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Inferences from Juvenile Redfish Found in Cod Stomachs from Flemish Cap

by

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INTRODUCTION

Programs of ecological observations are more valuable when they include observations of rates (of production, consumption, etc.) as well as standing stocks (see Platt et al., 1981). By collecting and analyzing cod stomachs, the Flemish Cap experiment gives us important information about one consumption rate. Stomach contents data, together with data on gastric evacuation times that can be collected separately in laboratory experiments (Garman & Lilly, in prep.), give information about the rate of consumption of prey items by a cod. Flemish Cap has a simple ecosystem, and consumption by cod is probably the dominant source of mortality for some prey items. For such items, a knowledge of cod stomach contents and cod populations enables us to infer the total rate at which the item is being removed.

Juvenile redfish (ages 1 to 4) are an example of animals which are probably eaten primarily by cod. This paper takes a first quick look at what we can infer about redfish population dynamics from this fact. It is deliberately naive about many things. It takes the consumption numbers at face value, without any consideration of the structure of their errors. It ignores spatial variation in the abundance of predator and prey. The main purpose is to demonstrate that there is something useful here, which may be worth the trouble of improving given more time.

If we believe that predation by cod is the only source of juvenile redfish mortality, and we know the numbers eaten by cod, then we can run the process backwards, considering the cod spitting out redfish and reconstructing the population with a sequential population analysis (SPA). As boundary conditions we need the numbers of redfish observed at the oldest age (age 5; these are all zero for the years we work with) and the latest year (1984; there are reasons to believe that the trawl survey underestimated populations in this year, but in fact the SPA is not greatly sensitive to an boundary conditions - the mortality rates are very high).

MATERIALS AND METHODS

Cod and redfish catches

Cod and redfish were captured during stratified-random bottom-trawl surveys (Doubleday, 1981) of Flemish Cap by the chartered research stern trawl GADUS ATLANTICA during January-February of 1978-85. An Engel high-rise otter trawl, with 29 mm mesh liner in the codend, was towed at 3.5 knots (108 m/min) for 30 min at each fishing station. Cod and redfish were measured as fork length to the nearest centimetre and numbers were recorded in 3 cm (cod) or 1 cm (redfish) groupings. The numbers of cod and redfish per length group on the Flemish Cap at the time of each survey was estimated by areal expansion of the stratified arithmetic mean number per length group per tow (Smith and Somerton, 1981), using strata defined in Doubleday (1981). Numbers of cod per 3 cm group were combined into 9 cm groups.

Lilly (MS 1986) estimated the number of juvenile redfish at age on Flemish Cap in each year by fitting mixtures of normal distributions to the numbers at length (Macdonald and Pitcher, 1979).

Cod stomach analyses

The design for collecting stomachs from cod catches during January-February surveys

(Table 1) varied during the period 1978-85. In 1978 the cod chosen for stomach examination were selected haphazardly, but with an effort to sample a wide size range of fish throughout the survey area. In 1979 the same method was used but the number of sets sampled and number of stomachs collected were small. In 1980 and 1981, cod were selected on a stratified-random basis (three cod per 10 cm length group) from those fish in each catch not chosen for other analyses (e.g. weighing of body parts). In 1982 and subsequent years, a full stratified sample was taken from each catch. In 1984 and 1985, the sampling frequency was three per 9 cm length group.

Additional stomachs were collected from cod caught by bottom-trawl during six ichthyoplankton surveys from March to May in 1979, 1980, and 1981 (Table 1). Only a few (≤ 10) sets were made during each survey and no specific design was used in the collection of stomachs. The number collected varied from 1 to 60 per set.

Most cod stomachs were excised at sea, individually tagged, and fixed and preserved in 10% formalin: sea water prior to examination on shore. Some cod were frozen whole at sea and thawed on shore prior to removal and immediate examination of the stomachs. Examination of the 1985 collection is not complete.

Examination involved separation of food items into taxonomic categories. Fish were identified to species. Items in each taxon were placed briefly on absorbent paper to remove excess liquid, and then weighed to the nearest 0.1 g. The number in each taxon of fish was recorded. Whenever digestive condition permitted, fish were measured to the nearest mm total length. In many instances the total length of redfish was estimated from standard length, as described by Lilly and Gavaris (1982). In addition, the approximate lengths of highly digested specimens were estimated from regressions of total length on otolith length. These estimates of length were used only as an aid in assigning ages.

Small redfish were assigned to age groups whenever lengths could be estimated. In 1984, boundaries between redfish age groups 1-4 were designated at 8.5, 12.5, and 16.5 cm on the basis of strong modes apparent in the length frequencies of some of the catches during the survey. In earlier years the same procedure was employed, but with fewer divisions because of fewer modes. In each year there was no sharp upper limit assigned to the largest mode of juveniles. In 1982 some redfish were designated simply as juveniles before it was realized that two modes (ages 1 and 2) were present. A few of these juveniles were subsequently assigned an age if it was clear that only one size-group was present in the cod stomach. The remaining 118 individuals (9.6% of all redfish from the stomachs collected that year) were assigned to ages 1 and 2 in the appropriate cod size-group in the same proportions as those originally assigned to ages 1 and 2. Each redfish age group was treated as a separate taxon during the stomach examinations.

