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Cod (Gadus morhua) on the Flemish Cap Fed Primarily on Redfish (Sebastes sp.) in Winter 1984

by

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INTRODUCTION

Knowledge of the food of Atlantic cod (Gadus morhua L.) is required for testing several hypotheses which have been proposed to explain variation in production and survival of year-classes of cod and redfish (Sebastes sp.) on Flemish Cap (Akenhead MS 1978, NAFO 1980). The quality and quantity of food consumed by adult cod are thought to be important in determining growth, maturity and fecundity. Hence, the number and quality of eggs produced by the cod stock may, in part, be controlled by the availability of food.

Also, predation by cod on smaller cod and small redfish may produce significant and variable mortality of juveniles, thus contributing to variability in year-class strength. The occurrence of cannibalism on 1-year-old cod increased in 1982 after several years of low incidence (Lilly MS 1982), and in winter 1983 cod were preying on both 1- and 2-year-old juvenile cod (Lilly MS 1983). Cod also feed intensively on juvenile redfish (Templeman, 1976). Between 1978 and 1982 most predation was on 1- and 2-year-olds (Lilly and Gavaris 1982), but in winter 1983 cod preyed upon redfish of ages 1-3 (Lilly MS 1983).

This paper presents preliminary analyses of the stomach contents of cod on Flemish Cap in winter 1984, compares the results with observations in 1978 and 1983, and provides crude estimates of the rate of consumption of juvenile redfish by the cod population.

METHODS

Cod were caught during a stratified-random bottom-trawl survey of Flemish Cap by the chartered research stern trawler Gadus Atlantica (Trip 90) during the period 2-14 February 1984. Stomachs were collected from a stratified random sample of 3 cod per 9 cm length group from the catch of every set.

Most cod stomachs were excised at sea and preserved in 9:1 seawater:formaldehyde solution, but some cod were frozen whole at sea and thawed in the laboratory prior to removal and immediate examination of the stomachs. 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. Polychaeta, Euphausiacea). Items in each taxon were placed briefly on absorbent paper to remove excess liquid, and then weighed to the nearest 0.1 g. The numbers in each taxon of fish and decapod crustacea were recorded. Whenever digestive condition permitted, fish were measured to the nearest mm total length and decapod crustacea were measured to the nearest mm carapace length. In many instances the total lengths of redfish and cod were estimated from standard length, as described for redfish by Lilly and Gavaris (1982). In addition, the approximate lengths of highly digested specimens were estimated from regressions of total length on otolith length.

Small redfish and cod were assigned to age-groups whenever lengths could be estimated. 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. Boundaries between cod age-groups 1-3 were designated at 14.5 and 23.5 cm on the basis of ages read from otoliths (R. Wells, pers. comm.). Lengths-at-age overlap across these boundaries, so an unknown proportion of redfish and cod will be assigned incorrect ages.

Feeding indices

The relative quantity of food in the stomachs and the relative importance of specific prey taxa, including individual age-groups of redfish and cod, were assessed using three indices:

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

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

3) 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 the 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.

Rate of consumption of redfish

Assuming that the survey constitutes a synoptic look at the prey composition of the cod, the rate of consumption of redfish by the cod population 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 for complete digestion. NR_i was estimated as

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

where S_{ji} 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 9-cm length-groups. S_{ji} is the unweighted mean number of redfish in the stomachs examined; there was no weighting by catch within set or stratum. NC_j was calculated by areal expansion of the stratified arithmetic mean number per 3-cm length-group per tow (Smith and Somerton, 1981) using strata defined in Doubleday (1981). Numbers per 3-cm group were combined into 9-cm groups.

RESULTS

The prey composition in winter 1984 was similar to that in other years, but the relative importance of some of the prey was markedly changed (Table 1). Redfish (Sebastes sp.) was the dominant prey (79% by weight and 71% of the total fullness index). Myctophids were much reduced from 1983, as were shrimp. Hyperiids were more important than in 1983, but remained far below their importance in 1978. The total fullness index was intermediate between levels in 1978 and 1983.

Four redfish age-classes, distinguished solely on the basis of length-class, were found in the cod stomachs. The frequency of occurrence of redfish and the number per cod decreased with increasing age, whereas the contribution to the total weight of stomach contents increased with age (Table 2). Three cod age-classes (ages 1-3) were found, the most important being the 2-year-olds (Table 2). All three cod age-classes were numerically and gravimetrically less important than the redfish age-classes.

The importance of the various age-groups of redfish as prey for cod varied with cod size (Table 3). The partial fullness index for each age-group of redfish first increased and then decreased with increasing cod length. The minimum size of cod preying on each age-class of redfish, and the size-class of cod at which PFI was highest, increased with increasing redfish age. All redfish together comprised more than 50% of the food (by weight) of cod from 27 to 89 cm, and more than 90% in cod from 54 to 80 cm. Cannibalism was found in a wide size range of cod. Shrimp were important only to cod <53 cm.

