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Diet of Greenland halibut off southern Labrador and northeastern Newfoundland (Div. 2J+3K) in autumn of 1981-82, emphasizing predation on capelin

by

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ABSTRACT

Examination of the stomachs of 7340 Greenland halibut (Reinhardtius hippoglossoides) collected off southern Labrador and northeastern Newfoundland (Div. 2J+3K) during the autumns of 1981 and 1982 revealed that small Greenland halibut (<20 cm) preyed mainly on small crustaceans and cephalopods, Greenland halibut of intermediate size (20-69 cm) preyed primarily on capelin (Mallotus villosus), and large Greenland halibut (>70 cm) preyed on a variety of demersal fish, particularly redfish (Sebastes sp.) and Greenland halibut. Predation on capelin was most intense on Hamilton Bank and on or near the coastal shelf off southern Labrador and northern Newfoundland. A rough estimate of the consumption of capelin by Greenland halibut is presented.

INTRODUCTION

Capelin (Mallotus villosus) is a major prey of many species of marine mammals, seabirds and fish in the Newfoundland-Labrador area (see Carscadden, MS 1983, 1984; Anderson and Lilly, 1985 for reviews). Most concern and study regarding the effect of a capelin fishery on the dynamics of a fish predator has concerned Atlantic cod (see Akenhead, et al., 1982; Lilly, MS 1984 for reviews), but the Greenland halibut (Reinhardtius hippoglossoides) is also a major component of the demersal fish assemblage off eastern Newfoundland and Labrador (Bowering, MS 1984) and has been shown to feed primarily on capelin, at least in Trinity Bay on Newfoundland's east coast (Lear, MS 1970). Thus, Greenland halibut could be a significant predator on capelin, and could be affected by changes in capelin abundance.

The purpose of this study is to describe the food of Greenland halibut off northern Newfoundland and southern Labrador in the autumn, with emphasis on size-related and geographic variability in predation on capelin. A crude estimate of the rate of consumption of capelin by Greenland halibut is provided.

MATERIALS AND METHODS

Stomachs were collected from Greenland halibut caught during stratified-random bottom-trawl surveys by the chartered research stern trawler Gadus Atlantica off southern Labrador and northeastern Newfoundland (Div. 2J, 3K) during the autumns of 1981 and 1982 (Table 1). A stratified-random sample of 3 fish per 5-cm length group was sampled from the catch of each set. Stomachs were individually tagged and preserved in 10% formalin: sea water solution.

Examination involved separation of food items into taxonomic categories. Fish and decapod crustaceans were identified to species, but other groups were combined into higher order taxa (eg. Gammaridea, Euphausiacea). Items in each taxon were placed briefly on absorbent paper to remove excess liquid, and then counted and weighed to the nearest 0.1 g. Whenever digestive condition permitted, fish were measured to the nearest mm total length.

The relative quantity of food in the stomachs and the relative importance of specific prey taxa were assessed using four indices:

1) Percent occurrence (number of stomachs with specific prey as percentage of total number of stomachs).

2) Percent number (total number of specific prey in all stomachs as percentage of total number of all prey).

3) Percent weight (total weight of specific prey in all stomachs as percentage of total weight of all prey) (gravimetric method).

4) Stomach fullness index:

Mean partial fullness index was calculated as

$$PFI_i = \frac{1}{n} \sum_{j=1}^{n} \frac{W_{ij}}{L_j^3} \times 10^4$$

where W_{ij} is the weight of prey i in fish j, L_j is the length of fish j, and n is number of fish in the sample.

Mean total fullness index was calculated as:

$$TFI = \frac{1}{n} \sum_{j=1}^{n} \frac{W_{tj}}{L_j^3} \times 10^4 = \sum_{i=1}^{m} PFI_i$$

where W_{tj} is the total weight of prey in fish j and m is the number of prey types.

Because the stomachs were collected from fish caught over a wide depth range (100-1000 m), they were divided into two groups: those from the continental shelf (≤400 m) and those from the upper slope. The division between shelf and slope is relatively deep (cf. Sverdrup et al. 1942) because of the deep shelf break off northeastern Newfoundland . Stomachs collected from depths greater than 400 m in Cartwright Channel, Hawke Channel, St. Anthony Basin and Funk Island Deep (NAFO Strata 204, 212, 227, 235, 622, 627, 631; Doubleday, 1981) were included in the shelf group.

For examination of relationships between predator size and both prey spectrum and feeding intensity, total and partial fullness indices were plotted against body length (5 cm length groups).

Coarse spatial variability in predation on capelin in 1981 and 1982 was examined by plotting the mean partial fullness indices for capelin in all stomachs collected from Greenland halibut (25-64 cm) caught in areas of 0.5° latitude x 1.0° longitude.

Rate of consumption of capelin

Assuming that each survey constituted a synoptic look at the prey composition of the Greenland halibut, the rate of consumption of capelin by the Greenland halibut population was crudely estimated as:

$$C_{ij} = \frac{2 W_{ij}}{DT}$$

where C_{ij} is the rate of consumption of capelin in Division i in year j, W_{ij} is the weight of capelin in the stomachs of the Greenland halibut population at the time of sampling, and DT is the time for complete digestion. W_{ij} was estimated as:

$$W_{ij} = \sum_{k=1}^{n} S_{ijk} \; N_{ijk}$$

where S_{ijk} is the mean weight of capelin in the stomachs of Greenland halibut in length-group k, N_{ijk} is the number of Greenland halibut of length-group k in the population, and n is the number of 10cm length-groups. S_{ijk} is the unweighted mean weight of capelin in the stomachs examined; there was no weighting by catch within set or stratum. N_{ijk} was calculated by areal expansion of the stratified arithmetic mean number per 2cm length-group per tow (Smith and Somerton, 1981) using strata defined in Doubleday (1981). Numbers per 2cm group were combined into 10 cm groups.

