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Predation by Short-finned Squid (*Illex illecebrosus*) in Newfoundland Inshore Waters

by

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ABSTRACT

Feeding intensity of squid in inshore areas appeared to be low, especially early in the season. Fish and squid were the most important components of the squid diet, with crustaceans being of minor importance. Cannibalism increased as the season progressed, indicating a deterioration of feeding conditions. Fish prey consisted almost exclusively of gadoids on the northeast coast whereas redfish, Sebastes sp., represented the sole fish prey for south coast (Hermitage) samples, where they were of only minor importance. Gadoids were preyed upon most heavily at LaScie, the most northern sampling site. Squid are opportunistic predators, with cannibalism being exhibited by all sizes and no size selectivity evident in their predation on gadoids. Gadoid prey sizes differed remarkably between years, presumably reflecting yearly differences in size composition in inshore nursery areas. Correlation analysis failed to demonstrate an effect of squid predation on year-class strength of cod.

INTRODUCTION

Although the short-finned squid is distributed between central Florida and southern Labrador it has historically been found in greatest abundance during May to November near the northern extreme of its range, on the Scotian Shelf and inshore at Newfoundland. Squid typically appear on the Grand Bank in May or June and usually move to Newfoundland inshore waters during July where they may remain until as late as December. Recently young squid have been captured during February-April in the vicinity of the Gulf Stream (Fedulov and Froerman MS 1980, Hatanaka et al. MS 1982).

Fluctuations in year-to-year abundance of short-finned squid in inshore waters are large and non-cyclic (Hurley 1980, Dawe 1981) as might be expected of a species which is believed to live approximately one year and die after spawning (Hurley and Beck 1979). Inshore abundance may be quite high in some years, such as in 1979 when the inshore catch was 83,000 t. Squid exhibit a tremendous growth rate while inshore, increasing almost three-fold in weight between July and November (Beck et al. MS 1980).

While inshore, squid are active predators, preying in part on fish (Squires 1957, Ennis and Collins 1979). Because of their great abundance in some years and rapid growth it was felt that squid may consume large quantities of young fish and concern has been expressed regarding the possible effect of inshore predation by squid on commercially important fish species (NAFO 1980). Identification of fish prey in squid stomachs is difficult since food is macerated during consumption. In Newfoundland inshore areas fish species most susceptible to squid predation might include cod (Gadus morhua), capelin (Mallotus villosus), and herring (Clupea harengus) since the young of these species have a coastal distribution (Lear et al. MS 1980, Reddin and Carscadden MS 1981, Moores 1980).

This paper examines sources of variation in feeding intensity and diet of short-finned squid from Newfoundland inshore waters. The relative importance of various fish species in the squid diet is described through collection and identification of fish otoliths from squid stomachs. For the dominant fish prey yearly, seasonal and areal variation in occurrence is examined as is size selectivity. Problems in quantifying the impact of squid predation on commercial fish species are considered. The possible effect on gadoids is examined by comparing recruitment of cod with squid abundance at the time when those cod were 0-group and 1-group juveniles.

MATERIALS AND METHODS

Squid samples were collected from the commercial fishery in 1980 from Twillingate and LaScie, on the northeast coast of Newfoundland (Fig. 1). In 1981 samples were obtained from Twillingate, LaScie, Holyrood, and Hermitage. When squid were available, samples were collected approximately weekly and combined for bimonthly periods. Seasonal sampling was incomplete for both years and all areas (Table 1) due to only intermittent availability of squid to the fishery. All samples were captured using mechanical jigging devices, frozen shortly after capture and later thawed prior to examination. Each specimen was initially dissected and examined for basic biological data. Dorsal mantle length was measured to the nearest 0.5 cm and whole weight to the nearest gram. Sex was determined and, for males, maturity stages were assigned according to Mercer (MS 1973). In females, nidamental gland length was measured to the nearest millimeter.

Detailed stomach analysis involved initially estimating the degree of stomach fullness on a scale ranging from 1 (empty) to 5 (full). Stomachs containing very samll quantities of food were recorded as one-quarter full. Stomachs were opened and contents identified to high order taxa (eg. crustacea, pisces). Additional stomachs from most sampling sites and periods were examined only for the presence of fish otoliths. Otoliths were collected and identified to the lowest taxonomic level possible by comparison with reference otoliths. Maximum otolith length was measured to the nearest 0.01 mm using a Wild M4A stereoscope with a Zeiss 2 mm ocular micrometer.

Material available from small cod surveys in eastern Newfoundland during 1959-1964 was used to develop a fish length-otolith length relationship for small Atlantic cod (Gadus morhua). Fish lengths were to the nearest millimeter and corresponding otolith lengths were measured to the nearest 0.05 mm using Vernier calipers. The relationship was best described by the equation: $y = 99.92 \ln X - 27.26$, ($r^2 = 0.81$), where X and y represent maximum otolith length and total cod length, respectively.

To determine the approximate length of gadoid prey it was assumed that gadoid otoliths from squid stomachs were those of Atlantic cod. For that purpose gadoid otolith lengths were applied to the fish length-otolith length relationship. A pair of otoliths of identical size was considered to represent a single fish.

RESULTS

For all years and localities the proportion of empty stomachs ranged 12.0% to 54.0% but was usually in excess of 30% (Table 1). Proportion empty fluctuated considerably but was generally highest in early season samples. Food material, when present, was in small amounts. The proportion of one-quarter full stomachs ranged 35.6% to 69.4% but was usually in excess of 50% and tended to be highest in the later samples. Categories of greater stomach fullness (half full, three-quarters full, and full) were much lower, ranging 0% to 13.27% but each category usually represented less than 5% of the sample. This was especially true for full stomachs. Yearly and areal comparison of stomach fullness are complicated by seasonal differences in collection of samples. However, feeding intensity was highest at LaScie as seen by the generally lower proportion of empty stomachs and relatively high proportion of stomachs which were at least half full in both years.

The relative importance of various broad prey categories in the squid diet is shown in Fig. 2. A large proportion of stomachs contained only well digested food material which could not be identified. Crustaceans represented a minor component of the diet and were present in only one sample from LaScie (September 1-15, 1980) and in none from Twillingate. They occurred more regularly in stomachs from Holyrood where, during 1981, they were present in three samples where their frequency of occurrence ranged from 0.5% for the earliest sample to 5.3% during August 16-31.

