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Distribution Of Shrimp And Fish By-catch Assemblages In The Canadian Eastern Arctic In Relation To Water Circulation

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Distribution of Shrimp and Fish By-Catch Assemblages in the 'anadian Eastern Arctic in Relation to Water Circulation '

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In the Canadian eastern Arctic, the catches of common species of decapods and fish in bottom trawls reveal a continuum of increasing species richness and abundance in an easterly direction through Hudson Strait. Species richness is greatest in Ungava Bay, where Arctic and Labrador Sea components of the fauna coexist. Over the study area, species could be divided in three associations corresponding to the origin of the predominant water masses: Arctic cod, cottids, zoarcids, and liparids predominate in the Arctic waters of western and central Hudson Strait; Greenland halibut, roughhead grenadier, and three-beard rockling are characteristic of the northern Lab rador Sea; pandalid shrimp are abundant in areas of deep (> 300 m), intensely mixed waters near the mouth of Hudson Strait. Pink shrimp (*Pandalus* borealis) predominates in Davis Strait–Labrador Sea, whereas it is replaced by the striped pink shrimp (*P. montagui*) in eastern Hudson Strait, reflecting environmental optima in subarctic and Arctic dominated waters, respectively. The yearly catches of striped pink shrimp are highly variable, possibly related to mixing intensity in eastern Hudson Strait. In Canadian Arctic waters, species richness, distribution, and abundance are related to temperature, salinity, mixing, and general circulation of water masses.

La richesse et l'abondance des captures de décapodes et de poissons clans les chaluts de fond clans l'arctique oriental canadien suivent un gradient croissant clans l'axe ouest-est du Détroit d'Hudson. La richesse en espèce est maximale clans la Baie d'Ungava, ou coexistent des composantes de la faune arctique et de la Mer du Labrador. Dans la region d'étude, les espèces peuvent être divisées en trois associations correspondent au degré d'influence des principals masses d'eaux. La morue arctique, les cottidés, les zoarcidés et les liparidés predominant clans les eaux a l'ouest et au centre du Détroit d'Hudson; le flétan du Greenland, le grenadier et la mustèle arctique a trois barbillons sent caractéristiques de la Mer du Labrador; les crevettes abondent clans les eaux profondes (> 300m), fortement mélangées pres de l'embouchure du détroit. La crevette rose (*Pandalus borealis)* prédomine clans le détroit de Davis et la Mer du Labrador, et est remplacée par la crevette ésope *(P. montagui)* à l'est du détroit d'Hudson, reflétant un optimum environnemental clans les eaux à dominance subarctiques et arctiques, respectivement. Les captures annuelles de crevette ésope varient beaucoup, possiblement en relation avec l'intensité du mélange clans l'est du Detroit d'Hudson. Dans l'arctique oriental canadien, la richesse spécifique, leur distribution et leur abondance sent reliées a la température, à la salinité, au melange et a la circulation générale des masses d'eaux.

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Fisheries resources of Hudson Strait and Ungava Bav are poorly known. especially in deeper waters, and until recently the offshore resources were not exploited. Early accounts of the fishes of Ungava Bay (Dunbar and Hildebrand 1952) and Labrador (Backus 1957) listed species commonly found in those areas. but did not evaluate [he potential for commercial exploitation. Fisheries surveys carried out in later years (see Table 1) revealed high concentrations of striped pink shrimp (*Pandalus montagui*) *west* of Resolution Island (eastern Hudson Strait) and in northeastern Ungava Bay (Veitch et al. 1981; Parsons et al. 198 I). The species is also found off the west coast of Greenland. Labrador, Newfoundland (Squires 1965), and in the Gulf of St. Laurence south to Cape Cod (Simpson et al. 1970).

In contrast with Hudson Strait and Ungava Bay, the adjacent areas of Davis Strait (NAFO Division OB) - Labrador Sea (NAFO Division 2G) support a developing fishery for the pink or northern shrimp (*Pandalus borealis),* a circumboreal species, found in both the Atlantic and the Pacific Oceans. In the northwest Atlantic, it occurs from around 75"N off West Greenland to 42° off Georges Bank (Squires 1965, 1966), and is commercially exploited in the Gulf of St. Lawrence, off the coast of Labrador, and in Davis Strait.

Although both pandalids occur in the same geographical range, they are not found in the same water masses: *Pandalus borealis* is found in the deeper, warmer water, while *P. montagui is* found in shallower. colder water. The former is generally the more abundant species, except west of the mouth of Hudson Strait, where the striped pink shrimp is dominant. This well-defined change reflects the existence of a sharp environmental gradient between Davis Strait–Labrador Sea and Hudson Strait waters. In addition. such a marked change in physical conditions might result in changes in the fish species assemblage associated with the shrimp. The animal community could therefore serve as an indicator of the origins of the different water masses meeting and mixing in this large area.

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TABLE 1. Summary of the information on the ships surveyed. WHS: western Hudson Strait and Northern Hudson Bay (74°00–82°00W); CHS: Central Hudson Strait (69°30–74°00W); EHS: Eastern Hudson Strait (64°40–69°30W); UB: Ungava Bay (south of 61 °05N); RI: Resolution Island; OB + 2G: NAFO Divisions 0B–Southern Davis Strait and 2G–Northern Labrador Sea.

Ship	Dates of survey	Type of trawl	Number of sets in region						Reference
			WHS	CHS	EHS	UB	RI	OB + 2G	
Canso Condor	Aug. 3-29.1978	Sputnik 1600	—	—	8	10	—	50	MacLaren Marex 1978
Torsbugvin	Aug. 15–Oct. 5. 1979	Sputnik 1600	—	—	17	103	71	—	Gillis, unpubl. data, pers. comm.[a]
Thalassa	Sept. 14-22.1979	Lofoten Expl.	—	—	2	22	—	—	Allard 1980
Lumaaq	Sept. 28–Oct. 7, 1980	Sputnik 1800	—	16	—	5	22	—	Imaqpik Fisheries Inc. 1981
Gadus Atlantica	Sept. 11-26, 1982	Sputnik 1600	—	—	—	40	53	18	Parsons 1982
Ocean *Prawns*	Oct. 4-16, 1986	Shjervøy	—	—	—	17	37	—	Anonymous 1986
A. Needler	Aug. 15–Sept. 9, 1988	Sputnik 1600	—	—	—	—	27	—	Parsons, unpubl. data. pers. comm.[b]
Kinguk	Aug. 9-19, 1989	Shjervøy, Hopedale	65	40	—	—	—	—	Allard 1990
		Total:	65	56	27	197	210	68	

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The present study synthesizes information from eight research and/or commercial cruises that aimed at assessing shrimp and groundfish resources in Northern Hudson Bay, Hudson Strait, and Ungava Bay. Comparisons of species composition, abundance, and distribution were made with southern Davis Strait (NAFO Division OB) and northern Labrador Sea (NAFO Division 2G), when those areas were fished by the same vessels. The density of commercially important species was mapped and year to year variability estimated. Their distribution and abundance were then related to relevant hydrographic and oceanographic information. The biology of most species of commercial interest, as well as their salinity and temperature tolerance, are fairly well known, allowing their use as indicators of water masses.

Description of the Study Area

The marine environment of eastern Canada is strongly influenced by interacting water masses from the Arctic Ocean and the central North Atlantic (Dunbar 1951; LeBlond et al. 1981). Cold, low-salinity water enters Baffin Bay from the Arctic Ocean and flows southward, forming the Baffin island current over the shelf off eastern Baffin Island (Fig. 1). On the opposite side of the Labrador Sea, the West Greenland Current, derived from mixed Arctic and Atlantic waters, flows northward. One branch of this wanner flow crosses Davis Strait and joins the Baffin Island Current.

