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Influence of the Labrador Current on Predation by Cod on Capelin and Sand Lance off Eastern Newfoundland

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Abstract

Catches of Atlantic cod, *Gadus morhua*, capelin, *Mallotus villosus*, and sand lance, *Ammodytes dubius*, during bottom-trawl research surveys of eastern Grand Bank were examined with respect to depth and temperature. Capelin and sand lance appeared to be associated with the cold core (<0° C) of the Labrador Current, whereas cod were most abundant in the underlying warmer, more saline water. It is postulated that cod can prey on sand lance throughout the year by migrating into the cold water. A similar vertical stratification of cod and capelin appears to exist on the northern slope of Grand Bank, particularly in winter, and along the coastal shelves of northeastern Newfoundland and southern Labrador in summer and autumn. The apparent association of capelin and sand lance with the Labrador Current has implications for the seasonal feeding behavior and growth of cod and other piscivores in the region.

Introduction

The cold (<0° C) inshore stream of the Labrador Current closely follows the coastline of Labrador and eastern Newfoundland, impinging on the bottom to depths of 200 m or more off the major headlands and on the offshore banks. The current divides north of the Grand Bank, one branch passing through the Avalon Channel and the other along the northern and eastern slopes of the Grand Bank (Smith *et al.*, 1937). Concentrations of Atlantic cod may be found in both summer and winter just below the cold core of the current on the slopes of coastal shelves and shallow offshore banks (Templeman, 1962; Templeman and Fleming, 1956, 1963; Templeman and May, 1965). In late spring and early summer, the surface water temperature rises and some of the cod, particularly the smaller individuals, migrate through or around the cold intermediate layer to warmer shallow water near the coast, where they feed intensively on capelin (Templeman, 1965). At the same time, some cod along the north slope of Grand Bank move onto the plateau of the bank (Templeman, 1979) and feed on capelin (Kovalyov and Kudrin, 1973). These migration patterns and the conspicuous predation by cod on capelin in inshore areas contribute toward an impression that the cold stream of the Labrador Current is simply a barrier between overwintering areas in deep water offshore and summer feeding areas in shallower water.

There is some evidence that feeding conditions for cod and other piscivores may be good both within and immediately below the cold water. Templeman and Handrigan (MS 1949) reported that, in the summer of 1948, concentrations of cod below the cold water on the northern slope of Grand Bank were feeding on capelin and those on the eastern slope of the Grand Bank were feeding heavily on sand lance with some capelin. The existence of some cod concentrations in cold water (-0.6° to -1.1° C) on the eastern slope of Grand Bank in 1949 prompted Templeman and Handrigan (MS 1949) to write "the occurrence of cod in numbers as during 1949 in water below zero centigrade temperature will need further investigation. The explanation may lie in the behaviour of the food fishes launce and caplin, the former being common toward the southern and the latter toward the northern part of the bank". This paper briefly examines the distribution of cod and two of its major prey, capelin and sand lance, on the eastern and northern edges of Grand Bank in relation to the influence of the Labrador Current on predation patterns of cod.

Materials and Methods

Data on depth distribution of cod, capelin and sand lance on the eastern slope of Grand Bank were obtained from bottom-trawl surveys in 1965–70 by the research vessel *A. T. Cameron* with a No. 41-5 Yankee otter trawl and in 1978 by the chartered research trawler *Gadus Atlantica* with an Engel high-rise otter trawl. The codends were equipped with 29-mm mesh liners in both cases, and both ships trawled at 3.5 knots (108 m/min) for 30 min at each fishing station. The system of surveying in 1965–70 was the standard line survey, in which fishing stations were located at selected depths on transects perpendicular to the slope (Pinhorn, MS 1971). Seasonal coverage was most extensive for line R at approximately 45° N (Fig. 1) during the early period and only the information for that transect is utilized. The stratified-random design (Grosslein, MS 1971; Grosslein and Pinhorn, MS 1971) was used for the 1978 survey of eastern Grand Bank,