Fish and squid represented the major prey types (Fig. 2). Fish was least important at Holyrood where during 1981 it was found in 1.2% to 28.0% of samples. It was most important at LaScie where feeding intensity appeared to be highest. During 1981 fish was found in 30.8% and 51.8% of the two LaScie samples. Seasonal trends were not evident. The occurrence of squid did not vary markedly among localities. It ranged, at Twillingate, from 2.2% during September 1-15, 1980 to 41.3% during August 16-31, 1981. Squid increased in importance later in the season as the proportion of empty stomachs declined.

Change in the prey spectrum with squid size was not very pronounced and was only evident in largest samples, noteably for Holyrood, 1981 (Fig. 3). With one exception crustaceans were preyed upon only by squid of less than 22 cm. The importance of squid relative to fish increased with predator length at Holyrood, mostly due to a decline in predation on fish by larger squid. This was also apparent for August 1-15 at Twillingate, another large sample. Lower numbers of specimens, especially for extreme predator sizes, probably masked such a relationship in other samples. The seasonal increase in cannibalism at Holyrood was not related to predator growth (Fig. 3). Even the smallest squid were capable of cannibalism and the seasonal increase was approximately proportional for all squid sizes.

Otoliths found in squid stomachs from northeast coast localities were almost exclusively gadoid (Table 2). Other species represented were herring (*Clupea harengeus*), redfish (*Sebastes* sp.) and capelin (*Mallotus villosus*). Eighteen capelin otoliths from Holyrood 1981 samples represented 10.3% of otoliths found in those samples. No gadoid otoliths were found in 1981 samples from Hermitage on the south coast. Only 23 redfish otoliths were present and they were of minor importance having been found in only 0.6% of the samples. Gadoid otoliths were most prominent from LaScie, the most northern locality, especially during 1981. For those samples otoliths occurred in 42.7% of samples and averaged 5.2 otoliths per stomach. Holyrood and Twillingate samples were similar, with otoliths occurring in 3.1 to 3.8% of stomachs and averaging between 2.68 and 4.25 otoliths per stomach. Gadoid prey sizes were remarkably similar among sampling localities but different between years (Fig. 4). For 1980, gadoid lengths ranged 43.07 mm to 117.66 mm. Modal length, not well defined, was between 80 and 95 mm. For 1981, lengths were much smaller, ranging 36.91 mm to 116.29 mm. The modal length interval was 40-45 mm for all three localities. There was no apparent relationship between the size of squid and gadoid prey (Fig. 5). This was most evident for LaScie samples where otoliths were most common. Gadoids consumed by largest and smallest squid were similar in size.

Because the number of squid coming into Newfoundland waters fluctuates dramatically and the major fish prey of squid in inshore waters appears to be cod, it was postulated that squid might impose on juvenile cod a mortality rate sufficiently high and variable to affect cod year-class strength. The hypothesis was that predation by squid will result in a negative correlation between squid abundance and year-class strength in those cod stocks which overlap spatially with squid. The null hypothesis was that the correlation is zero or positive.

There are no quantitative estimates of squid abundance in Newfoundland waters, but the catch is known (Table 3) and a subjective index of annual abundance (scale of 1-5) has been assigned (Table 3) based on landings and the reports and opinions of people associated with the fishery. Catches for 1965-67 appear to be higher than indicated by the trend between catch and the abundance index in earlier years (Table 3, Fig. 6). This might be related to increased catching efficiency attending introduction of the Japanese drum jigger to the Newfoundland inshore fishery in about 1965 (Hurley 1980). Also the very high catches since 1976 presumably reflect a marked improvement in market opportunities and thus increased effort rather than a dramatic increase in inshore abundance (Hurley 1980).

During the period June to late autumn when the squid migrate onto the continental shelf off Newfoundland they might overlap at least in part the geographic distribution of juveniles belonging to the cod stocks of northeastern and eastern Newfoundland (Div. 2J+3KL), the southern Grand Bank (Div. 3NO), and southern Newfoundland and St. Pierre Bank (Subdiv. 3Ps). Changes in year-class strength as determined by cohort analysis are similar in these stocks (Table 3, Fig. 7). The following Pearson correlation coefficients were significant ($P < 0.01$).

	2J+3KL	3Ps
3NO	0.89	0.74
3Ps	0.69	

Squid might prey on either 0-group or 1-group juvenile cod, so year-class strength in each cod stock was compared with squid abundance during the year when the cod were hatched (A_t), during the year after hatching (A_{t+1}), and during the two years combined ($A_t + A_{t+1}$). Associations between year-class strength in each cod stock and each of the three expressions of squid catch in the years 1958-75 were not significantly negative (Pearson correlation coefficient, P < 0.05). Similarly, associations between year-class strength and the squid abundance index in the years 1958-76 were not significantly negative (Kendall's tau-b, P > 0.05).

DISCUSSION

The high proportion of stomachs which were empty or contained only small quantities of food suggests that feeding intensity is low in Newfoundland inshore areas. Ennis and Collins (1979) similarly found that in 1967 very few stomachs were more than one-quarter full. However, they found a much higher ratio of empty to quarter full stomachs than described here. That may be an artifact since stomach examination in 1967, as part of routine biological sampling, was only cursory. In both studies stomachs containing even small fragments of food were designated quarter full so that squid with quarter full stomachs were not recently fed, and in most cases gastric evacuation was virtually complete. Squires (1957) found for the size range of squid described here that approximately 60% of stomachs were empty.

The paucity of food in inshore squid stomachs is difficult to reconcile with the rapid growth rate of this species, estimated at between 1.1 and 2.5 cm/month (Squires 1967, Lange and Sissenwine MS 1981). The apparently low feeding intensity may be related in part to the use of mechanical jigging devices. Effectiveness of such devices, used almost exclusively at Newfoundland, is likely related to feeding behaviour of squid (Williamson 1965). Thus, recently fed squid may rarely attack lures. Ennis and Collins (1979) found that in late autumn an offshore sample, collected using bottom trawl, contained a much lower proportion of empty stomachs than did an inshore jigged sample. Further, on the Scotian Shelf during July-November 1978 and 1979 the occurrence of at least half full stomachs fluctuated between approximately 20% and 85% for squid captured using bottom trawl (Amaratunga MS 1980). For large bottom-trawled squid (19-25 cm) Vinogradov and Noskov (1979) found only 26% of stomachs were empty for pooled May-October samples off Nova Scotia and New England. It appears that digestive capacity may regulate feeding activity. O'Dor <u>et al</u>. (1980) found that if squid take very large meals they may not feed the following day. In the laboratory complete digestion generally required 16 hours but ranged approximately 8-10 hours for small meals to 36 hours for large meals (Wallace <u>et al</u>. 1981).