In Hudson Strait, Arctic water from Hudson Bay and Foxe Basin flows eastward along the Quebec shore, while a mixture of Atlantic and Arctic waters from Davis Strait moves westward along the Baffin Island coast (Prinsenberg 1986, Fig. 1). At the eastern entrance to the strait, a crosschannel southward current merges with outflowing waters from Ungava Bay (Drinkwater 1986). The waters below 200 m in western Hudson Strait are mostly of Arctic origin. Temperatures are cold and nearly isothermal (<0°C; Drinkwater 1986). In the eastern portion of the strait, and in northeastern Ungava bay, there is an increase in both temperature and salinity at depths >200 m due to the influence of Labrador Sea water (Drinkwater 1986; Fig. 2). These deep waters are not subject to much seasonal variations (Schroeder 1963), and identify the major water masses and oceanic curents most likely to influence demersal organisms.

Water masses originating from the West Greenland Current. Baffin Island Current, and Arctic waters of Hudson Bay can be identified from their temperature and salinity (T-S) curves (Fig. 2). Overall, the waters within the Hudson Strait region constitute. a continuum of T-S, from the characteristic Arctic water in the west (Fig. 2, polygons 1–2) to the Labrador Sea water in the east (polygons 7-8). Ungava Bay water (polygon 4) is unique with T-S characteristics that overlap both Labrador Sea and northern Hudson Bay water; however, Ungava Bay contains warm, low salinity waters resulting from local river runoff (Dunbar 1951; Fig. 2). A distinct water mass is found at the eastern entrance of Hudson Strait, formed by the converging and mixing of water from the Baffin Island Shelf, the low salinity outflow from Hudson bay and Foxe Basin, and offshore Labrador Sea water (Dunbar 1951; Fig. 2).

During the summer, the degree of vertical density stratification in Hudson Strait and Ungava Bay varies spatially. Maximum stratification occurs along the Quebec side due to the advection of the low salinity surface water from Hudson Bay. Intense tidal mixing occurs in Ungava Bay and frontal areas have been observed across the mouth of Ungava Bay, across the eastern entrance of the Strait and around the southeastern tip of Baffin Island (Drinkwater and Jones 1987). The latter two areas also have high surface nutrients and phytoplankton biomass. Mixing in eastern Hudson Strait may enhance nutrient flux on the Labrador Shelf, with important biological consequences (Sutcliffe et al. 1983).

Methods and Statistical Analyses

Detailed set and catch data were obtained from the cruise reports of eight vessels operating in northern Hudson Bay, Hudson Strait, and Ungava Bay (Table 1). Set data include the date, time, position, duration, depth, and set type (research, commercial). Catch data include the weight (kg) of each species of decapod and fish caught during each set, standardized for a 0.5 h tow. The sets were divided among regions corresponding to western, central, eastern Hudson Strait, Ungava Bay, and OB + 2G (Fig. 1, Table 1). One additional region was delineated for shrimp fishing grounds west of Resolution Island (eastern Hudson Strait). Instead of the traditionally used oblique boundary from headland to headland, the northern boundary of

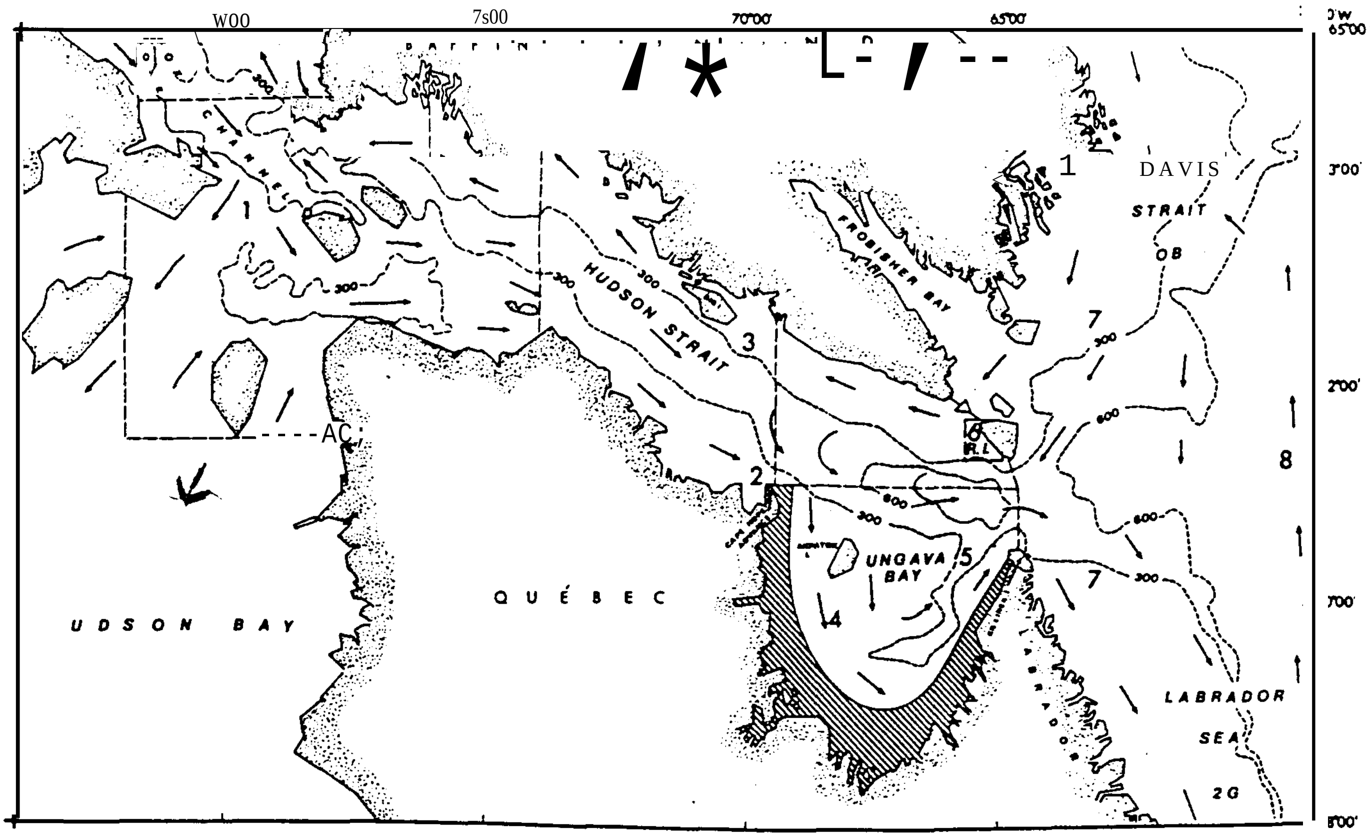

FIG. 1. Bathymetry (300 and 600 m isobaths) and general circulation (arrows, from Drinkwater (1986) and Prinsenberg (1986)) in the study area. Numbers correspond to T-S diagrams identified in Fig. 2 and indicate the general location of hydrographic stations. The shallow (< 100 m) coastal zone of Ungava Bay (hatched), to which demersal fish distribution could not be extrapolated, was not included in the mapping of species distribution. Enclosed areas for Resolution Island (R. I.) and Ungava Bay are examined in detail in Figs. 3-5.

Ungava Bay was set at 61°05' latitude, to facilitate mapping and include the entire area where shrimp fishing occurs. The coastal area of Ungava Bay was excluded from the mapping to avoid extrapolating demersal fish distribution into the coastal zone (< 100 m), potentially under the influence of the large freshwater outflow (Dunbar and Hildebrand 1952).

Catch data for each region were used to derive information on (A) relative species frequency and (B) quantitative abundance of common decapods and fish. Relative species frequency allocated all species to one of four classes corresponding to: (0) absent; (1) rare (species observed once); (2) occasional (species observed < 10% of sets); (3) common (species observed > 10% of sets). Relative species frequency observed in the six regions was used for a cluster analysis to determine the species of fish exhibiting similar patterns of occurrence over the territory. This was accomplished using an intermediate linkage clustering algorithm, with a threshold for linkage at the 0.75 level (i.e. groups were formed at the level at which their components shared 75% of information). The similarity matrix was calculated using Gower's coefficient modified for asymmetric data (Legendre and Legendre 1984), which excludes the double absence of any species in the calculation of species association. This procedure yielded interregional comparisons of species richness while reducing the bias induced by possible misidentification of rare species.