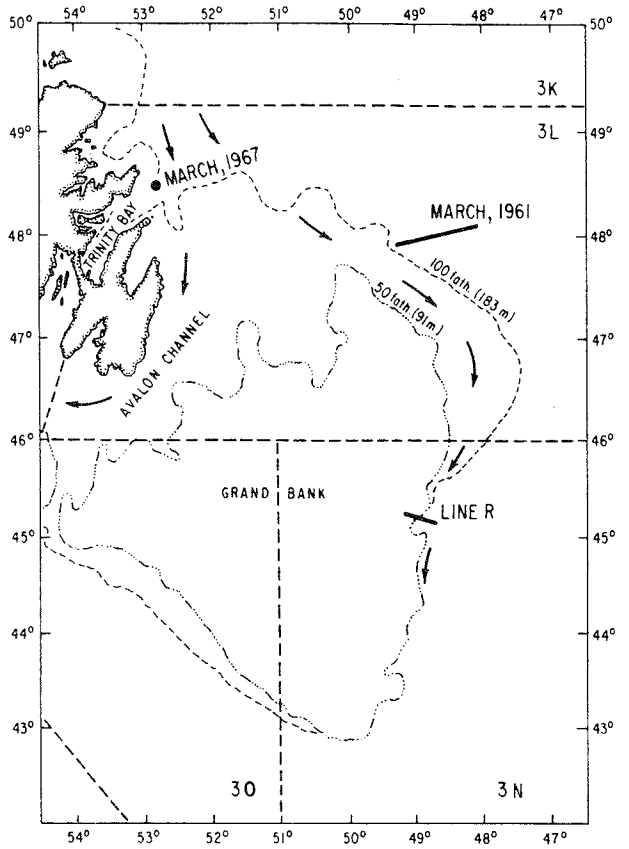

Fig. 1. Sampling positions and other locations mentioned in the text. Arrows indicate the general direction of Labrador Current flow.

but only the information from fishing stations near or on the slope between 43°30'N and 46°00'N was utilized. Water temperatures were taken approximately 2 m off the bottom.

Results

The seasonal distributions of cod, capelin and sand lance catches by depth along line R on the eastern slope of Grand Bank during surveys from March to October are given in Table 1. The location of the cold core of the Labrador Current on the slope is shown in a representative temperature profile (Fig. 2).

Cod catches were very small in the shallow cool water of the Labrador Current on the edge of the shelf in March 1968 (Table 1) but were moderate in the slightly warmer water at greater depths. Although no capelin or sand lance were caught, it was noted in the cruise report that cod from the largest catch at 117 m were feeding heavily on sand lance. Near-bottom temperatures in late April 1965 were slightly higher than in March 1968, and large catches of cod were taken in depths of 108–229 m. No capelin or sand lance were caught, but the cod were reported to be feeding heavily on sand lance.

TABLE 1. Seasonal distribution of capelin, sand lance and Atlantic cod by depth at approximately 45°N on the eastern slope of Grand Bank, 1965-70.

Bottom depth (m)	Bottom temp. (°C)	Catch per 30-min set			
		Capelin (kg)	Sand lance (kg)	Atlantic cod (No.)	Atlantic cod (kg)
12–13 March 1968					
71	0.0	—	—	—	—
91	0.2	—	—	1	18
117	0.3	—	—	1,620	1,755
146	0.4	—	—	368	465
187	0.6	—	—	166	210
230	1.0	—	—	388	546
271	1.6	—	—	746	802
318	2.4	—	—	826	605
30 April 1965					
73	0.6	—	—	454	179
108	1.0	—	—	4,910	5,479
185	0.9	—	—	4,220	3,384
192	—	—	—	1,414	1,158
229	1.3	—	—	4,250	4,200
309	—	—	—	—	8
21 May 1969					
64	0.1	—	—	13	15
93	-0.1	3	10	208	161
146	0.3	—	—	334	321
185	0.7	+	—	1,082	1,095
230	0.9	—	—	1,447	1,754
274	—	—	—	122	210
8 June 1967					
64	-0.1	—	—	35	22
73	-0.7	136	—	76	117
112	-1.2	23	—	214	226
143	-0.2	—	—	1,228	1,144
183	0.2	—	—	646	472
227	2.0	—	—	656	572
18 June 1970					
66	-0.9	1	1	—	—
104	-0.6	7	54	13	10
148	-0.1	—	—	26	43
187	0.4	—	—	18	11
229	2.4	—	—	486	346
4–5 October 1968					
73	-1.2	—	113	1	18
113	-0.2	1	1	1	1
130	-0.5	—	1	5	9
148	-0.4	—	—	19	24
168	-0.6	—	—	67	91
185	-0.2	—	—	67	79
223	1.0	—	—	106	99
16–17 October 1970					
66	-0.8	2	—	4	1
110	-0.6	7	+	31	6
144	-0.3	—	—	—	9
172	0.4	—	—	39	16
225	1.2	+	—	216	76
282	1.4	—	—	252	107