The gross prey spectrum consisted of fish, squid, and crustaceans, as previously found for inshore Newfoundland (Mercer MS 1965, Ennis and Collins 1979). These were also the major prey types found offshore on the Grand Bank, the Scotian Shelf, and off New England (Ennis and Collins 1979, Mercer and Paulmier MS 1974, Vinogradov and Noskov 1979, Amaratunga MS 1980). A similar prey spectrum has also been reported for <u>Loligo pealei</u> (Vovk 1972, Vovk and Khvichiya MS 1980, Macy 1982) and <u>Loligo opalescens</u> (Fields 1965, Karpov and Cailliet 1978). Insignificant components of the diet of <u>Illex illecebrosus</u> may sometimes include chaetognaths, pteropods, polychaetes, gastropods and algae (Mercer and Paulmier MS 1974, Amaratunga MS 1980, Squires 1957, Mercer MS 1965). Crustaceans are of minor importance to large inshore squid, as also found by Ennis and Collins (1979). Short-finned squid change from a largely crustacean diet during spring on the Grand Bank to one of mostly fish and squid during summer-autumn in Newfoundland inshore areas (Squires 1957, Ennis and Collins 1979). On the Scotian Shelf such a shift in prey preference was related to increse in squid size. Such a size-related shift from a crustacean diet to one of mixed fish and squid has also been described for <u>Loligo pealei</u> (Vovk 1972, Macy 1982) and <u>Loligo opalescens</u> (Fields 1965). For those species the change in diet occurred at much smaller sizes than are represented in this study.

As the season progressed the incidence of cannibalism increased as empty stomachs declined. O'Dor <u>et al</u>. (1980) noted that hierarchial feeding such as occurs in this species results in considerable intra-school size disparity. Late season size disparity could promote intra-school cannibalism. However, it was found here that cannibalism was only slightly more prevalent in large squid. It was common in even the smallest squid and a seasonal increase was approximately proportional for all squid sizes. Thus it appears that increased cannibalism is related to limitation of other prey later in the season. This is supported by Holyrood 1981 samples which showed an increase in predation on crustaceans later in the season as fish, presumably the preferred prey, declined. Based on laboratory experiments O'Dor <u>et al</u>. (1980) found that in the wild squid do not feed at their ad libitum rate later in the season and do not achieve their full growth potential during the last half of the year. Increase in cannibalism with length on the Scotian Shelf (Amaratunga MS 1980) may be an artifact related to the fact that data were pooled over the season. Thus, the increase in cannibalism may have been more closely related to season, since most large squid were likely collected later in the season.

Gadoids represented by far the most important fish prey on the northeast coast, with other species being of minor importance. Redfish (Sebastes sp.) represented the only fish prey in south coast samples, where they were of minor importance. Gadoids (cod and haddock) have been previously reported in the diet of squid inshore and on the Grand Bank (Squires 1957). However in that study capelin (Mallotus villosus) was the most important fish prey of large inshore squid, whereas small squid on the Grand Bank preyed more heavily on redfish. Other fish prey in the Newfoundland area has included mailed sculpin (Triglops pingeli) and flounders (Squires 1957). Gadoids are also represented in the squid diet on the Scotian Shelf, but their relative importance is unknown (Amaratunga MS 1980). Other fish prey on the Scotian Shelf included Myctophum punctatum, Ceratoscopelus maderensis, Urophycis chesteri, Merluccius bilinearis and Macrouridae. The greater importance of gadoids as prey, especially at the most northern locality, probably reflects their greater availability, as squid are believed to be opportunistic predators (Ennis and Collins 1979). However, little is known of gadoid distribution in inshore nursery areas. Short-finned squid in the laboratory feed readily on a wide variety of fish species, including capelin (Mallotus villosus), herring (Clupea harengus), mackerel (Scomber scombrus), smelt (Osmerus mordax), salmon smolts (Salmo salar), and Fundulus sp. (O'Dor et al. 1980).

Since there was no correlation between predator size and prey size when squid fed on gadoids, it is likely that the gadoid prey size spectrum is representative of those sizes available in inshore areas. This is supported by the virtual absence of gadoid prey larger than 65 mm in 1981. In the laboratory it was found that short-finned squid were not size selective, preying upon fish (herring) as large as the predator mantle length (O'Dor et al. 1980). It is unknown however if wild squid would attack such large fish. Largest gadoid prey in this study (ca. 120 mm) were generally half as large as the squid mantle length. Macy (1982) reported that for most fish species Loligo pealei did not prey upon individuals larger than 30% of the squid's mantle length although they have been observed to prey upon menhaden of nearly one-half their own length.

There was a striking difference in gadoid prey size between the two years, prey being much smaller in 1981. This is difficult to explain since otoliths could not be identified to species and it is possible that different age-groups of either Atlantic cod or Arctic cod (Boreogadus saida) were available in different years. If all otoliths were from Atlantic cod, then several interpretations are possible. For example, all specimens may be young-of-the-year and the difference in size between cod in the two years may reflect annual variability in growth rates, annual variability in spawning time, or annual differences in availability of the offspring from different spawning components. It is also possible that individuals in the 40-45 mm mode in 1981 are young-of-the year and that in 1980 individuals in the 80-95 mm mode are slow-growing 1-year-olds and young-of-the-year are weakly represented.

Quantification of the effect of predation by squid on gadoids is presently impossible due to a variety of problems. Most noteably these include uncertainty as to the annual squid biomass and the species composition of gadoid prey. Also, otoliths are selectively retained in stomachs after gastric evacuation so that the high number of otoliths in some stomachs are the remains of several meals. Further, injestion of gadoids may not always be reflected by the presence of otoliths in stomachs. O'Dor (pers. comm.) found that starved squid consume entire fish whereas those fed regularly generally eat only the fleshy portions and reject heads and skeletal material.

Although the food consumption by squid in a year of high squid abundance must be very large and many juvenile fish may be eaten, there is no evidence that predation by squid on juvenile cod is the major factor influencing cod year-class strength. It is possible that an effect due to squid predation might become more apparent when any effects due to climatic variability and variation in size of the spawning stock can be taken into account. A more direct assessment of the impact of squid predation requires comparison between the abundance of squid and mortality rates in juvenile cod. These mortality rates would have to come from independent estimates of abundance of cod at the early post-larval stage and at ages 1 and 2. One would expect that cod year-classes which are relatively weak after the larval stage may experience higher mortality rates than those which are relatively strong.

