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Predation on Shrimp (*Pandalus borealis*) by Greenland Halibut (*Reinhardtius hippoglossoides*) and Atlantic Cod (*Gadus morhua*) off Coastal Labrador (Div. 2H and 2J)

by

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ABSTRACT

Shrimp and small Greenland halibut were the major prey of Greenland halibut and Atlantic cod on shrimp fishing grounds in Hopedale and Cartwright Channels off Labrador. Both predators fed on a wide size range of shrimp, including a modal group at about 7-8 mm carapace length which was not taken by the lined research trawl. In July 1981 Greenland halibut were 100 times more abundant than Atlantic cod in Hopedale Channel and 25 times more abundant in the more southerly Cartwright Channel. However, the Atlantic cod were of a larger average size and at a given body length had more shrimp in their stomachs. Consequently, Atlantic cod were significant predators in Hopedale Channel but not as important as Greenland halibut, whereas in Cartwright Channel Atlantic cod appeared to be the more important predator. Gross estimates of potential shrimp consumption by the two predators indicated that predation mortality might be low (<10%) relative to shrimp biomass in Hopedale Channel, but greater (about 60%) in Cartwright Channel.

INTRODUCTION

A fishery for the northern or pink shrimp (Pandalus borealis) off Labrador began in 1977 in response to encouraging results obtained from exploratory and experimental fishing in the previous two years (Sandeman MS 1978). Three areas of concentration were identified: the Hawke, Cartwright and Hopedale Channels (Fig. 1). Concentrations of shrimp in these channels were considered subsequently in annual stock assessments which resulted in the implementation of total allowable catches (TAC). Advice on potential removals was obtained from research and commercial abundance indices. A summary of landings and TAC's in the channels from 1977 to 1982 is given in Table 1. Research cruises have been conducted in these areas in November 1977, September 1978, and in July from 1979 to 1982. In addition to the collection of data on the abundance and distribution of shrimp, details of the occurrence of finfish species in the catches also were closely monitored.

Preliminary observations indicated that Greenland halibut (Reinhardtius hippoglossoides) and Atlantic cod (Gadus morhua), the two most abundant fish on the shrimp grounds, often had shrimp in their stomachs and might be important predators. Greenland halibut in the Labrador Channels usually occur in depths where shrimp are plentiful (>400 m) while Atlantic cod are found in shallower water, generally less than 450 m. Information collected from the shrimp fishery shows that seasonal changes in abundance for both fish species may occur. By-catches usually are highest around July-August and November when concentrations of shrimp are characteristically high.

[1] Order of authorship arranged randomly.

Data from the fishery and research survey in 1980 indicated a marked increase compared to previous years in abundance of Greenland halibut in the Hopedale and Cartwright Channels (Parsons et al. MS 1981). This increase caused some concerns related to the management of the shrimp resources because of the known predator-prey relationship between the two species. A more detailed examination of the 1980 research survey data and similar data from other sources showed potential for heavy predation on shrimp, especially in areas where shrimp were highly concentrated (Bowering and Parsons MS 1981). It was also pointed out that the characteristic increase in shrimp catch rates during the late months of the year was not evident in Cartwright Channel in 1980. Because of these concerns, it was decided that predator-prey relationships be studied more closely in subsequent surveys. In 1981 and 1982 data were collected on stomach contents of both Greenland halibut and Atlantic cod in the Hopedale and Cartwright Channels. This paper presents data on the distribution and abundance of the three species in recent years (1979-82), examines in detail the food and feeding habits of both fish species, and relates these findings to the overall management of the shrimp resources in the Hopedale and Cartwright Channels.

METHODS AND MATERIALS

Data on the distribution and abundance of shrimp, Greenland halibut and Atlantic cod off coastal Labrador were collected during the July research trawl surveys of the M.V. Zagreb in 1979 and R.V. Gadus Atlantica from 1980 to 1982. Both vessels used a Sputnik 1600 shrimp trawl lined in the last 6 m of codend with 13 mm mesh. Mesh size of the trawl ranged from around 80 mm in the wings to 42 mm in the codend. The headline was 43 m, the footrope 51 m and the estimated horizontal opening of the trawl between wing tips was approximately 22 m (J. Carrothers, pers. comm.). The vertical opening was approximately 7 m (estimated by net sounder).

During the surveys, standard lines were fished in each channel (Parsons and Sandeman 1981) from 1979 to 1981. In 1982, a stratified random survey design was employed. Depth intervals of 40-50 m were fished for a standard trawling time of 30 min at a speed of 3.0 knots. Warp length to depth ratio was approximately 3 to 1. Fishing was conducted on a 24 hr basis.

Random samples of each of the three species were taken routinely from sets in which they occurred. Carapace lengths were recorded for shrimp and fork lengths were recorded for Greenland halibut and Atlantic cod.

Biomass estimates for each species were obtained for the Hopedale and Cartwright Channels by areal expansion (Smith and Somerton 1981). In some instances, the numbers of Atlantic cod and/or Greenland halibut were not recorded and such sets were not included in the final estimate. Also, on occasion, anomalously large catches were excluded from the estimate.

In 1981 stomachs were excised from Greenland halibut and Atlantic cod and stored in 10% formalin. 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. Items in each taxon were placed briefly on absorbent paper to remove excess liquid, and then weighed to the nearest 0.1 g. In addition, individuals in each taxon of fish and decapod crustaceans were counted and measured to the nearest mm if digestion was not too advanced.

The relative importance of the various prey taxa was assessed using two indices:

(1) Percent weight (total weight of prey$_p$ in all stomachs as a percentage of the total weight of all prey)

(2) Stomach fullness index:

Mean total fullness index (TFI) =

$$\frac{1}{n}\sum_{f=1}^{n}\frac{\text{weight of stomach contents of fish}_f}{(\text{length of fish}_f)^3}\times 10^4$$

where n is the number of stomachs examined.

Mean partial fullness index of prey $_p$ (PFI_p) =

$$\frac{1}{n}\sum_{f=1}^{n}\frac{\text{weight of prey}_p\text{ in fish}_f}{(\text{length of fish}_f)^3}\times 10^4$$

In addition to the detailed examination in the laboratory in 1981, a large number of the stomachs of Greenland halibut and Atlantic cod were examined at sea in 1981 and 1982. The two major food items in terms of mass were recorded for each fish. In 1982 all shrimp in the stomachs were measured, with the exception of those which were too digested and those which showed no signs of digestion and thus might have been consumed in the trawl.

RESULTS

Distribution and Abundance of Predators and Prey

Estimates of biomass for shrimp, Greenland halibut and Atlantic cod from 1979 to 1982 in the Hopedale and Cartwright Channels are given in Tables 2 and 3 respectively. In both areas, shrimp generally were most abundant in depths greater than 400 m (Fig. 2 and 3). However, in 1981 and to some extent 1982, a higher proportion of the total estimated biomass was found in shallower water (200-400 m) in the Hopedale Channel. The distribution of shrimp in the Hopedale Channel in 1981 was considerably different compared to other years and the estimate of 4,213 t is not considered reliable. With the exception of 1981, shrimp biomass in this area appears reasonably stable although confidence intervals are quite wide (Fig. 4a). The 1979 estimate for Cartwright Channel is likely an underestimate because the most shallow and deepest strata were not sampled and the total number of sets (n=22) was relatively low. Results from the 1980 to 1982 surveys suggest a decline in abundance during that period (Fig. 5a).

Distribution of Greenland halibut was similar to that of shrimp in that most biomass occurred in deeper water (>400 m) (Tables 2 and 3, Fig. 2 and 3). This pattern did not change in 1981 in the Hopedale Channel when more than 50% of the estimated shrimp biomass occurred in depths shallower than 400 m. Abundance of Greenland halibut was extremely high in 1980 in both channels compared to 1979 and 1981. Except for 1980, there appears to have been a steady increase in abundance in the Hopedale Channel during this period (Fig. 4b) whereas in the Cartwright Channel only variation in abundance between years is apparent (Fig. 5b).

Cod usually were more abundant in depths less than 450 m in the Hopedale Channel, while in the Cartwright Channel significant proportions of the estimated biomass occasionally were found to depths of 550 m (Tables 2 and 3, Fig. 2 and 3). In the former area, biomass appears to have varied between 1979 and 1982, with no indications of an increasing or decreasing trend (Fig. 4c). Although there is considerable variation in the data, abundance of cod in the Cartwright Channel appears to have been increasing (Fig. 5c).

Prey of Greenland halibut and Atlantic cod

The major prey of both Greenland halibut and Atlantic cod in Hopedale and Cartwright Channels in 1981 were Greenland halibut and shrimp (Pandalus borealis) (Table 4). Arctic or polar cod (Boreogadus saida) and capelin (Mallotus villosus) were of lesser importance. Other fish prey included Lycodes sp., Sebastes sp., Atlantic cod, Myctophidae, Anarhichidae and Stichaeidae. Invertebrates of minor importance included cephalopods, hyperiid and gammarid amphipods, mysids, euphausiids, and several species of shrimp. Greenland halibut from Hopedale Channel had far less shrimp and Greenland halibut in their stomachs than did Greenland halibut from Cartwright Channel. In Cartwright Channel, Atlantic cod appeared to feed much more intensively on shrimp than did Greenland halibut. Atlantic cod also had a lower proportion of empty stomachs than did Greenland halibut. The sample of Atlantic cod was small (96 individuals) and came from just eight sets. It might nevertheless adequately represent the population in the Channel, for the diet composition of the 146 Greenland halibut from the same eight sets was very similar to that of the 1003 Greenland halibut from the Cartwright Channel as a whole (Table 4).

Because diet composition may vary with fish size, the quantities of shrimp and Greenland halibut in predator stomachs, expressed as partial stomach fullness indices (PFI), were plotted as a function of predator length (Fig. 6). In Greenland halibut, the patterns of PFI (shrimp) and PFI (Greenland halibut) were very similar, with the indices being much higher in Cartwright Channel than in Hopedale Channel over most of the predator length range. In contrast, in cod (>49 cm) the values of PFI (shrimp) were much higher the than values of PFI (Greenland halibut). In these large cod, which comprised most of the population, the total fullness index was higher than in Greenland halibut of comparable length.