Results

Prey Spectrum

The percentage of stomachs which were empty and the contents of those with food were very similar in the two years (Table 2). Fish were the major prey, contributing about 96% of the total weight in both years and 90-94% of the total fullness index. The dominant fish was capelin (Mallotus villosus), which occurred in approximately 20% of the stomachs and contributed 46% of the total weight. Arctic cod (Boreogadus saida) was far less important. Various demersal fish occurred in small numbers but were important in terms of weight. Several invertebrates, particularly hyperiid and gammarid amphipods, occurred in relatively high numbers but contributed very little weight.

Because some of the variability in diet might be related to the depth of collection, the stomachs were divided into two groups: those from the continental shelf and those from the upper slope. The number of stomachs collected from the slope was relatively small and many (approximately 60%) were empty (Table 3). The major prey were capelin and several taxa of demersal fish, particularly redfish (Sebastes sp.) and grenadiers (Macrouridae). Stomachs collected from Greenland halibut caught on the shelf were dominated by capelin (Table 4). Redfish and grenadiers were less important than on the slope, and flatfish (Pleuronectidae), amphipods and shrimp (primarily Pandalus borealis) were more important.

Size relationships

The total fullness index and the relative importance of various prey varied with Greenland halibut length. Partial fullness indices (PFI) for hyperiid amphipods and cephalopods were low for all predator size groups, but were highest in very small specimens (<30 cm) (Fig. 1). The pink shrimp, Pandalus borealis, was preyed upon by a wide size range of Greenland halibut, but PFI's were consistently very low (Fig. 1). Predation on fish was distinctly size related, with an abrupt change at 65-69cm between feeding on capelin and feeding on various groundfish (Fig. 2). In 1982 there was a single peak in the PFI curve for capelin, but in 1981 there were two peaks. The total fullness index declined in Greenland halibut of intermediate size in 1982, reaching a minimum in the size range 50-68 cm, but this decline was less pronounced in 1981.

To examine why the total fullness index was bimodal (at least in 1982), we examined the length frequencies of all fish that had been measured. The Greenland halibut were divided into 10 cm length groups and data from 1981 and 1982 were combined (Fig. 3). For Greenland halibut less than 60 cm in length, there were virtually no prey larger than capelin, which dominated the length frequencies with an overall mode at 15 cm (range 10-19 cm). Other prey were Arctic cod, myctophids, and small groundfish (Sebastes sp. and Greenland halibut). Greenland halibut in the range 60-69 cm had eaten a few larger prey, and larger Greenland halibut (>70 cm) had eaten many larger prey, primarily Sebastes sp. and Greenland halibut.

The predominance of capelin in the diet of Greenland halibut ranging in length from 20 to 69 cm resulted in an inverse relationship between predator length and the quotient (prey length/predator length) (Fig. 4). Predation on larger groundfish by Greenland halibut >70 cm almost arrested the decline in this median. More importantly, the 90th percentile increased dramatically, indicating an improvement in prey:predator length ratios.

Spatial variability

The spatial pattern of predation on capelin, by Greenland halibut 25-64 cm in length, was similar in 1981 and 1982 (Fig. 5 and 6). Predation was most intense on Hamilton Bank and on or near the coastal shelf off southern Labrador and northern Newfoundland. Less intense predation was found on the southern Funk Island Bank. Lowest or nil predation occurred on eastern Belle Isle Bank, northern and eastern Funk Island Bank, and in the Funk Island Deep.

Rate of consumption of capelin

The weight of capelin estimated to be present in the stomachs of the Greenland halibut population at the time of sampling was about 4 times as great in Div. 2J as in Div. 3K in both years, despite the greater abundance of Greenland halibut in Div. 3K (Table 5, 6). If it be assumed that the time for digestion is 3-5 days, and that Greenland halibut feed on capelin for approximately 6 months of the year, then the rate of consumption of capelin by Greenland halibut in Div. 2J+3K in 1981 and 1982 may have been roughly as follows:

	per day (tons)	in 6 months (X 10^{-3} tons)
1981	511-851	93.2-155.2
1982	549-915	100.2-167.0

DISCUSSION

Prey Spectrum

The predominance of fish and the virtual absence of epibenthic invertebrates in the diet of Greenland halibut, as observed in this study, supports the widely accepted conclusion (eg. Smidt, 1969; de Groot, 1970; Lear MS 1970) that Greenland halibut feed almost entirely in the water column and primarily on fish. The pink shrimp (Pandalus borealis) is an important prey in areas where it is abundant, such as deep areas along the coasts of west Greenland (Smidt, 1969) and Labrador (Bowering, et al., MS 1984), but in Div. 2J+3K as a whole it is a minor prey.

In the present study, small Greenland halibut (<20 cm) fed primarily on small crustaceans (mainly hyperiids) and cephalopods, some of which were identified as Gonatus sp. Greenland halibut as small as 19 cm fed on capelin, and in Greenland halibut in the range 20-69 cm capelin was the major prey. Capelin was also the major prey of Greenland halibut in the size range 21-80 cm in Trinity Bay in 1966-69 (Lear, MS 1970). In the present study, Greenland halibut >69 cm fed primarily (by weight) on demersal fish larger than capelin.

The decline in the partial fullness index for capelin in Greenland halibut larger than about 39 cm, noted in 1982 in particular (Fig. 2), is probably attributable to a decline in the benefit from pursuit of prey of this size. The larger Greenland halibut (>70 cm) appear to be large enough to ingest demersal fish larger than capelin, and have total fullness indices (TFI) higher than Greenland halibut of intermediate size. A similar depression in the TFI curve in fish of intermediate size was found for Atlantic cod caught during the same surveys (Lilly, MS 1984). Further exploration of the causes for the changes in TFI with increasing size of predator will require construction of a size-frequency distribution for potential fish prey in Div. 2J+3K in autumn. We expect there is a gap in the distribution at the size which is just less than the maximum prey size for predators of intermediate size. Prey length alone is not an adequate measure of prey size, for clearly a capelin is more readily ingested than a redfish or Greenland halibut of the same length.