In May 1969, cod catches were smaller in shallow water at lower temperatures than in deeper water at higher temperatures (Table 1). Although both capelin and sand lance were caught in cold water, the main

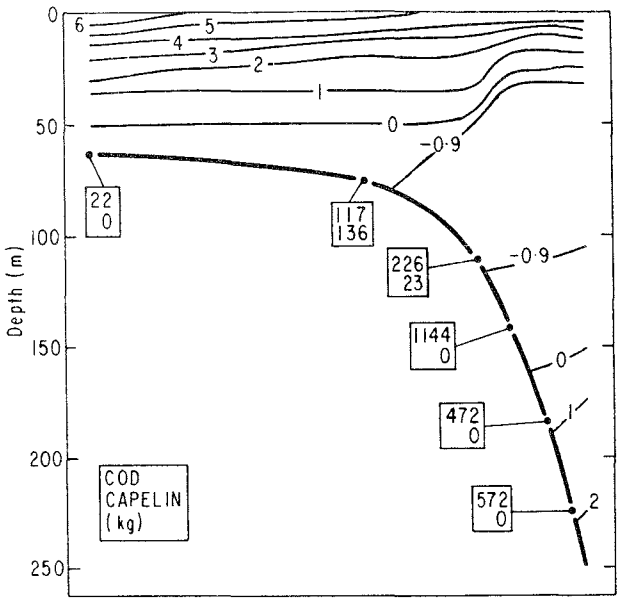

Fig. 2. Catches of cod and capelin in relation to temperature and depth at line R (see Fig. 1) on the eastern Grand Bank in June 1967.

food of cod was reported to be sand lance. In June 1967 (Fig. 2) and also in June 1970, the cold core (<0° C) of the Labrador Current extended deeper than in the preceding months of other years. Some cod were taken in very cold water (<−0.5° C), but the best catches were caught in deeper warm water. Capelin and sand lance were taken only from very cold water. There were no reports of cod stomachs being examined from catches at these stations on line R, but cod taken from similar depths at 46° 20'N in the June 1967 survey were feeding intensively on sand lance (Lilly and Fleming, 1981).

In the October surveys of 1968 and 1970, bottom water temperatures were generally below 0° C except at the deepest fishing stations. Catches of cod were small at all depths, but the best catches were taken in the deeper warm water. However, capelin and sand lance were taken only at the shallower cold-water stations on the edge of the bank. In 1968, stomachs were collected from 52 cod caught at 148, 185 and 223 m. Although no sand lance were retained by the trawl at these depths, they were the major prey of cod, occurring in 27% of the stomachs and constituting 64% of the total stomach contents by weight. Furthermore, 32% of the food was unidentified fish, and much of this may have been sand lance, as no other fish was identified in the stomach contents.

The distribution of cod and its potential prey with respect to temperature and depth during the July 1978 survey (Table 2) is not readily comparable with the results of the 1965–70 surveys because the fishing stations were not on line transects. However, to illustrate that the patterns described above occurred all along the eastern slope of Grand Bank south of 46° N during

TABLE 2. Distribution of capelin, sand lance and Atlantic cod by depth on the eastern slope of Grand Bank south of 46° N, 9–12 July 1978.

Bottom depth (m)	Bottom temp. (°C)	Catch per 30-min set			
		Capelin (kg)	Sand lance (kg)	Atlantic cod (No.)	Atlantic cod (kg)
46°00'N to 45°30'N					
91	0.1	—	5	4	5
100	0.0	—	583	—	—
170	1.2	—	—	57	55
322	2.1	—	—	347	314
330	2.5	—	—	40	53
45°30'N to 44°55'N					
88	-0.4	—	—	—	—
103	-0.8	—	432	—	—
318	2.1	—	—	155	159
44°55'N to 44°05'N					
54	-0.1	—	—	9	5
62	-0.9	—	—	—	—
44°05'N to 43°30'N					
72	-0.6	—	335	1	4
99	-0.3	—	223	—	—
98	0.7	—	—	136	211

the 1978 survey, catches from all sets except those near canyons were grouped by latitude and arranged by depth within each group. The largest catches of cod were from the deep warm-water stations, whereas sand lance were caught only in shallow cold water. Examination of cod stomachs at sea revealed that the major prey of cod was sand lance. No capelin were observed in the trawl catches or the cod stomachs.

