophon pacificus* (Dall, 1902) [may = *B. beringi*][3]
	G	*Boreotrophon* sp.
T		*Buccinum angulosum* J. E. Gray, 1839
T		*Buccinum ciliatum* Fabricius, 1780
T		*Buccinum glaciale* Linnaeus, 1761
T		*Buccinum plectrum* Simpson, 1865
T		*Buccinum polare* J. E. Gray, 1839
T	G	*Buccinum scalariforme* Møller, 1842
T		*Buccinum solenum* Dall, 1919
T		*Buccinum tenellum* Dall in Kobelt, 1883
T	G	*Buccinum* spp.
T		*Beringius beringii* (Middendorff, 1848)
T		*Beringius stimpsoni* (Gould, 1860)
T		*Clinopegma magna* (Dall, 1895)
T		*Colus* cf. *C. capponius* (Dall, 1919)
T		*Colus dautzenbergi* Dall, 1916
T		*Colus ombronius* (Dall, 1919)
T		*Colus* cf. *C. roseus* (Dall, 1877)
T	G	*Colus* sp.
T		*Liomesus ooides* (Middendorff, 1848)
	G	*Liomesus* sp.
T		*Neptunea borealis* (Philippi, 1850)
T	G	*Neptunea heros* J. E. Gray, 1850
T		*Neptunea middendorffiana* MacGinitie, 1959
T		*Neptunea ventricosa* (Gmelin, 1791)
	G	*Neptunea* sp.
T		*Plicifusus kroyeri* (Møller, 1842)
	G	*Plicifusus* sp.
T		*Volutopsius callorhinus* (Dall, 1877)
T		*Volutopsius deformis* (Reeve, 1847)
T		*Volutopsius attenuatus* (Dall, 1874)
T		*Volutopsius fragilis* (Dall, 1891)
T		*Volutopsius stefanssoni* Dall, 1919
	G	*Admete couthouyi* (Jay, 1839)
T		*Admete regina* Dall, 1911
	G	*Admete* sp.
T		*Oenopota harpa* (Dall, 1885)
T		*Oenopota murdochianus* (Dall, 1885)
T		*Oenopota simplex* (Middendorff, 1849)
T		*Oenopota turricula* (Montagu, 1803)
	G	*Oenopota* spp.
	G	*Propebela* spp. [= *Oenopota* spp.][4]
	G	*Cylichna alba* (Brown, 1827)

T		*Cylichna attonsa* (Carpenter, 1865) [questionable identification][5]
	G	*Cylichna occulta* (Mighels, 1841)
	G	*Philine* sp.
	G	*Retusa obtusa* (Montagu, 1803)
T		Tochuina tetraquetra Pallas, 1788
T		unidentified nudibranchs [in part, *Calycidoris geuntheri* Abraham, 1876, id. by N. Foster][2]
Bivalvia		
T	G	*Nucula tenuis* (Montagu, 1808) [= *N. bellotti* A. Adams, 1856][6]
T		*Nuculana buccata* (Møller, 1842) [= *N. pernula* Müller, 1779][6]
T		*Nuculana fossa* (Baird, 1863) [questionable identification][5]
	G	*Nuculana minuta* (Fabricius, 1776)
	G	*Nuculana radiata* (Krause 1885) [= *N. pernula*][6]
	G	*Yoldia amygdalea* (Valenciennes, 1846) [= *Y. hyperborea*][6]
T	G	*Yoldia hyperborea* Torell, 1859
T	G	*Yoldia myalis* (Couthouy, 1838)
T	G	*Yoldia scissurata* Dall, 1897 [= *Y. seminuda* Dall, 1871][6]
	G	*Musculus corrugatus* (Stimpson, 1851) [may = *M. glacialis* Leche, 1883 or *M. discors*][6]
T		*Musculus discors* (Linnaeus, 1767)
T		*Musculus niger* (J. E. Gray, 1824)
T		*Chlamys behringiana* (Middendorff, 1849) [id. by N. Foster][2,6]
T		*Pododesmus macroschisma* (Deshayes, 1839)
	G	*Axinopsida serricata* (Carpenter, 1864)
T		*Thyasira equalis* A. E. Verrill and Bush, 1898
	G	*Thyasira gouldii* (Philippi, 1845)
	G	*Diplodonta* sp.
	G	*Montacuta* sp.
	G	*Mysella planata* (Krause, 1885)
	G	*Mysella* sp.
	G	Montacutidae, unidentified
T	G	*Astarte borealis* (Schumaker, 1817)
T	G	*Astarte montagui* Dillwyn, 1817
T		*Cyclocardia crassidens* (Broderip and Sowerby, 1829)
T		*Cyclocardia crebricostata* (Krause, 1885)
	G	*Cyclocardia ovata* (Rjabinina, 1952)
T		*Cyclocardia* cf. *C. ventricosa* (Gould, 1850)
T		*Clinocardium californiense* (Deshayes, 1839)
T	G	*Clinocardium ciliatum* (Fabricius, 1780)
T	G	*Serripes groenlandicus* (Bruguière, 1789) [may include *Yagudinella notabilis* (Sowerby, 1815)][6]
T	G	*Serripes laperousii* (Deshayes, 1839)
T	G	*Macoma calcarea* (Gmelin, 1791)
	G	*Macoma loveni* (A. S. Jensen, 1905)
T		*Macoma middendorffi* Dall, 1884
	G	*Macoma moesta* (Deshayes, 1855)

	G	*Tellina lutea* W. Wood, 1828
T	G	*Liocyma fluctuosa* (Gould, 1841)
	G	*Liocyma viride* Dall, 1871 [may = *L. fluctuosa*][6]
	G	*Psephidia lordi* (Baird, 1863)
T		*Mya pseudoarenaria* Schlesch, 1931
T		*Mya truncata* Linnaeus, 1758
	G	*Mya* sp.
T	G	*Hiatella arctica* (Linnaeus, 1767)
T	G	*Lyonsia arenosa* (Møller, 1842)
T		*Lyonsia bracteata* (Gould, 1850) [questionable identification][5]
	G	*Lyonsia* sp.
T		*Pandora filosa* (Carpenter, 1864)
	G	*Pandora glacialis* Leach, 1819
	G	*Thracia devexa* G. O. Sars, 1878
	G	*Lampeia adamsi* (MacGinitie, 1959)
	G	*Periploma aleuticum* (Krause, 1885)

Polyplacophora

T		*Amicula vestita* (Broderip and Sowerby, 1829)
T	G	*Stenosemus albus* (Linnaeus, 1767)
	G	*Tonicella rubra* (Linnaeus, 1767) [questionable identification][5]

Cephalopoda

T	*Octopus leioderma* (S. S. Berry, 1911) [questionable identification] [7]

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[1] Baxter (pers. comm. and 1987) separated the northern Pacific *Natica* into three species, based on shell color and morphology and on the shape of egg cases (see Kessler, 1985).