Spatial variability

The highest fullness indices for capelin were found on Hamilton Bank and on or near the coastal shelf off southern Labrador and northern Newfoundland. This is very similar to the pattern found for cod predation on capelin (Lilly, MS 1984), and corresponds to the capelin distribution found during hydroacoustic surveys (Bakanev, MS 1981, MS 1983; Mamylov and Bakanev, MS 1984; Bakanev and Gorchinsky, MS 1985; J. Carscadden, Department of Fisheries and Oceans, St. John's, Newfoundland, pers. comm.). It also corresponds to the distribution of the offshore capelin fishery (eg. Bakanev, MS 1981). Capelin were also found in stomachs of both Greenland halibut (this study) and Atlantic cod (Lilly, MS 1984) from the southern Funk Island Bank, an area not included in hydroacoustic surveys.

Annual consumption of capelin

The estimated annual consumption of 90-170 thousand tons of capelin by Greenland halibut in Div. 2J+3K in 1981 and 1982 may be compared with capelin biomass estimates from hydroacoustic surveys: 1792 thousand tons from a Canadian survey in 1981 (Miller, et al. MS 1982) and 611 thousand tons from a USSR survey in 1982 (Bakanev, MS 1983).

The present estimates of capelin consumption are very crude, and may be improved in several ways. For example, estimates of the quantity of capelin in stomachs of the Greenland halibut population (Tables 5, 6) should be weighted by catch and should consider spatial variability in stomach contents. The estimates of population size assume a catchability coefficient of 1.0, but if the true value is lower then the estimate of capelin consumption will be correspondingly higher.

We also require information on the stomach contents of Greenland halibut throughout the year. Chumakov and Podrazhanskaya (MS 1983) reported that the main feeding of Greenland halibut occurs in summer-autumn, so it was assumed in calculating annual consumption that predation on capelin occurred for only 6 months. However, Lear (MS 1970) found that Greenland halibut in Trinity Bay preyed on capelin throughout the year, and that percent volume and frequency of occurrence of capelin were high in the period mid-January to mid-April. Thus, Greenland halibut will probably prey on capelin in winter-spring in Div. 2J+3K if the distributions of the two species overlap.

Calculation of consumption rates from stomach content data require much better information on gastric evacuation rate (GER). There have been no studies of GER in Greenland halibut, but Minet and Perodou (1978) assumed for Atlantic cod that the rate of digestion is linear over time and requires 3-5 days. Laboratory studies of gastric evacuation of capelin by cod have demonstrated that a linear gastric evacuation model is appropriate and that a time to complete digestion of 3-5 days should be appropriate for the bottom temperatures (median

2-3°C) in which the Greenland halibut were caught (Garman and Lilly, unpublished). The effects of meal size, prey size, and predator size must also be considered (Durbin, et al., 1983).

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Table 1. Dates and sample sizes of stomach samples of Greenland halibut collected during stratified-random surveys by the Gadus Atlantica in NAFO Div. 2J+3K in Autumn 1981-82.

Year	Trip number	Sampling period	NAFO div.	No. of[a] tows	No. of stomachs
1981	58	Nov. 15-29	2J	90	1240
			3K	18	305
	59	Dec. 3-13	3K	87	1371
				195	2916
1982	71	Oct. 30-Nov. 15	2J	152	2381
			3K	12	199
	72	Nov. 20-Dec. 8	3K	121	1844
				285	4424
Total 1981, 1982				480	7340

[a]Number of tows from which at least one stomach was collected.

Table 2. The food of Greenland halibut in NAFO Div. 2J+3K in the autumns of 1981 and 1982.

	Occurrence(%)		Number(%)		Weight(%)		Mean PFI	
	1981	1982	1981	1982	1981	1982	1981	1982
Invertebrata (misc.)			8.1	6.2	0.9	0.4	.02	.01
Cephalopoda			2.9	1.3	2.0	0.6	0.07	0.04
Hyperiidae	8.8	3.6	14.7	10.9	0.1	+	0.02	0.01
Gammaridea	4.7	2.9	7.0	7.9	0.1	0.2	0.01	+
Pandalus borealis	3.6	4.8	4.1	5.4	1.0	1.1	0.02	0.02
Pisces								
Mallotus villosus	18.9	23.1	42.1	45.9	46.2	45.9	0.89	0.99
Boreogadus saida	1.5	0.6	3.2	0.6	4.5	0.6	0.06	0.01
Gadus morhua	0.4	0.5	0.3	0.4	5.1	5.6	0.02	0.03
Macrouridae			0.3	0.1	3.8	1.3	0.01	0.01
Zoarcidae			0.4	0.5	5.9	7.5	0.02	0.03
Sebastes sp.			1.1	1.3	13.1	11.1	0.04	0.04
Pleuronectidae			1.9	1.8	10.0	13.2	0.06	0.05
Others			1.9	0.4	1.4	1.8	0.02	0.01
Unidentified			12.0	17.4	5.8	9.6	0.16	0.19
Unidentified & misc.			0.1	0.1	0.1	1.2	+	+
Total							1.42	1.44
No. of stomachs	2916	4424						
Percent empty	41.6	44.1						

+ Trace

Table 3. The food of Greenland halibut on the upper continental slope in NAFO Div. 2J+3K in the autumns of 1981 and 1982.