Quantitative abundance (kg·30 min standard tow-') of common species was calculated only with species occurring in > 10% of the tows in each region. In some cases (multivariate analyses and average catch statistics) species had to be lumped together at the genus or family level. Abundance 'data were ln-transformed ($\ln(x + 1)$) due to the large number of zero values. When more than one set was carried out in the same location (19 cases), the average catch was used for mapping.

In order to identify the origin of catch variability within regions, zones of homogeneous species composition and abundance were identified within the Resolution Island and Ungava Bay areas. This was carried out using a cluster analysis with a spatial constraint (BIOGEO), producing maps of homogeneous species composition and abundance for Resolution Island and Ungava Bay. The similarity matrix between each pair of sets was computed using Gower's (1971) similarity coefficient. The homogeneous zones were delimited using clustering with spatial contiguity constraint (Legendre 1987), computed from the Gower similarity matrix. The term "homogeneous zone" is used here to mean a region of space, made of adjacent (contiguous) stations that are also similar for the variables under study. In the first step, proportional-link linkage agglomerative clustering (50% connectedness level) was computed with a spatial contiguity constraint (Legendre and Legendre 1984). The groups obtained were then defined using a non-hierarchical 'K-means' clustering, minimizing the within-group variance (MacQueen 1967), also with spatial contiguity constraint. Both programs used for these computations are part of the "R package" (Legendre 1985). Each of these homogeneous zones was then characterized in relation to the prevailing hydrographic conditions (spatial variability) as well as the identity of the ship and year of sampling (differences in performance and/or temporal variability).

The distribution of common species was mapped using the Symap® package (Dougenik and Sheehan 1977), proceeding

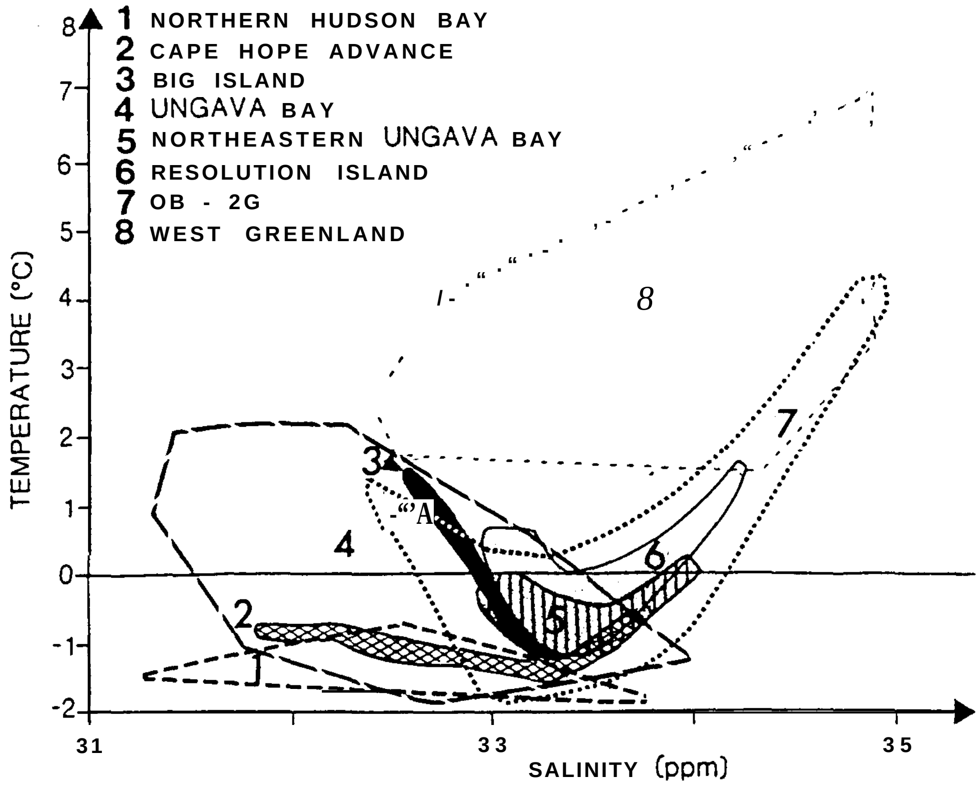

FIG. 2. T-S diagrams for various locations in the study area (see Fig. 1). Temperature and salinity values were taken at 50 m interval to the bottom, while omitting values from the surface to 50 m to eliminate the effect of seasonal variations. Hydrographic data were obtained from K. Drinkwater (Department of Fisheries and Oceans, BIO, C.P. 1006, Dartmouth, N.S. B2Y 4A2, pers. comm.: regions 1 and 7 (1982) region 4 (1986)); C. Hudon (unpubl. data: regions 2, 3, 5, 6 (1987)); Dunbar (1951: regions 4 and 8).

with the point distribution coefficient calculated by the nearest neighbour method (Clark and Evans 1954). The expected species density between two sampling points is calculated by interpolation, thus providing a map of the spatial distribution of any given species. The precision of the interpolation depends on the density of sampling stations. Mapping was not carried out for Hudson Strait (Fig. 1), due to low biomass of decapods and fish. The complete series of distribution maps of the most abundant species of fish and decapods for Resolution Island, Ungava Bay, and NAFO Division OB and 2G can be found in Jarry (1988).

Fish associations were identified using a principal coordinate analysis (Legendre and Legendre 1984). In this analysis, the projection of the coordinates of each species on each of the first two principal coordinates axes is examined to determine which species account for most of the variability among sets. Species found in the same quadrat of the two-dimension space are associated. This analysis was carried out on the similarity matrix of fish abundance data while excluding catches of pandalid shrimps.

Finally, the affinity of the different regions with respect to their common species composition and abundance was determined using an intermediate linkage clustering algorithm (0.75 level). The similarity matrix of the average catch rates per standard tow unit was calculated on normalized data ($\ln(x+1)$) using Gower's (1971) similarity coefficient. This coefficient includes double absence in the calculation of the similarity coefficient between two regions. For example, the double absence of Myctophids in western and central Hudson Strait was taken as a similarity between the regions, rather than omitted from the calculation, as was the case with the analysis of frequency data.

Results

Relative Frequency of Fish and Decapod Species

Eighteen species of decapods and 58 species of fish were identified in the catches of the eight ships (Table 2). The degree of precision in specimen identification varied greatly from one ship to the next, sometimes being restricted to the family. Species reported only once and absent from adjacent areas could be attributed to either the depth range sampled, limits of geographical distribution, or misidentification. Although few specimens were kept for formal identification, most species were commonly caught in several sets by different ships operating in the same or adjacent areas (Table 2).

Ungava Bay exhibits a highly diversified decapod fauna (18 groups), more than twice the number reported in other areas (7-8 groups) (Table 3). For fish, Ungava Bay (51) and Resolution Island (48) support the largest number of groups (Table 3), although this could result from the heavier sampling effort in those two areas (Table 1). There is a gradient of increasing number of fish groups from the west to the east end of Hudson Strait. This gradient remains apparent even when rare species are not taken into account.

The cluster analysis on fish frequency data over the entire study area (Table 2) resulted in five groups of fish species (A-E) corresponding to specific geographic regions. Group A corresponds to species common in all regions, whereas groups

TABLE 2. List of fish and decapod species reported in each region- Frequency classes: 1, species recorded once; 2, species Or group recorded for less than 10% of the sets; 3, species or group recorded for more than 10% of the sets. Regions are designated as in Table 1. * Specimen identification verified by D. McAllister (Museum of Natural History, Ottawa). (More recent taxonomic apellation). Gr.: Group to which each fish species was assigned by the cluster analysis of the regional pattern of abundance (see text).