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Table 1. Percentage of stomachs of various fullness categories for Newfoundland inshore squid, broken down by year, sampling locality, and bimonthly period.

Location	Year	Period ending	Sample size	Stomach fullness (%) Empty	1/4	1/2	3/4	Full
Holyrood	1981	July 15	211	54.0	41.7	4.29		-
		July 31	391	37.3	57.3	2.81	1.53	1.02
		Aug. 15	399	31.1	65.1	3.01	0.5	0.25
		Aug. 31	564	35.1	62.6	1.24	1.06	-
LaScie	1981	Sept. 15	226	12.0	69.4	13.27	2.65	2.65
		Oct. 15	104	26.9	67.3	4.81	0.96	-
LaScie	1980	Aug. 31	154	44.2	51.9	3.3	0.65	-
		Sept. 15	152	23.0	57.3	12.5	1.97	5.26
		Sept. 30	175	21.8	66.2	9.7	-	2.29
Twillingate	1981	Aug. 16	289	49.5	48.8	1.73	-	-
		Aug. 31	155	31.6	67.1	1.29	-	-
Twillingate	1980	Aug. 31	188	52.1	35.6	4.8	5.9	1.6
		Sept. 15	90	51.1	48.9	-	-	-
		Oct. 15	156	37.4	56.2	5.1	-	1.3

Table 2. Breakdown by lowest taxonomic level possible of fish otoliths found in squid stomachs at inshore Newfoundland localities during 1980 and 1981. Values in parentheses represent percentages by taxon of otoliths found.

Location	Year	Sample size	Stomachs with otoliths N	%	# otoliths per stomach	# of otoliths per taxon Gadoid	Capelin	Herring	Redfish	Unknown
Holyrood	1981	2065	65	3.1	2.68	153 (87.9%)	18 (10.3%)	-	-	3 (1.7%)
LaScie	1981	480	205	42.7	5.20	1050 (98.4%)	2 (0.2%)	1 (o.09%)	5 (0.5%)	10 (0.9%)
LaScie	1980	681	75	11.0	4.22	317 (100%)	-	-	-	-
Twillingate	1981	594	19	3.2	2.74	51 (98.1%)	1 (1.9%)	-	-	-
Twillingate	1980	734	28	3.8	4.25	118 (99.2%)	-	-	-	- (0.8%)
Hermitage	1981	1394	9	0.65	2.44	-	-	-	23 (100%)	-

Table 3. Inshore Newfoundland squid catch (t), index of inshore squid abundance and yearclass strength of Div. 2J+3KL, 3NO, and 3Ps cod stocks during the period 1958-80.

Year	Squid catch	Squid abundance	Cod year-class strength		
			2J+3KL[a]	3NO[b]	3Ps[c]
1958	718	2	542	820	510
1959	2853	3	578	1077	487
1960	5067	4	506	781	430
1961	8971	5	685	1117	708
1962	482	2	817	1623	810
1963	2119	3	925	2101	844
1964	10408	5	670	1832	985
1965	7832	4	578	1006	702
1966	5017	3	536	1279	544
1967	6917	4	589	804	355
1968	13	1	476	848	602
1969	21	1	208	625	393
1970	111	1	125	347	309
1971	1607	2	125	361	422
1972	26	1	247	236	568
1973	600	2	397	306	587
1974	17	1	359	533	766
1975	3751	4	389	374	382
1976	11257	4	192	155	208
1977	29678	5			
1978	34941	4			
1979	83118	5			
1980	32466	4			

[a] $N \times 10^{-6}$ at age-group 4 (Gavaris and Bishop, MS 1983)

[b] $N \times 10^{-5}$ at age-group 3 (Bishop and Gavaris, MS 1983b)

[c] $N \times 10^{-5}$ at age-group 3 (Bishop and Gavaris, MS 1983a)

