Abstract.–We documented the distribution and abundance of demersal fishes in the northeastern Chukchi Sea, Alaska, in 1990 and 1991, and described 1990 demersal fish assemblages and their relationship to general oceanographic features in the area. We collected samples using an otter trawl at 48 stations in 1990 and 16 in 1991, and we identified a total of 66 species in 14 families. Gadids made up 83% and 69% of the abundance in 1990 and 1991, respectively. Cottids, pleuronectids, and zoarcids together made up 15% of the species in 1990, 28% in 1991. The number of species, species diversity (H), and evenness (V') generally were greater inshore than offshore and greater in the south than in the north. There were significant differences in ranks of species, species diversity, and evenness at 3 of 8 stations sampled both years. From data collected in 1990, 3 nearshore and 3 offshore station groupings were defined. The northern offshore assemblages had the fewest species, lowest diversity and evenness, and least abundance, whereas two southern assemblages had the most species, highest diversity and evenness, and greatest abundance. We determined that bottom salinity and percent gravel were probably the primary factors influencing assemblage arrangement.

Demersal fish assemblages of the northeastern Chukchi Sea, Alaska

Willard E. Barber

School of Fisheries and Ocean Sciences
University of Alaska Fairbanks,
Fairbanks, Alaska 99775-7220
E-mail address: wbarber@ims.alaska.edu

Ronald L. Smith
Mark Vallarino

Institute of Marine Sciences
University of Alaska Fairbanks
Fairbanks, Alaska 99775-7220

Robert M. Meyer

USGS Biological Resources Division, Eastern Regional Office
1700 Leetown Road
Kearneysville, West Virginia 25430

The distribution and abundance of commercially important demersal fishes inhabiting temperate and tropical seas are relatively well studied (e.g. Pearcy, 1978; Mahon and Smith, 1989; Weinberg, 1994). Results from such studies have been used to examine relationships between environmental factors and fish assemblage distributions. Important environmental variables that have been identified include sediment type, water depth, bottom temperature, and bottom salinity.

Overholtz and Tyler (1985) found that six species assemblages on Georges Bank, northwestern Atlantic, remained consistent over depth for a number of years. Fargo and Tyler (1991), sampling at depths of 18–240 m in Hecate Strait off British Columbia, found four species assemblages separated by depth. Pearcy (1978) described shallow and deep demersal fish assemblages in the northeast Pacific Ocean off the coast of Oregon at depths ranging from 70 to 102 m. Although there was an interaction between depth

and sediment type, he concluded that depth was a primary factor and that sediment type was of secondary importance. Mahon and Smith (1989) looked for interactions between sediment characteristics, water depth, bottom temperature, and bottom salinity but concluded that assemblages were related more to depth than to other attributes. Scott (1982) reported that although fish distributions were related to sediment types, the latter was related to depth. Studies of other fishes indicated that temperature and salinity are important; Jahn and Backus (1976), using salinity and temperature to characterize slope waters, the Gulf Stream, and northern and southern Sargasso Sea waters in the Atlantic Ocean, concluded that mesopelagic fishes associated with slope and Gulf Stream waters were distinct and different from fish assemblages associated with the other two water masses. Bianchi (1992, a and b) determined that water depth, bottom temperature, bottom salinity, and

dissolved oxygen content determined benthic fish assemblages observed off the west coast of central Africa.

Relatively few fisheries resource surveys have been conducted in Arctic waters off Alaska; only three have been conducted in the northeastern Chukchi Sea (Alverson and Wilimovsky, 1966; Frost and Lowry, 1983; Fechhelm et al.[1]). These were limited in geographic coverage and not designed to address questions on environmental factors influencing fish distribution. The studies were, however, important first steps in determining factors influencing the distribution and abundance of fishes in Arctic waters.

The goal of our study was to determine the distribution and abundance of demersal fishes, the presence of species assemblages, and the relationship of such assemblages to oceanographic features in the northeastern Chukchi Sea, Alaska. Results from investigations of the distribution and relative abundance of infaunal and epifaunal mollusks in the eastern Chukchi Sea suggest that invertebrate assemblages may be associated with differences in hydrographic conditions and sediment types (Feder et al., 1994, Feder et al.[2]). On the basis of these findings, we hypothesized that there would be onshore–offshore and north–south differences in demersal fish abundance, biomass, and assemblages, and that these differences would be related to hydrographic conditions and sediment type.

Materials and methods

Our study area was north of 68°N (Point Hope, Alaska), east of 168°58'W, and limited in northward extent by weather and sea ice (Fig. 1).

The shelf of the northeastern Chukchi Sea is relatively shallow, gently sloping offshore to depths of 30–50 m in the study area. Bottom sediments in the region are poorly sorted, trending to relatively coarse sediments on the inner shelf between Point Hope and Point Barrow, and shifting offshore to muds containing various proportions of gravel and sand (Sharma, 1979; Naidu, 1988). Sediments in the more northerly offshore region contain a higher percentage of water and a lower percentage of gravel than sediments found in the more southernly offshore area (Feder et al.[2]).

The Chukchi Sea consists of several water masses (Weingartner, in press): Alaska Coastal Water (ACW) and the Resident Chukchi Water (RCW) commonly dominate the study area. The ACW is relatively warm, low-salinity water lying nearshore. It is a mixture of Bering Shelf water and freshwater that comes from western Alaskan rivers, primarily the Yukon. The RCW is relatively cold, high-salinity water that lies seaward of the ACW. The RCW is either advected onshore from the upper layers of the Arctic Ocean or is remnant ACW from the previous winter. The ACW and RCW masses are separated by a hydrographic front that tends to be located between the 25-m and 40-m isobaths and that intersects the coast between Icy Cape and Point Franklin (Johnson, 1989; Weingartner, in press; Feder et al.[2]).