Common Name	Family/Genus	Species	WHS	CHS	EHS	UB	RI	OB
			Frequency class in regions					
Decapods								
Pink shrimp	*Pandalus*	*borealis*	2	2	2	2	2	3
Striped pink shrimp	*Pandalus*	*montagui*	3	3	2	3	3	2
	Lebbeus	*polaris*	2	1	2	2	2	2
	Lebbeus	*groenlandicus*				2		
	Lebbeus	*spinosus*				2		
Brown shrimp	*Argis*	*dentata*	3	3	3	3		
	Pasiphea	*tarda*					2	
	Pasiphea	*multidentata*				1		
Unidentified	*Pasiphea*					2		
	Sclerocrangon	*boreas*	3	3	2	2	2	2
	Sclerocrangon	*ferox*				2		
Unidentified	*Sclerocrangon*					2		
	Spirontocaris	*gaimardi*			2			
	Spirontocaris	*phippsi*				2		
	Spirontocaris	*spinus*	2			1	2	
Unidentified	*Spirontocaris*			2	2	2		
	Eualus	*gaimardi*				2		
	Eualus	*belcheri*				2		
	Eualus	*fabricii*				2		
Unidentified	*Eualus*					2		
	Sabinea	*septemcarinata*	3	2				
Unidentified	*Sabinea*				2			
	Crangon	*septemspinosus*	1	1				

Common Name	Family/Genus	Species	WHS	CHS	EHS	UB	RI	O B + 2G	Gr.
			Frequency class in regions						
Fish									
Hagfish	*Myxine*	*glutinosa*						1	E
Greenland shark	*Somniosus*	*microcephalus*			2				E
Thorny skate	*Raja*	*radiata*	3	*2	3	3	●3	3	A
Spinytail skate	*Raja*	*spinicauda*				1	I		E
Jensen's skate	*Raja*	*jenseni*			1	1			E
Unidentified	Rajidae				2	2			
Unidentified	Chimaeridae						1		E
Capelin	*Mallows*	*villosus*	2	2	2		2		D
Viperfish	*Chauliodus*	*sloani*					1		E
Krøyer's lanternfish	*Notoscopelus*	*krøyerii*						2	E
Largescale lanternfish	*Symbolophorus*	*veranvi*				1			E
Unidentified	Myctophidae				3	3	3	3	,
Daggertooth	*Anotopterus*	*pharao*					1		E
Arctic cod	*Boreogadus*	*saida*	3	*3	2	3	•>	3	A
Atlantic cod	*Gadus*	*morhua*		1	1	1	i	2	E
Threebeard rockling	*Gaidropsarus*	*ensis*			2	3	●Z	3	B
Longfin hake	*Urophycis*	*chesteri*				1			E
Roughhead grenadier	*Macrourus*	*berglax*				3	3	3	B

TABLE 2. (*continued*)

Common Name	Family/Genus	Species	WHS	CHS	EHS	UB	RI	OB + 2G	Gr.
			Frequency class in regions						
Nonhero wolffish	*Anarhichas*	*denticulatus*				2			D
Atlantic wolffish	*Anarhichas*	*lupus*					1	2	E
Sported wolffish	*Anarhichas*	*minor*				1	2	1	D
Unidentified	Anarhichadidae				2	2	2	2	
Stout eelblenny	*Anisarchus*	*medius*				2	2		D
Fourline snakeblenny	*Eumesogrammus*	*praecisus*		*1		1			E
Daubed shanny	*Leptoclinus*	*maculatus*					*2		E
Snake blenny.	*Lumpenus*	*lumpretaeformis*			2		2		E
Unidentified	Stichaeidae				3	2	2	2	
Fish doctor	*Gymnelus*	*viridis*				1			E
Checkered wolf eel	*Lycenchelys*	*koethoffi*					*I		E
Common wolf eel	*Lycenchelys*	*paxillus*				2	1		D
Wolf eelpout	*Lycenchelys*	*verrilli*				2	2		D
Esmark's eelpout	*Lycodes*	*esmarki*		*2	2	2	2	3	B
Laval's eelpout	*Lycodes*	*lavalaei*				1			E
	Lycodes	*mucosus*	1	*1					E
Pafe eelpout	*Lycodes*	*pallidus*	*2			1			E
Arctic eelpout	*Lycodes*	*reticulatus*	*2	•3	2	2	*2	2	A
Polar eelout	*Lycodes*	*polaris*				1			E
Vahl's eelpout	*Lycodes*	*vahlii*			2	2	2	3	B
Unidentified	Zoarcidae		3	3	3	3	3	2	
Redfish	*Sebastes*	Spp.		*1	3	3	*3	2	B
Arctic hookear sculpin	*Artediellus*	*uncinatus*			2	3	•2	2	B
Polar sculpin	*Cottunculus*	*microps*				2	*I	1	D
Arctic staghom sculpin	*Gymnocanthus*	*tricuspis*				1			E
Twohom sculpin	*Icelus*	*bicornis*				2			D
Spatulate sculpin	*Icelus*	*spatula*		*1	2	2	*2		D
Grubby	*Myoxocephalus*	*aenaeus*			2	1	1		E
Longhorn sculpin	*Myoxocephalus*	*octodecemspinosus*			2				E
Shorthorn sculpin	*Myoxocephalus*	*scorpius*			2		2		E
Nybelin's sculpin	*Triglops*	*nybelini*	3	*3	3	3	*3	3	A
Mailed sculpin	*Triglops*	*murrayi*	1		3	3	*3	3	B
Ribbed sculpin	*Triglops*	*pingeli*	3	*3	3		*3		A
Unidentified	Cottidae		3	3	3	2	3	2	
Atlantic sea poacher	*Agonus(Leptagonus)*	*decagonus*	3	*3	2	2	*2	2	A
Atlantic alligatorfish	*Aspidophoroides*	*monopterygius*			2	2	2	2	B
Arctic alligatorfish	*Aspidophoroides*	*olriki*	2	*3	3	3	2	3	A
Lumpfish	*Cyclopterus*	*lumpus*			2	2	2	2	B
Leatherfin lumpsucker	*Eumicrotremus*	*derjugini*	2	*3		2	1		C
Spiny lumpsucker	*Eumicrotremus*	*spinosus*	3	*3	3	3	3	2	A
Longfin seasnail	*Careproctus*	*longipinnis*					2		E
Sea tadpole	*Careproctus*	*reinhardti*		*2	1	2	2		D
Atlantic seasnail	*Liparis*	*atlanticus*				2			D
Greenland seasnail	*Liparis*	*tunicatus*	*3	3		2	1	1	C
Polkadot seasnail	*Liparis*	*cyclostigma(gibbus)*	2	*3		2	*1		C
Gelatinous seasnail	*Liparis*	*koefoedi(fabricii)*	3	*3	3	3	*3	3	A
Unidentified	Cyclopteridae		3	3	3	3	3	3	
American plaice	*Hippoglossoides*	*platessoides*			2	2	2	2	B
Greenland halibut	*Reinhardtius*	*hippoglossoides*	3	•3	3	3	*3	2	A

B, C, and D were more frequent *in the* eastern, western, or central part of the study area, respectively. The remaining group (E, 25 species) comprised species found in only one region or too rare to establish a geographic pattern.

The first group (A) comprised 10 species occurring commonly (present in >1O% of sets) in all regions (Table 2), among which were the thorny skate, Arctic cod, and Greenland halibut (also called turbot). The second group (B, 10 species) comprised species which were most frequent in the regions OB + 2G and eastern Hudson Strait, often disappearing towards the central and western part of the strait. Representative species of this groups were the redfish, Atlantic lumpfish, roughhead grenadier, threebeard rockling, and American plaice. Clusters A and B were joined together at the 0.5 similarity level.

Group C comprised three species that are discontinuous but present at each end of the study area, with predominance in the west: the leatherfin lumpsucker, the Greenland and the polkadot seasnails. This discontinuous distribution could be due to insufficient sampling in eastern Hudson Strait proper (Table 1). Group D encompassed 11 species that *occur less* frequently (in

TABLE 3. **Summary of the number of fish and decapod groups of each frequency class for each region.** Frequency classes and regions are the same as *in* **Tables 1 and 2.**

	Frequency class	Region					
		WHS	CHS	EHS	UB	RI	0B + 2G
Decapods	1	1	2020				0
	2	2	2	7	14	5	6
	3	4	3	1	2	3	1
	Total	7	7	8	18	8	7
Fish	1	2	5	3	13	12	4
	2	6	4	19	23	23	16
	3	12	15	14	15	13	12
	Total	20	24	36	51	48	32

less than 10% of the sets) than groups A-C. Group D is most abundant in Ungava Bay and/or Resolution Island. Representative species are the stout eelblenny, the common wolf eel, the spatulate and two-horn sculpins. The importance of this group may be an artifact of the large sampling effort in these two regions. Finally, group E represented rare species such as the Greenland shark, the Atlantic cod, the shorthorn sculpin, and the longtail seasnail. Groups C and D merged at the 0.5 similarity level and clustered to group E at the ***0.55*** level before agglomerating (0.75) with the larger cluster formed by groups A and B.