[2] Based on specimens collected in 1991.

[3] The taxonomy of boreal and arctic species of *Boreotrophon* is in need of revision. Baxter (1987) called both B. *pacificus* and B. *beringi* subspecies of B. *truncatus* (Strøm). There is much variation in the shape and proportions of the shells and number of varices, among the species of *Boreotrophon.*

[4] Vaught, 1989.

[5] Specimens were not found among the UA Museum voucher specimens. This species has not been reported in the northeastern Chukchi Sea (Baxter, 1987).

[6] E. V. Coan and P. H. Scott, pers. comm., based on an unpublished manuscript revision of northeastern Pacific bivalves.

[7] *Octopus leioderma* appeared in Baxter's species list. Cephalopod specimens collected in the northeastern Chukchi Sea in 1991 were sent to J. Voight, cephalopod taxonomist at the Field Museum. She placed them in the genus *Benthoctopus*, but could not determine the species

with confidence. (J. Voight pers. comm. 1993).

CHAPTER 11

THE REPRODUCTIVE BIOLOGY AND DISTRIBUTION OF SNOW CRAB FROM THE NORTHEASTERN CHUKCHI SEA[1]

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Abstract.—This study determined size at maturity, fecundity, distribution, and abundance of the snow crab *Chionoecetes opilio* during 1990 and 1991 in the northeastern Chukchi Sea. Snow crab abundance and biomass varied extensively between stations but tended to be greatest in the southern part of the study area and offshore rather than inshore. Biomass estimates varied extensively ranging from 4,000 kg/km^2 to 1.2 kg/km^2. At all latitudes most females with mature shaped abdominal flaps were gravid. The smallest ovigerous *C. opilio* was 34 mm carapace width (CW). The average CW of ovigerous females was 46 mm (±sd = 4) and carried 19,900 (±sd = 6,500) eggs. The equation describing the relationship between CW (Y) and the number of eggs (X) per clutch was: $Y = 0.672\ X^{2.688}$, $r^2 = 0.54$. The vas deferens of males were examined for the presence of spermatophores. All males 35 mm CW and greater had spermatophores vs. only 19% with CW of 25-29 mm. Spermatophore diameters increased from about 44 μm in 25-29 mm CW males to about 64 μm in males 35 - 44 mm CW. Spermatophore diameters for crabs between 45 and 70 mm CW were similar in diameter, generally between 75 and 80 μm.

INTRODUCTION

The snow crab, *Chionoecetes opilio* (O. Fabricius), is a circumpolar species for which there are substantial fisheries in the Atlantic and the Pacific. In the northwest Pacific snow crabs occur in the northern Sea of Japan, the Bering and Chukchi Seas from Wrangel Island to Point Barrow, and the Beaufort Sea at the mouth of the Mackenzie River (Slizkin 1989). Most of the existing information on the biology of this species has been developed for Northwest Atlantic Ocean or the Sea of Japan stocks (Bowerman and Melteff 1984).

In the Chukchi Sea snow crab are a dominant benthic species but because they are not harvested their basic biology is poorly described. This preliminary survey provided new

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[1] Submitted for publication in Fish Ecology in Arctic North America.

information on distribution trends, and reproduction, for a seldom sampled population.

METHODS

The sampling sites were dictated by oil lease sales in the area north and east of Pt. Hope (north of approximately 68° 20'N, east of the international boundary (168° 58'W) and limited to the north by sea ice. Prior to sampling, eleven transects and 56 stations were located perpendicular to the coast on a nautical chart. Stations were positioned approximately 30 to 60 nm apart depending on transect length. Nearshore stations were established nearer one another so that within a transect there were at least two stations bounded by the coastal current. In 1990 there were 48 stations occupied and in 1991 eight additional stations were sampled to examined snow crab abundance and biomass (Figure 1). Sea ice or weather precluded actually collecting at some of the predetermined station positions, so samples were taken as close as possible to the desired site.

During 1990 the bottom temperature averaged 3.8°C (± 3.3) and ranged from -1.0 to 12°C and salinity was 29 to 33 psu. Contour maps of bottom temperature and salinity for 1990 occur in Weingartner (this volume). During 1991 the bottom temperature averaged 0.1°C (± 2.0) and ranged from -1.0 to 7°C while salinity was 29 to 33 psu.

A 34 m trawler, *Ocean Hope III*, was used between 16 August and 17 September 1990 and 10 to 23 September 1991 to collect snow crab abundance and distribution data. Otter trawling from this vessel was conducted with the National Marine Fisheries Service's standard 83-112 survey trawl; it was fished hard on the bottom. The trawl had a 34.1 m foot rope set back 7 cm from a tickler chain and a 25.2 m head rope. The mesh of the codend was 90 mm and contained a 32 mm stretched mesh liner. The effective opening of the net was monitored by a Scanmar mensuration unit hung from one wing that indicated the net fished as expected. At most stations there were two 30 minute tows side by side along the same track.

At most stations a gross weight of all snow crabs combined was measured and then all the *C. opilio* counted. Periodically catches had more crabs or other species than could be processed before the next trawl sample. In those cases all the crabs in the catch were put into baskets. Baskets were filled one at a time as the crew cleared the sorting area and no bias such as size selection was apparent. All baskets were then weighed and some were randomly selected to obtain the number and weight of crabs. The average weight of crabs at a station was estimated by dividing the total weight of all individuals in the sample by the number of crabs. Weighing individuals was not feasible aboard ship.