Size of prey

Length-frequencies of shrimp from stomachs of Atlantic cod and Greenland halibut were very similar to length-frequencies of shrimp caught by the trawl in the same sets (Fig. 7 and 8). In several instances (e.g. the 15-16 mm mode in cod from Cartwright Channel in 1982, Fig. 8) the modes in samples of shrimp from predator stomachs were lower than corresponding modes in samples from the catch. These differences may be caused, at least in part, by errors during measurement of shrimp in various states of digestion, but it is also possible that at times the predators selected smaller shrimp than did the trawl. The most important difference between shrimp from the two sources was the presence of shrimp about 7-8 mm in length in stomachs of predators and the absence of this mode from the trawl catches, despite the use of a codend liner of 13 mm mesh.

The Greenland halibut from stomachs of Atlantic cod and Greenland halibut ranged in length from 8 to 59 cm, with the majority <20 cm. Modes were apparent at 11 and 15 cm.

Annual variability in diet

The frequency of occurrence of various food categories in stomachs of Atlantic cod observed at sea varied considerably between 1981 and 1982 (Table 5). The most frequently recorded prey in both channels was shrimp (Pandalus borealis). In Hopedale Channel the percentage occurrence of shrimp was higher in 1982 than in 1981, and this change was observed in all length-groups of Atlantic cod (Fig. 9). In contrast, in Cartwright Channel shrimp were recorded more frequently in 1981 than in 1982 (Table 5) and again this difference was noted in all Atlantic cod length-groups (Fig. 10).

Many of the Greenland halibut stomachs observed at sea were empty (Fig. 11 and 12). The frequency of occurrence of shrimp increased with predator length, but remained low compared with frequency of occurrence of shrimp in stomachs of Atlantic cod. For Greenland halibut >30 cm in length, shrimp were recorded in 18% of the stomachs in 1981 and 13% in 1982 in Hopedale Channel and 7% in 1981 and 5% in 1982 in Cartwright Channel.

The difference between years in frequency of occurrence of shrimp and other prey (Table 5) in the stomachs of predators are difficult to interpret, for the taxonomic level of prey identification may vary with the experience of the investigator and the time available for stomach examination. In addition, only the two major prey were noted, so an increase in predation on one prey might result in reduced recording of a second prey, even if consumption of the second prey had not changed. Despite these uncertainties, it is clear that shrimp were consumed by most Atlantic cod in both channels in both years, and the proportion of Greenland halibut feeding on shrimp was low in both channels in both years.

Predatory impact

The relative predatory impact of Greenland halibut and Atlantic cod on shrimp stocks was assessed by comparing the weights of shrimp within the stomachs of the population of each predator in each channel at the time of sampling in 1981. The number of each predator in each channel was estimated by areal expansion of stratified arithmetic mean catch (number) per tow, assuming a catchability coefficient of 1. Mean population numbers ($\times 10^{-3}$) (and 95% confidence intervals) were:

Hopedale Channel	Greenland halibut	21563	(13791-29335)
	Atlantic cod	214	(43-384)
Cartwright Channel	Greenland halibut	10129	(6690-13567)
	Atlantic cod	380	(17-744)

The biomass of shrimp in the stomachs of the population of each predator was calculated (Table 6) as $\sum_{l}^{n} N_l \bar{W}_l$, where

N_l is the number of individuals in length-group l, assuming that the length-frequency of the

total catch represents the population length-frequency, and $\bar{W}_l$ is the mean weight of shrimp in the stomachs of those individuals of length-group l examined in the laboratory. There was no stomach sample for cod in Hopedale Channel, so the mean weights from Cartwright Channel were applied. These weights were divided by four to reflect the smaller stomach contents observed in Greenland halibut from Hopedale Channel compared with those from Cartwright Channel (Table 4, Fig. 6). In Hopedale Channel there was more shrimp in the stomachs of Greenland halibut than in stomachs of Atlantic cod (12.8 t vs. 3.1 t), but in Cartwright Channel the Atlantic cod contained more shrimp that did the Greenland halibut (19.5 t vs. 10.3 t) (Table 6).

The weight of shrimp removed annually by the two major predators may be crudely estimated under the following assumptions.

1) The numbers of Greenland halibut and Atlantic cod in the two channels is as reported above for 1981, and remains unchanged from June to December.

2) Greenland halibut and Atlantic cod refill their stomachs every four days. The rate of evacuation of shrimp from the stomachs of these predators at 2-4°C is not known. Other investigators (e.g. Minet and Perodou, 1978; Tiews, 1978) have assumed a refilling time of three days, based on results from experiments conducted at higher temperatures.

3) The period of feeding by these predators on shrimp is one half year. There are no data to support this, but Turuk (1968) reported that Atlantic cod in southern Labrador feed most intensively from June to December.

Under these assumptions, the annual consumption of shrimp by Greenland halibut and Atlantic cod might be 723 t in Hopedale Channel and 1357 t in Cartwright Channel.

DISCUSSION

Predation by Greenland halibut and Atlantic cod on Pandalus borealis, as reported here for Hopedale and Cartwright Channels off Labrador, is a phenomenon common to many shrimp grounds throughout the North Atlantic (e.g. at Greenland (Hansen, 1949; Horsted and Smidt, 1965; Smidt, 1969), Iceland (Palsson, 1983), and Norway (Klemetsen, 1982)). In the Labrador area shrimp appeared to be less important to Greenland halibut than to Atlantic cod. Greenland halibut feed almost entirely in the water column (Smidt, 1969; Huag and Gulliksen, 1982) and seldom consume epibenthos, such as crabs, which are frequently consumed by Atlantic cod. Perhaps most of the shrimp consumed by Greenland halibut are taken when the shrimp migrate off the bottom.

Additional information on shrimp distribution and biological parameters can be obtained by sampling the shrimp eaten by the two predators. It appears that smaller sizes (younger age groups) are better represented in stomachs of predators than in the research trawl. The benefits of this are threefold. Most obvious is the occurrence of an additional mode of very small animals which may represent the young of the year. Better estimations of parameters of growth and mortality can be obtained since such data contribute to solving some of the problems in ageing shrimp. Secondly, it may be possible to obtain at least some qualitative information on recruitment potential one year earlier than from trawl data alone, provided strict standardization procedures are employed. Finally, problems of availability to and selectivity of the research trawls could be approached by observing the differences in proportions at length between the two data sources. Atlantic cod contain more measureable shrimp than Greenland halibut and therefore can be considered better shrimp samplers, but because Atlantic cod are not abundant in the deeper regions of the shrimp grounds, it is advisable to obtain shrimp from both predators.

The number of Greenland halibut far exceeds the number of Atlantic cod in both the Labrador channels. However, at the time of sampling in July 1981, the Atlantic cod had a larger average size and at a given body length had more shrimp in their stomachs. Consequently, although the population of Greenland halibut in Hopedale Channel had more shrimp in their stomachs than did the Atlantic cod, the relative predatory importance was reversed in Cartwright Channel, where the cod were relatively more abundant.

Progress in the study of predation on shrimp in the channels off Labrador requires further investigation of the abundance of shrimp and its predators and improved understanding of digestion physiology and feeding behavior in the two predators.

Abundance. The actual abundance of each species at the time of the annual surveys remains uncertain because catch rates are highly variable and the catchability coefficient for each species is unknown. Furthermore, it is not known if the abundance of predators on the shrimp grounds is a function of overall stock size, and whether abundance changes seasonally as a result of migration or annually as a result of changes in physical factors such as temperature and ice cover.

Digestion physiology. Estimates of feeding rate require information on the rate of evacuation of shrimp from stomachs of Greenland halibut and Atlantic cod at the relatively low temperatures (2-4°C) prevailing in the channels. Also required is information on variability in gastric evacuation rate caused by differences in predator size, quantity of material in the stomach, and the presence of other food types.

Feeding behaviour. We need to know the relationship between feeding rate and prey abundance, whether the predators aggregate at sites where shrimp are abundant, and whether predators vary their feeding rate with season independently of changes in prey availability. It was assumed when calculating annual consumption that predation on shrimp occurs only from July to December. However, Atlantic cod are most abundant on shrimp grounds at Greenland in winter (Horsted and Smidt, 1965), and Atlantic cod off northeast Newfoundland (NAFO Div. 2J, 3K) feed on shrimp in March (unpubl. observ. G. Lilly). If Atlantic cod occur on the Labrador shrimp grounds in winter, they probably prey on the shrimp.

We also need more information on prey preference and whether true switching occurs. Both predators feed primarily on small crustaceans when they are small and gradually shift to larger crustaceans and fish as they grow (see, for example, Powles, 1958; Rae, 1967; Smidt, 1969). The change in prey taxa with increasing predator length may be a consequence of an energetic requirement for larger prey (Kerr, 1971; Daan, 1973). The intensity of predation on shrimp therefore may vary with changes in the availability of small and medium-sized fish. Year-class strength in Greenland halibut may be of particular significance, for in 1981 small Greenland halibut were as important as shrimp to Greenland halibut, and were the second most important prey of Atlantic cod. Other potentially important and variable prey are Arctic cod, which were caught in the trawl and were eaten by both predators in both channels, and capelin, which were caught in the trawl and consumed by both predators only in Cartwright Channel. The possibility of annual variation in availability is indicated by a larger average catch of capelin in 1982 (2.6 kg) than in 1981 (0.5 kg) and the recording of capelin in stomachs of Atlantic cod only in 1982.