Sampling occurred during August and September in 1990 and 1991. In 1990, 48 stations were occupied along 11 transects perpendicular to shore; 16 stations were occupied in 1991, including 8 that were sampled in 1990 (Fig. 1; station locations, water depths, bottom temperatures, and bottom salinities are given in Smith et al., in press, b). In 1990, nearshore stations were established closer to one another than were stations farther offshore in order to increase the probability of having two stations in each transect inshore of the historical position of the "bottom (hydrographic) front." Weather and ice conditions dictated the sequence of stations sampled. Stations were numbered to reflect the sampling sequence.
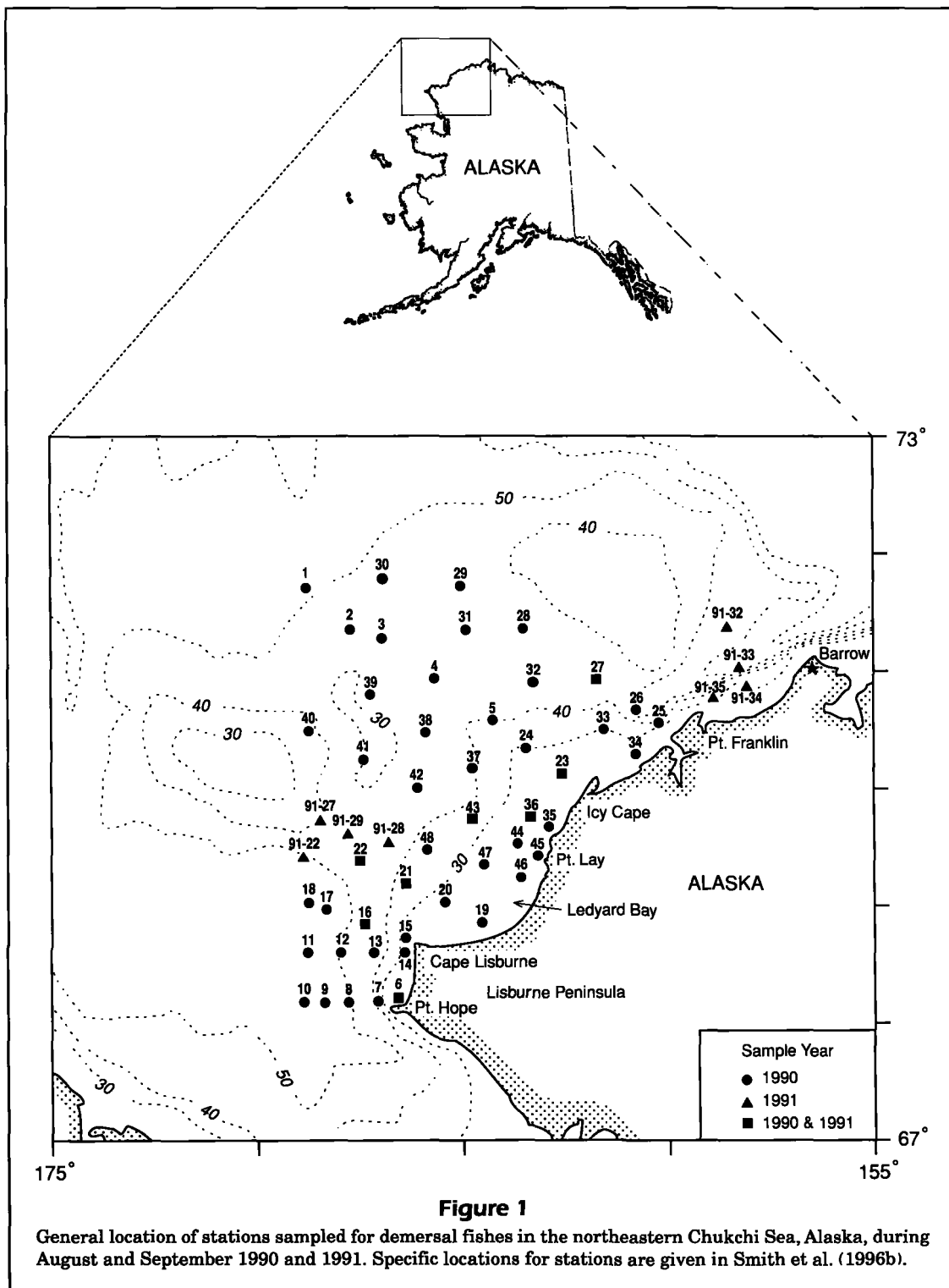
Two samples for each category (fishes and invertebrates) were collected at each station by towing a standard 83–112 survey otter trawl[3] for 30 minutes. However, because of weather condition and torn nets, only one haul was made at station 31 in 1990 and at stations 16, 91–33, 91–34, and 91–35 in 1991. The trawl had a 25.2-m head rope, 34.1-m footrope, tickler chain, and codend of 8.9-cm stretched mesh with a 3.2-cm stretched mesh liner. The area swept by the trawl was calculated by multiplying the length of each trawl haul (beginning and ending location of each tow was determined with "Global Positions System") by the width of the trawl during fishing (the trawl width at the wings and height of the headrope above the footrope were determined with a Scanmar™ electronic mensuration unit).

Upon retrieval of the trawl, the entire catch was either weighed in the net with an electronic load cell or in baskets on a mechanical platform. Fish were sorted to the lowest taxa possible, counted, and weighed with a mechanical platform scale. Fish abundance (fish/km^2) and biomass (g/km^2) were deter-

[1] Fechelm, P., C. Craig, J. S. Baker, and B. J. Gallaway. 1985. Fish distribution and use of near shore waters in the northeastern Chukchi Sea. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 32, p. 121–297.

[2] Feder. H. M., A. S. Naidu, M. J. Hameedi, S. C. Jewett, and W. R. Johnson. 1990. The Chukchi Sea continental shelf: benthos-environmental interactions. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 68:25–311.

[3] Sample, T. E. 1994. Alaska Fisheries Science Center, Natl. Mar. Fish. Serv., NOAA, Seattle, WA. Personal commun.

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. (1996b).

mined by the area-swept method (Wakabayashi et al., 1985).

Following the last trawl at each station, bottom temperature and bottom salinity were measured with a Seabird™ SBE 19 internally recording conductiv-

ity-temperature-depth recorder. Owing to a malfunction, however, salinity and temperature could not be recovered for 7 of 48 stations sampled in 1990.

The total number of unique species captured at each station was determined by pooling results from

the 2 trawl hauls. Mean abundance and biomass of each species at each station were determined by averaging the results from the 2 trawl hauls, except at the few stations where only 1 sample could be collected.

To investigate diversity, we used the number of species for richness (S) and calculated Shannon's Index (H) (Pielou, 1977). Abundance and total unique species of both samples were combined for each station. Shannon's index was calculated as

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

where n = total number of fish;
f_i = number of individuals in species i; and
k = the number of species (Zar, 1984).

By using Shannon's Index (H), "evenness" was estimated with the equation

$$v' = \frac{H}{\ln s},$$

where v' = measure of evenness; and
s = the number of species present.

Fish assemblages were identified and their relationship to physical oceanographic conditions determined in a two-stage process. The first stage used cluster analysis of species abundance by station, followed by discriminant function and principal coordinate analyses of environmental data. Cluster analysis based on species abundance at each station was used to determine fish assemblages. Following the recommendation of Clifford and Stevenson (1975), the most commonly occurring species (21 species, each of which made up >0.1% of abundance) were chosen on the basis of a preliminary examination of abundance data. These species made up 99.6% of the total abundance, 98% of the biomass. Prior to calculating similarity indices, abundance (X) was transformed (ln [X+1]) to normalize the data (Clifford and Stevenson, 1975). Similarity indices were calculated as 1 – D, where D is the Bray-Curtis dissimilarity index (Clifford and Stevenson, 1975) adapted from Lance and Williams (1967).

The algorithm for D is

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

where n = number of individuals in species i; and
j = number of stations.

Similarity index values range from 0 to 1; a value of 1 indicates identical species composition between 2 stations and a value of 0 indicates no common species between stations. Following Clifford and Stevenson (1975), a range of similarity indices was used to determine major groupings. From preliminary inspection of the data, it appeared that groupings could be distinguished with indices of 0.5–0.6. These indices were used as our reference for examining the resulting dendrograms.

Relationships between environmental conditions and fish assemblages were evaluated by using the following data subsets: 1) environmental (water depth, bottom temperature, and bottom salinity); 2) sediment type (arcsine-transformed percent of mud, sand, and gravel); and 3) abundance of infaunal and epifaunal mollusks. Sediment type and mollusk data values for those stations nearest ours were taken from Feder et al. (Footnote 1, sediment type) and Feder et al. (1994, mollusks).

Multiple discriminant function analysis (DFA) and principal coordinate analysis (PCA) were used to evaluate the relationship between fish assemblages and environmental parameters. Mud, bottom temperature, epifaunal biomass, and invertebrate infaunal biomass were not included in the analyses because they were highly correlated with gravel, bottom salinity, epifaunal abundance, and infaunal invertebrate abundance, respectively. PCA was used to validate the results of the DFA and to determine whether other variables were influencing assemblages. To control for multicollinearity, we discarded one of any pair of variables with $-0.8 < r > 0.8$.