All fish from stomachs collected in 1980-84 were assigned a state of digestion based on a 6-point scale, where 1 was very fresh and 6 was bones. All other stages had flesh showing some sign of digestion. Only redfish in digestive states 2-5 were included in estimates of the rate of consumption of redfish by cod. Digestive states were not determined in 1978 and 1979. Numbers of redfish in cod stomachs in those years were multiplied by 0.95. This is the unweighted mean of the yearly ratios of the sum of digestive states 2-5 to the sum of digestive states 1-6, determined separately for age 1 redfish in 1981-84 and age 2 redfish in 1982-84 (i.e. 7 ratios; $\bar{x} = 0.95$; range = 0.92-0.97).

Rate of consumption of redfish by cod

Assuming that each survey constitutes a synoptic look at the prey composition of cod, the rate of consumption of redfish by the cod population at the time of each January-February survey was estimated as:

$$C_i = \frac{NR_i}{DT}$$

where C_i is the rate of consumption (number per day) of redfish of age i, NR_i is the number of redfish of age i in the stomachs of the cod population at the time of sampling, and DT is the time required for a redfish to be digested to bone. DT was assumed to be 3 days. NR_i was estimated as:

$$NR_i = \sum_{j=1}^{n} S_{ji} NC_j$$

where S_{ij} is the mean number of redfish of age i in the stomachs of cod in length group j, NC_j is the number of cod of length group j in the population, and n is the number of length groups. S_{ij} is the unweighted mean number of redfish in the stomachs examined; there was no weighting by catch within set or stratum. Because the number of sets sampled and the number of stomachs collected were small in 1979, the stomachs collected in March (Trip 19) and April-May (Trip 20) were added to those collected in February (Trip 17) to provide estimates of the number of redfish in cod stomachs in that year.

The data on cod stocks, cod stomach contents, and redfish stocks were collected during winter cruises. (There are some USSR data that could be added, but we haven't done it.) This means we have, say, information on the consumption of age 2 redfish in February 1982 and of age 3 redfish in February 1983, from which we must interpolate the consumption rate throughout the year. Linear interpolation is conceptually the easiest. Exponential interpolation (assuming that the mortality rate is constant throughout the year) has some biological attraction, but cannot be used if one of the consumption rates is zero. In practice the numbers don't change much (on a logarithmic scale) whichever method is used - in fact we used a quadratic interpolation scheme that lies somewhere in between. Denoting by $R_{a,y}$ the number of redfish of age a in year y, and by $C_{a,y}$ the rate of consumption of such redfish by cod, our interpolation scheme led to the formula:

$$R_{a,y} = R_{a+1,y+1} + (C_{a,y} + C_{a+1,y+1} + \sqrt{C_{a,y}\, C_{a+1,y+1}})/3.$$

RESULTS AND DISCUSSION

The mean number of juvenile redfish at age in the stomachs of cod varied considerably during the winters of 1978-84 (Table 2; Fig. 1). During winters when only 1-year-olds were abundant (1979, 1981) the mean number per cod increased rapidly with cod size, but in other years the patterns were more complex. Some means, particularly for large cod, are based on very small sample sizes (Fig. 1).

The number of cod at length also varied over time (Table 3; Fig. 2). Most notable were the decrease after 1978 in the number of cod greater than 54 cm, and the low numbers caught in 1982. Numbers at age are provided by Wells and Baird (MS 1985).

The results of the sequential population analysis are compared with the results of the research trawl surveys (Lilly, MS 1986) in Table 4 and Fig. 3. Two general comments: we knew before we started that the research trawl was not good at catching age 1 redfish, so the appearance of all the age 1 points below the 1-1 line is reassuring. The scatter in these points is less reassuring. Possible reasons for this include variation in the catching power of the trawl, higher variability in space of age 1 redfish leading to more variance in the estimates, and some source of mortality for age 1 redfish other than cod predation, which varied greatly between years.

The next stage in exploring what we can learn from stomach contents data is to infer some functional response of cod feeding to changes in the density of their prey. Given this, we can examine what would have been the effect of different cod populations on redfish population dynamics. In other words, having run the model backwards with the actual cod populations to determine the number of age 0 redfish we started with, we can take that number and run the model forward with different levels of cod populations to determine their effect on recruitment. We need to infer a functional response before we can do this, because different numbers of cod will rapidly produce different numbers of redfish, for which we have no data. In an ideal world we would also determine how these different numbers of redfish would influence cod growth and subsequent feeding ability, but this is probably a small effect and in any case we can't do anything with it at the moment.