	Occurrence(%)		Number(%)		Weight(%)		Mean PFI	
	1981	1982	1981	1982	1981	1982	1981	1982
Invertebrata misc.			9.5	4.7	1.1	0.6	0.01	0.02
Cephalopoda			8.8	3.1	5.3	1.3	0.16	0.03
Pisces								
Mallotus villosus	6.4	9.8	55.1	54.9	18.9	41.2	0.39	0.65
Gadus morhua	0.6	0.7	0.7	0.6	7.4	4.1	0.08	0.03
Macrouridae			2.7	0.8	15.5	3.3	0.11	0.04
Zoarcidae	0.3	1.4	0.7	1.1	2.1	8.1	0.02	0.05
Sebastes sp.			9.2	5.3	43.7	26.7	0.32	0.17
Others			6.5	1.1	1.5	0.8	0.03	0.01
Unidentified			6.8	28.4	4.6	13.9	0.06	0.20
Unidentified & Misc.					+	+	+	+
Total							1.16	1.21
Number of stomachs	312	277						
Percent empty	61.9	57.8						

+ Trace

Table 4. The food of Greenland halibut on the continental shelf (landward of the 400 m isobath at the shelf break) in NAFO Div. 2J+3K in the autumns of 1981 and 1982.

	Occurrence(%)		Number(%)		Weight(%)		Mean PFI	
	1981	1982	1981	1982	1981	1982	1981	1982
Invertebrata misc.			8.3	6.3	0.8	0.4	0.02	0.01
Cephalopoda			2.5	1.2	1.0	0.4	0.06	0.04
Hyperiidae	9.7	3.9	15.5	11.6	0.2	+	0.02	0.01
Gammaridea	5.2	3.1	7.4	8.4	0.2	0.2	0.01	0.01
Pandalus borealis	4.1	5.1	4.4	5.8	1.3	1.2	0.02	0.02
Pisces								
Mallotus villosus	20.4	24.0	41.2	45.3	54.6	46.5	0.95	1.01
Boreogadus saida	1.6	0.7	3.4	0.7	5.8	0.7	0.06	0.02
Gadus morhua	0.4	0.5	0.2	0.4	4.4	5.9	0.02	0.03
Zoarcidae			0.4	0.4	7.0	7.5	0.02	0.03
Sebastes sp.			0.5	1.0	3.7	9.0	0.01	0.03
Pleuronectidae			2.0	1.9	12.9	14.9	0.06	0.05
Others			1.8	0.3	1.9	2.7	0.02	0.01
Unidentified			12.4	16.7	6.2	9.1	0.18	0.19
Unidentified & misc.			0.1	0.1	0.1	1.6	+	0.01
Total							1.45	1.45
No of stomachs	2604	4147						
Percent empty	39.1	43.2						

+Trace

Table 5. Quantity of capelin in stomachs of Greenland halibut population in Div. 2J +3K in Autumn, 1981.

Length group (cm)	Number of stomachs	Capelin in stomachs PFI	Capelin in stomachs av. wt.(g)	Greenland halibut abundance (x 10^{-3})	Total capelin in stomachs (t)
1981 Division 2J					
<10	4	0.0	0.0	411	0.0
10-19	48	0.27	0.19	6,384	1.2
20-29	129	1.11	1.88	14,381	27.0
30-39	205	2.29	10.09	13,170	132.9
40-49	293	1.99	17.90	16,924	302.9
50-59	259	1.97	31.06	13,754	427.2
60-69	137	1.10	27.11	3,576	96.9
70-79	91	0.35	13.85	2,001	27.7
80-89	52	0.00	0.00	1,222	0.0
≥90	21	0.00	0.00	718	0.0
Total	1,239			72,541	1015.8
Division 3K					
<10					
10-19	97	0.12	0.07	7,240	0.5
20-29	327	0.68	1.13	26,742	30.2
30-39	312	0.72	2.82	19,892	56.1
40-49	445	0.35	2.94	35,490	104.3
50-59	286	0.30	4.26	15,577	66.4
60-69	117	0.05	1.16	2,593	3.0
70-79	57	0.00	0.01	1,305	0.0
80-89	30	0.00	0.00	627	0.0
≥90	5	0.00	0.00	169	0.0
Total	1,676			109,635	260.5
Grand Total(2J+3K)					1276.3

Table 6. Quantity of capelin in stomachs of Greenland halibut population in Div. 2J+3K in Autumn, 1982.

Length group (cm)	Number of stomachs	Capelin in stomachs PFI	Capelin in stomachs av. wt.(g)	Greenland halibut abundance (x 10^{-3})	Total capelin in stomachs (t)
1982 Division 2J					
<10				11	
10-19	51	0.00	0.00	1,625	0.0
20-29	220	2.62	4.68	14,222	66.6
30-39	394	2.10	9.20	21,416	197.0
40-49	625	1.69	14.52	25,290	367.2
50-59	561	1.01	15.88	20,498	325.5
60-69	254	0.89	21.99	5,047	111.0
70-79	147	0.16	6.77	2,150	14.6
80-89	92	0.14	8.01	1,649	13.2
≥90	37	0.05	4.34	710	3.1
Total	2,381			92,618	1098.2
Division 3K					
<10					
10-19	60	0.36	0.23	1,571	0.4
20-29	429	0.91	1.57	23,228	36.5
30-39	484	0.77	3.18	26,353	83.8
40-49	537	0.33	2.97	30,456	90.5
50-59	403	0.25	3.85	16,272	62.6
60-69	89	0.01	0.22	2,129	0.5
70-79	28	0.02	0.63	713	0.5
80-89	12	0.00	0.00	476	0.0
≥90	1	0.00	0.00	89	0.0
Total	2,043			101,287	274.8
Grand Total(2J+3K)					1373.0