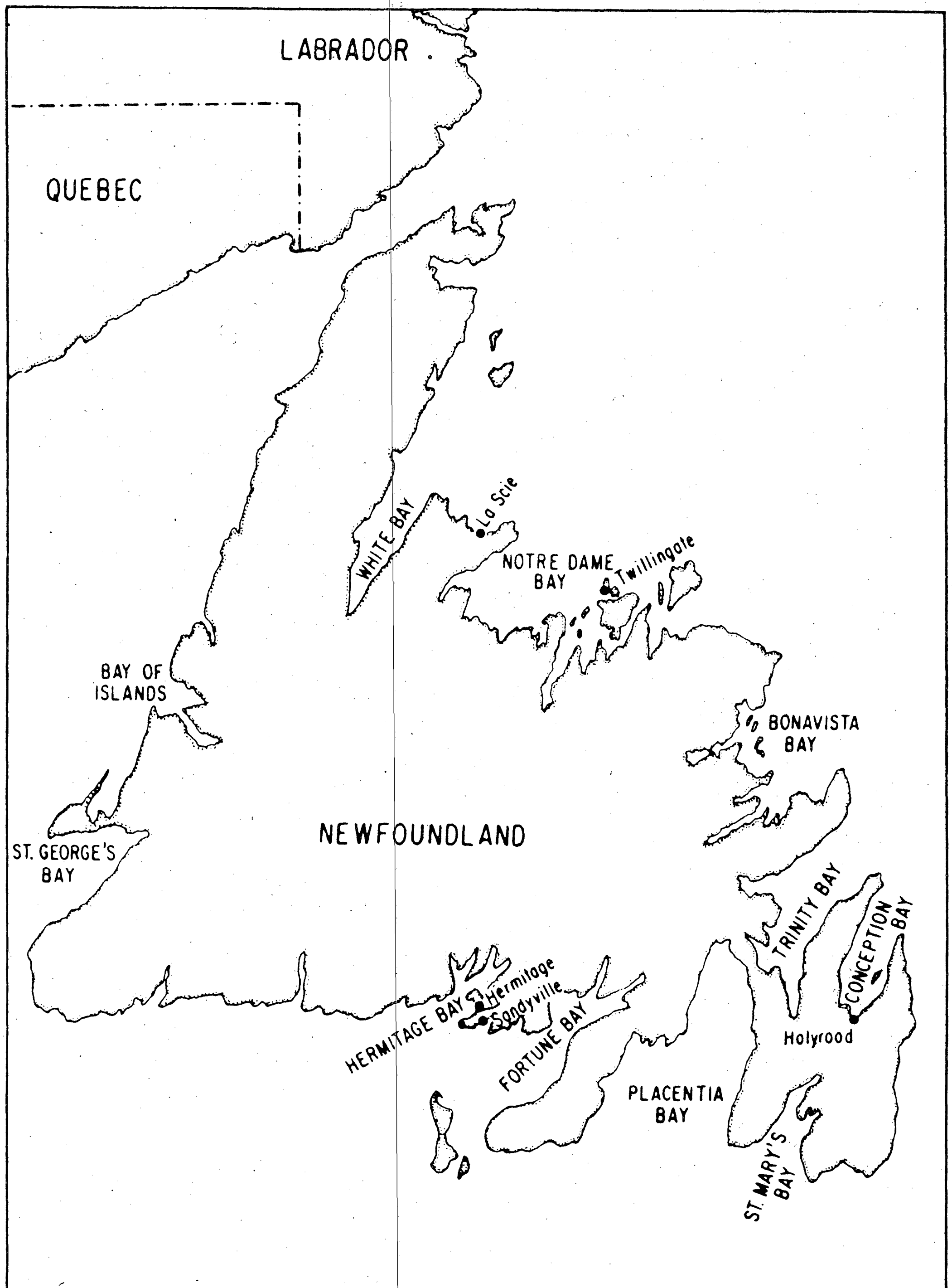

Fig. 1. Sampling locations mentioned in the text.

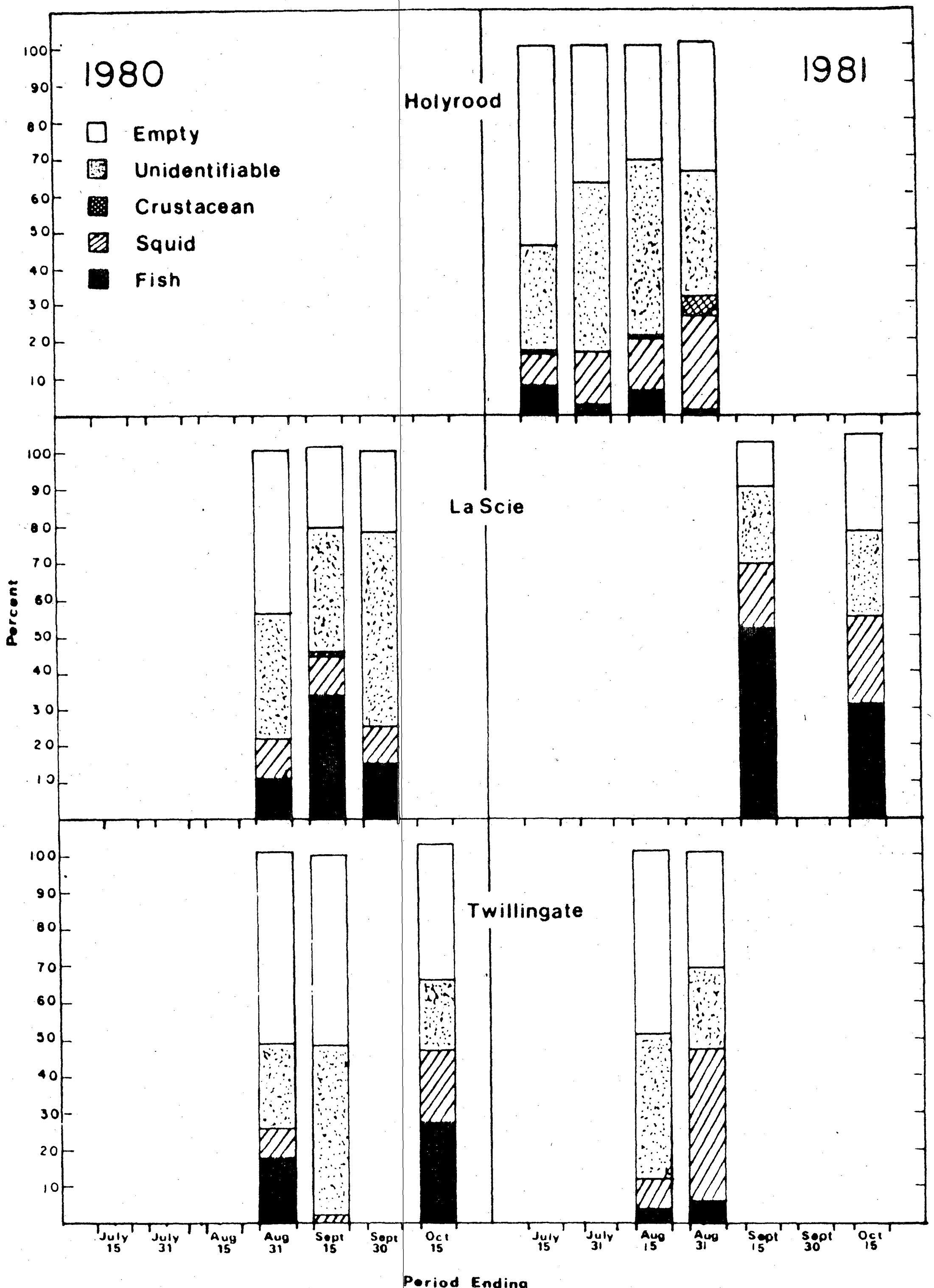

Fig. 2. Percentage of squid stomachs which were empty or contained various prey categories for bimonthly periods at Newfoundland northeast coast localities in 1980 and 1981. Totals sometimes exceed 100% due to mixed diets.