Abundance, commonality in species occurrence, ranks, and diversity were used to determine whether there was congruity between years at stations sampled in 1990 and 1991. Species ranks were compared by using the Wilcoxon signed-ranks test (Siegel and Castellan, 1988).

Results

Abundance and biomass

A combined total of 66 species of 14 families were collected in 1990 and 1991 (Table 1). In 1990, two species of gadids, *Boreogadus saida* and *Eleginus gracilis*, made up 82% of the abundance and 69% of the biomass. Cottids, pleuronectids, and zoarcids made up an additional 15% of total abundance and 24% of total biomass in 1990. On the basis of percent

Table 1

Estimated mean abundance (no. of fish/km^2), biomass (g/km^2), and the percent (%) of each demersal fish species collected in the northeastern Chukchi Sea, Alaska, during 1990 and 1991. The 21 most abundant species are labeled in parentheses according to a decreasing scale of abundance from 1 (most abundant) to 21 (less abundant).

Species	1990 Abundance (%)		1990 Biomass (%)		1991 Abundance (%)		1991 Biomass (%)	
Cottidae (sculpins)								
Icelus spatula[1]	2	3	12	3	0.00	0.00	0.00	0.00
I. spiniger[1]	2	3	10	3	0.00	0.00	0.00	0.00
Cottidae sp.	0.00	0.00	0.00	0.00	5	(0.05)	272	(0.20)
Artediellus sp. (21)	26	(0.10)	280	(0.06)	0.00	0.00	0.00	0.00
A. pacificus	2	(0.01)	47	(0.01)	0.00	0.00	0.00	0.00
A. scaber (7)	141	(0.55)	583	(0.12)	197	(2.28)	704	(0.51)
Blepsias bilobus	1	3	169	(0.03)	0.00	0.00	0.00	0.00
Enophrys diceraus	5	(0.02)	188	(0.04)	130	(1.50)	1,106	(0.81)
Eurymen gyrinus	2	3	31	(0.01)	1	(0.01)	17	(0.01)
Gymnocanthus tricuspis (4)	783	(3.06)	9,070	(1.84)	494	(5.71)	5,228	(3.81)
Hemilepidotus papilio (20)	28	(0.11)	571	(0.12)	9	(0.11)	414	(0.30)
Megalocottus platycephalus	15	(0.06)	944	(0.19)	10	(0.12)	944	(0.72)
Microcottus sellaris[1]	2	3	12	3	0.00	0.00	0.00	0.00
Myoxocephalus sp. (3)	1,573	(6.15)	49,167	(9.99)	90	(1.05)	1,295	(0.94)
M. polyacanthocephalus	1	(.01)	167	(0.03)	0.00	0.00	0.00	0.00
M. quadricornis	6	(0.02)	442	(0.09)	0.00	0.00	0.00	0.00
M. verrucosus (6)	238	(0.93)	12,604	(2.56)	1,033	(11.95)	35,017	(25.51)
Myoxocephalus sp. 2	0.00	0.00	0.00	0.00	108	(1.25)	4,550	(3.31)
Myoxocephalus sp. 1	0.00	0.00	0.00	0.00	2	(0.02)	318	(0.23)
Nautichthys pribilovius[1]	2	3	12	3	4	(0.05)	15	(0.01)
Triglops forficatus[1]	2	3	20	3	0.00	0.00	0.00	0.00
T. pingeli	137	(0.54)	1,698	(0.35)	131	(1.52)	1,294	(0.94)
		(11.56)		(15.46)		(25.61)		(37.29)
Pleuronectidae (flounders)								
Hippoglossoides robustus (5)	486	(1.90)	17,406	(3.54)	25	(0.29)	940	(0.68)
Pleuronectes aspera	20	(0.08)	746	(0.15)	101	(1.17)	1,505	(1.10)
P. proboscideus	5	(0.02)	181	(0.04)	0.00	0.00	0.00	0.00
P. sakhalinensis[1]	2	3	12	3	0.00	0.00	0.00	0.00
P. quadrituberculatus	18	(0.07)	2,467	(0.50)	16	(0.19)	2,016	(1.47)
Platichthys stellatus	2	(0.01)	1,365	(0.28)	0.00	0.00	0.00	0.00
Reinhardtius hippoglossoides	2	(0.01)	85	(0.02)	0.00	0.00	0.00	0.00
Hippoglossus stenolepis[1]	2	3	256	(0.05)	0.00	0.00	0.00	0.00
		(2.11)		(4.59)		(1.65)		(3.25)
Zoarcidae (eelpouts)								
Lycodes palearis (11)	133	(0.52)	4,802	(0.98)	24	(0.27)	536	(0.39)
L. polaris (14)	83	(0.33)	7,780	(1.58)	0.00	0.00	0.00	0.00
L. raridens (15)	67	(0.26)	8,078	(1.64)	71	(0.82)	5,241	(3.82)
L. turneri	8	(0.03)	580	(0.12)	0.00	0.00	0.00	0.00
L. rossi	4	(0.02)	137	(0.03)	0.00	0.00	0.00	0.00
Lycodes sp. 1	0.00	0.00	0.00	0.00	8	(0.09)	92	(0.07)
Lycodes sp. 2	0.00	0.00	0.00	0.00	8	(0.09)	92	(0.07)
Lycodes sp.	0.00	0.00	0.00	0.00	4	(0.04)	112	(0.08)
Gymnelis hemifasciatus[1]	2	3	12	3	0.00	0.00	0.00	0.00
G. viridis	1	3	30	(0.01)	30	(0.35)	72	(0.05)
		(1.16)		(4.37)		(1.66)		(4.48)
Agonidae (poachers)								
Aspidophoroides bartoni[1]	1	3	24	3	0.00	0.00	0	(0.00)
A. olriki	2	(0.01)	85	(0.02)	0.00	0.00	0	(0.00)
Podothecus acipenserinus (16)	57	(0.22)	1,077	(0.22)	24	(0.28)	147	(0.11)
Occella dodecaedron[1]	2	3	11	3	0.00	0.00	0	(0.00)
Pallasina barbata	0.00	0.00	0.00	0.00	2	(0.02)	9	(0.01)

Table 1 (continued)

Species	1990				1991			
	Abundance (%)		Biomass (%)		Abundance (%)		Biomass (%)	
Stichaeidae (pricklebacks)								
Chirolophis snyderi	0.00	0.00	0.00	0.00	1	(0.01)	57	(0.04)
Lumpenus fabricii (13)	90	(0.35)	1122	(0.23)	52	(0.61)	102	(0.07)
L. medius[1]	1	[3]	38	(0.01)	0.00	0.00	0.00	0.00
Stichaeus sp.	0.00	0.00	0.00	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 (cods)								
Boreogadus saida (1)	19,456	(76.06)	301,878	(61.34)	5,728	(66.27)	63,913	(46.56)
Eleginus gracilis (2)	1642	(6.42)	38,769	(7.88)	255	(2.95)	7150	(5.21)
Gadus macrocephalus (17)	44	(0.17)	1869	(0.38)	0.00	0.00	0.00	0.00
Theragra chalcogramma (8)	138	(0.54)	1883	(0.38)	0.00	0.00	0.00	0.00
		(83.19)		(69.98)		(69.22)		(51.77)
Cyclopteridae (snailfishes)								
Eumicrotremus andriashevi[1]	2	[3]	11	[3]	31	(0.34)	753	(0.55)
E. orbis	4	(0.02)	116	(0.02)	2	(0.02)	112	(0.08)
Liparis sp.	1	[3]	34	(0.01)	4	(0.05)	373	(0.27)
L. tunicatus	10	(0.04)	373	(0.08)	0.00	0.00	0.00	0.00
L. gibbus (18)	44	(0.17)	442	(0.90)	17	(0.20)	2408	(1.75)
Osmeridae (smelts)								
Osmerus mordax (19)	32	(0.13)	1903	(0.39)	13	(0.15)	129	(0.09)
Mallotus villosus (10)[4]	133	(0.52)	710	(0.14)	1	(0.01)	6	[3]
Hexagrammidae (greenlings)								
Hexagrammos stelleri	4	(0.01)	151	(0.03)	0.00	0.00	0.00	0.00
Clupeidae (herring)								
Clupea harengus pallasi (12)	126	(0.49)	17,469	(3.55)	1	(0.01)	57	(0.04)
Ammodytidae (sand lances)								
Ammodytes hexapterus	0.00	0.00	0.00	0.00	5	(0.06)	10	(0.01)
Anarhichadidae (wolffish)								
Anarhichas orientalis[1]	1	[3]	61	(0.01)	0.00	0.00	0.00	0.00