The impact of predation by Greenland halibut and Atlantic cod on the shrimp stocks in Hopedale and Cartwright Channels can be assessed only in a very general way at present. The estimated consumption by the two predators of 723 t of shrimp in Hopedale Channel is less than 10% of the estimated trawlable biomass, whereas the estimated consumption of 1357 t in Carwright Channel is about 60% of the mean trawlable biomass. The shrimp resource in the Hopedale Channel has shown declines in abundance from virgin levels, likely in response (in part) to exploitation. No effects of the high abundance of Greenland halibut in 1980 were apparent. The last year of a significant fishery in the Cartwright Channel was 1979. Since then, there has been no noticeable recovery of the resource despite the reduction in fishing mortality. The impact of predation and the possible consequences of changes in predator abundance may be more thoroughly assessed when improved understanding of recruitment, growth rate and age-specific predation permit a comparison between predation and production.

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Table 1. Summary of landings* and total allowable catches (TAC's) of northern shrimp (Pandalus borealis) in the Labrador Channels, 1977-82.

	Hopedale		Cartwright		Hawke	
	Catch	TAC	Catch	TAC	Catch	TAC
1977	1200		1400		-**	
1978	2100	4500	1500	800	-	800
1979	2700	3200	1000	800	-	1700
1980	3900	4000	200	800	-	850
1981	3400	4000	-	800	100	850
1982	1700	4000	200	800	-	850

* to the nearest 100 t
** < 100 t

Table 2. Estimates of mean biomass (t) for shrimp, Greenland halibut and cod in the Hopedale Channel, 1979-82.

Stratum	Depth range (m)	1979 No. of sets	1979 Shrimp	1979 Greenland halibut	1979 Cod	1980 No. of sets	1980 Shrimp	1980 Greenland halibut	1980 Cod
102	202-238	2	68	30	4				
103	239-274	2	338	18		2	14	42	21
104	275-311	2	53	20	13	3	24	51	39
105	312-348	2	119	63	78	4	148	136	72
106	349-384	2	343	82		4	88	289	132
107	385-421	2	728	138	73	4	143	451	139
108	422-457	2	583	132	42	4	454	723	156
109	458-494	2	1,900	398	43	4	838	1,330	25
110	495-530	2	2,001	1,021	0	3	3,798	2,556	110
111	531-567								
112	568-603	4	1,973	370	1	4	1,849	2,154	17
113	604-639								
204	275-311					3	150	72	81
205	312-348	2	62	182	84	2	142	95	142
206	349-384	2	734	79	21	3	230	69	31
207	385-421	2	17	16	0	4	269	246	80
208	422-457	3	2,137	148	0	3	2,160	544	110
209	458-494	2	46	153	8	3	259	1,067	77
210	495-530	3	23	107	0	3	104	1,124	18
211	531-567	3	129	541	1	3	39	2,914	11
212	568-603	2	16	396	0	2	127	2,509	0
213	604-639					3	39	1,468	0
214	640-675								
304	275-311					2	18	173	267
305	312-348	2	12	105	44	2	48	276	183
306	349-384	2	78	62	19	2	97	333	
307	385-421	2	144	51	4	2	128	199	18
308	422-457	2	98	24	0	2	130	330	23
309	458-494	3	4	2	0	2	82	156	5
310	495-530					2	71	164	1
311	531-567					2	120	302	2
312	568-603	2	2	2	0	2	67	514	3
313	604-639					4	204	2,758	0
314	640-675								
Total		54	11,608	4,140	435	83	11,840	23,045	1,763
Upper 95%			19,730	5,422	899		19,134	25,894	2,284
Lower C.I.			3,487	2,857	-30		4,545	20,197	1,242

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Table 2. (Cont'd.)

Stratum	Depth range (m)	1981 No. of sets	1981 Shrimp	1981 Greenland halibut	1981 Cod	1982 No. of sets	1982 Shrimp	1982 Greenland halibut	1982 Cod
102	202-238	3	302	23	18	3	86	15	22
103	239-274					3	148	59	106
104	275-311	3	219	55	4	3	189	101	153
105	312-348	4	634	156	22	3	997	374	410
106	349-384	3	629	286	56	4		335	177
107	385-421	3	203	207	26	4	984	664	61
108	422-457	3	301	412	0	4	727	482	40
109	458-494	3	184	619	44	3	204	637	4
110	495-530	3	349	1,886	25	4	367	1,588	9
111	531-567	2	50	485	0	3	181	1,061	0
112	568-603								
113	604-639								
204	275-311	2	367	34	56	3	589	74	101
205	312-348	3	197	36	21	2	209	40	164
206	349-384					3	419	212	135
207	385-421	3	296	372	159	4	3,587	351	272
208	422-457					2		1,107	275
209	458-494	4	207	2,621	0	3	297	781	209
210	495-530					3	217	706	11
211	531-567					2	25	762	0
212	568-603					2	98	1,114	0
213	604-639					2	17	213	0
214	640-675								
304	275-311								
305	312-348	2	13	33	16	3	11	68	46
306	349-384	2	21	44		2	17	8	4
307	385-421	3	87	251	54	2	51	69	5
308	422-457					2	7	3	0
309	458-494	2	33	66	1	2	18	5	0
310	495-530	2	23	13	1	2	28	28	0
311	531-567	2	9	7	0	2	21	30	0
312	568-603	2	14	14	1	2	4	231	0
313	604-639	2	75	930	0				
314	640-675								
Total		56	4,213	8,550	504	77	9,498	11,118	2,204
Upper 95%			5,974	12,805	900		12,003	15,218	3,247
Lower C.I.			2,452	4,295	107		6,993	7,018	1,162

Table 3. Estimates of mean biomass (t) for shrimp, Greenland halibut and cod in the Cartwright Channel, 1979-82.

Stratum	Depth range (m)	1979 No. of sets	1979 Shrimp	1979 Greenland halibut	1979 Cod	1980 No. of sets	1980 Shrimp	1980 Greenland halibut	1980 Cod
702	301-350					2	190	381	42
703	251-300								
704	<250								
705	251-300								
706	301-350	3	7	41	82	2	3	118	47
707	351-400	4	17	94	58	6	99	241	37
708	401-450	6	116	320	35	5	405	536	24
709	451-500	3	529	554	52	3	513	1,018	42
710	501-550	6	1,223	730	17	8	992	1,805	77
711	451-500					2	64	304	20
712	>551					6	523	930	42
Total		22	1,892	1,739	224	34	2,789	5,332	331
Upper 95%			2,879	2,685	426		3,422	6,189	502
Lower C.I.			904	793	62		2,157	4,476	160

Stratum	Depth range (m)	1981 No. of sets	1981 Shrimp	1981 Greenland halibut	1981 Cod	1982 No. of sets	1982 Shrimp	1982 Greenland halibut	1982 Cod
702	301-350	2	54	44	47	2	103	168	
703	251-300				3	3	5	5	
704	<250	8	9	18	6	3	3	4	
705	251-300				64				49
706	301-350	3	25	30	250	4	93	85	308
707	351-400	9	240	94	130	5	87	149	159
708	401-450	10	887	401	140	6	489	764	211
709	451-500	9	612	316	60	6	345	489	94
710	501-550	3	342	233	41	6	335	623	95
711	451-500	2	67	93	3	4	59	159	21
712	>551	3	131	147	7	3	397	615	72
Total		49	2,367	1,376	751	42	1,916	3,061	1,017
Upper 95%			3,380	2,042	1,403		2,867	3,934	1,414
Lower C.I.			1,355	710	99		965	2,188	620

Table 4. Food of Greenland halibut and Atlantic cod from Hopedale and Cartwright Channels, July 1981, as determined from stomachs examined in the laboratory.

Prey	Hopedale		Cartwright					
	Greenland halibut		Greenland halibut					
			All data		Eight sets[a]		Atlantic cod	
	Percent by weight	Mean PFI	Percent by weight	Mean PFI	Percent by weight	Mean PFI	Percent by weight	Mean PFI
Mallotus villosus	+		1.6	0.07				
Boreogadus saida	3.6	0.07	2.2	0.10	2.1	0.06	3.9	0.12
Reinhardtius hippoglossoides	34.1	0.08	36.2	0.39	41.6	0.42	20.4	0.54
Fish (miscellaneous)	8.3	0.02	15.4	0.07	7.2	0.06	5.4	0.08
Fish (unidentified)	24.7	0.08	6.4	0.11	4.4	0.08	1.4	0.06
Pandalus borealis	19.4	0.12	32.9	0.40	38.5	0.40	65.8	1.78
Invertebrates (misc. and unid.)	9.9	0.27	5.4	0.16	6.2	0.24	3.0	0.09
Mean TFI		0.65		1.30		1.26		2.68
No. stomachs	992		1003		146		96	
Percent empty	37.2		25.4		24.7		2.1	

+trace

[a]Stomach contents of those Greenland halibut caught in the eight sets from which the Atlantic cod sample was taken.

Table 5. Frequency of occurrence (percent) of various prey categories as first or second most important prey in stomachs of Atlantic cod observed at sea in Hopedale and Cartwright Channels, 1981-82.

	Hopedale Channel		Cartwright Channel	
	1981	1982	1981	1982
Mallotus villosus	-	-	-	9.3
Boreogadus saida	5.2	0.8	1.1	1.2
Reinhardtius hippoglossoides	9.5	4.6	22.2	3.4
Fish (miscellaneous)	3.5	11.6	0.5	1.2
Fish (unidentified)	2.6	11.0	6.3	25.4
Pandalus borealis	56.9	86.9	85.2	69.9
Invertebrates (misc)	1.7	8.1	0.4	17.9
Unidentified	2.6	3.5	0.8	7.8
Empty	22.4	5.4	7.1	7.1
N	116	373	784	524

Table 6. Quantity of shrimp in stomachs of populations of Greenland halibut and Atlantic cod in Hopedale and Cartwright Channels, July 1981.