This step has not been carried out. All we can say from the data at the moment is that it's complicated. In 1979 and 1981 predation on age 1 redfish increased with the length of cod. In 1982 and 1983 predation on age 1 redfish was greatest for 45-53 cm cod and decreased for longer ones. It is tempting to speculate that this happened because there were age 2 redfish for the 54+ cm cod to eat, which are not available to smaller cod even when they are present in the water. However, inferring a functional response to cod length and a vector of redfish densities would more than exhaust the available data.

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Table 1. Dates of sampling and numbers of Atlantic cod stomachs collected during winter stratified-random bottom trawl surveys and spring-summer ichthyoplankton surveys by the R.V. GADUS ATLANTICA on the Flemish Cap (NAFO Div. 3M) during the period 1978-84.

Year	Trip Number	Sampling Period	Number of[a] tows	Number of stomachs
1978	5	Jan.28-Feb.12	98	403
1979	17	Feb.08-17	13	94
	19	Mar.25-28	6	153
	20	April 28-May 09	4	207
1980	30	Jan.06-21	80	456
	35	April 05	9	72
	37	May 19-28	8	135
1981	45	Jan.08-21	83	484
	50	April 29-May 10	5	71
	51	May 28-30	8	72
1982	61	Jan.29-Feb.14	92	519
1983	74	Feb.05-20	103	878
1984	90	Feb. 02-13	97	989
Total			606	4533

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

Table 2. Number (per thousand cod) of redfish at age in stomachs of cod of different length groups on Flemish Cap in January-February, 1978-84. (NK includes specimens estmated to be older than age 4 and some specimens whose size could not be measured).

Redfish age	Cod length (cm)										
	9-17	18-26	27-35	36-44	45-53	54-62	63-71	72-80	81-89	90-98	>98
1978											
1	-	0	54	154	259	41	77	0	0	0	0
2	-	0	0	0	0	0	0	0	0	0	475
3	-	0	0	0	0	0	0	0	0	0	0
4	-	0	0	0	0	0	0	0	0	0	0
NK	-	0	0	0	0	151	246	518	259	0	475
1979											
1	0	95	447	950	2832	5246	7863	14900	0	-	34200
2	0	0	0	0	9	55	0	0	0	-	0
3	0	0	0	0	0	0	0	0	0	-	0
4	0	0	0	0	0	0	0	0	0	-	0
NK	0	0	0	0	0	0	81	300	11083	-	0
1980											
1	-	0	29	43	63	34	0	0	0	-	-
2	-	0	0	0	0	0	19	0	0	-	-
3	-	0	0	0	0	0	19	0	0	-	-
4	-	0	0	0	0	0	38	0	0	-	-
NK	-	0	0	0	0	0	38	0	250	-	-
1981											
1	-	-	1200	1360	2304	3653	5960	4609	-	86333	-
2	-	-	0	0	5	0	14	87	-	0	-
3	-	-	0	0	0	20	0	0	-	0	-
4	-	-	0	0	0	0	14	0	-	0	-
NK	-	-	0	0	0	0	27	3478	-	1000	-
1982											
1	0	200	850	1270	2032	1522	1320	2133	800	500	1118
2	0	0	103	373	723	849	1029	1834	3637	5200	2412
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	10	0	0	0	0	0
NK	0	0	0	0	0	0	48	133	0	300	529
1983											
1	91	296	625	1330	1534	818	703	1500	1091	571	3000
2	0	0	45	220	261	500	426	580	303	0	250
3	0	0	0	30	155	682	505	1280	1000	643	0
4	0	0	0	0	0	0	0	0	0	0	0
NK	0	4	0	50	62	45	59	40	61	71	0
1984											
1	0	106	350	400	408	848	955	306	535	190	0
2	0	0	51	161	301	478	629	750	279	95	154
3	0	0	17	151	291	359	716	639	372	190	154
4	0	0	0	15	78	228	403	556	279	95	462
NK	0	21	60	107	223	293	104	111	47	333	231

Table 3. Numbers (X 10^{-3}) of cod per 9cm length group on the Flemish Cap in January-February, 1978-85, estimated from the mean catch per tow during bottom-trawl surveys.

Year	Cod length (cm)											
	<18	18-26	27-35	36-44	45-53	54-62	63-71	72-80	81-89	90-98	>98	Total
1978	6	1544	12893	15623	32063	12051	3547	736	387	158	242	79249
1979	26	4268	1652	7016	6053	4244	1455	424	158	71	248	25614
1980	24	1005	7909	13452	2143	4076	2417	1118	479	95	53	32744
1981	32	0	1326	5895	13397	2545	2260	761	455	269	79	27018
1982	627	78	1687	86	1024	1177	478	201	123	50	99	5629
1983	762	62886	8417	2707	4558	488	2239	714	244	79	103	83196
1984	233	2104	7311	7064	1070	1046	564	319	659	197	101	20668
1985	57	2610	5162	8661	7743	2479	381	416	141	106	80	27837

Table 4. Numbers (X 10^{-6}) of juvenile redfish on Flemish Cap in the winters of 1978-85 as estimated from catches in bottom-trawl surveys[a] (upper) and inferred by SPA from cod stomach contents (lower).