[1] Found at only one station in 1990.
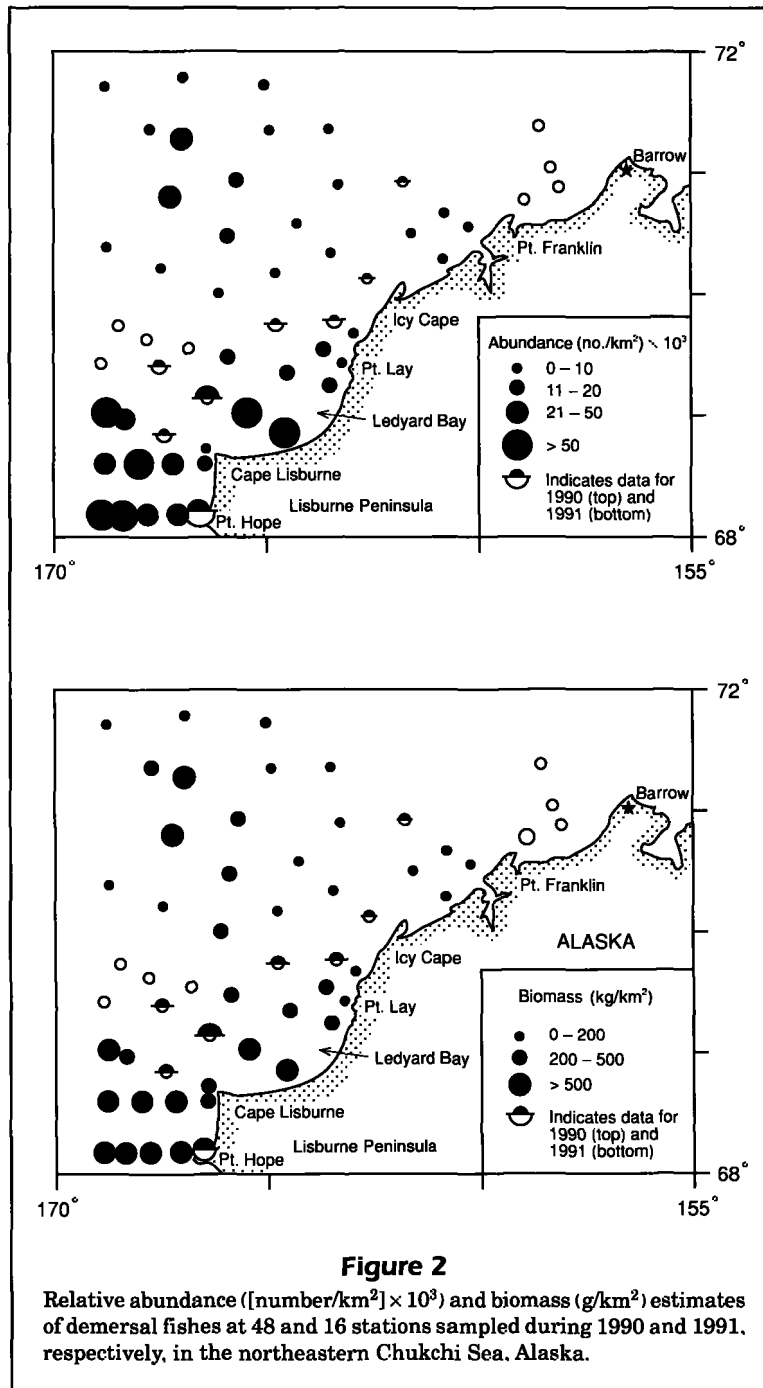[2] Less than 0.49.
[3] Less than 0.01%.
[4] Found at only one station in 1991.

of total abundance, the 45 species captured in 1990 fell into four general categories: category 1 (extremely abundant) consisted only of *B. saida* and made up 76.1% of total abundance and 61.3% of total biomass; category 2 included five moderately abundant species (*Myoxocephalus verrucosus, Myoxocephalus* sp., *E. gracilis, Gymnocanthus tricuspis,* and *Hippoglossoides robustus*) and made up 18.4% and 25.8% of total abundance and biomass, respectively (Table 1); category 3 included 13 occasional species and made up 5.9% and 13.7% of total abundance and biomass, respectively; and category 4 included 26 rare species that accounted for only 0.46% of the abundance and <5.0% of the biomass in 1990 (Table 1). The fish in the first two categories accounted for more than 94.4% and 87.1% of the total abundance and biomass, respectively. This pattern was generally reflected in the 1991 catches.

In 1990, there was a tendency for abundance and biomass of all species combined to be greatest in the southern part of the study area and lowest in the northern part of the study area (Fig. 2). Seven stations south of Ledyard Bay yielded more than 50,000 fish/km^2. In contrast, many stations off and north of Icy Cape had fewer than 10,000 fish/km^2.

Figure 2

Relative abundance ([number/km^2] × 10^3) and biomass (g/km^2) estimates of demersal fishes at 48 and 16 stations sampled during 1990 and 1991, respectively, in the northeastern Chukchi Sea, Alaska.

In 1991, abundance and biomass estimates were low over the entire study area and there was no trend towards greater abundance or biomass in the southern area (Fig. 2). At the eight stations sampled in both 1990 and 1991, biomass and abundance estimates differed widely between years (Table 2). For example, at station 22, *B. saida* was 2.4 times as abundant in 1990 as in 1991, and *H. robustus* was 23 times as abundant in 1991 as in 1990.

Species richness and diversity

Families contributing the most species were Cottidae (21), Zoarcidae (10), Pleuronectidae (8), Stichaeidae (6), and Agonidae (5) (Table 1). Ten families contributed only 16 additional species. Fifty-five percent of the species were represented by less than 10 individuals and some 45% were represented by a single specimen.

Table 2

Estimated mean abundance (fish/km^2) of demersal fishes collected at stations sampled during both 1990 and 1991 in the northeastern Chukchi Sea. Species sequence is based on the overall abundance of 1990 (Table 1), and the probability value (P) is from the Wilcoxon signed-ranks test. Species diversity was calculated from Shannon's Index (H).