Length group (cm)	Hopedale Channel			Cartwright Channel		
		Weight of shrimp			Weight of shrimp	
	Abundance[a] ($\times 10^{-3}$)	Per stomach (g)	In population (kg)	Abundance[a] ($\times 10^{-3}$)	Per stomach (g)	In population (kg)
Greenland halibut						
<10	215	0.0	0.0	77	0.0	0.0
10-19	8,259	0.002	16.5	6,699	0.016	107.2
20-29	2,936	0.289	848.5	1,328	0.458	608.2
30-39	5,011	0.837	4,194.2	1,121	1.578	1,768.9
40-49	3,337	0.804	2,683.0	508	4.542	2,307.3
50-59	1,267	2.398	3,038.3	236	12.066	2,847.6
60-69	323	3.500	1130.5	86	18.868	1622.7
70-79	125	4.694	586.8	39	16.625	648.4
≥80	67	4.292	287.6	25	14.950	373.8
Total	21,540		12,785.4	10,119		10,284.1
Atlantic cod						
18-26	8.1	0.007	0.1	6.7	0.029	0.2
27-35	7.3	0.200	1.5	3.2	0.800	2.5
36-44	-	-	-	3.2	4.400	14.0
45-53	5.6	2.141	11.9	30.4	8.564	260.4
54-62	74.0	10.516	778.7	189.3	42.063	7,963.2
63-71	94.2	18.920	1,781.5	125.9	75.678	9,524.5
72-80	20.1	20.033	403.0	17.2	80.133	1,379.4
81-90	3.2	17.044	54.7	1.9	68.175	131.3
90-98	1.7	21.825	37.4	2.2	87.300	187.5
Total	214		3,068.6	380		19,463.1
Grand total			15.9 t			29.8 t

[a] Estimated by applying percentage length-frequency in the catch to the total population size estimated by areal expansion, and assuming a catchability coefficient of 1.

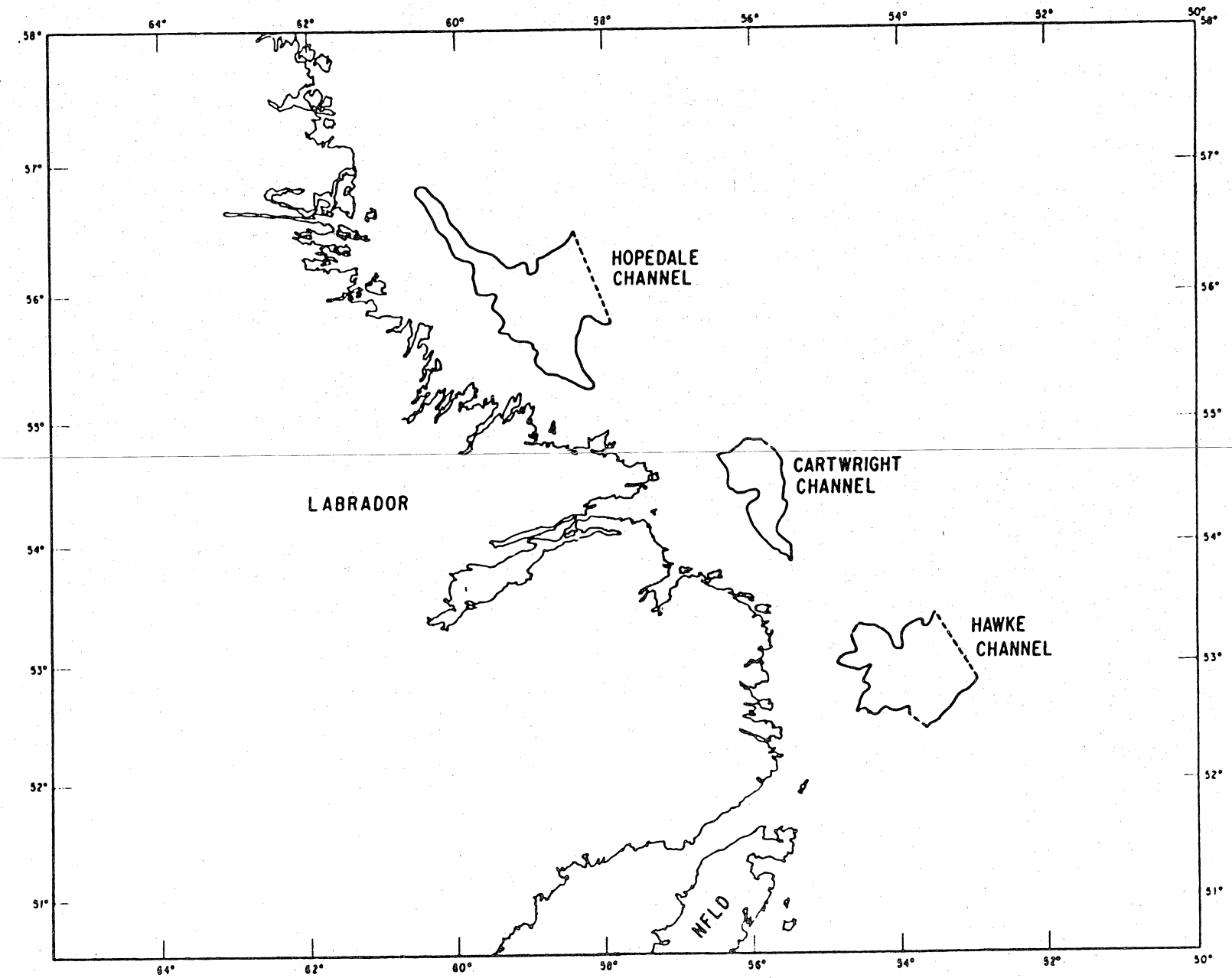

Fig.1. Areas of shrimp (Pandalus borealis) concentration on the Labrador Shelf defined by the 200 m. contour.

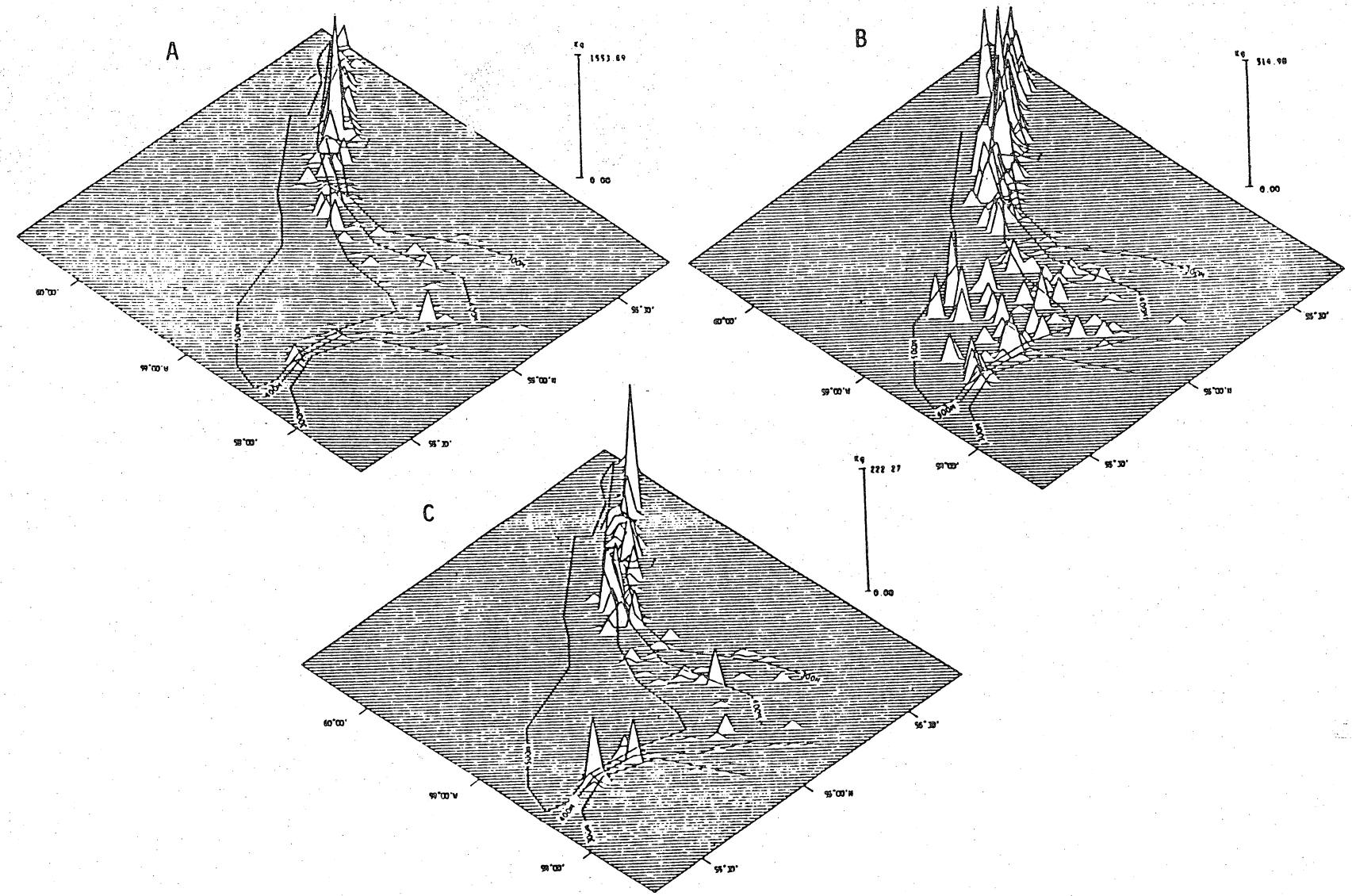

Fig. 2. Distribution of shrimp (A), Greenland halibut (B), and cod (C) in the Hopedale Channel, 1979-1982.