Age	1978	1979	1980	1981	1982	1983	1984	1985
1	0	2.67	+	56.00	108.57	5.90	5.22	0.03
	605	3070	74.3	5310	1060	2130		
2	+	1.92	+	0.18	394.09	267.48	8.46	0.80
	12.1	24.2	9.90	6.86	765	420		
3	+	+	+	0.64	0.64	380.04	16.58	5.23
	0	7.45	5.97	4.01	0	327		
4				0.66	+	1.40	64.05	53.30
	0	0	3.72	1.28	0.477	0		
5								63.98

[a]From Lilly (MS 1986).

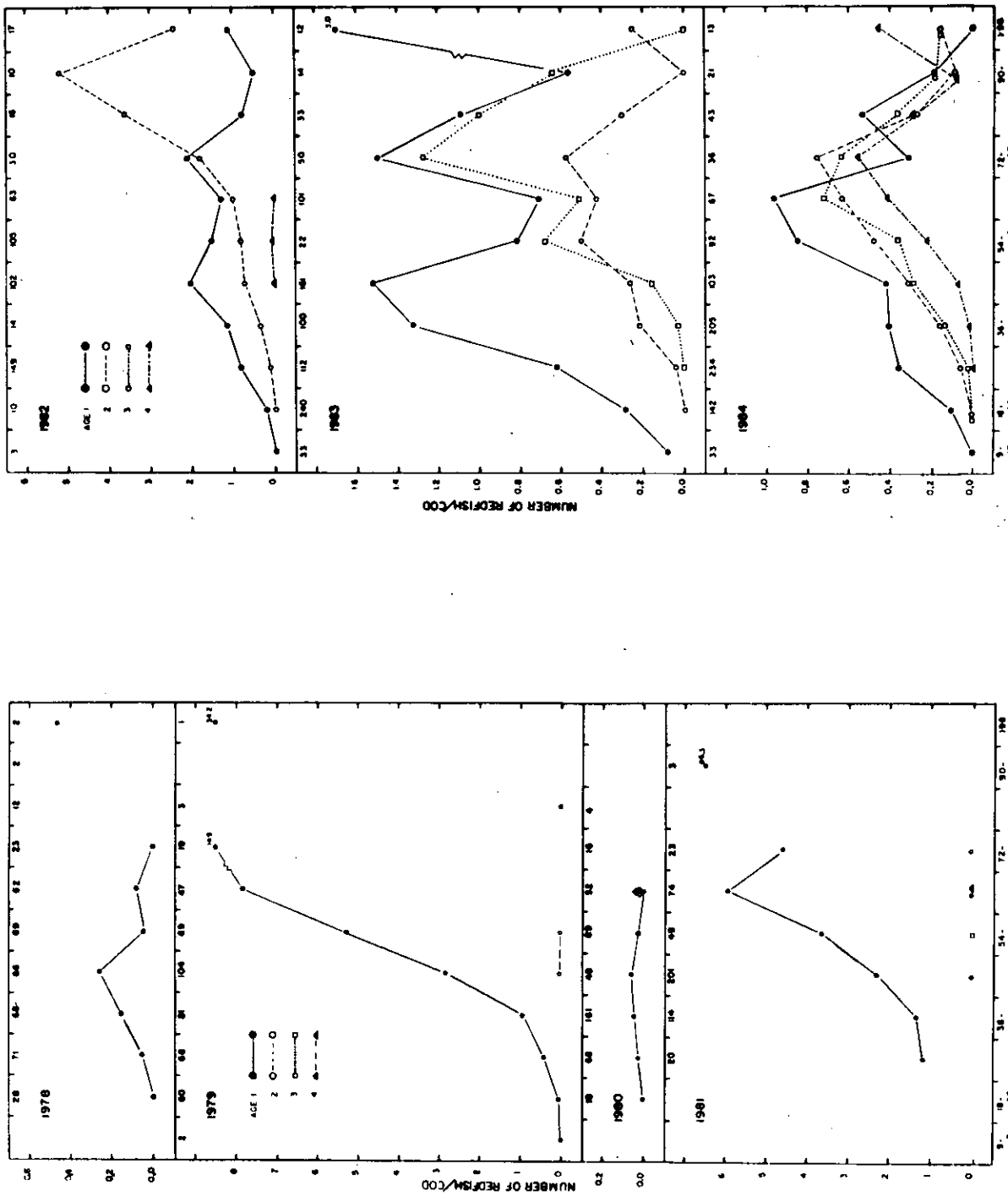
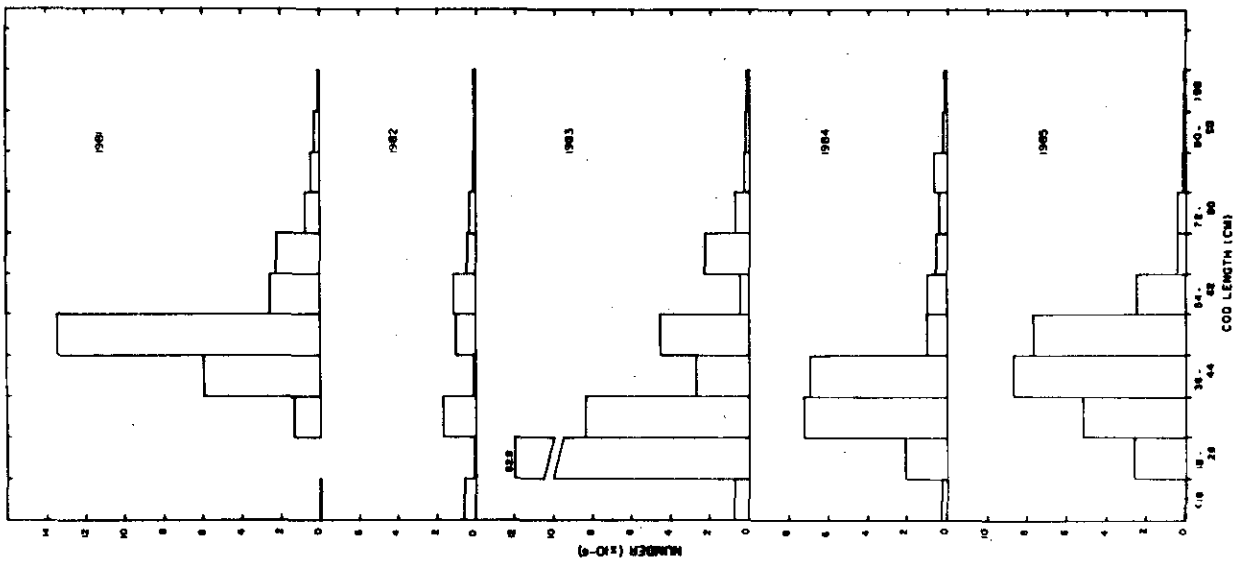