The number of redfish estimated to be in the stomachs of the cod population at the time of sampling declined from 8.5 million 1-year-olds to 1.1 million 4-year-olds (Table 4). Assuming that the time for digestion is 3-5 days, the daily consumption of redfish by the cod population may be as follows:

Age 1	2.8-1.7 million
" 2	1.1-0.7 "
" 3	0.5-0.3 "
" 4	0.4-0.2 "

DISCUSSION

Prey spectrum

The prey spectrum of cod on the Flemish Cap is relatively narrow (Konstantinov et al. 1985; this paper), and the importance of the major prey (redfish, cod, myctophids, hyperiids, and the shrimp, Pandalus borealis) varies annually. The importance of juvenile redfish and cod varies with the strength of their year-classes. For example, the 1980 and 1981 redfish year-classes were relatively strong in the bottom-trawl surveys (Lilly and Gavaris, 1982; Atkinson MS 1984), and they have been important prey for cod since they appeared. In contrast, the 1978 year-class was only moderately strong in the survey in 1979, and although it was the major prey of cod in 1979, it was virtually absent from the diet in subsequent years (Lilly and Gavaris, 1982). Variability in intensity of predation on myctophids, hyperiids and shrimp may reflect changes in availability of these prey, but there are no independent measures of their abundance.

Feeding rate

The mean total stomach fullness index (TFI) of cod in winter has varied from 0.81 to 1.23 in the three years reported here (Table 1). In addition, within each year the TFI has varied considerably among cod length-groups (Table 3; Lilly MS 1983). The relationship between this variability in TFI and changes in growth rate of the cod (Wells, MS 1983) has not been examined. Of course, information from winter alone may not provide an adequate measure of annual food consumption, for there could be considerable variability at other times of the year. For example, planktonic crustacea could be providing high but variable feeding opportunities in the summer (Konstantinov et al. 1985), myctophids could vary in abundance seasonally, and squid (Illex illecebrosus) could be available in summer and autumn of some years. Nevertheless, examination of the hypothesis that growth rate of cod on Flemish Cap is related to the abundance of juvenile redfish (Lilly, 1980) should be possible.

Mortality of juvenile redfish and cod

Cod eat large numbers of juvenile redfish (Table 4; Lilly and Gavaris, 1982) and smaller numbers of juvenile cod. The number of prey which can be consumed by a population of cod in a given period of time will decrease with increasing age (size) of the prey because of a decrease in (1) the number of cod capable of ingesting the prey (Table 4) and (2) the number of prey which can be ingested and digested per unit time by a cod of given size. The number of each age-class of each species consumed by the cod population can be expected to vary with the abundance and availability of that age-class, the abundance and availability of alternate prey, especially other age-classes of redfish and cod, and the numbers-at-length in the cod population.

The contribution of predation by cod to variability in year-class strength of redfish and cod will be difficult to assess with the information available. The estimates of number of redfish and cod in the stomachs of the cod population (eg. Table 4) can be improved by considering geographic variability in both the distribution of cod and the intensity of predation by cod on each age-group of prey. However, calculation of consumption rates requires much better information on gastric evacuation rate. Minet and Perodou (1978) assumed that the rate of digestion is linear over time and requires 3-5 days. Laboratory studies of gastric evacuation of capelin (Mallotus villosus) 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 (3-4°C) on Flemish Cap (Garman and Lilly; unpublished). However, no information on digestion of redfish is available, and the effect of meal size, prey size and predator size must also be considered (Durbin et al. 1983).

Estimation of the number of juveniles of each age-class of each species consumed by cod also requires (1) more complete seasonal information on cod feeding, particularly in the autumn when 0-group juveniles are first becoming available to demersal predators and (2) reliable information on cod numbers-at-length. Even if removal rates due to cod predation could be reliably estimated, mortality rates could not be calculated without independent measures of abundance. Present estimates from research bottom-trawl surveys are not adequate because the young age-classes are not fully recruited to the gear (Lilly and Gavaris 1982; Atkinson MS 1984; Wells and Gavaris MS 1984).

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Table 1. The food of cod on Flemish Cap in the winters of 1978, 1983 and 1984, expressed as percentage of total weight of stomach contents and partial stomach fullness index (PFI).