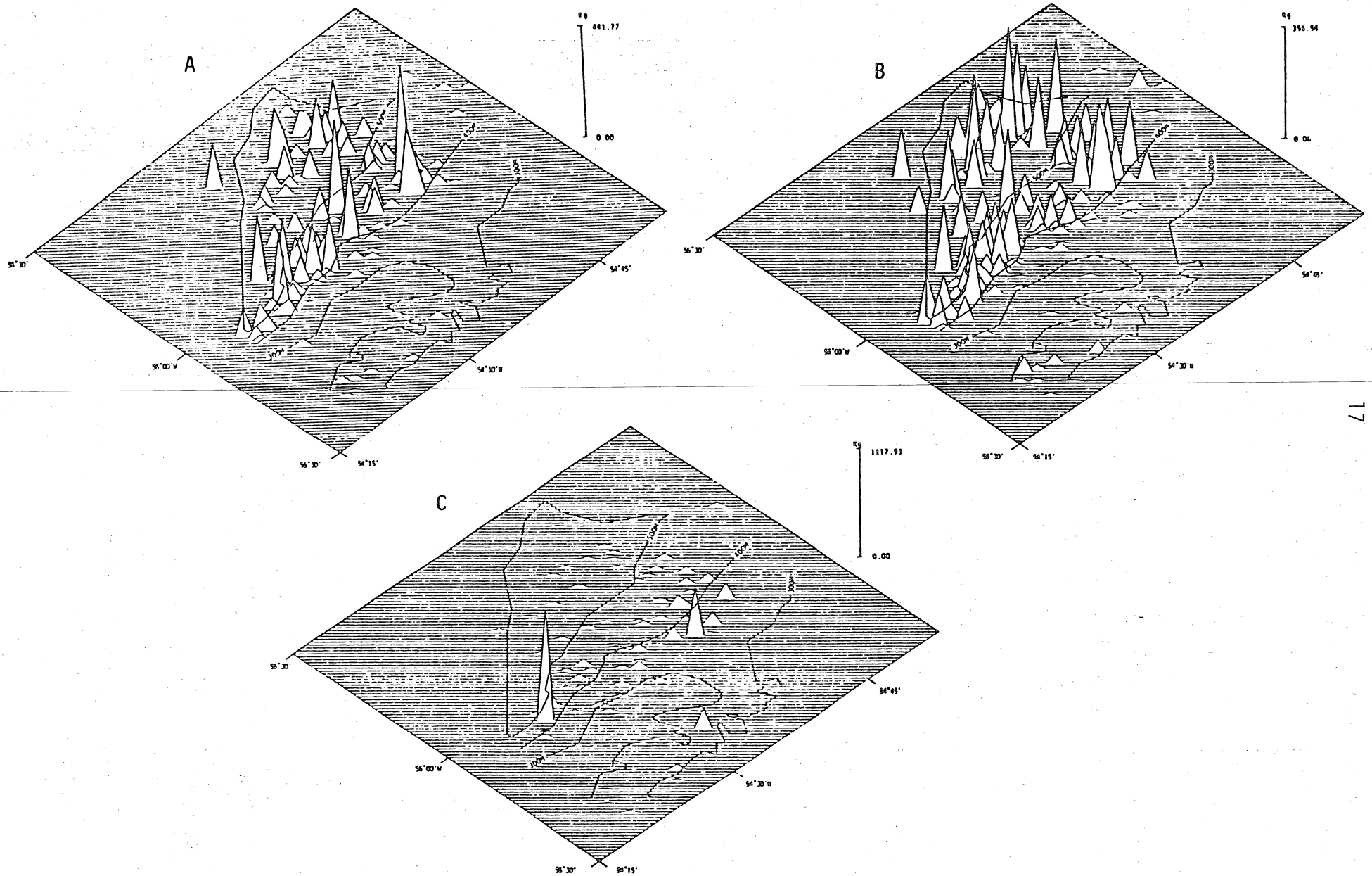

Fig. 3. Distribution of shrimp (A), Greenland halibut (B), and cod (C) in the Cartwright Channel, 1979-1982.

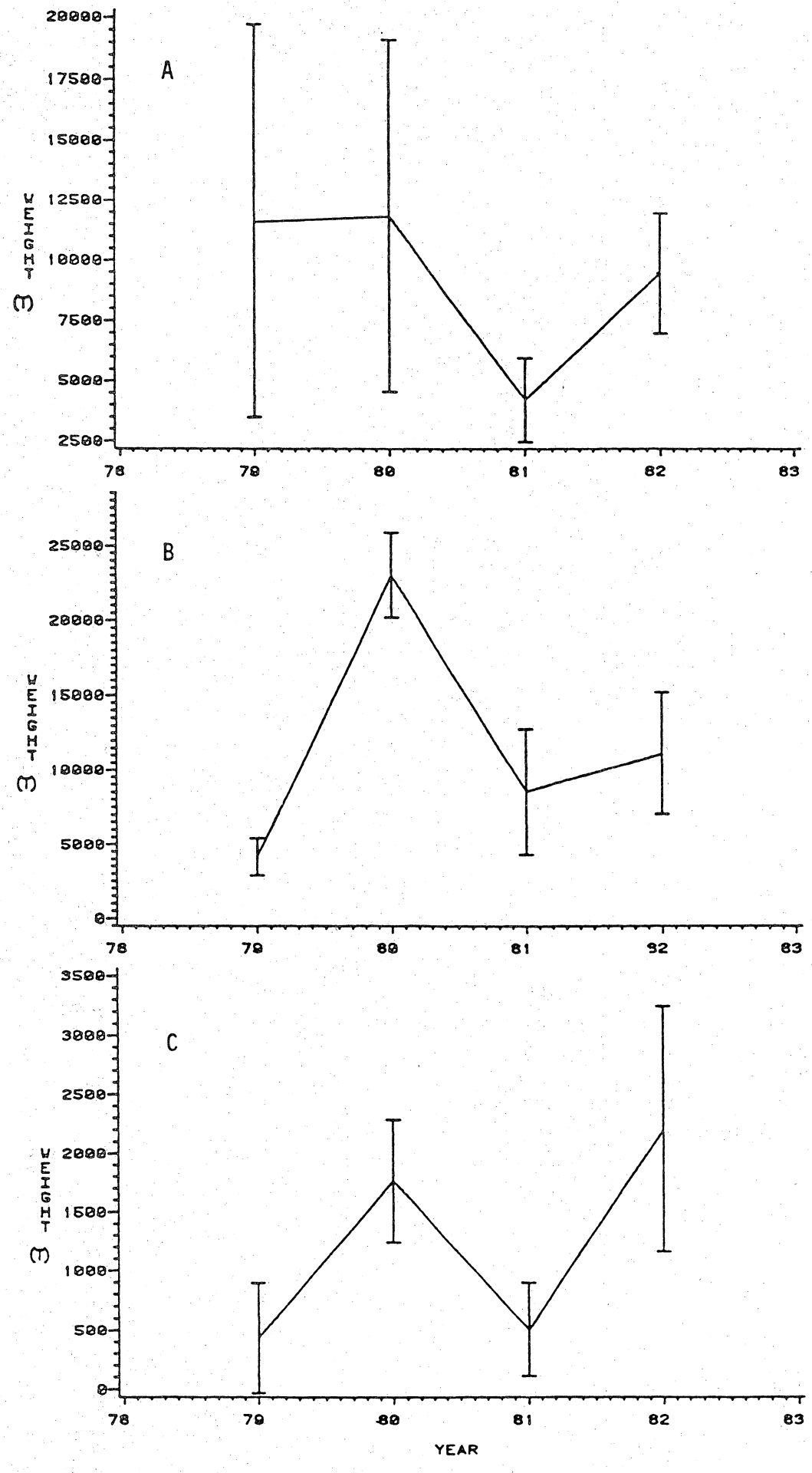

Fig. 4. Mean estimates of shrimp (A), Greenland halibut (B), and cod (C) biomass and 95% confidence intervals, 1979-1982 in the Hopedale Channel.