Fig. 1. The mean number of juvenile redfish at age in stomachs of cod from Flemish Cap, 1978-84. The scale in 1979, 1981 and 1982 differs from that in the other four years.



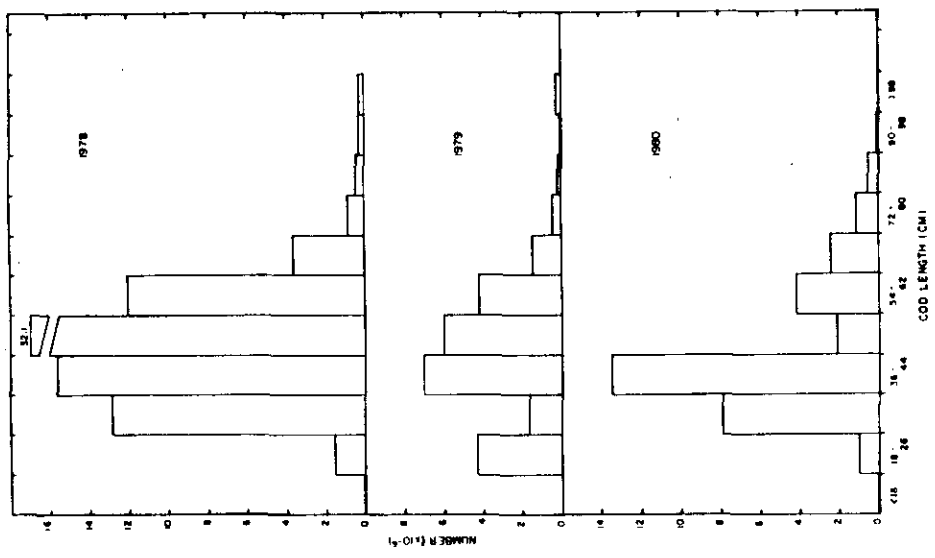


Fig. 2. The number of cod at length on Flemish Cap, 1978-85.