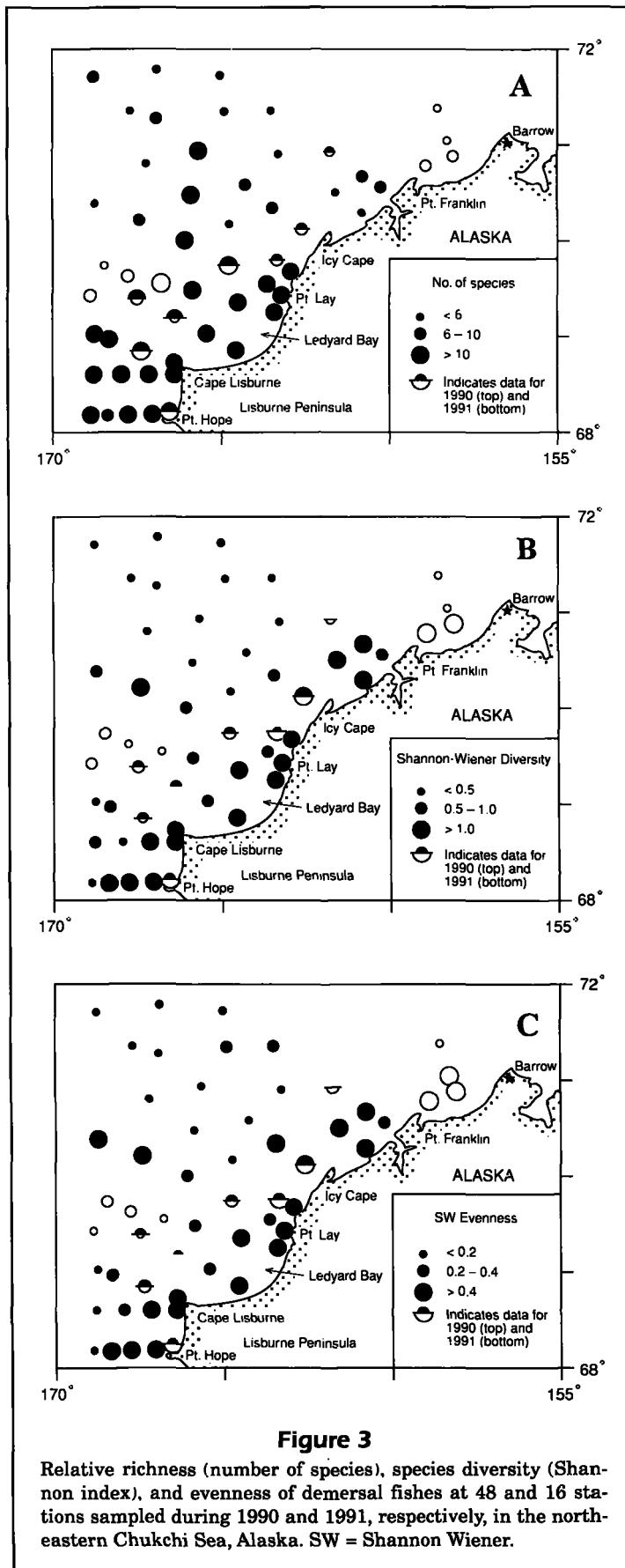| Species	Station 6 1990	Station 6 1991	Station 16 1990	Station 16 1991	Station 21 1990	Station 21 1991	Station 22 1990	Station 22 1991	Station 23 1990	Station 23 1991	Station 43 1990	Station 43 1991	Station 36 1990	Station 36 1991	Station 27 1990	Station 27 1991
Boreogadus saida	56,373.8	14,183.5	22,386.5	2,273.4	32,184.6	393.0	20,475.3	8,527.7	3180	2,379.4	13,684.7	5,090.2	19,104.8	2,139.4	3,017.3	2,180.3
Gymnocanthus tricuspis	207.3	3,047.0	157.6	0	386.8	0	494.5	124.8	778.3	2,041.0	160.2	244.5	728.4	969.1	0	0
Myoxocephalus verrucosus	324.7	0	0	27.0	630.5	0	0	568.8	1,163.1	1,016.2	170.6	189.8	246.7	702.2	0	0
Enophrys diceraus	59.4	1,932.8	11.6	0	0	0	0	0	0	0	0	0	0	0	0	0
Myoxocephalus sp.	0	0	712.2	0	599.4	0	608.9	0	6	55.9	0	11	0	0	0	0
Pleuronectes aspera	400.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hippoglossoides robustus	0	37.5	1,113.5	0	229.7	0	254.8	10.8	0	0	66.8	88.2	0	33.4	0	0
Lycodes raridens	0	102.4	0	54.1	0	0	1,061.0	0	0	0	550.5	22.0	0	0	0	34.6
Myoxocephalus sp.2	0	1,621.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lycodes palearis	0	37.5	492.1	162.4	199.8	0	416.1	0	0	0	0	0	0	0	0	0
Lumpenus fabricii	22.1	651.8	147.3	0	129.8	0	124.0	0	0	0	43	111.0	0	11.1	0	0
Triglops pingeli	0	519.1	0	0	27.4	0	0	0	57.8	111.8	375.4	22.2	49.1	11.1	0	0
Clupea harengus	221.8	0	10.7	0	804.1	0	26	0	0	0	34.1	0	0	0	0	0
Gadus macrocephalus	830.6	0	102.7	0	0	0	62.5	0	6	0	0	0	0	0	0	0
Number of other species	2,853.2	6,807.0	492.1	0	376.5	0	551.6	135.6	28.9	86.3	178.0	99.2	49.0	100.3	0	251.1
P	0.562		0.003		0.001		0.004		0.444		0.42		0.975		0.498	
Number of species	19	24	15	4	15	1	17	8	7	9	14	13	8	10	1	5
Total number of species, both years combined	32		17		15		19		10		18		14		5	
Percent in common both years	40.6		17.6		6.7		42.1		60		50		28.6		20	
Species diversity	0.47	1.83	0.62	0.4	0.52	—	0.74	0.4	1.01	1.25	0.53	0.54	0.38	1.18	—	0.37

There was a trend towards higher species richness in the southern and offshore areas than in the northern and inshore areas (Fig. 3). The greatest numbers of species per station (19) were recorded at stations 6 (Point Hope), 45 (Point Lay), and 48 (Ledyard Bay) in 1990 and at station 6 (23 species) in 1991 (Fig. 3). The fewest species (2 or 3) occurred at four stations in the more northern area (stations 28 through 32). There was a tendency for the stations south of Icy Cape to have 11 or more species and those stations to the north to have 10 or less; the majority of the latter had fewer than 8 species.

The number of species at stations sampled during both 1990 and 1991 differed considerably (Table 2). For example, catches at three stations northeast of Cape Lisburne consisted of 15 and 17 species in 1990 but·in 1991 comprised 1 to 8 species. In contrast, farther north at station 21, 1 species was collected in 1990 and 5 species in 1991.

Those stations with a species diversity of >0.90 occurred south of a line extending south-westward from Point Franklin. The greatest species diversity (1.99) occurred at station 45 off Point Lay; species diversity at two stations off Cape Lisburne (15 and 14) was nearly as large (1.56 and 1.87, respectively). Nearly all stations with a diversity of >1.0 occurred alongshore from Point Franklin to Point Hope. Lowest species diversity occurred at station 39 (0.02). Evenness followed the same pattern as species diversity indices (Fig. 3).

Assemblages

Fishes collected in 1990 formed, at a similarity level of 0.5–0.6, three nearshore (I, III, and V) and three offshore (II, IV, and VI) associations (Fig. 4). One station (15) was not classifiable (Fig. 4). Two clusters of stations formed an association (I) off the Lisburne

Figure 3

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

Peninsula. A second association (II) was formed near a station cluster that bisected the northern offshore association (VI) but was more closely related to association I. The northern offshore association (VI) consisted of two relatively distant clusters, whereas the northern inshore association (III) consisted of two closely related clusters, one 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. The cluster analysis yielded similar results when *B. saida* was not included in the analysis. In all associations, *B. saida* made up over 90% of the abundance (Table 3).