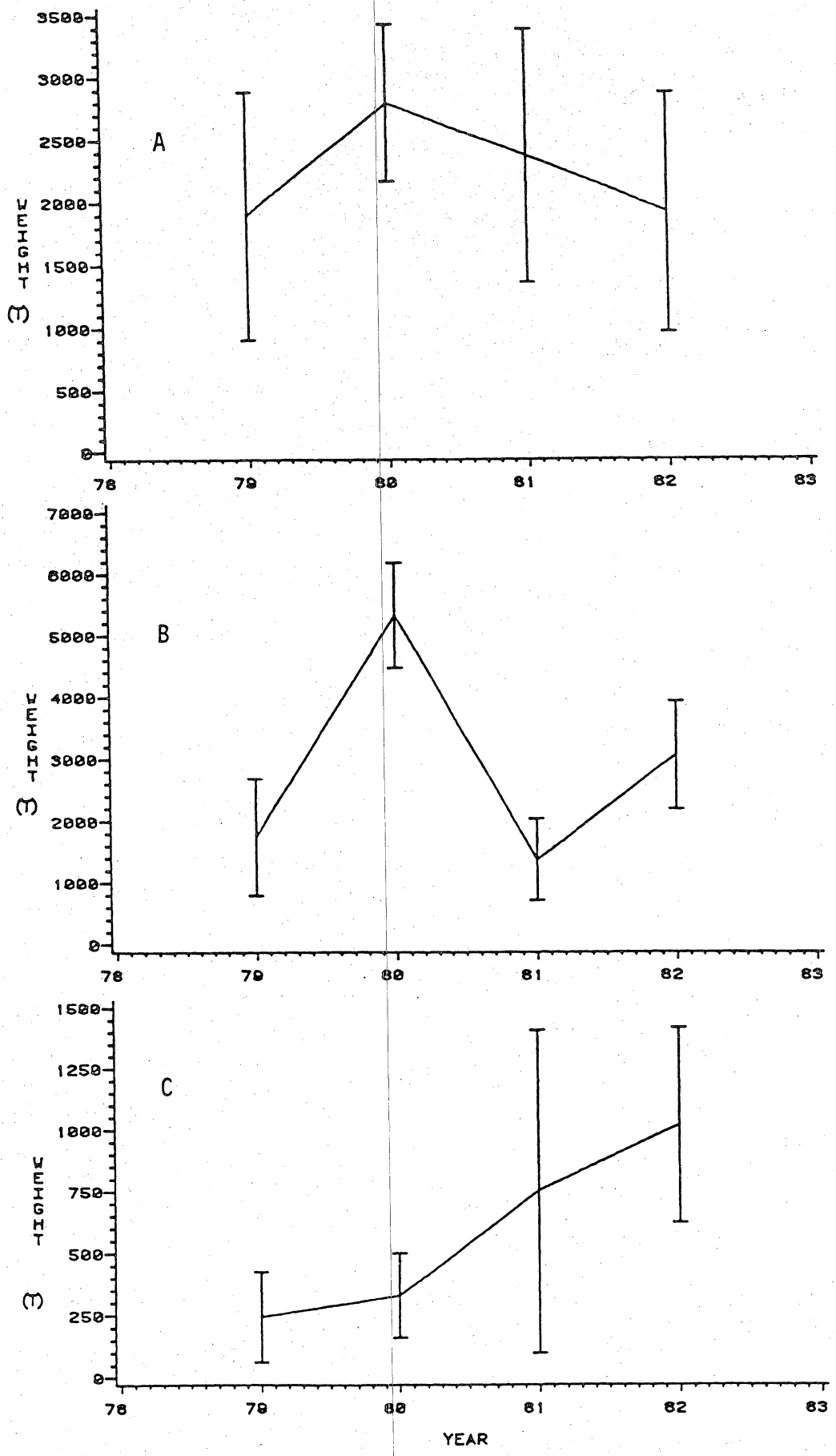

Fig. 5. Mean estimates of shrimp (A), Greenland halibut (B), and cod (C) biomass and 95% confidence intervals, 1979-1982 in the Cartwright Channel.

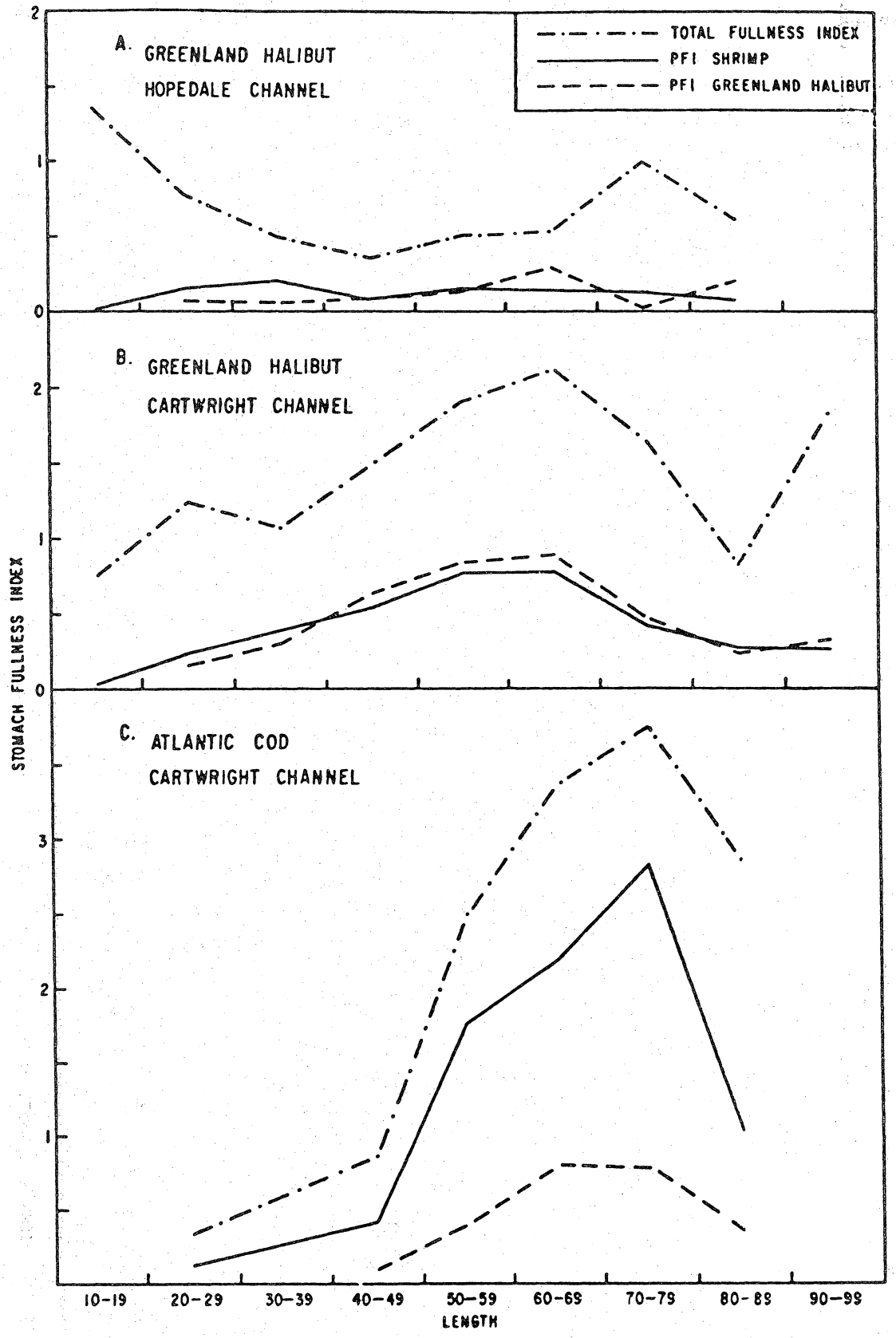

Fig. 6 Stomach fullness indices for Greenland Halibut in Hopedale and Cartwright Channels and Atlantic cod in Cartwright Channel, July 1981.

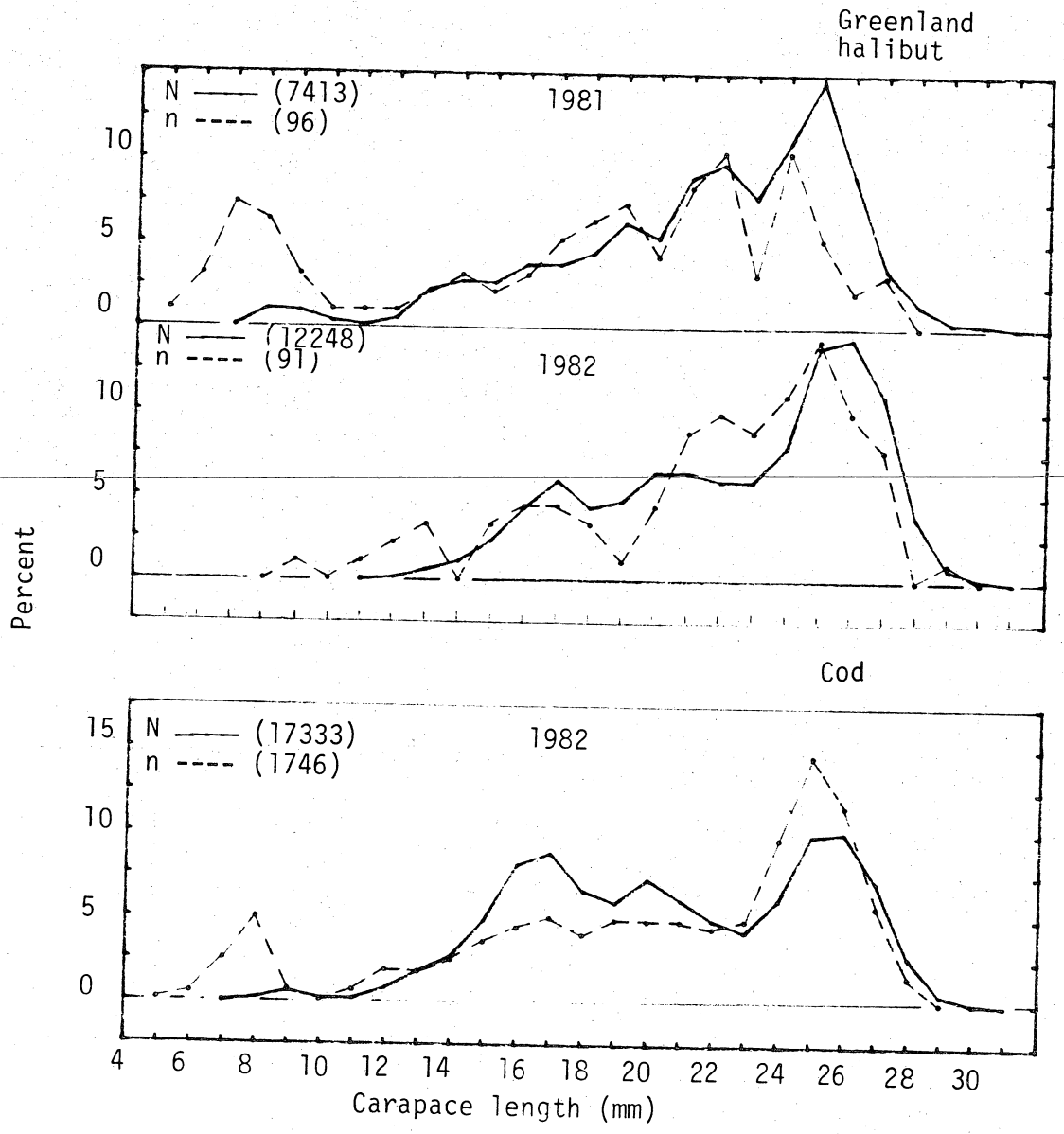

Fig. 7. Length frequencies of shrimp caught by the trawl (N) and recovered from Greenland halibut (n) and cod (n) stomachs in the Hopedale Channel, 1981-1982. Number of shrimp measured is indicated.