Abundance and biomass (kg) estimates were based trawl opening width, the distance trawled, and the numbers and biomass of the catch. The distance trawled was determined from the ship's location at the beginning and end of each set by a Global Positioning System. To estimate the relative abundance (number/km^2) and biomass (kg/km^2) at each station the data from both tows taken at a station were averaged.

The 73 m *Oshoro Maru* was used in July 1991 to collect snow crab for additional reproductive observations. Its otter trawl net had a 43.3 m head rope, a 48.6 m foot rope with roller gear, and 90 mm stretched mesh with a 32 mm stretched mesh liner. These samples were not used to estimate abundance or biomass. The locations for stations sampled on this cruise occur in Table 1.

To examine crab size vs. latitude the carapace width (CW) of all the females collected at station 21 (n = 25) in July of 1991 and stations 23 (n = 51), and 91-32 (n = 88) in September of 1991 were measured to the nearest mm. The locations of stations 21, 23 and 91-32 are on

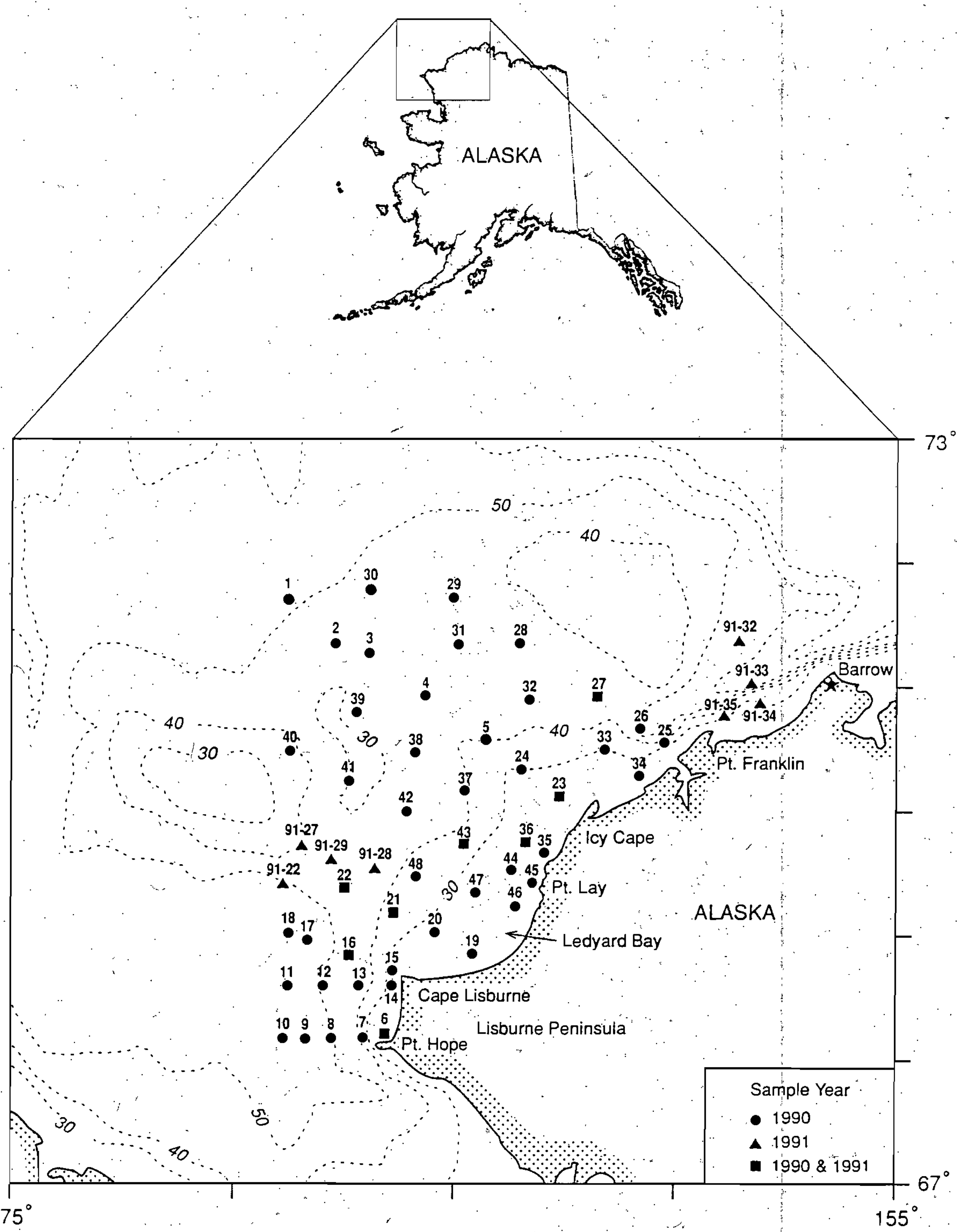

Figure 1. Stations sampled for distribution and abundance of snow crab *Chionecetes opilio* in the northeastern Chukchi Sea during 1990 and 1991. Dashed lines are depth contours in meters.

Figure 1. The CW of all males from stations 91-1 (n = 125) and 91-8 (n = 131) collected in July of 1991 were also measured to the nearest mm. The position of station 91-1 was 69°02'N, 167°38'W, and 91-8 was at 70°31'N, 166°08'W.

Table 1.—Number of northeastern Chukchi Sea female *Chionoecetes opilio* with mature shaped abdominal flaps carrying eggs.