Abundance of Common Species

Quantitative comparison of average catch rates (kg·0.5-h tow ˙‘) of common types of organisms (Table 4) characterizes each region and determines the inter-regional affinities. In western and central Hudson Strait, the average catch comprised Arctic cod, liparids, and spiny lumpsuckers, in decreasing order of abundance. The eastern part of the strait appeared as a transition zone in community composition, where pandalid shrimp and myctophids are not abundant, but turbot catches exceed those of western and central Hudson Strait. In Ungava Bay and off Resolution Island, catch composition was dominated by the striped pink shrimp, although the associated fish species differed between the two regions. Turbot, Arctic cod, and grenadiers were found in Ungava Bay, whereas low abundances of turbot, spiny skate, and lanternfish characterized catches off Resolution Island. In the Labrador Sea-Davis Strait areas, striped pink shrimp was replaced by pink shrimp (1 1.28 kg·tow⁻¹) as the most abundant pandalid. Fish species in OB and 2G included Arctic cod, roughhead grenadier, and spiny skate. For all areas, average fish catch was low (< 50 kg·0.5-h tow˙1, and, if the massive catches of pandalid shrimps were excluded from the total, were highest in Ungava Bay and eastern Hudson Strait. In decreasing ranks, the abundance of pandalid shrimps, turbot, liparids, and Arctic cod exhibited the highest variance in average catch sate among regions.

Spatial vs. Temporal Variability in Catch Composition

The biogeographical analysis of all sets clustered with a spatial constraint (Fig. 3) showed the occurrence of three different types of clusters for both areas. First, numerous small clusters comprising one to three sets made by a single ship could be seen in the southeast and northeast areas of Resolution Island (Fig. 3a) and of Ungava Bay (Fig. 3b), respectively. For both

TABLE 4. **Average catch rate of common decapods and fish by-catch species. Common species are given** a frequency of 3 in Table 2, corresponding to an occurrence of at least 10% of sets in each region. (+), frequency 2 and 1, species present in fewer than 10% of the sets. (–) not recorded in the region. Regions are identified as in Table 1.

Species	Average catch rate (kg. 0.5-h tow˙1,					
	WHS	CHS	EHS	UB	RI	OB + 2G
Decapods						
Pandalus borealis	+	+	2.06	0.9	0.32	11.28
Pandalus montagui	0.07	0.03	24.01	364.24	1271.08	+
Lebbeus spp.	+	+	+	0.51		–
Argis dentata	0.30	0.91	+	1.40		
Sclerocrangon spp.	0.11	0.41	+	0.43		+
Fish and others						
Raja radiata	0.50	+	0.67	0.89	2.97	0.55
Myctophidae			2.40	0.02	0.93	0.49
Boreogadus saida	12.89	4.52	+	4.95	+	1.23
Gaidropsarus ensis		–	+	0.49	+	0.22
Macrourus berglax				3.79	0.20	3.17
Zoarcidae	1.36	0.33	0.77	0.57	0.01	+
Sebastes spp.		+	0.31	0.86	0.28	+
Artediellus uncinatus			0.28	0.16	+	+
Triglops spp.	1.41	0.45	0.23	0.14	0.67	+
Aspidophoroides spp.	0.03	0.02	0.19	0.07	0.07	0.13
Cyclopterus lumpus			+	+	+	0.28
Eumicrotremus spinosus	1.93	1.30	0.73	0.39	0.57	+
Liparidae	9.67	5.62	1.62	2.52	0.32	0.23
Reinhardtius hippoglossoides	0.35	0.63	7.12	15.32	1 .03	
Gonatus sp.	+	+	0.01	0.02	0.01	0.0:
Total	28.62	14.22	40.40	396.86	1278.53	17,63

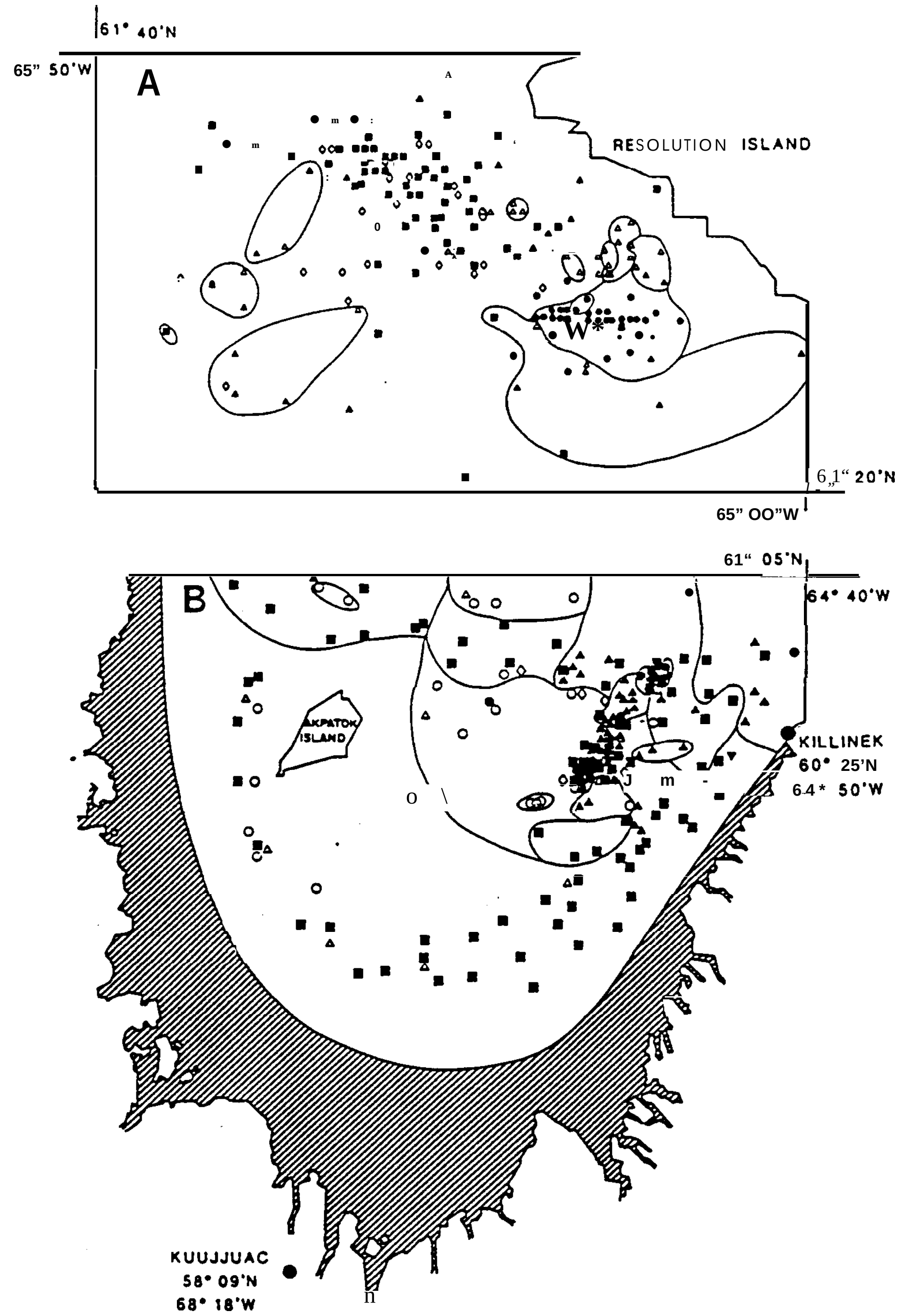

FIG. 3. Results of the cluster analyses with a geographical constraint (BIOGEO). Each symbol represents a standard set carried out by a different ship. Zones circled by a continuous line indicate groups of sets exhibiting a homogeneous species composition and abundance.
A. Resolution Island
B. Ungava Bay.

areas, these sets were located in deep water (> 300 m), where high shrimp catches were made. Both areas had similar T-S characteristics (Fig. 2). It is possible that the very large number of sets made in those areas could have artificially increased the number of clusters, although their density also corresponds to the high year-to-year variability in shrimp catches in both areas.