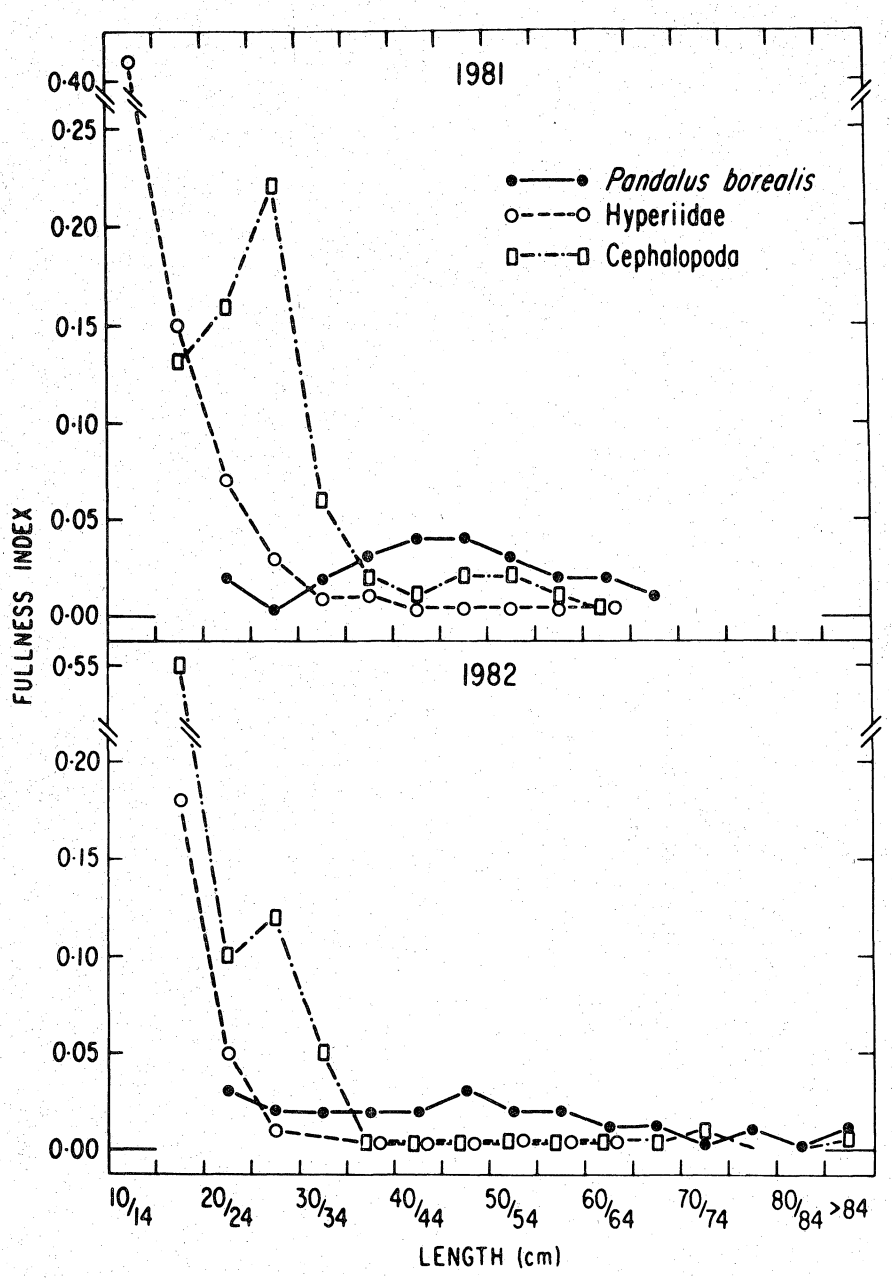

Fig. 1. Relationship between Greenland halibut length (5 cm groups) and partial fullness indices for 3 invertebrate taxa.