Station	**Location**	**Total Number of Females**	**Number With Mature Shaped Abdominal Flap**	**% Mature With Eggs**
(Lat. N	Long. W)			
69° 02'	167° 38'	100	97	98
69° 03'	166° 43'	12	2	100
69° 23'	166° 28'	22	16	100
60° 32'	165° 59'	8	7	100
69° 38'	167° 41'	50	48	98
69° 40'	168° 31'	50	44	100
69° 54'	168° 42'	35	34	100
70° 00'	165° 03'	4	2	100
70° 13'	167° 04'	27	24	96
70° 21'	162° 53'	41	0	0
70° 31'	166° 08'	50	42	98
70° 33'	162° 20'	4	0	0
70° 58'	163° 39'	2	1	100
71° 37'	159° 02'	88	7	100

To determine if mature female snow crab occurred throughout the sampling area 503 females from 20 to 74 mm CW (Table 2) were collected at 14 sites (Table 2) in July and September of 1991. They were examined for the presence of a mature shaped abdominal flap and eggs.

In the August and September collections eggs were too developed for fecundity estimates but 93 females collected at station 91-1 in July had clutches of bright orange eggs that appeared to be recently extruded. Two females with new eggs had damaged abdominal flaps so the eggs from only 91 clutches were counted. The dry weight of 100 eggs subsampled from each of the 91 clutches was measured. Eggs were dried at 60°C in a convection oven until a constant weight was reached. The remaining eggs on the pleopods of each female were removed and dried as previously stated. Fecundity estimates were determined by dividing the dry weight of the total egg mass by the average dry weight of eggs in the subsample. The number of eggs was related to carapace width with a power curve; $y = ax^b$ $(a > 0)$.

Males (n = 318) used for maturity studies were all captured in September of 1991 at stations 16, 21, 22, 27, 91-29, and 91-32 (Figure 1). Males over 20 mm CW were divided into groups based on five mm increments and had to be taken from several stations to get a minimum of 25 males of the desired sizes (Table 1). In the group with the largest males (70 - 74 mm CW) only 14 individuals were captured. Size at the onset of physiological maturity was determined by histological examination of the vas deferens for spermatophores. The vas deferens were fixed in Bouin's solution followed by embedding, sectioning to 10 to 12 microns thick, and mounted following the techniques of Paul and Paul (1989). Standard Ehrlich's hematoxylin and eosin-y staining sequence (Clarke 1973) was used to enhance morphological identification of spermatophores.

Table 2.—Number of *Chionoecetes opilio* from the northeastern Chukchi Sea examined for the presence of eggs and spermatophores.

Carapace Width (mm)	**No. Females**	**Percent With Eggs**	**No. Males**	**Percent With Spermatophores**
15 - 19	0	0	1	0
20 - 24	17	0	36	0
25 - 29	27	0	37	19
30 - 34	54	2	49	49
35 - 39	29	52	25	100
40 - 44	156	73	25	100
45 - 49	169	86	26	100
50 - 54	41	93	29	100
55 - 59	9	75	25	100
60 - 64	1	100	25	100
65 - 69	0	---	26	100
70 - 74	0	---	14	100
Total	503		318	

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RESULTS

Snow crabs were present at all stations with the largest abundance and biomass tending to be in the southern part of the study area, but varying extensively between stations (Figures 2A and 2B). Abundance and biomass estimates also varied considerably between trawls at most stations. The highest estimated abundance was at station 1 (mean = 100,000/km^2). The largest biomass (mean = 4,000 kg/km^2) was at station 8 although station 1 biomass was nearly equivalent (mean = 3,100 kg/km^2). Lowest abundance was at station 28 (mean = 190/km^2), whereas the lowest biomass estimates occurred at station 35 (mean = 1.2 kg/km^2). Average crab weight (total weight of catch/number of crabs) was generally greater in the southern area than the northern area and less inshore than offshore (Figure 3). Although individuals from stations south of about 70°N generally had greater average weight, it varied extensively. This trend was also reflected in carapace width. The smallest female crabs occurred at the northern sample sites (Figure 4). At the most northern station they were captured (91-32) the average size of all females (n = 88) was 33 mm CW (±sd = 9, range 20 - 54 mm). At the more southern stations 23 (n = 51) and 21 (n = 22) female CW averaged 35 mm (±sd =5, range 28 - 44 mm) and 45 mm (±sd = 4, range 36 - 50 mm) respectively. Male size at the north (91 - 8) and south (91 - 1) stations follows this same pattern 8 (Figure 4). Gravid females were found at all latitudes sampled and 99% of those with mature shaped abdominal flaps carried eggs (Table 1). Egg bearing females ranged from 34 to 60 mm CW and averaged 46 mm (±sd = 4). Most females over 35 mm CW were carrying eggs (Table 2). Average size of the gravid females from southern station 21 was 45 mm (n = 16, ±sd = 4, range = 36 - 50 mm). At the more northern station 91-32 gravid females had a mean CW of 50 mm (n = 7, ±sd = 4, range 44 - 54 mm). No females below 30 mm CW had mature shaped abdominal flaps or eggs. Of those in the 30 to 34 mm CW size group only 2% had mature shaped abdominal flaps and eggs. In the size groups of females that were larger than 35 mm CW, no less than 52% of them were gravid (Table 2). Of the gravid females examined for fecundity during July, 93 carried recently extruded bright orange eggs while 4 females had eyed eggs that appeared ready to hatch. The average number of eggs carried by the 91 females was 19,900 (±sd = 6,500). The equation Figure 2a (Chapter 11) describing the relationship between CW (Y) and the number of eggs (X) per clutch was: $Y = 0.672\ X^{2.668}$, $r^2 = 0.54$ (Figure 5).

Presence of spermatophores in the vas deferens suggests males begin to mature between 25 to 29 mm CW (Figure 6). No males smaller than 25 mm CW contained spermatophores whereas only 19% from those in the 25 to 29 mm CW range did. All males 35 mm CW and larger contained spermatophores (Table 1). Spermatophore diameters increased from about 44 µm in 25 - 29 mm CW size group to 64 µm in males over 35 mm CW. In males between 45 and 70 mm CW spermatophore diameters were 9 similar, between 75 and 80 µm (Figure 6).

DISCUSSION

Although snow crabs are widely distributed through the northwest Atlantic (Elner 1982), Bering Sea (Otto 1982; Slizkin 1989) and Chukchi Sea (this study) little is known about the factors which influence their distribution and abundance. These factors must include larval recruitment dynamics, benthic habitat requirements, thermal tolerance, water depth preferences, predation, competition and cannibalism, but the relative importance of these factors is unknown.