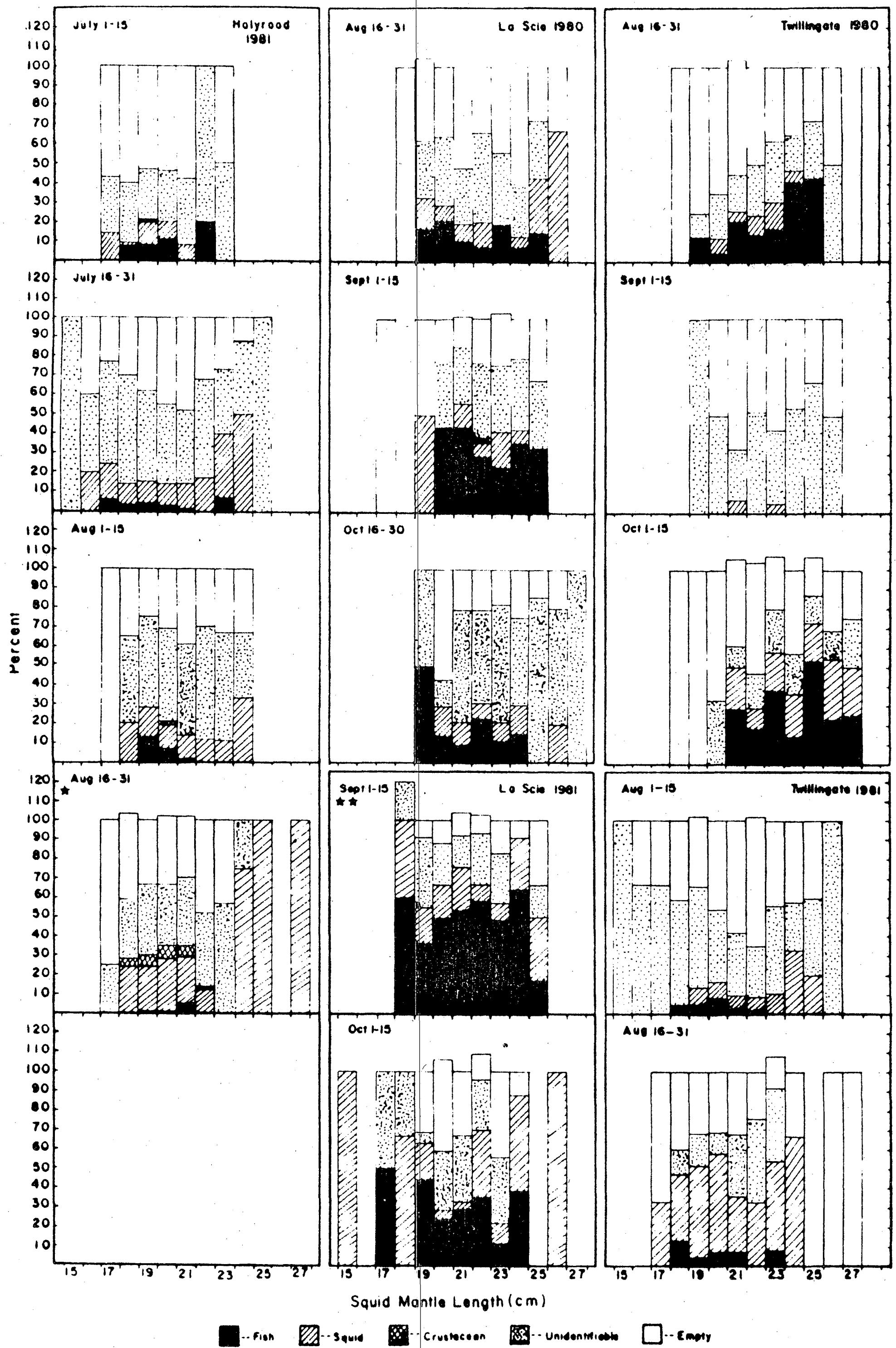

Fig. 3. Relationship between size of squid and gross prey composition for bimonthly periods at Newfoundland northeast coast localities in 1980 and 1981. Totals sometimes exceed 100% due to mixed diets.

* not represented is one 39 cm squid with squid remains only in its stomach

** not represented is one 31 cm squid with squid remains only in its stomach

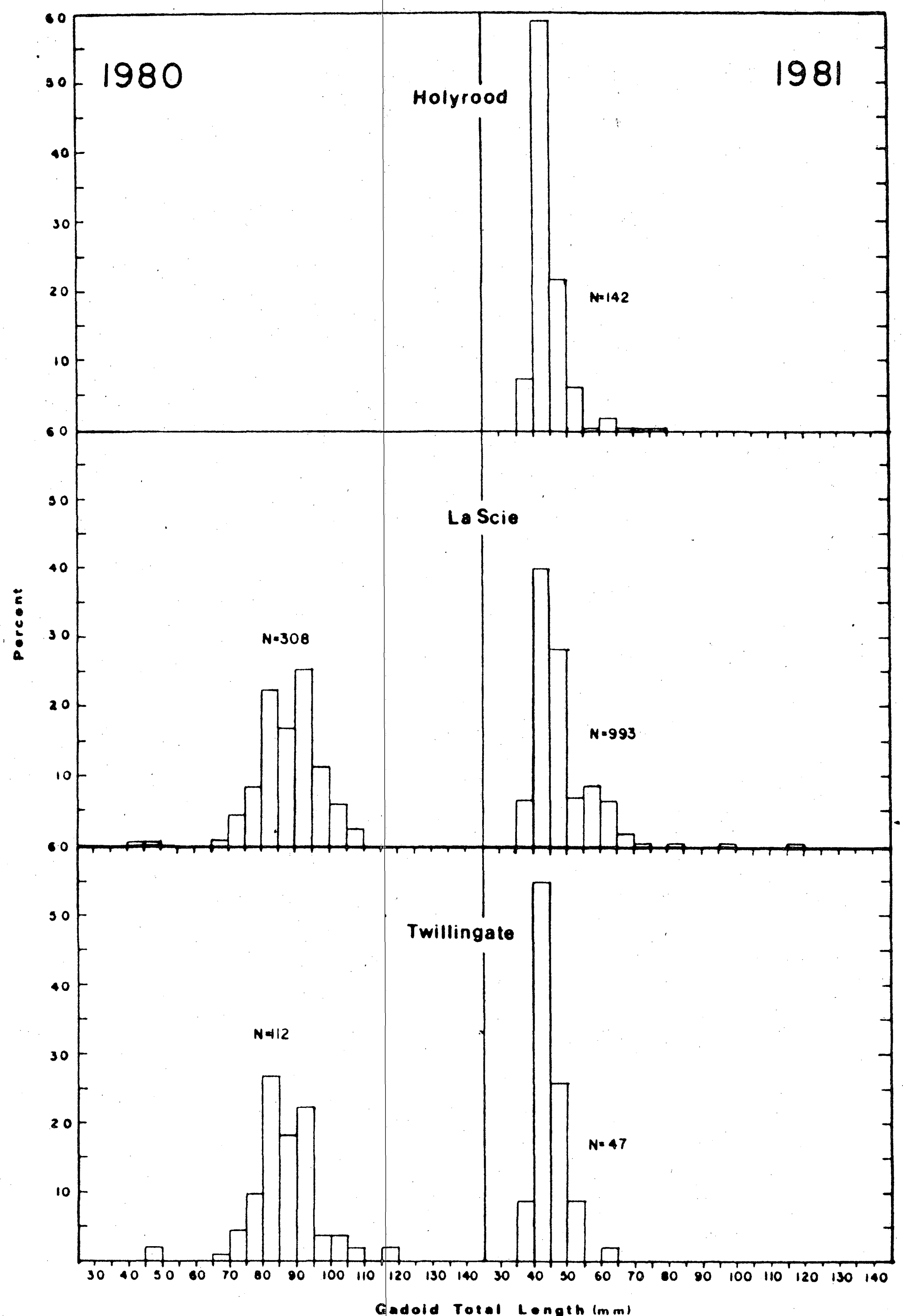

Fig. 4. Length composition of gadoid prey consumed by squid at Newfoundland northeast coast localities in 1980 and 1981.