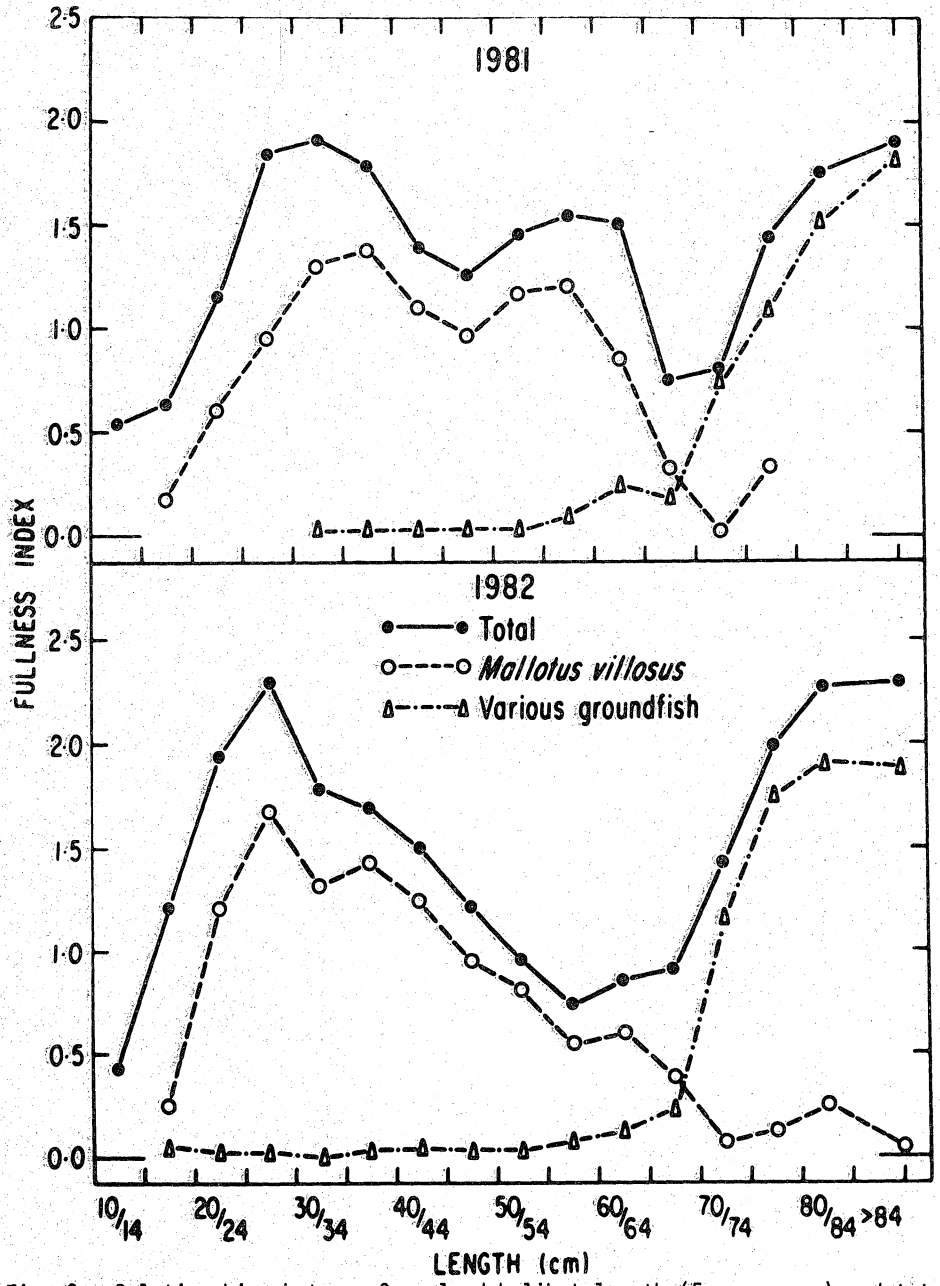

Fig. 2. Relationships between Greenland halibut length (5 cm groups) and total fullness index, partial fullness index (PFI) for capelin, and PFI for combined groundfish (Gadus morhua, Sebastes sp., Anarhichadidae, Pleuronectidae, Zoarcidae).

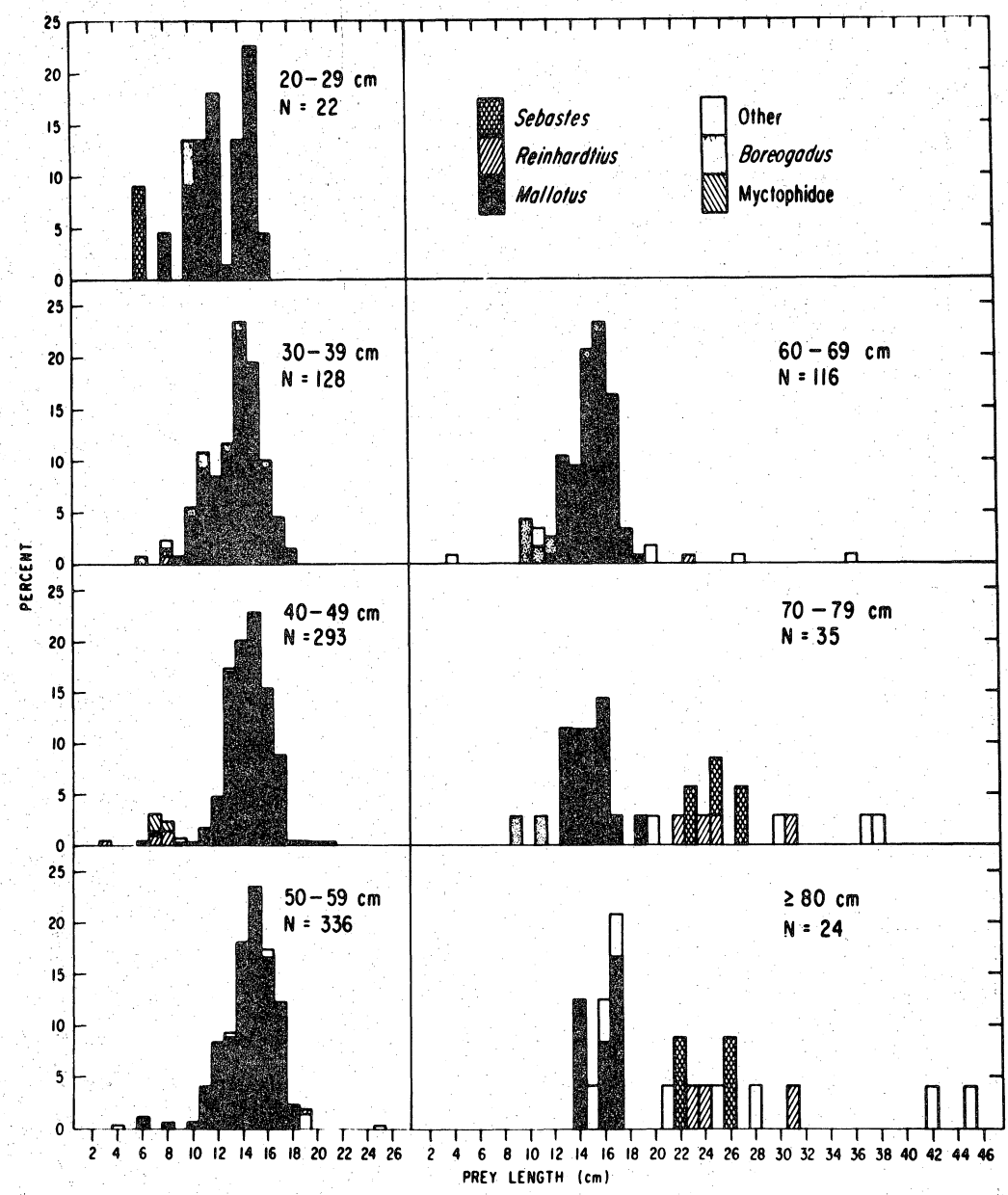

Fig. 3. Length frequencies of measured fish prey of 10 cm length groups of Greenland halibut. Data from 1981 and 1982 were combined.