Prey preference for specific sediment types or depths may explain some of the distribution pattern observed for snow crab. In the northwestern Gulf of St. Lawrence, where

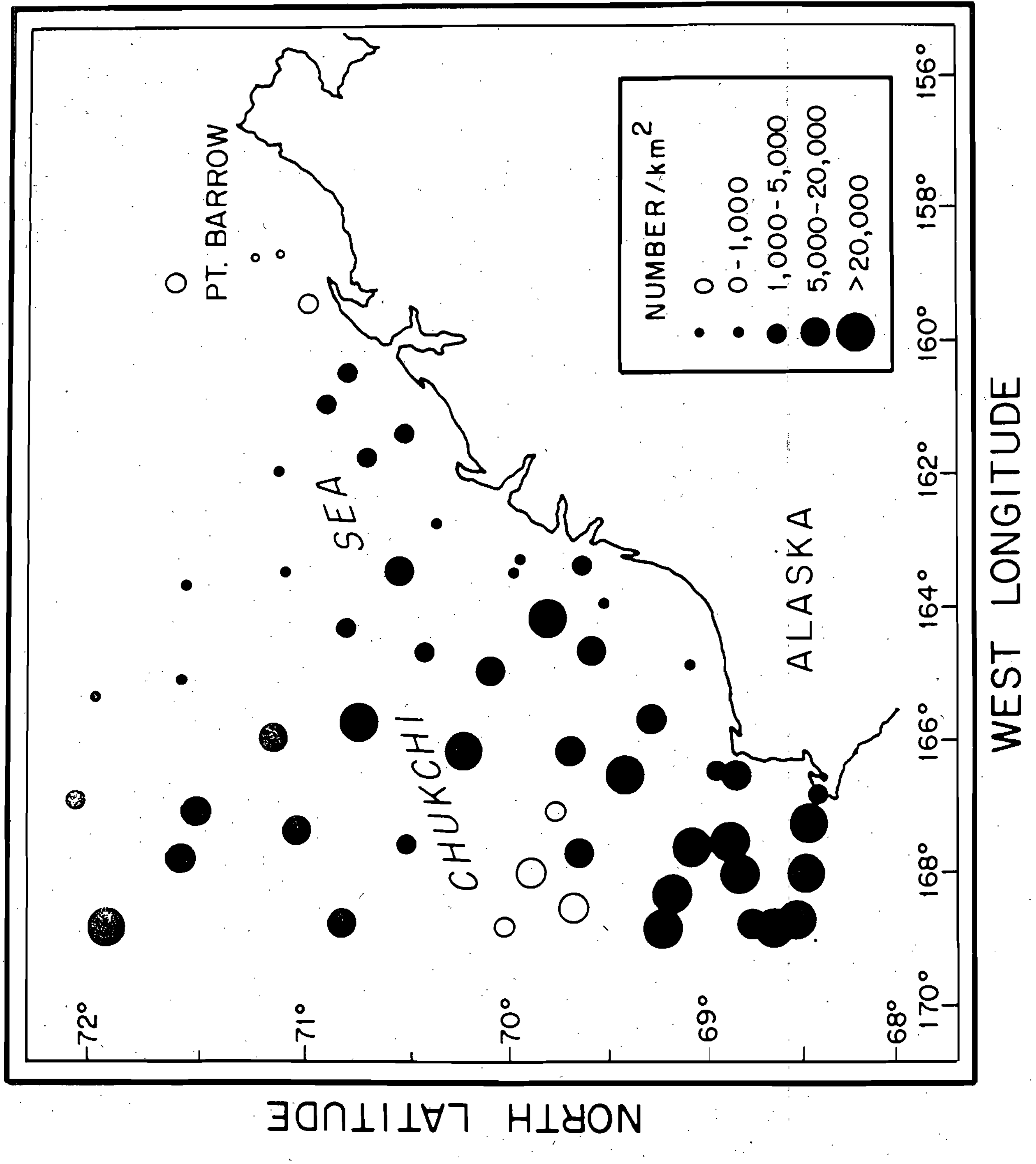

Figure 2a. Abundance of the snow crab *Chionoecetes opilio* captured by otter trawl at stations occupied in the northeastern Chukchi Sea during 1990 (filled O) and 1991 (open O).