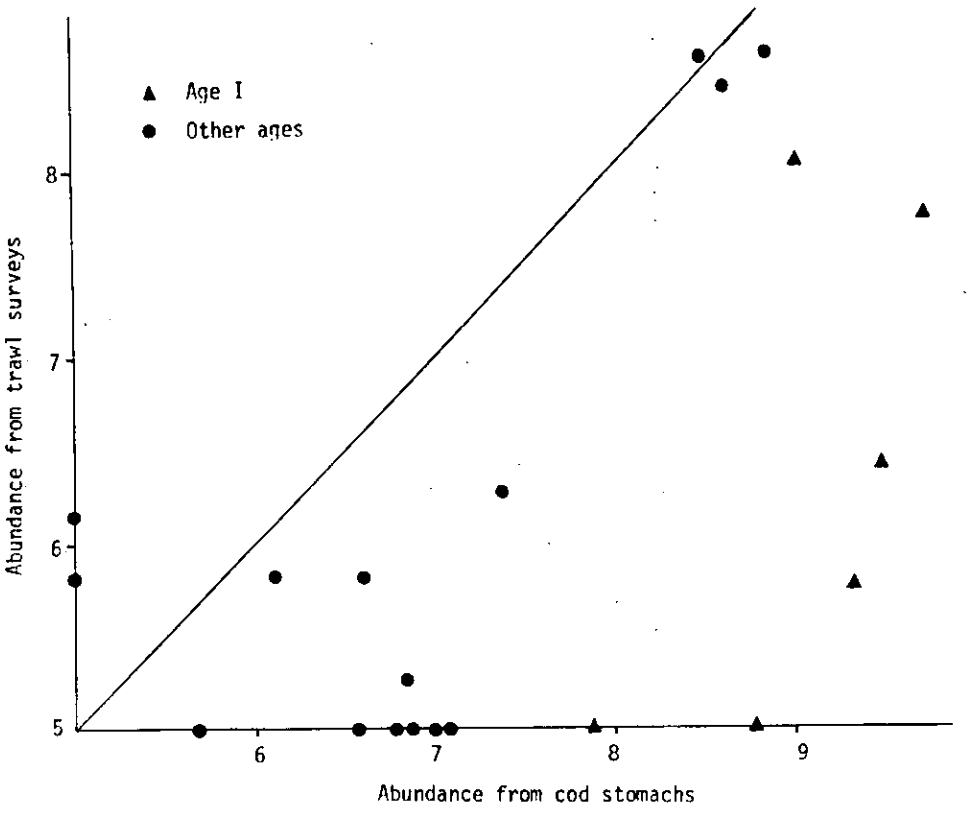


Fig. 3. Comparison of methods for estimating juvenile redfish abundance on Flemish Cap. Abundance = log(max(abundance,10^5)).

Appendix A. Size and quantity of redfish consumed by cod.

The sizes of redfish ingested by cod during the winters of 1978-84 are shown in Fig. A1 and may be compared with catch at length during the same surveys (Atkinson, MS 1985). In 1978 there were modes at 6 cm and 19-20 cm, representing 1-year-olds and the early 1970's year-classes respectively. In later years the early 1970's year-classes were not well represented, for their increasing size made them less vulnerable to predation and the number of large cod was reduced. The 1978 year-class at 7 cm dominated in 1979, no size-group was abundant in 1980, and the 1980 year-class at 7 cm dominated in 1981. An additional year-class was then added each year, so that by 1984 there were four modes of juveniles in the cod stomachs. In each year 1-year-olds were more strongly represented in cod stomachs than in the catch.

The tendency for prey size to increase with predator size was evident throughout the series, and is illustrated with data from 1984 (Fig. A2). Small cod (27-35 cm) preyed primarily on small (age 1) redfish. With increasing cod size, the size (and age) of the redfish prey gradually increased.

Juvenile redfish were an important part of the cod diet, at least in winter (Fig. A3). Annual changes in the total quantity of food in the stomachs of cod was strongly dependent on the quantity of juvenile redfish consumed, especially in the period 1979-84. Hyperiid amphipods formed a large portion of the diet in 1978, but were not found in large quantities in later years (Lilly, MS 1985). Consumption of the two other major prey, myctophids and shrimp (Pandalus borealis), varied considerably among years. Lilly (1980) speculated that the growth rate of cod would vary with the size and quantity of juvenile redfish available.