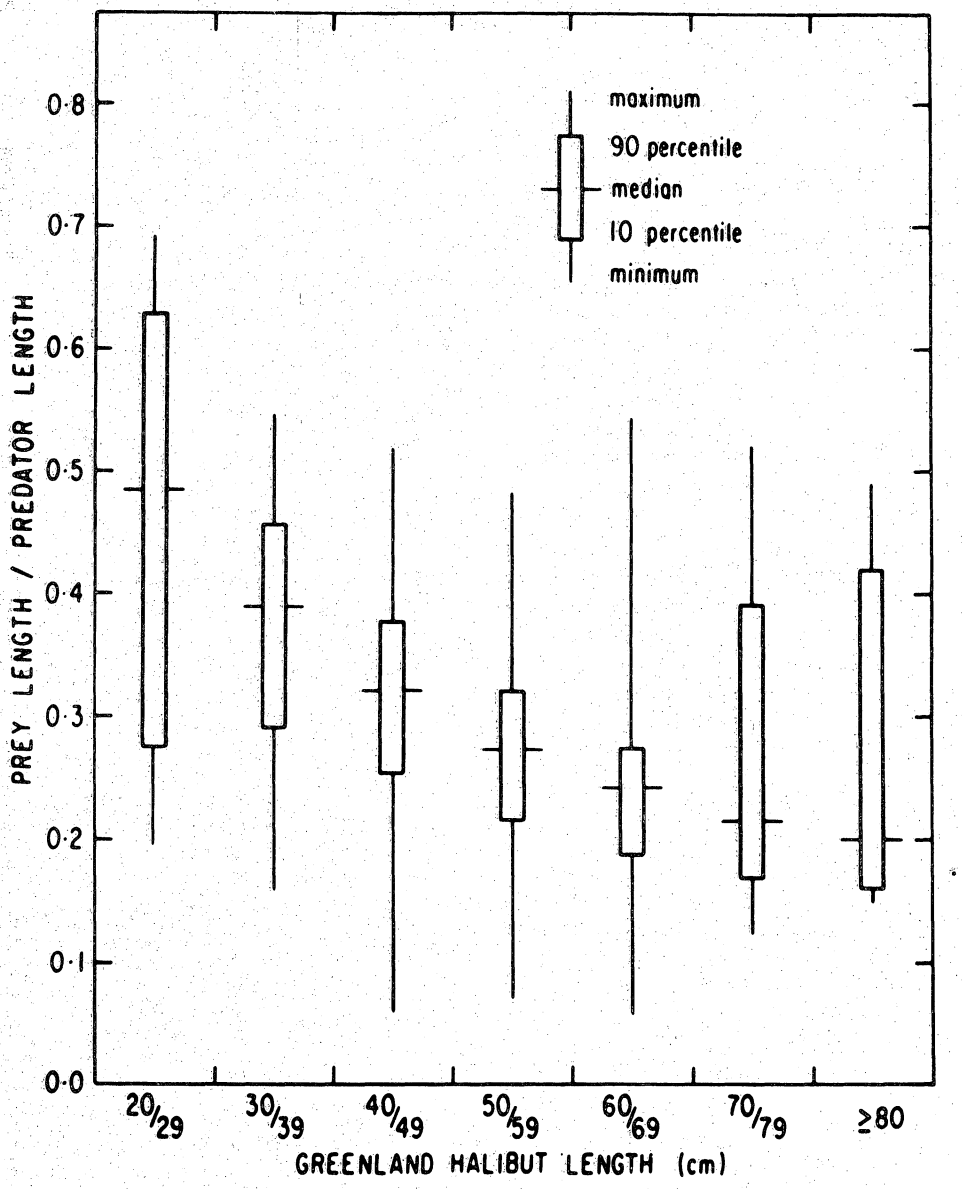

Fig. 4. Relationship between Greenland halibut length (10 cm groups) and the quotient (prey length/predator length). Data from 1981 and 1982 were combined.