	Weight (%)			Average PFI		
	1978	1983	1984	1978	1983	1984
Polychaeta	0.3	0.1	0.2	0.01	0.01	0.01
Mollusca[a]	1.1	0.4	1.3	0.01	0.01	+
Echinodermata[b]	0.2	0.1	0.2	+	0.02	0.01
Crustacea						
Copepoda	0.2	+	+	0.01	0.01	+
Mysidacea	0.1	+	+	+	+	+
Amphipoda						
Hyperiidea	13.8	0.1	0.7	0.20	0.01	0.03
Other + unid.	0.3	0.1	0.1	0.01	0.01	0.01
Decapoda						
Natantia[c]	2.2	14.0	2.7	0.05	0.30	0.08
Reptantia	0.1	0.1	0.1	+	+	+
Other + unid.	0.4	1.1	0.4	0.01	0.08	0.02
Crustacea Total	16.9	15.4	3.9	0.29	0.41	0.14
Pisces						
Sebastes sp.	47.0	52.2	79.1	0.27	0.53	0.71
Gadus morhua	6.8	9.7	8.5	0.04	0.05	0.05
Myctophidae	0.8	10.4	1.1	0.01	0.12	0.03
Miscellaneous	1.8	6.4	3.2	0.01	0.03	0.02
Unidentified	8.1	2.1	1.7	0.08	0.03	0.02
Pisces Total	64.5	80.9	93.7	0.40	0.77	0.83
Offal + bait	16.4	2.9	0.3	0.09	0.01	+
Miscellaneous + unid.	0.6	0.2	0.4	0.01	0.01	0.01
Total				0.81	1.23	1.00
No. of stomachs:	403	878	989			
Percent empty	15.4	13.5	16.9			

[a]Mainly cephalopods.
[b]Mainly brittle stars.
[c]Predominantly Pandalus borealis.
+Trace.

Table 2. Stomach content indices for individual age-classes of redfish and cod within the sample of 989 cod stomachs.

Age	Percent Occurence	Percent weight	PFI	Number per 1000 stomachs
Redfish				
1	20.9	8.3	0.17	433
2	12.1	11.2	0.13	225
3	11.0	23.2	0.22	201
4	5.9	25.5	0.14	106
Unknown[a]		10.9	0.06	
Total		79.1	0.71	
Cod				
1	0.9	0.8	0.02	11
2	2.4	2.8	0.03	27
3	0.7	3.2	0.01	7
Unknown[a]		1.7	+	
Total		8.5	0.05	

[a]Unknown includes specimens estimated to be older than age 4 (redfish) or age 3 (cod), and some specimens whose size and hence age could not be determined.

Table 3. Partial fullness indices for various age-groups of redfish and other major prey in cod of different length-groups.

Prey	9-17	18-26	27-35	36-44	45-53	54-62	63-71	72-80	81-89	90-98
Redfish										
Age 1		0.16	0.28	0.20	0.13	0.13	0.08	0.02	0.03	+
2		0.05	0.13	0.20	0.22	0.19	0.14	0.11	0.04	0.01
3			0.10	0.40	0.44	0.27	0.45	0.23	0.11	0.03
4				0.07	0.20	0.48	0.43	0.50	0.20	0.03
Unknown[a]	0.07	0.04	0.03	0.04	0.91	0.08	0.03	0.04	0.16	0.20
Total	0.07	0.25	0.54	0.91	1.08	1.15	1.12	0.91	0.54	0.28
Cod			0.04	0.11	0.08	0.05	0.01	+	0.16	0.09
Shrimp	0.09	0.18	0.10	0.07	0.10	0.02	0.01	0.01	+	
TFI	0.45	0.72	0.88	1.22	1.32	1.25	1.19	0.94	0.71	0.65
No. of stomachs	33	142	234	205	103	92	67	36	43	21
% empty	21	13	17	17	15	14	15	19	35	24
Redfish (% of TFI)	16	34	61	74	82	92	94	96	75	42

[a]Unknown includes specimens estimated to be older than age 4 and some specimens whose size could not be measured.
+Trace (<0.05).

Table 4. Number of cod in Flemish Cap population and number of redfish at age in stomachs of the cod in winter 1984.

Cod length group	No. of cod ($x10^{-3}$)	No. of redfish per 1000 cod stomachs			
		Age 1	Age 2	Age 3	Age 4
9-17	233.1				
18-26	2104.3	105.6	7.0		
27-35	7310.6	367.5	51.3	17.1	
36-44	7064.1	429.2	175.6	151.2	14.6
45-53	1070.0	466.0	349.5	291.3	77.7
54-62	1046.4	891.3	521.7	380.4	228.3
63-71	564.3	1000.0	641.8	776.1	417.9
72-80	319.1	333.3	777.8	666.7	638.9
81-89	659.4	604.7	302.3	395.3	325.6
90-98	196.8	190.5	142.9	190.5	95.2
>98	100.6		153.9	153.9	461.5
No. of redfish in stomachs of cod population ($x10^{-3}$)		8478.9	3403.4	1674.1	1144.7