The most distinctive assemblage was VI, which had the fewest species, lowest abundance, and least diversity and evenness (Table 3). In comparison, associations I and V had much greater values for all these measures. Association I had the greatest number of species; the top five species in order of abundance were *B. saida*, *Myoxocephalus* sp., *H. robustus*, *G. tricuspis*, and *Lrycodes palearis*. Association II had the second most abundant species; the top five species in order of abundance were *B. saida*, *L. raridens*, *M. verrucosus*, *G. tricuspis*, and *Clupea harengus pallasi*.

Bottom salinity and percent gravel were identified through discriminant analysis as key factors separating assemblage groups. The first axis accounted for 72%, the second axis for 28% of the variation (Table 4). Bottom salinity showed the strongest association with axis 1, whereas percent gravel was strongest in axis 2. The lines superimposed on Figure 5 enclose stations of similar environmental conditions. There is relatively little overlap of groups III and V; the former is characterized by low bottom salinity and high gravel, whereas the latter is intermediate in salinity and gravel (Fig. 5). Stations 14 and 15 were classified together, with lowest salinity and percent gravel. There is overlap at the boundaries of groups I and VI, which suggests that there is a gradation in environmental conditions. Group VI is associated with more saline water but includes a wide range of percent gravel.

A principal component analysis, which included all environmental data, supports the discriminant analysis but suggests that other variables are also important determinants of fish associations (Table 5). This analysis indicated that bottom salinity, water depth, and
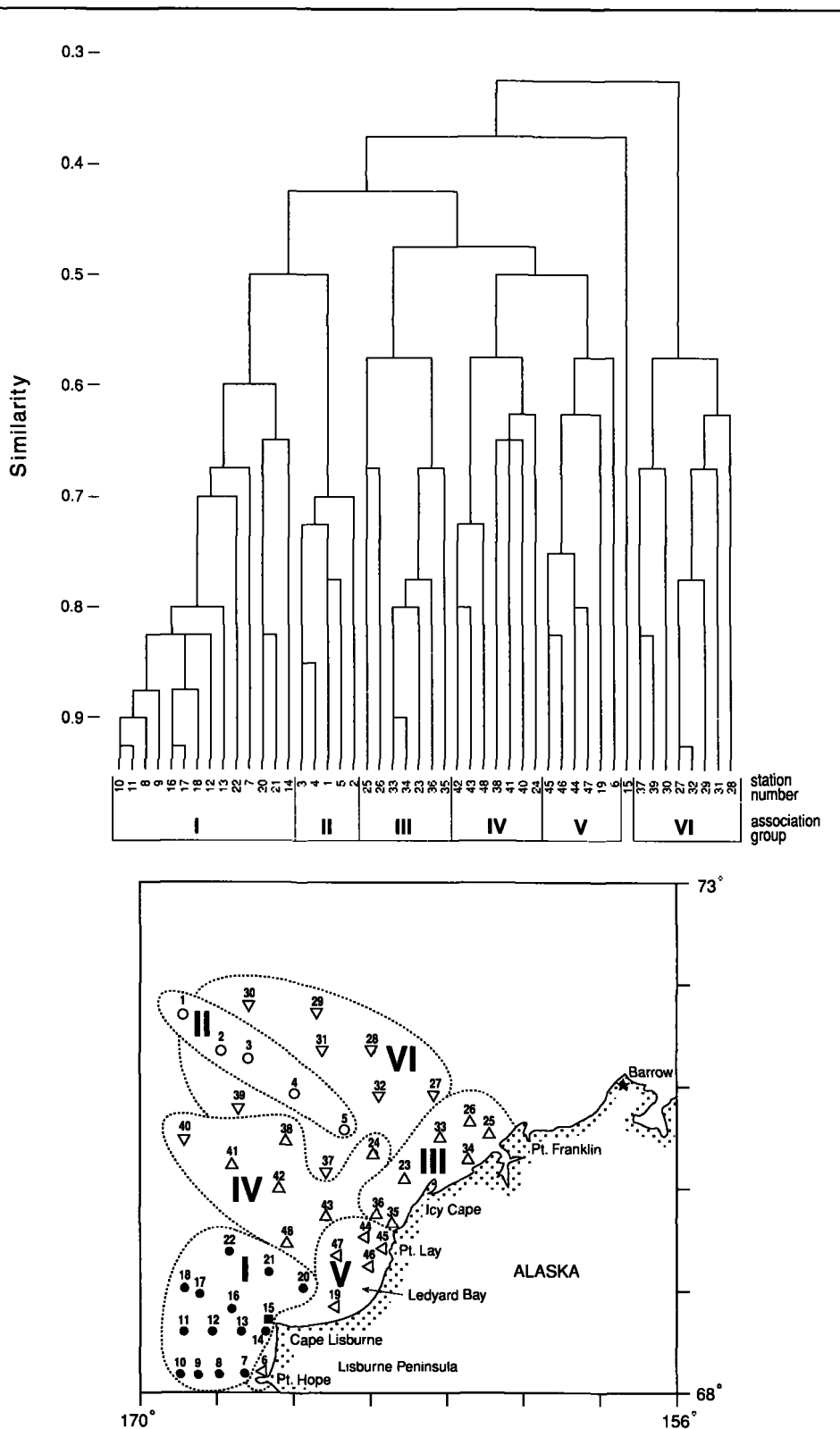
Figure 4

Similarity dendrogram (upper) and demersal fish associations (lower) for fishes captured in the northeastern Chukchi Sea, Alaska, during 1990. The criterion for determining associations was a similarity index of 0.5–0.6. Arabic numerals are station numbers and Roman numerals represent station associations.

gravel accounted for 37.1% of the variance among stations, that epifaunal and infaunal abundances and gravel accounted for 27.8% of the variation, and that gravel and sand accounted for an additional 15.6% of the variation.

Discussion

The northeastern Chukchi Sea lies between the Arctic Ocean and the Bering Sea and serves as a conduit for water flowing between these two bodies of water. In terms of oceanographic flow, this is a dynamic region, with a net water transport from the Bering Sea into the Arctic Ocean. Flow reversals occur in response to regional storm events (primarily during the seasonal ice-forming period). Therefore, oceanographic information used in this study represents but a short-term snapshot of environmental conditions within the region. Information on sediment distribution and associated invertebrate fauna was considered to provide a long-term integration of oceanographic conditions within the region. Even though invertebrate fauna may be influenced by hy-

drographic conditions in much the same way as ichthyofauna are influenced by these conditions, in this study they were used as independent variables. This designation was made in part because invertebrates tend to be less mobile than fishes and because, in ecological terms, invertebrates provide habitat and food for many fish species.

During this study, 66 species representing 14 families were collected, 56 in 1990 and an additional 10 in 1991. This number is similar to the number of species (52) collected in the Chukchi Sea by Alverson and Wilimovsky (1966) and is greater than the 29 species taken in the nearshore Chukchi Sea by Fechelm et al.[1] and the 19 species captured west of Point Barrow by Frost and Lowry (1983). As in our study, *Boreogadus saida* was the dominant species captured during each of these surveys. Other important species reported by these authors that were important in our study included *Mallotus villosus*, *Liopsetta glacialis*, *Lycodes polaris*, and *Icelus bicornus*.