Discussion

Certain trends in the seasonal pattern of bottom water temperature and the distributions of cod, capelin and sand lance on eastern Grand Bank are apparent in Tables 1 and 2. The temperatures reported here and temperature-depth profiles from the various surveys reveal a seasonal pattern similar to the average conditions observed at Station 27 in the Avalon Channel off St. John's (Templeman, 1966). In March, April and May, bottom temperatures on the edge of the shelf were generally greater than 0° C, with only a small volume of colder water (<0° C) impinging on the bottom in the May 1969 section at depths less than 100 m. In June, the volume of cold water (<0° C) was much greater, reaching a depth of about 160 m in both years of observation, and very cold water (<−0.5° C) impinged on the bottom to depths exceeding 100 m. In October, the volume of cold water (<0° C) was quite large, extending to about 200 m in 1968 and 150 m in 1970, and very cold water (<−0.5° C) impinged on the bottom in both years. Thus, in the sections described here, the core of the Labrador Current was colder and greater in volume in June and October than in March-May, but annual variation was apparent.

The seasonal patterns of cod, capelin and sand lance catches could be biased by annual changes in abundance and diel changes in availability to the trawl. Nevertheless, the cod catches tended to be largest in winter and spring. Many of the cod presumably migrated onto the shelf in summer and remained there in autumn (Templeman, 1974). Capelin were neither caught in the trawl nor found in cod stomachs before late May, which is about the time of their arrival on the Southeast Shoal of Grand Bank in preparation for spawning (Kovalyov and Kudrin, 1973). Sand lance were not caught in March and April when bottom temperatures were slightly above 0° C but were found in cod stomachs in both months. However, sand lance were caught in cold water (<0° C) in May, June and October. This apparent seasonal difference in catches may have reflected the migration of sand lance to the fishing area in May–June or low availability to the trawl earlier in the year when bottom temperatures were higher.

No capelin were caught in July 1978, but the catches of sand lance were much higher than in the May and June surveys of the 1965–70 period. The absence of capelin corresponds with their failure to spawn in significant numbers on the Southeast Shoal of Grand Bank in 1978 (Carscadden and Miller, MS 1979; Ulltang and Sangolt, MS 1979). The high catches of sand lance are consistent with an apparent recent increase in abundance on Grand Bank (G. H. Winters, Northwest Atlantic Fisheries Center, St. John's, Nfld., pers. comm.) but also could be related to seasonal variation in abundance (no July surveys in the 1965–70 period) or to greater susceptibility to capture by the high-lift trawl used in 1978.

As stated above, the capelin and sand lance were caught only where the cold water (<0° C) impinged on the bottom, whereas the best cod catches occurred in slightly warmer water below the cold core of the Labrador Current. It is possible that both prey species are pelagic within the much larger volume of cold water over the slope and that cod prey upon them by moving along the bottom to shallower depths or by migrating vertically.

A similar stratification of predator and prey appears to exist on the northern slope of Grand Bank in winter. Templeman (MS 1962; 1965), for a transect of fishing stations from 185 to 666 m in March 1961 (Fig. 1), found that cod were abundant at 185 m (1.2° C) and 230 m (2.0° C) but decreased in numbers in the deep warmer water. The cod in these two catches were feeding well on juvenile (10–12 cm) and adult capelin. Templeman's (1979) interpretation of the catches and the echo-sounder records was that both cod and capelin live just below the overlying cold water. Similarly, two sets at the mouth of Trinity Bay in March 1967 (Fig. 1) in 228 and 278 m (0.7° and 1.4° C) yielded good catches of cod which had been feeding intensively on capelin, but no capelin were taken in the trawl (Lilly and Fleming, 1981). These 1961 and 1967 observations may be interpreted in the light of reports by Winters (MS 1968, MS 1969) that concentrations of capelin in nearby Trinity Bay overwinter in the cold intermediate layer, which is continuous with the cold core of the Labrador Current (Bailey, MS 1958). It seems probable that the concentrations of capelin on northern Grand Bank in winter are primarily in cold water (<0° C) and are preyed upon by cod which migrate vertically from the warmer water below.