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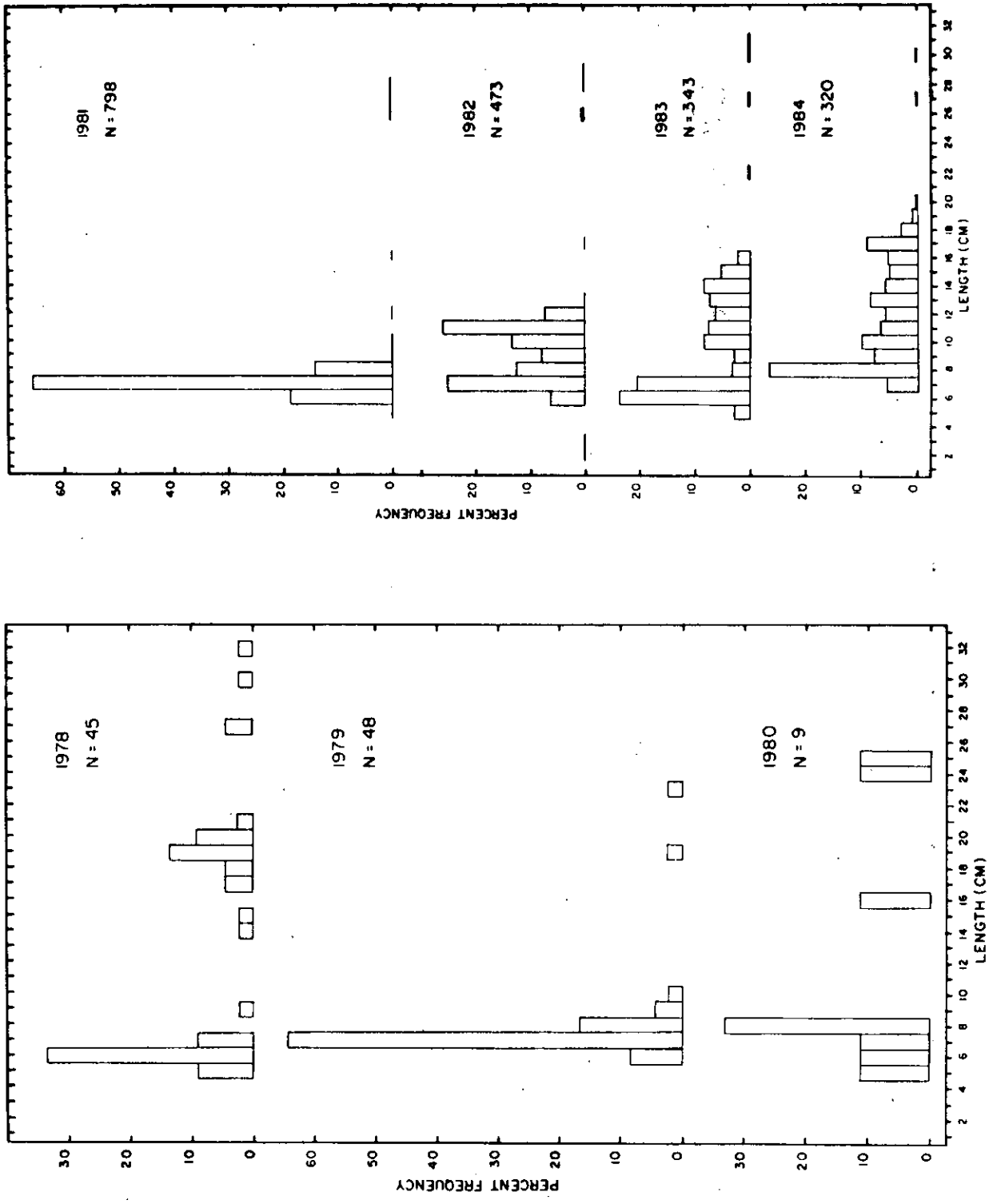

Fig. A1. Length-frequencies of redfish from cod stomachs, 1978-84.