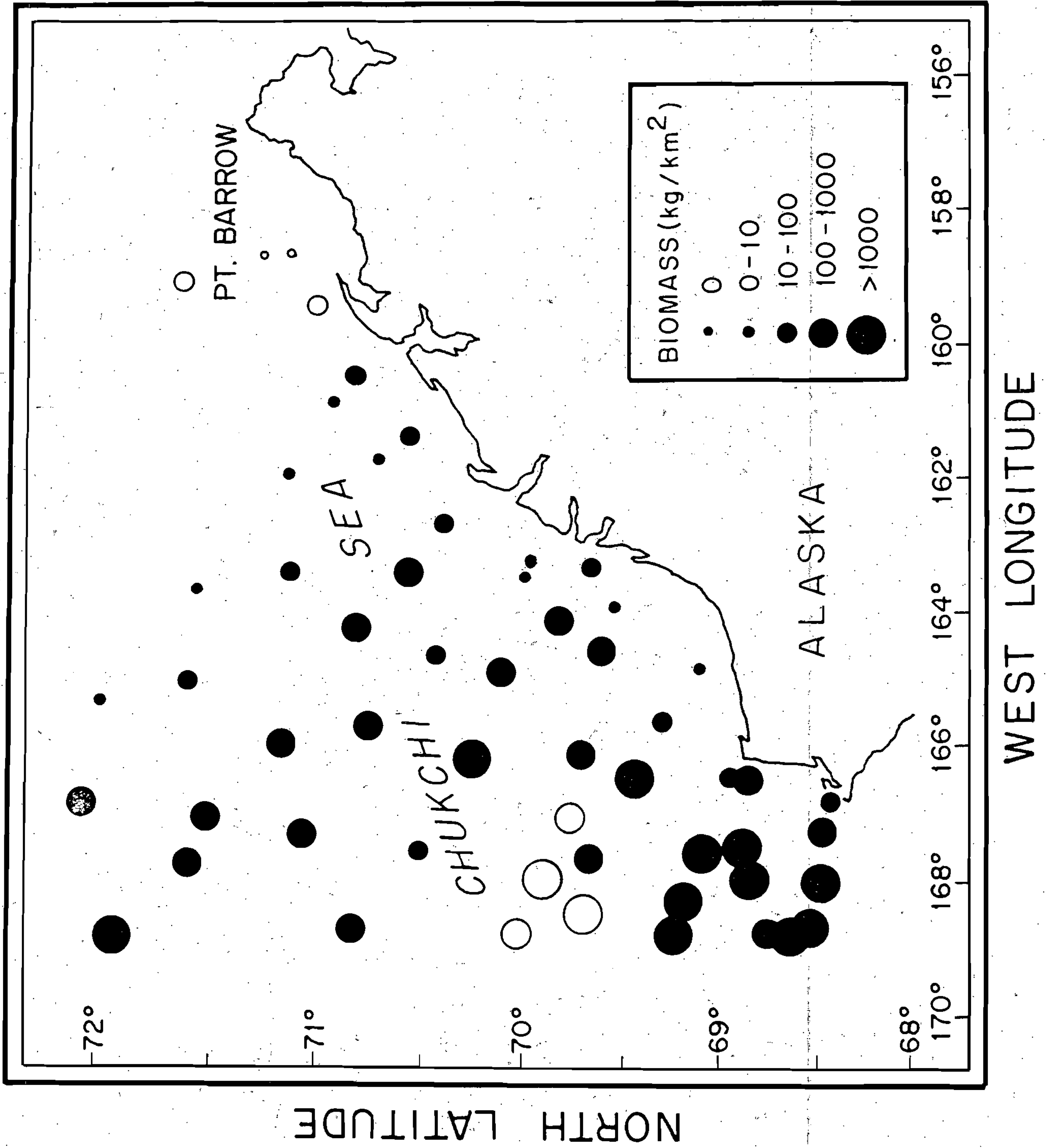

Figure 2b. Biomass of the snow crab *Chionoecetes opilio* captured by otter trawl at stations occupied in the northeastern Chukchi Sea during 1990 (filled O) and 1991 (open O).

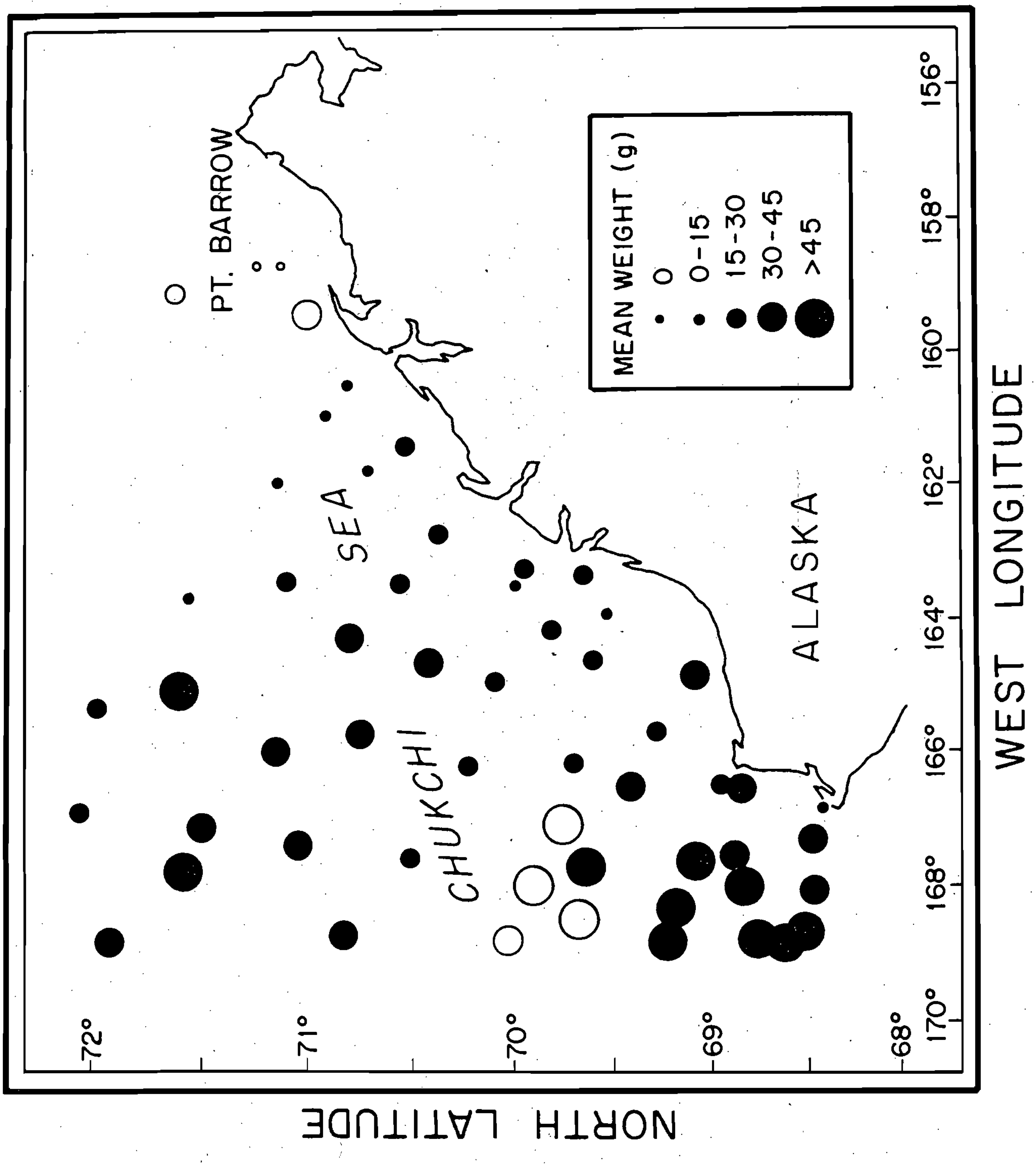

Figure 3. Mean weight of snow crab *Chionoecetes opilio* captured by otter trawl at stations occupied in the northeastern Chukchi Sea during 1990 (filled O) and 1991 (open O).