The number, diversity, and biomass of fish species documented during our study are comparable to those in more southerly areas of the North Pacific Ocean. Day and Pearcy (1968) found 67 species represent-

Table 3

Estimated mean abundance (fish/km^2), number of species, Shannon Wiener diversity, and evenness found in the six assemblages for the 21 most abundant demersal fish species determined from the cluster analysis with the Bray-Curtis dissimilarity index.

Species	Assemblage					
	1	2	3	4	5	6
Boreogadus saida	43,733	16,419	5,280	8,172	16,096	6,100
Eleginus gracilis	684	2	170	19	10,956	0
Myoxocephalus sp.	3,391	49	44	2	4,492	0
Gymnocanthus tricuspis	1,005	87	889	156	2,618	7
Hippoglossoides robustus	1,599	72	0	61	15	3
Myoxocephalus verrucosus	178	0	429	177	773	9
Artediellus scaber	20	0	0	11	1,061	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 acipenserinus	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 Wiener 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

ing 21 families offshore of central Oregon at depths of 40–1,829 m. Fargo and Tyler (1991) reported more than 50 species of demersal fish in Hecate Strait, British Columbia. Species diversity seems to be somewhat lower in our study area than off Oregon, where diversity indices varied from 0.7 to 2.47 (Pearcy, 1978).

As noted, in terms of biomass and abundance, *B. saida* was the most common species in our study area; however, this species varied extensively between stations and years. For example, at station 15 (off Cape Lisburne), *B. saida* accounted for 0.23% of the number and 0.18% of the biomass. In contrast, at station 27 (northwest of Point Franklin), 100% of the catch comprised *B. saida*.

Observed trends of fish distribution, abundance, biomass, and assemblages were qualitatively similar to those of epifaunal mollusks found by Feder et al. (1994) but not to those of infaunal mollusks. These qualitative similarities suggest that common variables are influencing the distribution of fishes and epifaunal mollusks in the study area. Feder et al. (1994) found epifaunal mollusk abundance and biomass to be highest along the coast, with very high values adjacent to Point Hope and north of Cape Lisburne. Additionally, the 5 epifaunal mollusk assemblages described by Feder et al. were configured in the same way as the fish assemblages described in our study. However, in contrast to results from our study, abundance and distribution of infaunal mollusks were highest north of and adjacent to the hydrographic front associated with the Alaska Coastal Current (ACC) and along the coast north of Icy Cape and adjacent to or north of Cape Lisburne. The multivariate, cluster,
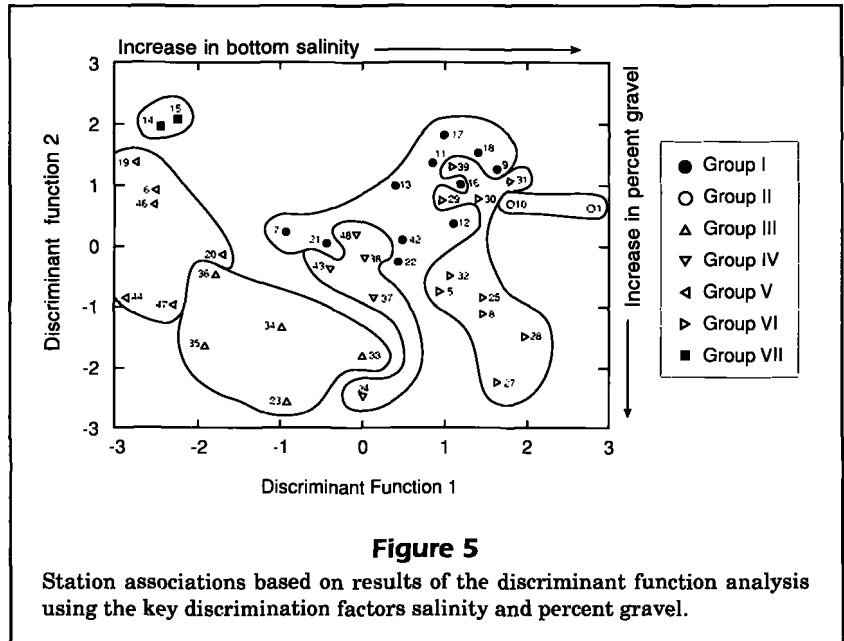

Figure 5

Station associations based on results of the discriminant function analysis using the key discrimination factors salinity and percent gravel.

discriminant, and principal component analyses yielded similar results: stations tended to be grouped by bottom salinity and percent gravel.

Because of the relatively shallow (30–50 m) depth of the northern Chukchi Sea and its gradual, featureless northward slope (Fig. 1), it seems surprising that the principal component analysis identified depth as a significant variable. Depth may have been significant because it acted in concert with other factors, such as sediment (which tends to be relatively coarse, grading to muds containing various proportions of gravel and sand) on the inner shelf between Point Hope and Point Barrow (Sharma, 1979; Naidu, 1988).

Fargo and Tyler (1991) found assemblages related to depth and sediment type, where sediment type

Table 4

Discriminant function analysis of environmental factors with Chukchi Sea demersal fish abundance as the class criterion. Significant relationships are underlined.

Independent variable	Standardized discriminant function coefficients	
	1st axis	2nd axis
Bottom salinity	0.94189	0.48469
Percent gravel	–0.14688	1.04905
Percent variance	71.81	28.19
Eigen value	1.887	0.741

Table 5

Results of the principal component (PC) analysis using both environmental factors and infaunal and epifaunal abundance. Significant relationships are underlined.

Variable	PC1	PC2	PC3
Percent sand	0.563	–0.451	–0.643
Percent 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

was different for each species assemblage. Their species assemblages and sediment types, however, did not coincide exactly; two sediment types were found in the same depth range of species assemblages. They suggested that faunal similarities were maintained in regions of sediment transition and that factors other than sediment type governed distribution of assemblages. Similarly, Pearcy (1978) found a clear separation in the effects of depth but not in the effects of sediment for two assemblages, one shallow and one deep. There was, however, an interaction between depth and sediment type where the shallow assemblages showed a high similarity between stations of different sediment types.

In respect to the hydrography of this area, the ACC sweeps through the area in a general northwest flow. However, change in wind conditions may cause periodic and persistent reversals in the southerly flow of the ACC (Johnson, 1989; Weingartner[4]). Flow reversals tend to be more common during winter ice cover. A review of long-term ice records suggests that in summer, an oceanographic front (as represented by the southern ice edge) may exist to the south and east of Point Franklin. However, there is much interannual variation in the location of this front, in related flow patterns, and in potential transport of adult and larval fishes into the area from the south.

Variations in hydrographic conditions, coupled with differences in catches and changes in year-class strength, strongly suggest that there are interannual changes in abundance and distribution of fishes within the study area. How, or if, the dynamics of oceanographic parameters are translated into distributions and relative abundances of fishes and fish assemblages is unknown. Differences in catches at stations sampled in 1990 and 1991 may have been due to interannual changes in fish distribution and abundance, or even to sampling error. However, differences in the age-class structure of fishes captured during the two years are striking. In 1990 approximately 42% of *G. tricuspis* (Smith et al., 1996b) were older than 4 years, but in 1991 only 9% were older than 4 years. Similarly, ages of *H. robustus* in 1990 ranged from 1 to 11, and age class 5 was most abundant (Smith et al., 1996a), whereas ages reported by Pruter and Alverson (1962) for this species were 6 to 13, and ages 7 through 9 accounted for 90% of the fish samples.