A similar situation may exist in more northerly areas off southern Labrador and northeastern Newfoundland (Div. 2J and 3K) in summer and autumn. On the offshore part of the Labrador shelf in late July and early August, the largest concentrations of cod were in the shallow cold water feeding heavily on capelin (Templeman, 1965). During the autumn, capelin concentrations are found in cold water on or near the edge of the coastal shelf in Div. 2J and 3K and on Hamilton Inlet Bank (Letaconnoux, 1967). Cod along the slope and on the bank have been reported to feed on capelin at this time (Rojo, 1958; Templeman and May, 1965), and unpublished data from surveys of the area in 1979 and 1980 indicated that Atlantic cod were feeding on capelin and Arctic cod (*Boreogadus saida*).

The limited data available indicate that capelin may be associated with the cold stream of the Labrador Current for much of the year and that much of the predation by cod on capelin occurs within or near the lower boundary of this cold water layer. Although cod appear to prefer water temperatures higher than 0° C, particularly in winter, their ability to withstand temperatures below 0° C is well documented (Thompson, 1943; Templeman and Fleming, 1955; Harden-Jones and Scholes, 1974). Lee (1952) reported cod feeding on capelin in cold water (<0° C) on the Spitsbergen Shelf. An important exception to this interaction at the lower boundary of the cold water layer occurs when cod prey on capelin in shallow solar-warmed water both inshore and offshore during the capelin-spawning season (Templeman, 1965).

The availability of capelin to cod on northern Grand Bank in winter may in part explain why the growth of cod in Div. 3L exceeds that in Div. 2J. This difference in growth (Fleming, 1960) has been attributed to differences in temperature (May *et al.*, 1965), there being a trend from north to south of increasing surface temperature and decreasing volume of cold Labrador Current water. However, in both areas, cod overwinter in the deep warm water along the slopes of the banks but in spring and summer many cod migrate to shallower warm water above the intermediate cold

layer. Templeman (1979) noted that cod overwintering in deep water on the bank slopes off Labrador appear to have little food available. Presumably, most capelin are in cold water much nearer the coasts of Labrador and northeast Newfoundland. In contrast, cod on northern Grand Bank can prey on capelin in winter, and cod on the northwestern Grand Bank and in the Avalon Channel can prey on capelin in the spring (Seliverstov and Kovalev, MS 1976; Lilly and Fleming, 1981). Cod on the northeastern and eastern slopes of Grand Bank have access also to sand lance in winter and spring. Thus, the period of availability of food, particularly capelin, appears to be longer in Div. 3L than in Div. 2J. This probably results in greater annual food consumption and hence explains the higher growth rate of cod in Div. 3L.

The presumed concentration of capelin and sand lance within the cold core of the Labrador Current also has implications for the feeding behavior of other piscivores, particularly American plaice (*Hippoglossoides platessoides*), and Greenland halibut (*Reinhardtius hippoglossoides*). American plaice are most abundant in cold water (Templeman, 1966) and presumably can prey on capelin and sand lance without extensive migration. Pitt (1973) found that sand lance was the major prey (by weight) of American plaice in Div. 3N and that sand lance and capelin were the major preys in Div. 3L. Greenland halibut are most abundant in the warmer water below the cold Labrador Current, but the significance of capelin in their diet (Lear, MS 1970) indicates that they migrate vertically in pursuit of capelin. Predation by Greenland halibut on capelin in Trinity Bay was reported by Lear (MS 1970) to be most intensive in winter when the prey were concentrated in deep cold water, as noted above.

The data presented in this paper and the review of other studies indicate that the Labrador Current produces a vertical habitat stratification of the major commercial bottom fishes and their prey in the Newfoundland area. This stratification may be particularly important to the trophic interaction between cod and capelin. More detailed studies are required to determine if capelin, and particularly sand lance, are indeed concentrated pelagically in cold water which overlies warmer, more saline water, and if cod living in this warmer water do prey on capelin and sand lance by migrating vertically. In addition, the intensity and seasonality of this feeding pattern should be investigated to determine its contribution to the annual food consumption by the cod stocks and to the mortality imposed upon the capelin and sand lance stocks.

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