Second, clusters of five to 20 sets, covering a larger surface area than the previous types, could be observed along the outer edge of the bank. Those medium-sized clusters comprised the catches of two or more ships, indicating a more stable catch composition from year to year than the previous type. Five clusters were identified along the northern edge of the bay, distinguishing catches made on the Ungava Bay shelf (< 300 m) from those made at the edge of Hudson Strait (> 300 m).

Third, the remainder of the sets located on the inside part of the bank clustered in a single large group, indicating the occur-

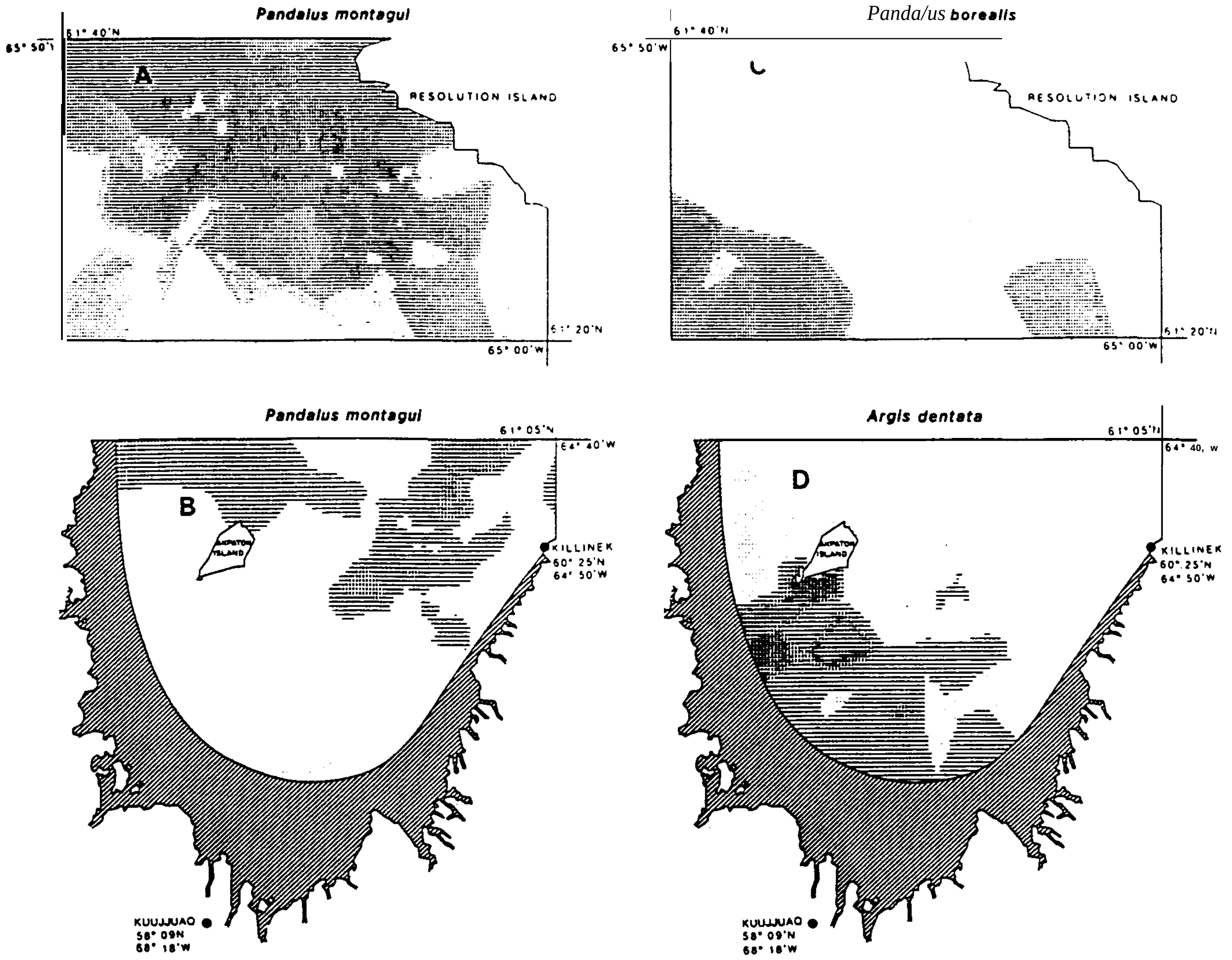

FIG. 5. **Distribution of fish by-catch species off Resolution Island and in Ungava Bay. Each shade** of grey represents an abundance class expressed as the naperian logarithm ($\ln(x + 1)$) of the total weight (kg) caught during a standard O. S-h tow.
A. *Raja radiata off* Resolution Island.
B. ***Boreogadus saida*** *in* Ungava Bay.
C. ***Reinhardtius hippoglossoides*** *off* Resolution **Island.**
D. *Reinhardtius hippoglossoides* in Ungava Bay.

89 fishing season, only low concentrations were found in small sectors off **Cumberland** Sound (Div. OB) and along the northern Labrador coast (Div. 2G), increasing towards Divisions 2JH to the south and Divisions OA, 1A, and **1B** to the north (**NAFO** 1987).

The brown shrimp, ***Argis dentata,*** *was* abundant only in southwestern **Ungava** Bay (Fig. **4d),** in the area of Arctic waters. It has been reported mostly in waters **<0°C** between 50 and 200 m (Squires 1966). This species was recorded as having the second largest catch in **Ungava** Bay, with a total weight of 208.6 kg (**Allard** 1980). Its apparent abundance in **Ungava** shelf waters makes it a possible target for local exploitation.

Mapping of Regional Fish Distribution

Thorny skate were found over the entire area near Resolution Island with a patchy distribution, without a particular pattern (Fig. 5a). On the **Scotian** Shelf, this species inhabits a wide **range** of depth (30 to >400 m), temperature (**0–13°C**) and **sal**inity (31-34 $mg \cdot L^{-1}$), although it is most concentrated in cool (**2–5°C**) and shallow (40-100 m) water (Scott 1982). The **tol**erance of thorny skate-with **respect** to environmental conditions is demonstrated by its occurrence in the Labrador Sea (**Backus** 1957), Hudson Strait, and in Hudson Bay (**Vladykov** 1933).

Arctic cod was not abundant off Resolution Island, but occurred everywhere in **Ungava** Bay. It exhibited a circular pattern of density from the highest in the south and west of **the** bay, progressively decreasing to a near absence in the center **of** the bay (Fig. **5b**). This distribution pattern was similar to that of the **seasnails.** Sizes ranged from 7.4 to 24.6 cm, with many between **10–16** cm. Arctic cod is pelagic, from the surface to 800 m (**Leim** and Scott 1966), and its occurrence in a shrimp trawl is not representative of its real abundance. Previous collections of Arctic cod in the Labrador Sea were made at temperatures ranging **from** $-1.85°C$ to **2.52°C,** although in only one instance was the temperature above $-1.0°C$ (**Backus** 1957).