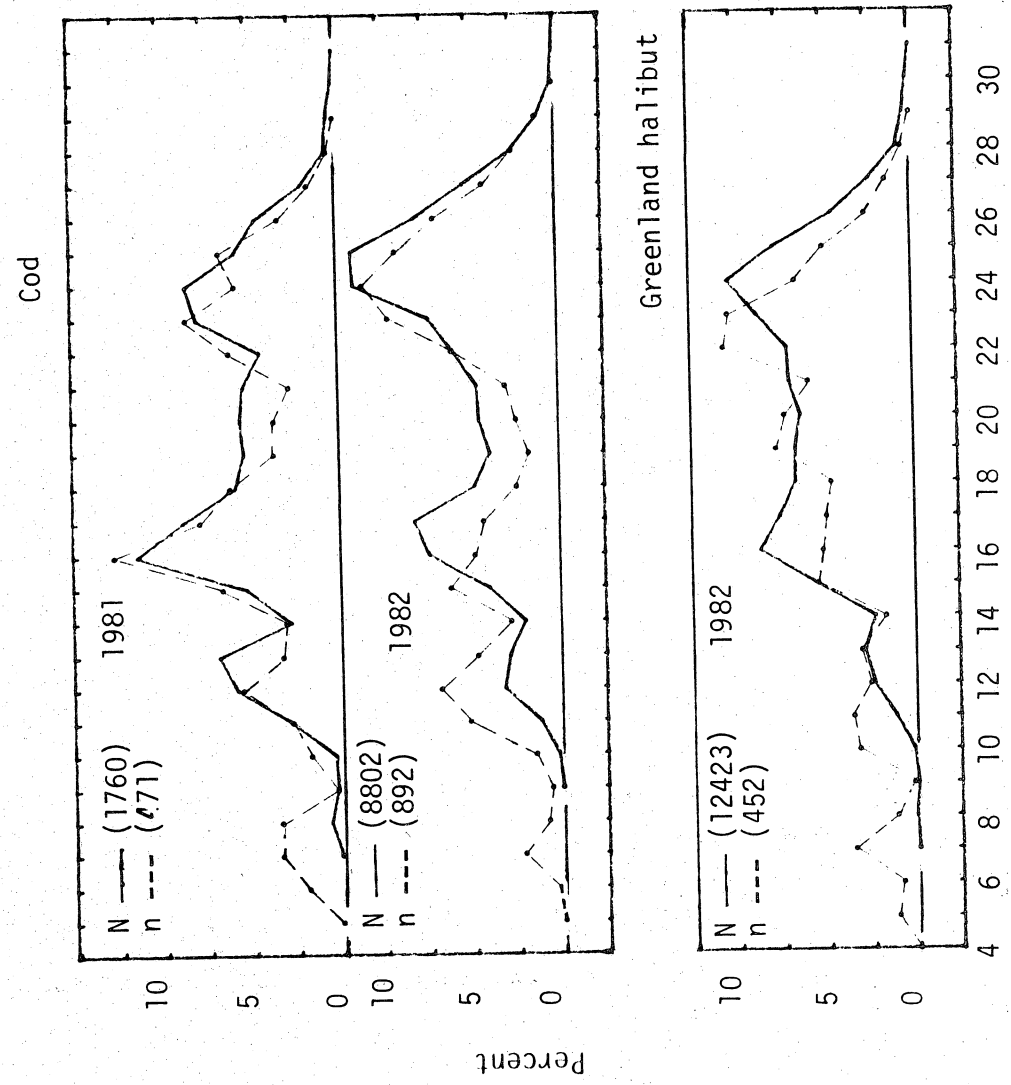

Fig. 8. Length frequencies of shrimp caught by the trawl (N) and recovered from cod (n) and Greenland halibut (n) stomachs in the Cartwright Channel, 1981-1982. Number of shrimp measured is indicated.

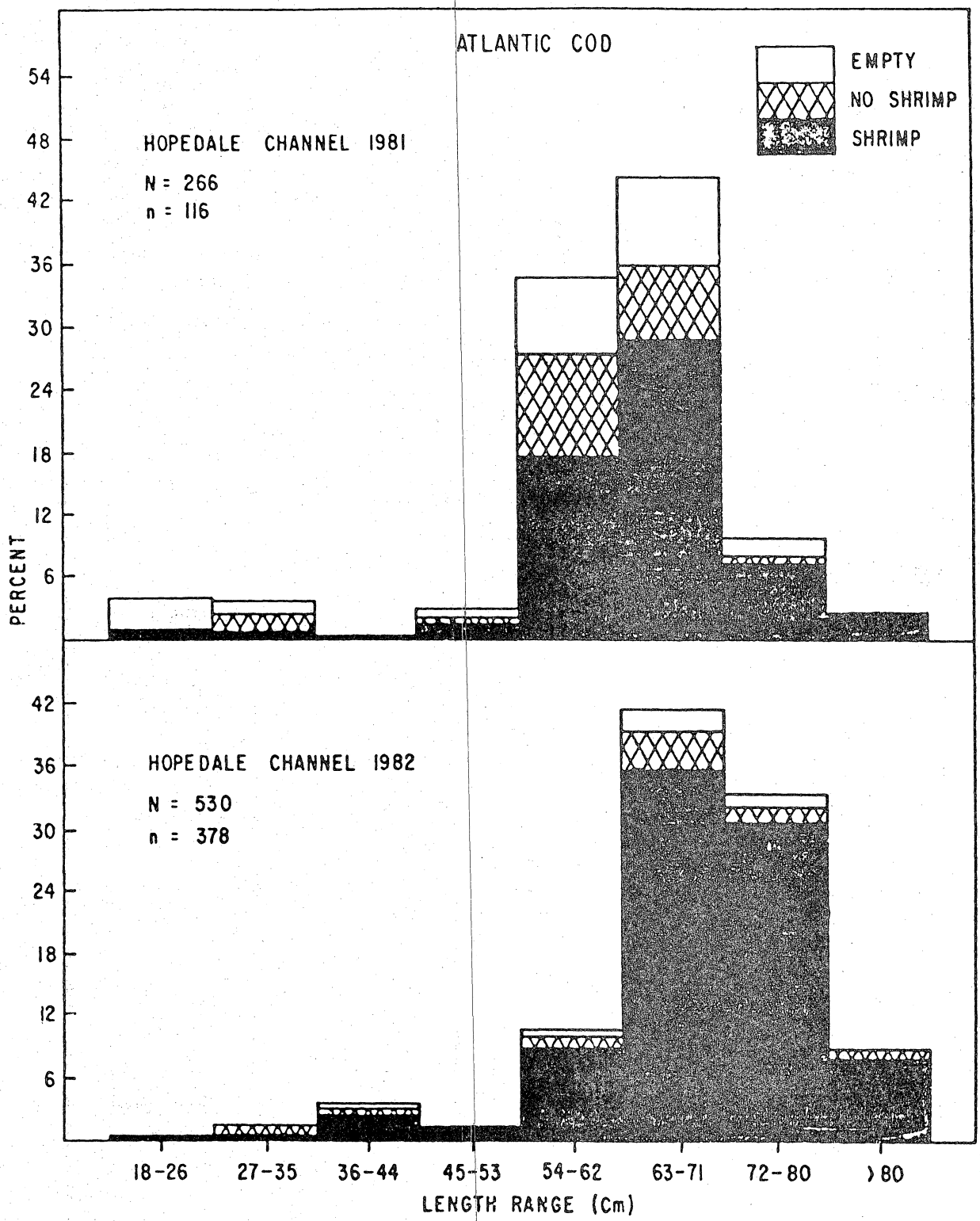

Fig. 9 Length Composition of Atlantic cod from Hopedale Channel, 1981-82, and within each length-group, the proportion of stomachs which were empty, which contained food but no shrimp, and which contained shrimp. N is the number of fish on which the length-frequency is based and n is the number of stomachs examined.