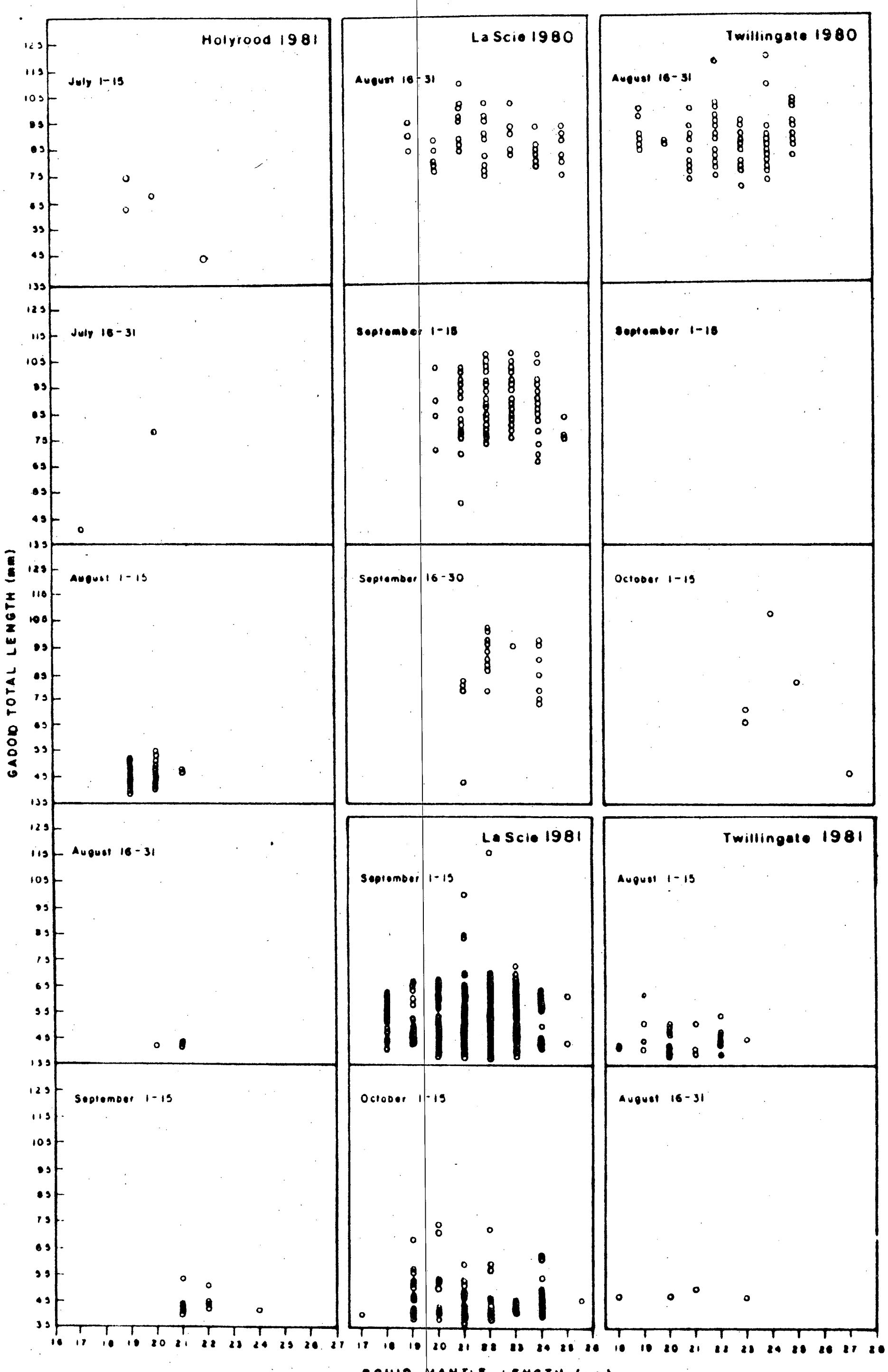

Fig. 5. Relationship between length of squid and length of gadoid prey for bimonthly periods at Newfoundland northeast coast localities in 1980 and 1981.