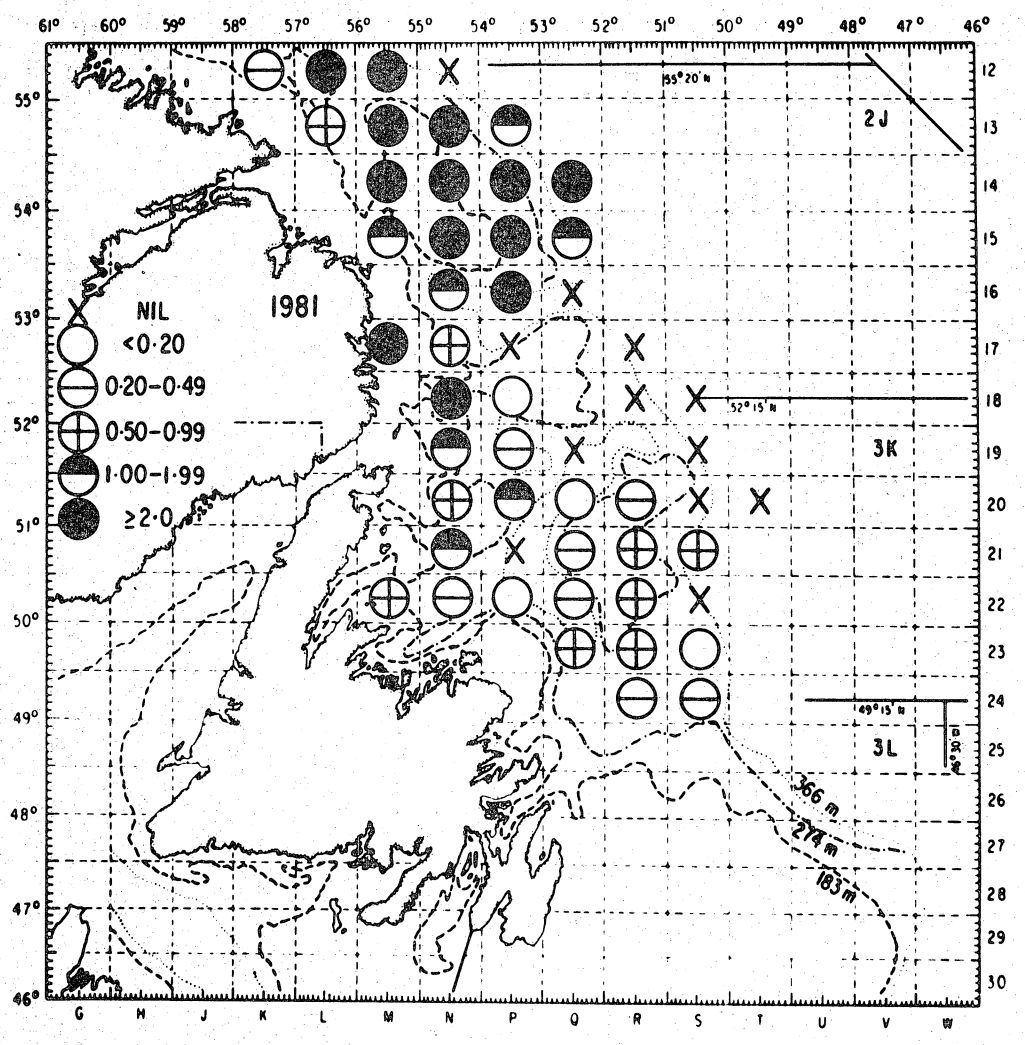

Fig. 5. Geographic variation in mean partial fullness index for capelin in 1981. All stomachs collected from Greenland halibut (25-64 cm) caught in each 0.5° latitude x 1.0° longitude area were combined. Data from areas with fewer than 5 stomachs were not plotted.

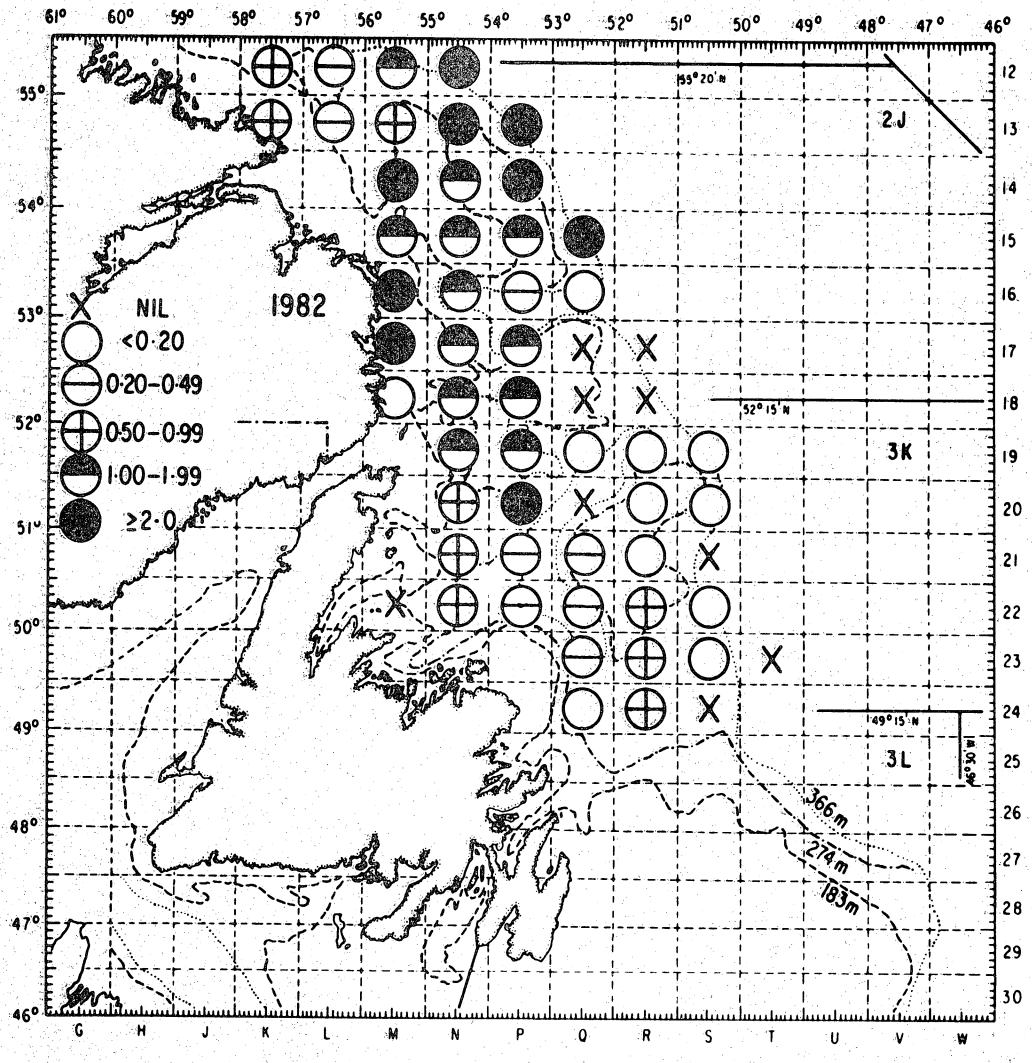

Fig. 6. Geographic variation in mean partial fullness index for capelin in 1982. Data analysis and presentation as in Fig. 5.