Greenland halibut exhibited a patchy abundance along the edge of the Resolution Island bank, extending towards the

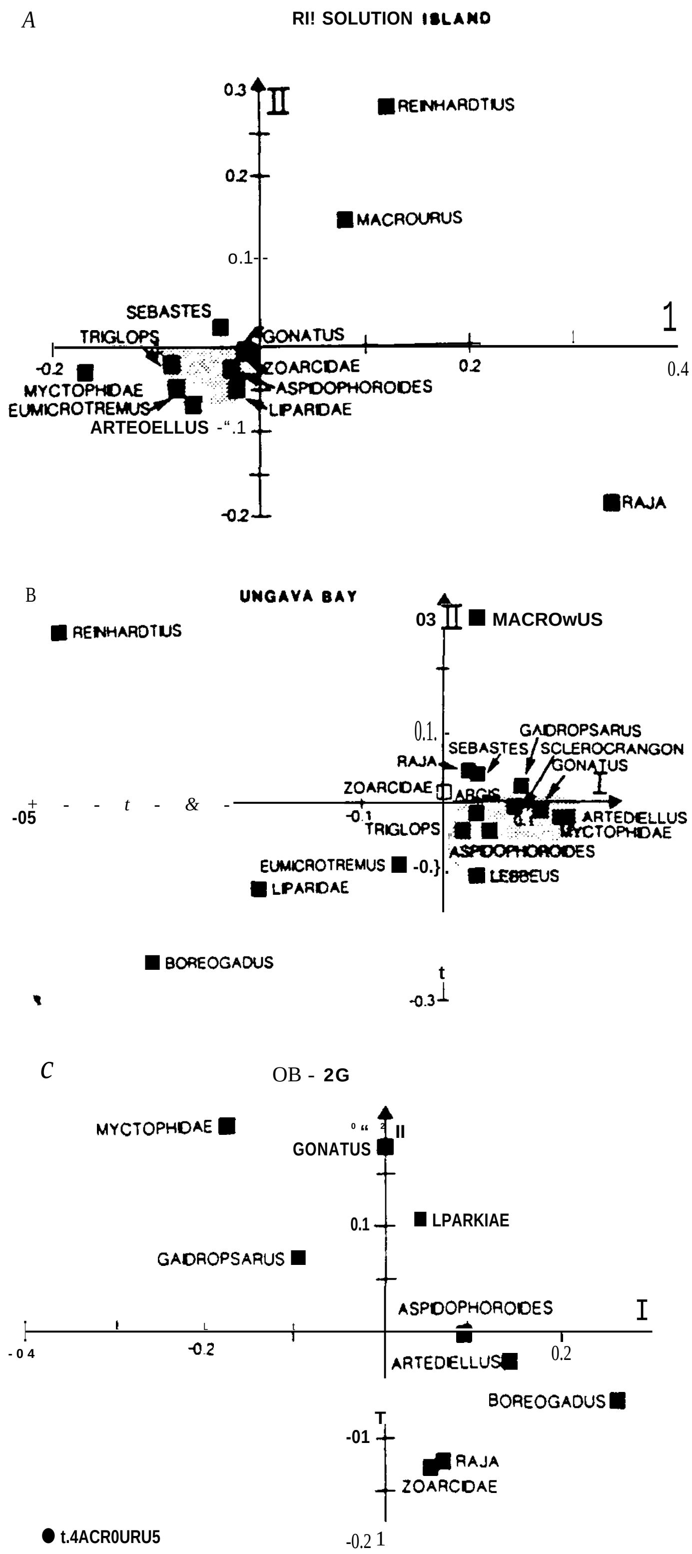

FIG. 6. Principal coordinate analyses of fish by-catch abundance (ln(x + 1) transformed), allowing comparison of the relative positioning of associated species in the reduced, two-axes space. Species located in the same quadrat, or in the neighborhood of each other relative to others are associated. Pandalid shrimp were excluded from the analysis since their single variability in abundance masked that of fish by-catch.
A. Resolution Island.
B. Ungava Bay.
C. OB + 2G.

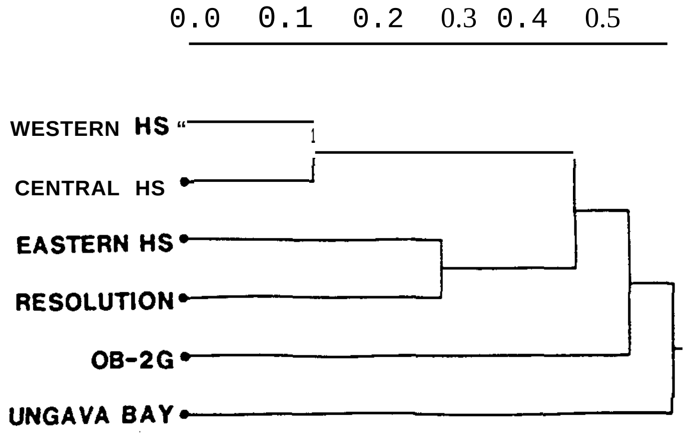

FIG. 7. Cluster analysis of the species abundance (ln(x + 1)) for the six regions of the study area, showing the biogeographic affinities with respect to common species abundance.

northwest (Fig. 5c). Similarly, in Ungava Bay, its highest concentrations were located along the eastern edge of Akpatok bank and across the mouth of the bay, in water >400 m (Fig. 5d). This species is abundant in deep water (200-600 m or more) (Bigelow and Welsh 1924; Scott 1982), usually at temperatures of -0.5°C to 3°C (Templeman 1973). Turbot was commonly found throughout the study area to western Hudson Strait, but was not captured west of 79"OOW (northern Hudson Bay, Foxe Channel, 26 sets).

Redfish were concentrated at the southeastern edge of Resolution Island, in the deeper areas (>200 m) influenced by Labrador Sea waters. A similar distribution was found in northern Ungava Bay, where redfish occurred sporadically, concentrated in the deep waters (Jan-y 1988). Most individuals were smaller than 10 cm. Redfish inhabit a wide range of temperature, and although it has been described as an Arctic species (which is hue in the sense that its range extends into the Arctic Seas), it is confined to deep (100-600 m), relatively warm (>1.7°C) waters of Atlantic origin and avoids the layers of cold Arctic waters in Davis Strait, Labrador Sea, as well as in the Gulf of St. Lawrence (Bigelow and Welsh 1924; Leim and Scott 1966; May 1969).

Fish Species Assemblages

A more detailed look at species associations within regions can be obtained using the projection of the fish species on the first two axes of the principal coordinates. For each region, species belonging to the same quadrat and exhibiting high values of the projection were examined (Fig. 6) in relation with species occurring in opposing quadrats. The first group consisted of small, noncommercial species such as *Triglops* spp., *Aspidophoroides* spp.. *Eumicrotremus* spp.. and Myctophids, which formed a low-~ variability, background assemblage in Resolution Island (Fig. 6a) and Ungava Bay regions (Fig. 6b). Another more distinct Arctic association was that of *Boreogadus* and Liparidae, located in the same (Ungava Bay, Fig. 6b) or adjacent (OB + 2G. Fig. 6c) quadrats.

In OB + 2G, Axis II separated the previously described Arctic from the Labrador Sea (Myctophidae, *Gaidropsarus*, and *Macrourus*) assemblages. For the three regions, *Macrourus* and *Reinhardtius* exhibited a loose association, being either in the same or in adjacent quadrats. *Reinhardtius* appeared more closely associated to the Labrador Sea component than with the arctic assemblage. as it was located in the quadrat opposite to the arctic assemblage in Ungava Bay and Resolution Island. This indicates a negative co-variation in abundance between these two groups.

Depending on the area, *Raja* exhibited a strong variability on its own (Fig. 6a), an intermediate variability with an arctic group (Zoarcidae, Fig. 6e), or a low variability with Labrador Sea components (*Sebastes, Gaidropsarus*, Fig. 6b). This observation reflects the adaptability of the thorny skate to a variety of environmental conditions in the north Atlantic (Scott 1982). To summarize, the analysis indicates the occurrence of two basic fish associations. showing the predominance of western (Arctic) or eastern (Labrador Sea) fauna, which broadly overlap in the study area. The Arctic association dominate in Resolution Island and Ungava Bay, while the Labrador Sea association is more important in 0B + 2G.

Large Scale Geographic Zonation

The cluster analysis on the regional abundance of common. species of fish and invertebrates shows that Hudson Strait is a continuum along the west to east gradient (Fig. 7). The common species and their abundance levels are most similar in the western and central areas. These two areas have a less diverse fauna and a lower biomass than the more easterly regions. Western and central regions do not have any exclusive species: they comprise species that are found commonly elsewhere.

The second regional group is composed of eastern Hudson Strait and Resolution Island. This is to be expected since Resolution Island was somewhat artificially distinguished from the rest of the eastern strait on the basis of its high pandalid shrimp catches. However, the remainder of the fish and decapod fauna is sufficiently similar, both in terms of species frequency as well as abundance, to warrant their early clustering.