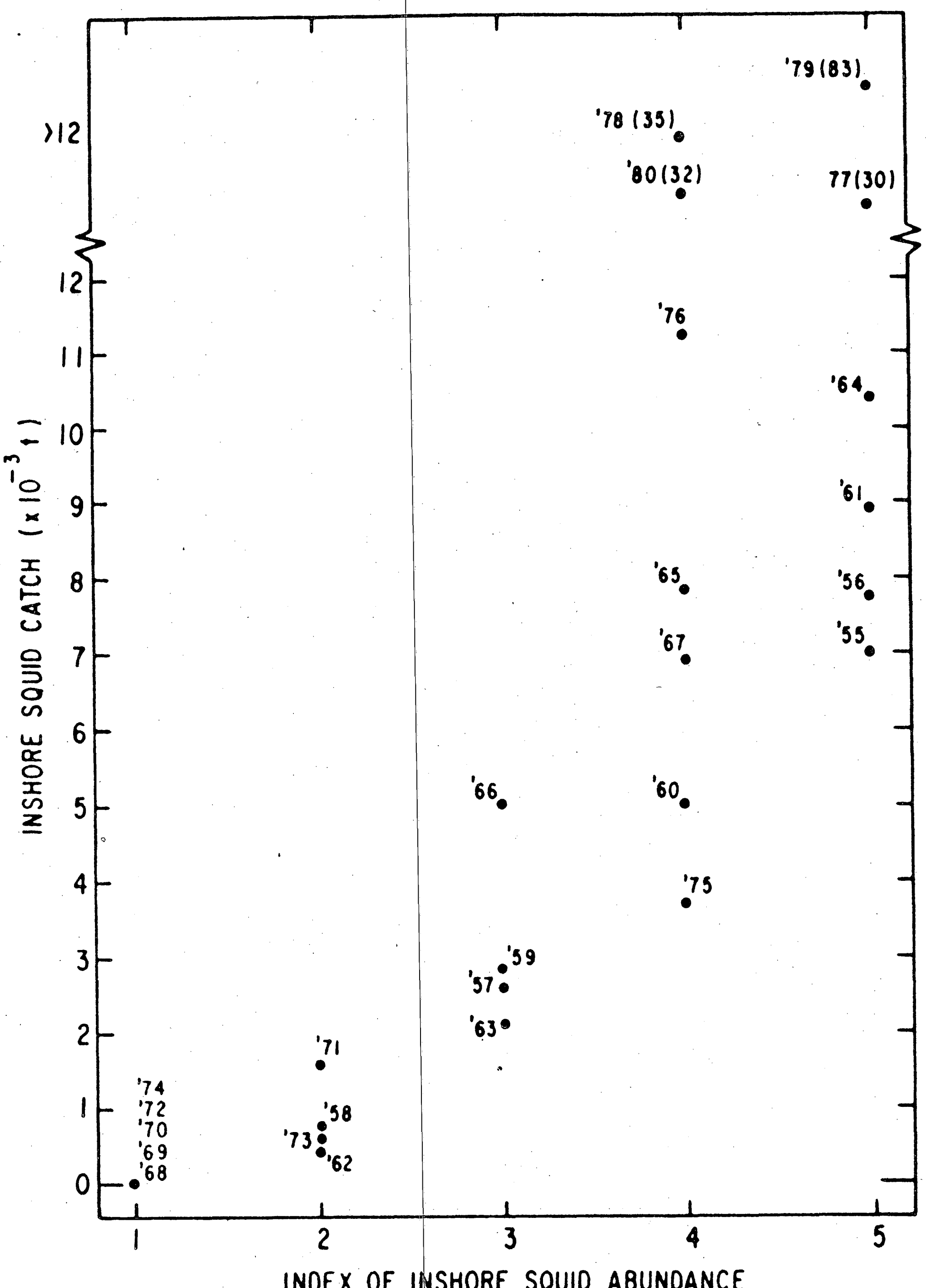

Fig. 6. Relationship between annual inshore squid catch and index of inshore squid abundance 1958-80 (catches for 1977-80 in brackets).

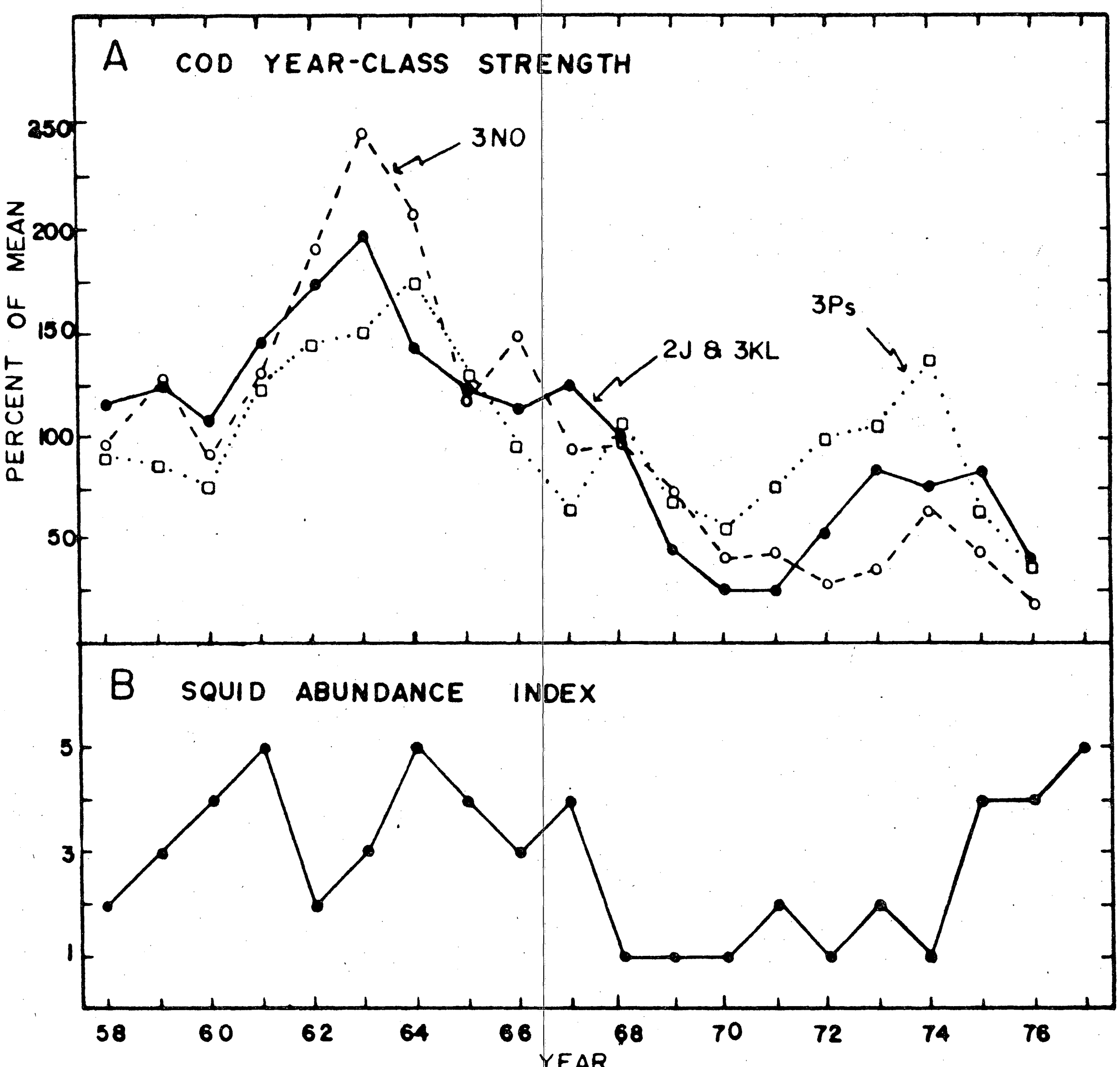

Fig. 7. (A) Yearclass strength in the 2J + 3KL, 3NO, and 3Ps cod stocks, expressed as a percentage of the mean in each stock. (B) Index of squid abundance.