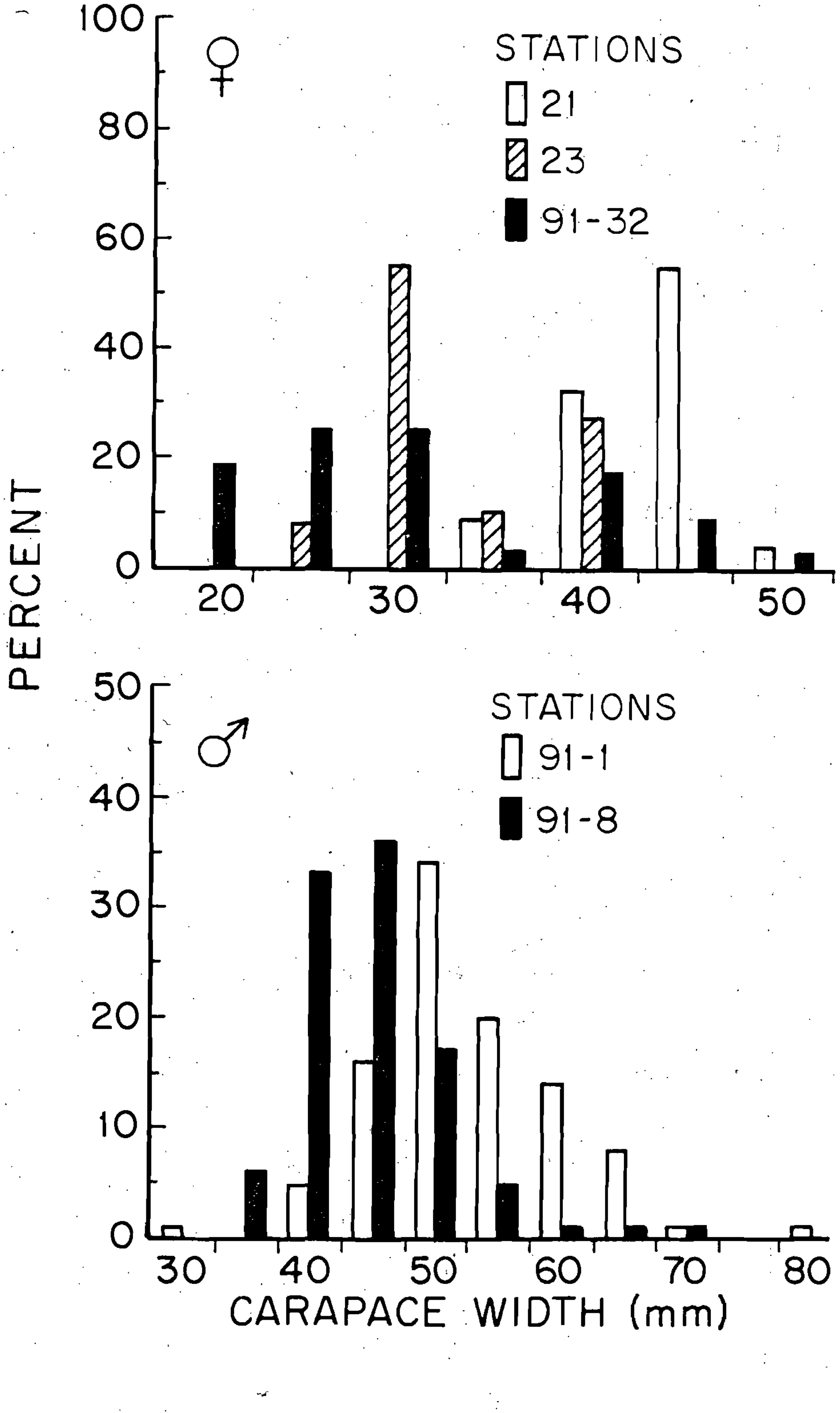

Figure 4. Carapace widths of Chukchi Sea female snow crab *Chionoecetes opilio* (upper) from stations 21 (69°26' 166°31'), 23 (70°22' 162°43'), and 91-32 (71°37' 159°02'), and males (lower) from stations 91-1 (69°02' 167°38'), and 91-8 (70°31' 166°08').

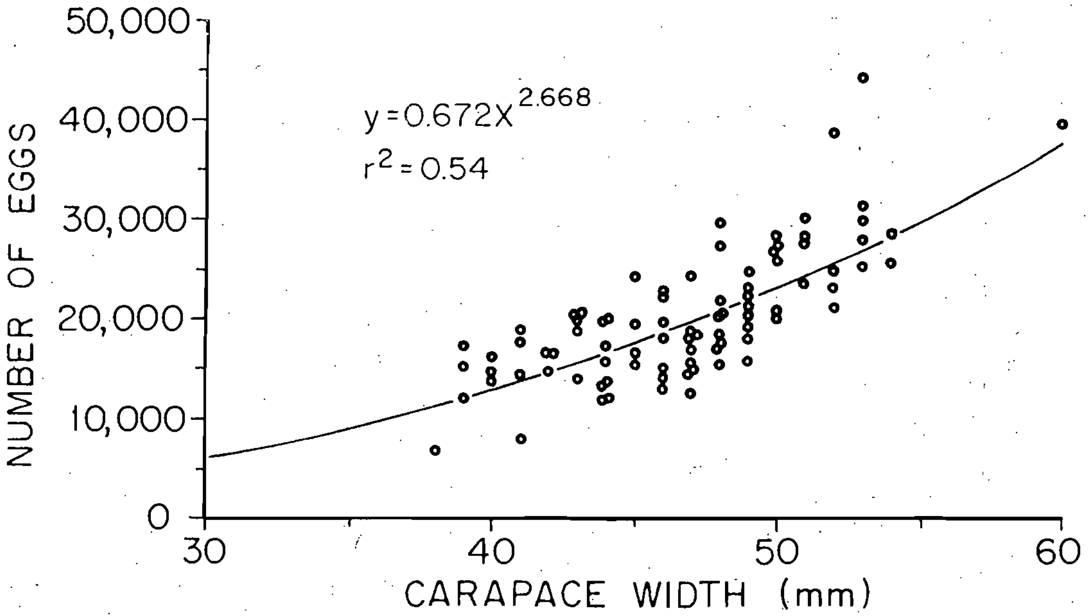

Figure 5. Number of eggs in clutches of various sized snow crab *Chionoecetes opilio* captured by otter trawl in the northeastern Chukchi Sea during July 1991.