Interannual change in the distribution and relative abundance of fish species may not lead to different associations or result in a change in the locations of these fish within the study area. 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 these were relatively constant over 9 years within seasons (Mahon and Smith, 1989). Colvocoresses and Musick (1984) examined 9 years of trawl data from the Middle Atlantic Bight, and the distributional patterns that were found were largely structured by temperature on the innershelf and midshelf and by depth on the outer shelf and shelf break. They also found that there was sedimentary and topographical uniformity for both the innershelf and midshelf and that there were no strong relationships between species group and sediment. Like Mahon and Smith (1989), Colvocoresses and Musick (1984) found good geographic definition in both autumn and spring groups and overlap between groups. The groups that made up the communities had much in common but differed between seasons. Colvocoresses and Musick (1984) also found relationships between groups and depth, and shifts in the groups with changes in temperature. For example, the geographic extent of assemblages varied between years depending on the southward extent of the cooler 8°C water. The fish apparently behave as a group in response to environmental variation.

The fish assemblages in our study were depicted as having clear assemblage boundaries related to sediment type and oceanographic features. Results from a principal coordinate analysis, however, indicate that these boundaries are related to other features as well. Therefore, the assemblages shown in the ordination plots should more appropriately be thought of as transitional species abundances and proportional compositions. This conclusion is similar to that reached by McKelvie (1985), namely that assemblages of mesopelagic fishes were best interpreted as gradations between faunas associated with different water masses. Consequently, our study area may be viewed as a transition zone between fish communities of the southern Chukchi Sea and those of the Arctic Ocean. In this view, the presence of different species assemblages in the northeastern Chukchi Sea represents a mixture of 2 fish communities whose abundance and biomass vary, shifting somewhat offshore–onshore or northerly–southerly, according to variations in the oceanographic structure of the area.

Acknowledgments

---

[4] Weingartner, T. J. 1994. Institute of Marine Sciences, Univ. Alaska Fairbanks, Fairbanks, AK 99775-7220. Personal commun.

Literature cited

Alverson, D. L., and N. J. Wilimovsky.
   1966. Fishery investigations of the southeastern Chukchi Sea. *In* N. J. Wilimovsky and J. N. Wolfe (eds.), Environment of the Cape Thompson region, Alaska, p. 843–860. U.S. Atomic Energy Commission, Washington, DC.
Bianchi, G.
   1992a. Demersal assemblages of the continental shelf and upper slope of Angola. Mar. Ecol. Prog. Ser. 81:101–120.
   1992b. Study of the demersal assemblages of the continental shelf and upper slope off Congo and Gabon Based on the trawl surveys of the RV 'Dr. Fridtjof Nansen.' Mar. Ecol. Prog. Ser. 85:9–23.
Clifford, H. T., and W. Stevenson.
   1975. An introduction to numerical classification. Academic Press, New York, NY, 229 p.
Colvocoresses, J. A., and J. A. Musick.
   1984. Species associations and community composition of Middle Atlantic Bight continental shelf demersal fishes. Fish. Bull. 82(2):295–313.
Day, D. S., and W. G. Pearcy.
   1968. Species associations of benthic fishes on the continental shelf off Oregon. J. Fish. Res. Board Can. 25:2665–2675.
Fargo, J., and A. V. Tyler.
   1991. Sustainability of flatfish-dominated fish assemblages in Hecate Strait, British Columbia, Canada. Neth. J. Sea Res. 27 (3/4):237–253.
Feder, H. M., N. R. Foster, S. C. Jewett, T. J. Weingartner, and R. Baxter.
   1994. Molluscs in the northeastern Chukchi Sea. Arctic 47:145–163.
Frost, K. J., and L. F. Lowry.
   1983. Demersal fishes and invertebrates trawled in the northeastern Chukchi and western Beaufort seas 1976–1977. U.S. Dep. Commer., NOAA Tech. Rep. NMFS-SSRF-764, 22 p.
Jahn, A. E., and R. H. Backus.
   1976. On the mesopelagic fish faunas of Slope Water, Gulf Stream and northern Sargasso Sea. Deep-Sea Res. 23:223–234.
Johnson, W. R.
   1989. Current response to wind in the Chukchi Sea: a regional coastal upwelling event. J. Geophys. Res. 94:2057–2064.
Lance, G. N., and W. T. Williams.
   1967. A general theory of classificatory sorting strategies. 1: Hierarchical systems. Comput. J. 9:373380.

Mahon, R., and R. W. Smith.
   1989. Demersal fish assemblages on the Scotian Shelf, Northwest Atlantic: spatial distribution and persistence. Can. J. Fish. Aquat. Sci. 46 (suppl.):134–152.
McKelvie, D. S.
   1985. Discreteness of pelagic faunal regions. Mar. Biol. 88:125–133.
Naidu, A. S.
   1988. Marine surficial sediments. Section 1.2 *in* Bering, Chukchi, and Beaufort seas: coastal and ocean zones strategic assessment data atlas, p. 1.4. U.S. Dep. Commer., NOAA, Strategic Assessment Branch, Ocean Assessment Division, Rockville, MD.
Overholtz, W. J., and A. V. Tyler.
   1985. Long-term responses of the demersal fish assemblages of Georges Bank. Fish. Bull. 83(4):507–520.
Pearcy, W. G.
   1978. Distribution and abundance of small flatfishes and other demersal fishes in a region of diverse sediments and bathymetry off Oregon. Fish. Bull. 76(3):629–640.
Pielou, E. C.
   1977. Mathematical ecology. John Wiley and Sons, New York, NY, 385 p.
Pruter, A. T., and D. L. Alverson.
   1962. Abundance, distribution and growth of flounders in the southeastern Chukchi Sea. J. Cons. Cons. Int. Explor. Mer 27:81–99.
Scott, J. S.
   1982. Selection of bottom type by groundfishes of the Scotian Shelf. Can. J. Fish. Aquat. Sci. 39:943–947.
Sharma, G. D.
   1979. The Alaskan shelf: hydrographic, sedimentary and geochemical environment. Springer-Verlag, New York, NY, 498 p.
Siegel, S., and N. J. Castellan Jr.
   1988. Nonparametric statistics for the behavioral sciences. McGraw-Hill Book Co., New York, NY, 399 p.
Smith, R. L., W. E. Barber, M. Vallarino, E. Barbour, and E. Fitzpatrick.
   In press, a. Biology of the Bering flounder, *Hippoglossoides robustus*, from the northeastern Chukchi Sea. *In* J. B. Reynolds (ed.), Fish ecology of Arctic North America. Am. Fish. Soc. Symp.
Smith, R. L., W. E. Barber, M. Vallarino, J. A. Gillispie, and A. Ritchie.
   In press, b. Biology of *Gymnocanthus tricuspis*, the Arctic staghorn sculpin, from the northeastern Chukchi Sea. *In* J. B. Reynolds (ed.), Fish ecology of Arctic North America. Am. Fish. Soc. Symp.
Wakabayashi, K., R. G. Bakkala, and M. S. Alton.
   1985. II: Methods of the U.S.-Japan demersal trawl surveys. *In* R. G. Bakkala and K. Wakabayashi (eds.), Results of cooperative U.S.-Japan groundfish investigations in the Bering Sea during May–August 1979, p. 7–29. Int. North Pac. Fish. Comm. Bull. 44.
Weinberg, K. L.
   1994. Rockfish assemblages of the middle shelf and upper slope off Oregon and Washington. Fish. Bull. 92(3):620–632.
Weingartner, T. J.
   In press. The physical oceanography of the northeastern Chukchi Sea: a review. *In* J. B. Reynolds (ed.), Fish ecology of Arctic North America. Am. Fish. Soc. Symp.
Zar, J. H.
   1984. Biostatistical analysis. Prentice Hall, Englewood Cliffs, NJ, 718 p.