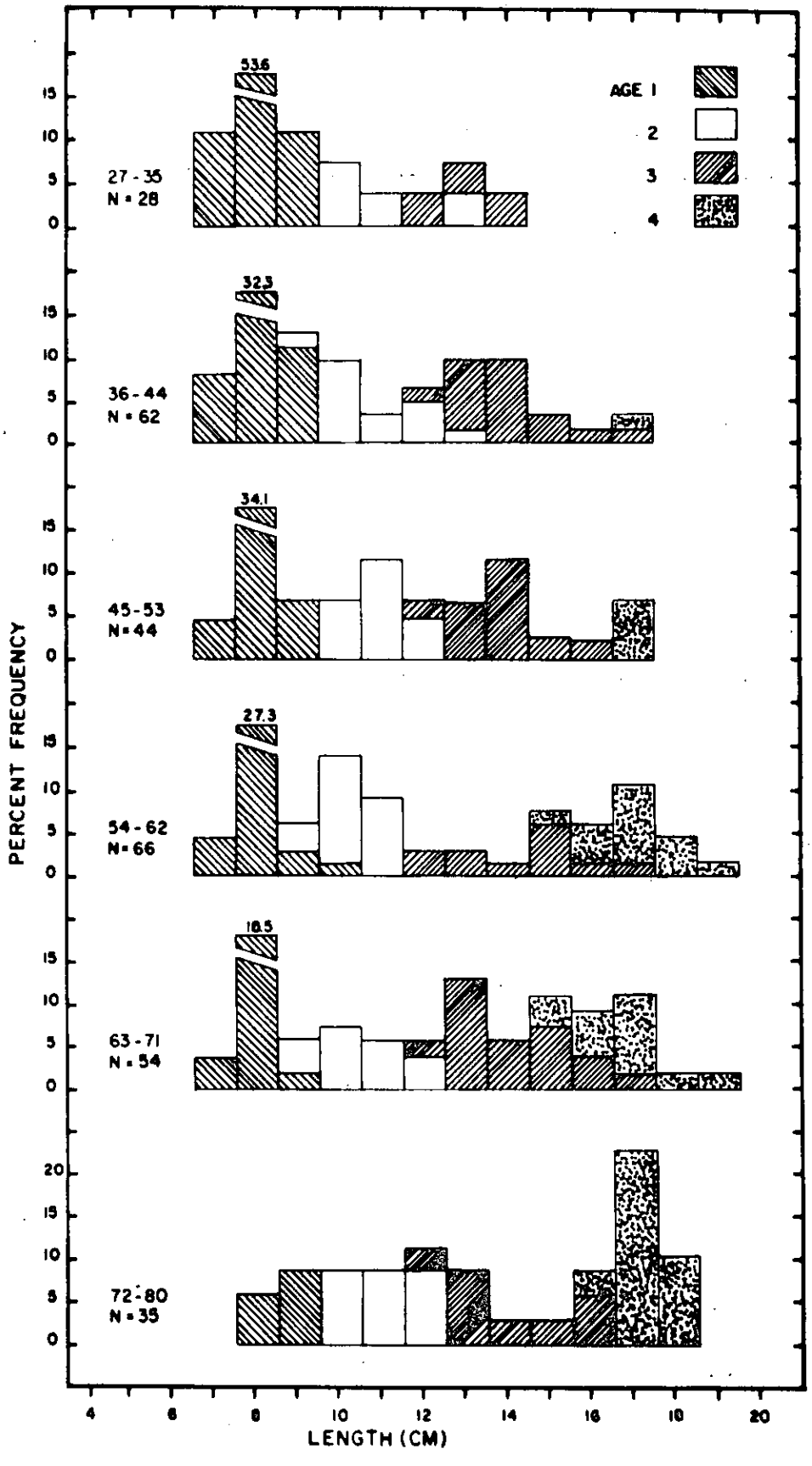

Fig. A2. Length-frequencies of redfish from stomachs of cod of different sizes in 1984.

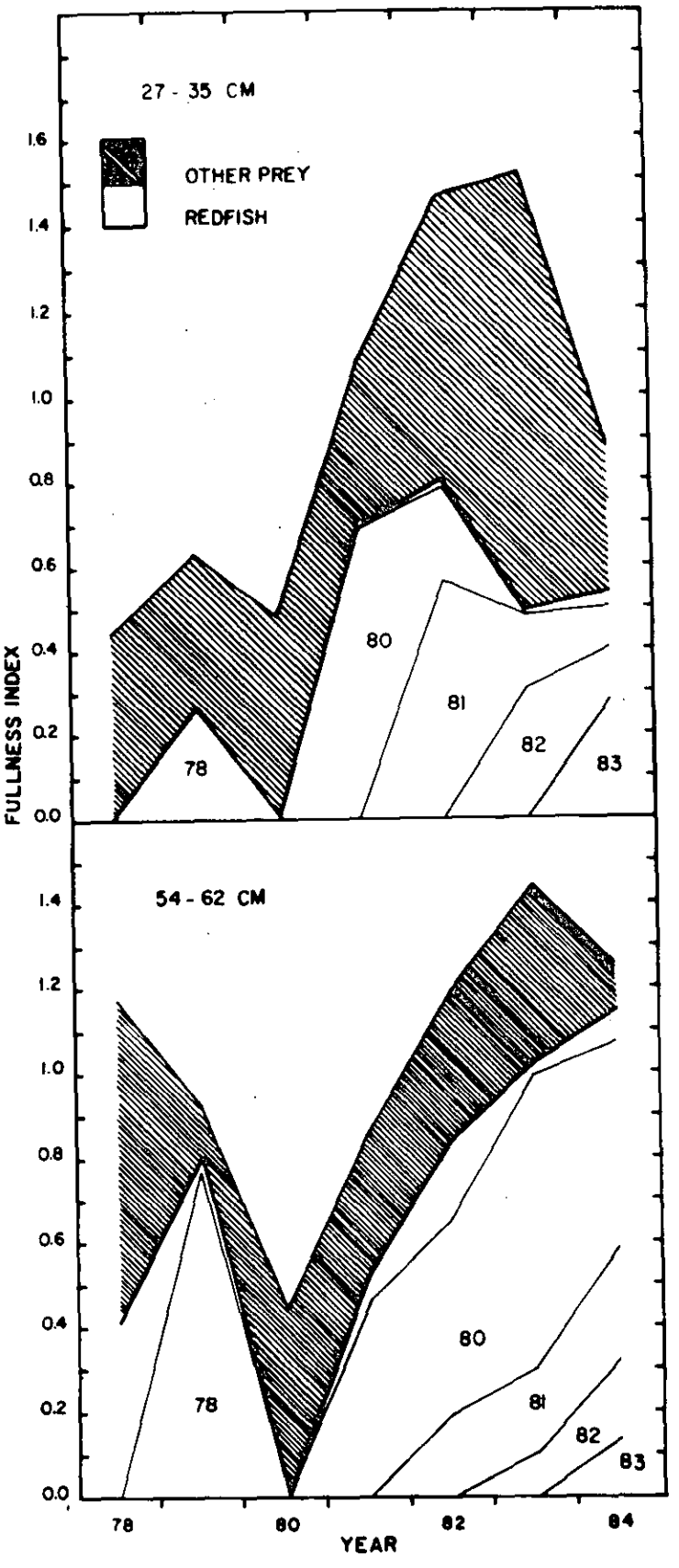

Fig. A3. Fullness indices for two size groups of cod, 1978-84. Numbers refer to birth dates of redfish year-classes. (See Lilly, MS 1985 for a definition of fullness index.)