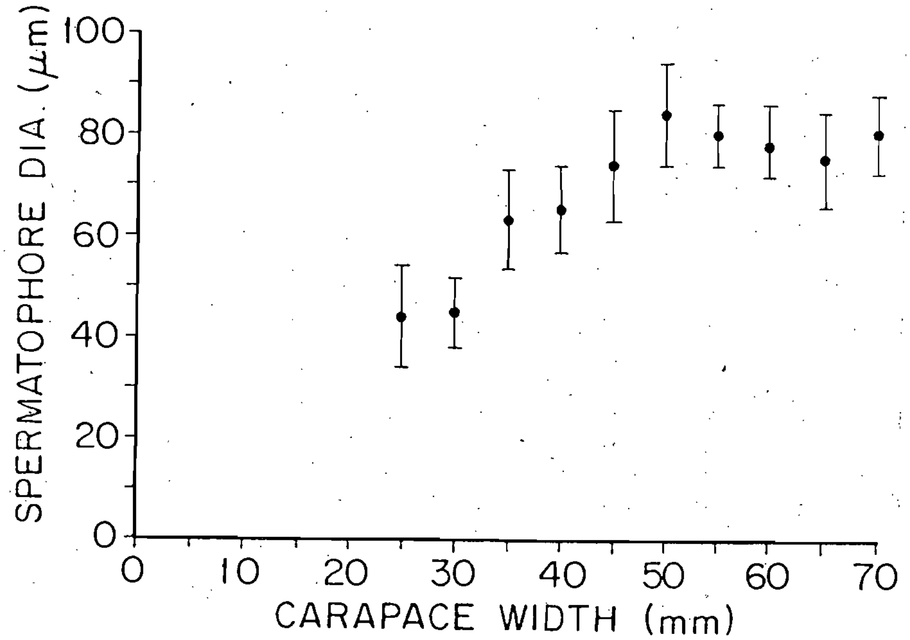

Figure 6. Diameter of spermatophores in relation to size of male snow crab *Chionoecetes opilio* captured by otter trawl in the northeastern Chukchi Sea during September 1991. Vertical bar represents ± one standard deviation.

depths exceeded 135 m, Desrosiers *et al.* (1982) found increases in snow crab size with increasing depth. The Chukchi Sea stations sampled (Figure 1), with one exception (91-33), had depths with a range of only 14 to 52 m and snow crab were found at every station. In the northeast Chukchi Sea the benthic sediments (Sharma 1979) form a general pattern of long narrow gravel belts along the shore and in a few isolated patches in offshore regions. Sand predominates in near-shore areas, and silts and clays predominate offshore. Within this broad pattern, however, there is a mosaic of sediment types (Naidu 1988). This suggests that during sampling we trawled across several bottom types each with its own prey community. Sampling smaller areas will have to be done to better identify sediment habitats preferred by snow crab.

Chukchi Sea snow crab tend to be smaller than Bering Sea or North Atlantic individuals. Chukchi Sea females averaged 46 mm (this study) to 50 mm CW (Jewett 1981) vs. 63 to 72 mm CW in the Bering Sea (Somerton 1981). In commercial fisheries the legal size limit for males ranges from 78 mm CW in Japan (Sinoda 1982) to > 94 mm CW in Atlantic Canada (Elner 1982). Chukchi Sea males seldom reach 78 mm CW.

Fecundity estimates for snow crab from this study are similar to other estimates (Jewett 1981). Fecundity of snow crabs is positively correlated to increasing body size (Haynes *et al.* 1976; Paul and Fuji 1989). In the southeast Bering Sea a 55 mm CW female would have about 24,500 eggs (Haynes *et al.* 1976) vs. 29,000 (Figure 6) for Chukchi Sea specimens 55 mm CW. In Atlantic Canada multiparous females typically carry 52,000 to 80,000 eggs, depending on geographic region (Davidson *et al.* 1985). There they reach maturity around 50 mm CW (Watson, 1970) and a 55 mm female would carry about 26,600 eggs (Haynes *et al.* 1976).

In 1976 Jewett (1981) found only 3.3% of mature Chukchi Sea females were ovigerous vs. 99% in this study. He collected during September to October, with a benthic trawl so the sampling period and collection gear were similar. He reported that 93% (n = 63) of mature females without external eggs had developing orange ova, so it is possible that they had not yet ovulated. In 1991 snow crab had extruded eggs prior to 25 July. These contrasting observations suggests that the dates that snow crab ovulate varies interannually.

Based on claw morphometrics Somerton (1981) estimated that 50% of male snow crab in the Bering Sea that reached 65 mm CW were mature. In the Chukchi Sea males > 65 mm are rare and all > 35 mm have sperm. However, Hartnoll (1965) emphasized that spermatophore presence in small males is only circumstantial evidence of maturity. Laboratory studies, and *in situ* observations, are needed to identify the size at which male Chukchi Sea snow crab mate with primiparous and multiparous mates.

Recently there has been considerable speculation on the reproductive habits of snow crab, especially the importance of male carapace and claw size (Conan and Commeau 1986). Comparison of size at maturity of female snow crab from the Chukchi Sea, Bering Sea, and the North Atlantic suggests that this species has a considerable capacity to modify size at maturity in response to environmental factors. A comprehensive comparison of snow crab mating behavior from several geographical areas, including the Chukchi Sea where there is no fishery, could improve our understanding of the reproductive biology of this valuable circumpolar species.

ACKNOWLEDGMENTS

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