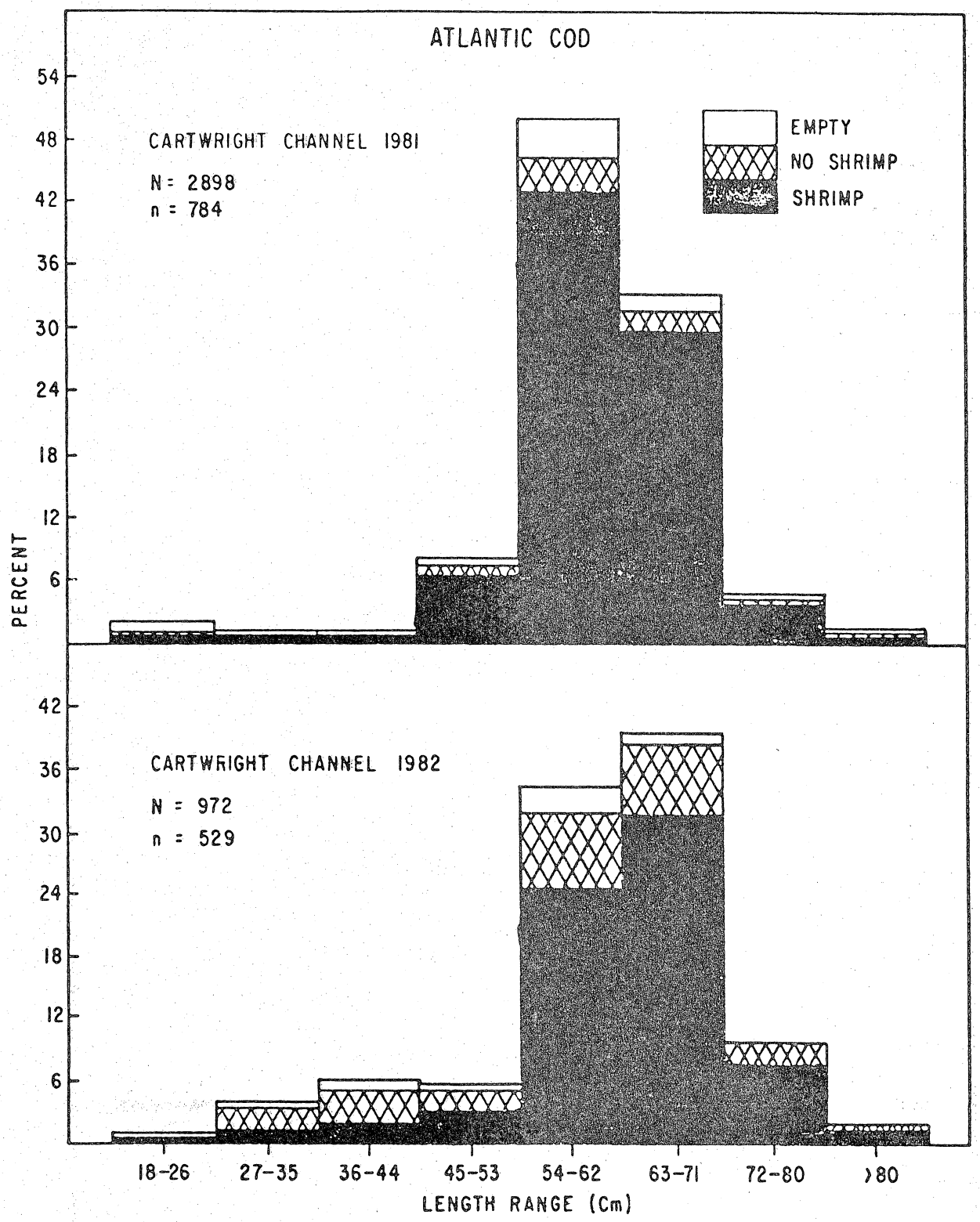

Fig. 10 Length composition of Atlantic cod from Cartwright Channel, 1981-82, and within each length-group, the proportion of stomachs which were empty, which contained food but no shrimp, and which contained shrimp. N is the number of fish on which the length-frequency is based and n is the number of stomachs examined.

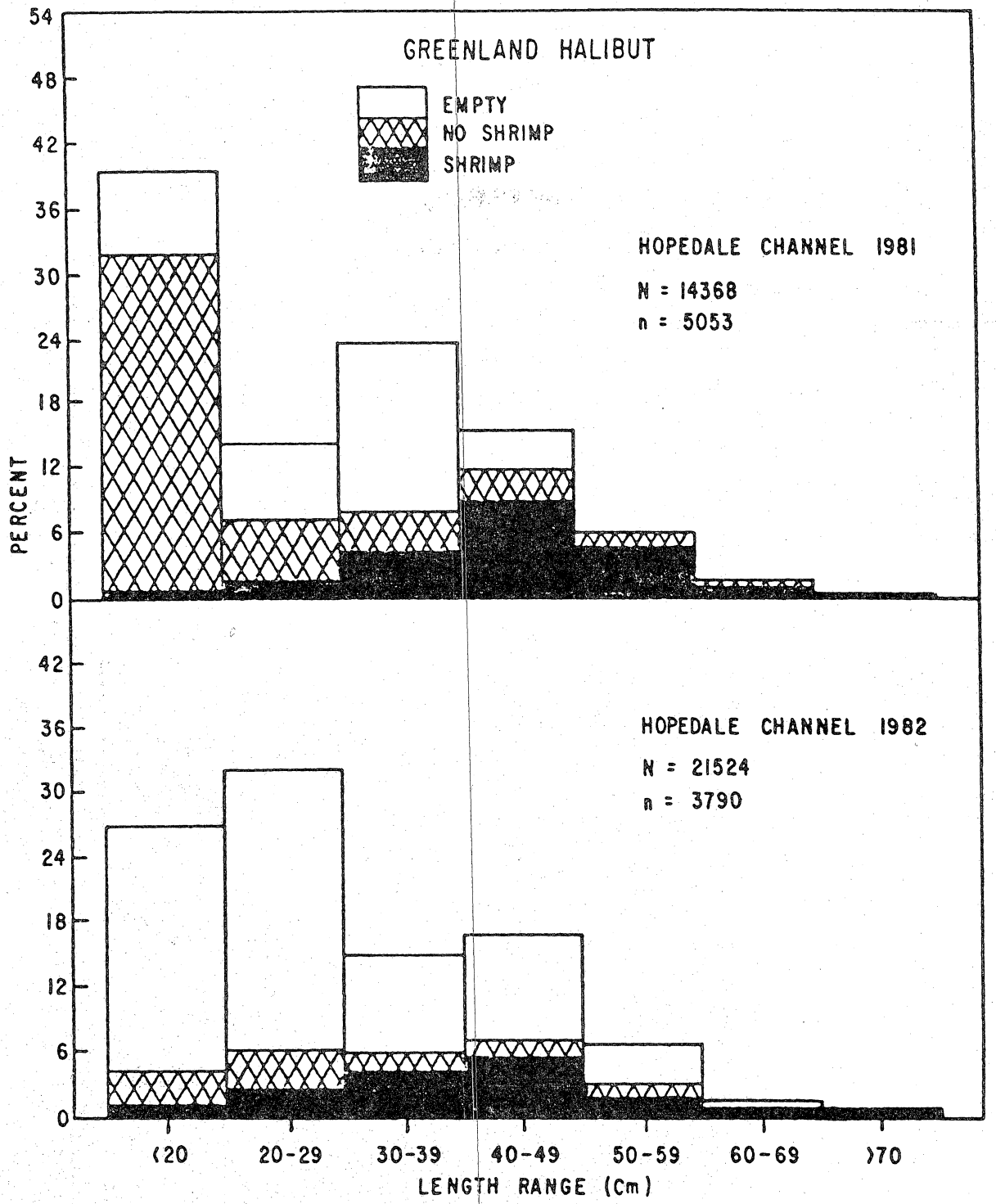

Fig. 11 Length compostion of Greenland Halibut from Hopedale Channel, 1981-82, and within each length-group, the proportion of stomachs which were empty, which contained food but no shrimp, and which contained shrimp. N is the number of fish on which the length-frequency is based and n is the number of stomachs examined.

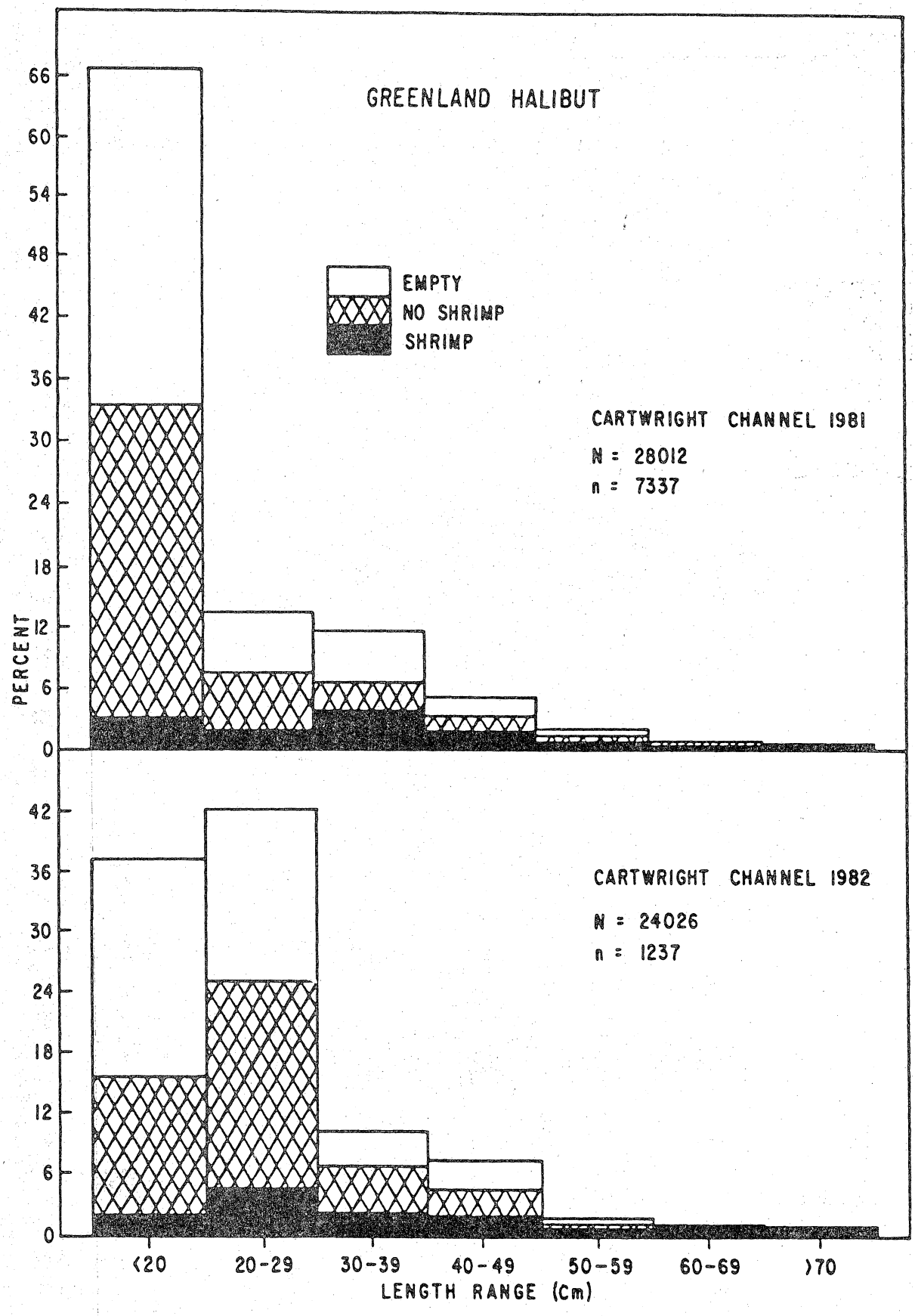

Fig. 12 Length composition of Greenland Halibut from Cartwright Channel, 1981-82, and within each length-group, the proportion of stomachs which were empty, which contianed food but no shrimp, and which contained shrimp. N is the number of fish on which the length-frequency is based and n is the number of stomachs examined.