The east-west continuum of Hudson Strait is demonstrated by the subsequent clustering of the four above regions, followed by the integration of the region 0B + 2G. It is only after the formation of that large group that Ungava Bay eventually joins it. The late clustering of Ungava Bay to the rest of the study area emphasizes the very distinct, diverse nature of its faunal composition and abundance in comparison with the other regions.

Discussion

Comparisons among several ships must be made with caution due to the differences in performances of vessels, gears, and crews, which are indistinguishable from year-to-year variations in catchable biomass. For exploratory/cost-recovery cruises without a predetermined randomized sampling plan, sets converged and clustered in areas of high shrimp concentration. The lack of an accurate positioning system in Hudson Strait and Ungava Bay caused imprecision in location and area covered by each tow. Also, the absence of accurate depth charts contributed to gear damage and resulted in inadequate depth stratification of fishing grounds. The fish species sampled in this study reflect the fishing gear used and correspond to those associated with shrimp, which was the principal target species. Such sampling has its limitations, since characteristic coastal Arctic species such as Greenland cod (*Gadus ogac*) and four-homed sculpin (*Myoxocephalus quadricornis*) were not reported in the samples. Also, pelagic species such as Arctic cod, myctophids, and Greenland shark cannot be adequately sampled with deep-water bottom trawling. However, once the above factors are accounted for, the information on decapod and fish assemblages provides a valid basis for large scale geographic comparisons.

The segregation of two pandalid species over the study area is consistent with previous studies of their temperature tolerance. *Pandalus montagui* tolerates a wider range of temperature (–1-20"C) (Allen 1963; Squires 1968) and of depth than *P. borealis* (0–11°C) (Simpson et al. 1970; Fontaine 1970). Of all the pandalids in the northwest Atlantic, *P. montagui* is the only one which inhabits colder Arctic waters (Squires 1957, 1966). The dominance of *P. borealis* in the Davis Strait-Labrador Sea area to 75°N (Squires 1966) therefore appears related to the extent of the influence of Atlantic waters, maintaining bottom water temperatures above l°C (Schroeder 1963) independent of latitude. Central Ungava Bay, western, and central Hudson Strait supported consistent catch of other arctic decapod species (*Lebbeus* spp., *Argis dentata, Sclerocrangon* spp.), showing their Arctic dominated waters.

There have been few attempts to formally define the nature and characteristics of "Arctic" fish species (Dunbar and Hildebrand 1952; McAllister 197 S). Generally, that definition includes species with their center of distribution in the Arctic and exhibiting tolerance to low temperatures (Bigelow and Welsh 1924; Backus 1957; Morin and Dodson 1986). Arctic species listed in McAllister et al. (1975) comprise all fish species found in the Arctic, even though some of them belong to temperate regions (e.g. brook trout).

Cottids (McAllister 1960), and other species of non specialist benthic feeders (McAllister 1975) are the best represented fish groups in the Arctic. The low number of total and endemic fish species in the Arctic was attributed to the low temperature and low productivity, lack of food resources, and ice action in the littoral zone (McAllister 1960; McAllister et al. 1975). In this study, Ungava Bay and Resolution Island supported roughly twice as many species of Zoarcidae, Cottidae, and Cyclopteridae as reported in the waters adjacent to northern Labrador Sea-Davis Strait. Of all regions, Ungava Bay supported the highest diversity and abundance of fish and decapod species. Its fauna comprised elements of 0B–2G and of the Hudson Strait regions. Such species overlap from adjacent regions is in part made possible by the simultaneous Arctic and Labrador Sea influences. However, other regions (Resolution Island and eastern Hudson Strait) under such influence do not exhibit a comparable richness. In Ungava Bay, a variety of bottom types are likely to occur in shallow bank, sloping shelf, and deep trench areas. In addition, it is likely that the intense tidal mixing with local freshwater result in increased nutrients and warmer temperatures, and thus could enhance local primary production relative to other regions of Hudson Strait.

With respect to biological production, it is noteworthy that Resolution Island and northeastern Ungava Bay, where high striped, pink shrimp concentrations are found, exhibited common hydrographic features. Both areas are subjected to strong tidal currents (Canadian Hydrographic Service 1987), and are located in the transition zone between heavily mixed and stratified waters (Drinkwater and Jones 1987). This likely explains the high level of temporal variability in the biogeographical analysis of catches found off Resolution Island and in the northeastern area of Ungava Bay. Areas of extensive water mixing combined with high planktonic primary productivity, located along the southern edge of Baffin Island (Drinkwater and Jones 1987) could possibly generate high levels of secondary production off Resolution Island. The high standing stock of striped pink shrimp in eastern Hudson Strait could thus be related to the high copepod biomass on which it primarily feeds (C. Hudon, unpubl. data).

Oceanographic zonation can be mapped and defined on the basis of combined physical characteristics of temperature-salinity relationships and biogeographical data (Dunbar 1951; Dunbar and Hildebrand 1952). Three zones can be defined in our study area, corresponding to the major groups of fish, species observed in the principal coordinates analysis. First, an Arctic zone, in which water temperature equals or is below O°C and salinities are 31-34 ‰ (Fig. 2). These waters were found in western and central Hudson Strait and southern Ungava Bay. These areas have a low species richness and are characterized by a scattered biomass of non-commercially exploitable species such as Arctic cod (*Boregadus saida*) and liparids.

At the other end of the continuum is the subarctic zone, under the simultaneous influence of the cold Baffin Island Current and the warmer West Greenland and Labrador Currents, where temperatures are between – 1 and 4.0°C and salinities are 32-34.5 ppm (Fig. 2; Dunbar 1951). Fish inhabiting these waters endure a considerable Arctic influence, although not tolerating the very cold water of pure Arctic origin (Backus 1957). This group is represented by the Greenland halibut, grenadiers, three beard rockling and, occasionally, by the thorny skate (Fig. 6; see Dunbar and Hildebrand 1952 for additional species). In divisions 0B–2G, these species were the foremost demersal species captured, accounting for more than 95% of the total catches in those areas (NAFO 1987).

The transition zone between Arctic and subarctic waters begins at the mouth of Hudson Strait and extends over Ungava Bay and eastern Hudson Strait in a SE—NW wedge. Its most remarkable feature is the change of dominance from *Pandalus borealis* to *P. montagui*, attributable to the greater influence of Arctic waters west of the entrance. However, a small population of *P. borealis*, either indigenous or carried by water movements, occurs in the deep portion of the strait where deep Labrador Sea water penetrates (Fig. 2). Water circulation exerts a strong influence on shrimp distribution in eastern Hudson Strait, explaining the high year-to-year variability in catches off Resolution Island and northeastern Ungava Bay (Fig. 3). Furthermore, the occasional high catches of *P. montagui* observed outside of the areas of concentrations (NE of Cape Hope Advance and across the mouth of Ungava Bay) (Fig. 4b) could result from advective losses from the Resolution Island area into the gyre located north of Ungava Bay (Fig. 1). The influence of circulation on pandalid shrimp stock identity in eastern Hudson Strait should be further studied.

Year-to-year variation is also perceptible in pink shrimp catches in the Labrador Sea-Davis Strait areas. Until 1988, total catches in neighboring Divisions OA, 1CDE, and 2JH, located north, east, and south, respectively, constantly exceeded those in 0B–2G by one to (wo orders of magnitude. This difference has been attenuated by a recent increase in shrimp catches in the OB–2G Divisons m 1988 and 1989.

Large scale environmental phenomena, such as climatic or hydrographic changes, could exert influence over the location and abruptness of the transition zone, possibly explaining spatial and temporal variability of shrimp catches. One example is the effect of ice distribution along the west Greenland coast on Atlantic cod abundance (Jensen 1948; Vibe 1967). Off the coast of northern Labrador, a similar phenomenon could at least partially explain the variability in the abundance of capelin (Dunbar 1975) and Atlantic cod (Gillis and Allard 1986). The fluctuations of pandalid catches in this highly dynamic transition zone could offer some potential to monitor long term climatic changes affecting eastern Canadian Arctic waters.

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