Diurnal Feeding of Juvenile Cod (*Gadus morhua*) which Migrate into Shallow Water at Night in Eastern Newfoundland

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Abstract

In Bonavista Bay, Newfoundland, juvenile cod (*Gadus morhua*) (age-group-0 and -1) were found to move into shallow water at night, where they mostly rested near the bottom. This nocturnal inshore migration was not associated with feeding, as stomach contents data suggested that feeding takes place mainly during the day, with little or no feeding at night. Most prey were planktonic, even in age-group-1 cod. This contrasted with earlier studies in Conception Bay, Newfoundland where age-group-1 cod were mainly obtaining benthic prey. These results suggested that juvenile cod predation on benthic invertebrates was likely to be patchy in space and time. Results are discussed in view of previous knowledge of the dietary and activity patterns of juvenile cod from elsewhere.

Introduction

The inshore waters off Newfoundland probably are important as nursery areas for juvenile cod (*Gadus morhua*) of the severely depleted Labrador-East Newfoundland cod stock-complex (Lear and Wells, 1984; Keats *et al.*, 1987; Keats, 1990). Despite the economic importance of this stock, and its recent history of over-fishing (Anon., 1992), it is only within the last few years that the ecology and behaviour of juveniles in inshore nursery areas have begun to be studied (Brown *et al.*, 1989; Clark and Green, 1990; Keats *et al.*, 1987, Keats, 1990, Lear *et al.*, MS 1980). Knowledge of the ecology of juvenile cod is of particular importance as it has been suggested that the abundance of juveniles is a good indicator of year-class strength (Campana *et al.*, 1989), and interest has been shown in using the near-shore abundance of juveniles to predict fishery recruitment (Keats, MS 1986; Lear *et al.*, MS 1980).

Keats (1990) documented a nocturnal migration of juvenile cod into shallow water in Bonavista Bay, Newfoundland, but did not determine if the migration was related to feeding. Data presented by Keats *et al.* (1987) suggest that juvenile cod fed diurnally in Conception Bay, Newfoundland, while European workers have shown that juvenile cod were nocturnal or crepuscular feeders (Arntz, 1973; Pihl, 1982, Zarkeschwari, 1978).

The diet of juvenile cod has been fairly well studied. Most studies have shown that juvenile cod switch from feeding mainly on plankton to feeding mainly on benthic organisms as they change from a pelagic to a demersal existence (Hawkins *et al.*, 1985; Keats *et al.*, 1987, Palsson, 1983, Robb, 1981; Syoseva and Degtereva, 1965). Nevertheless, much can still be learned about variation in the importance of different food items, as well as variation in the potential impact of juvenile cod on the nearshore benthos.

The purpose of the present work is to answer the following questions: Do juvenile cod (age-group-1) feed at night when they migrate into shallow water in eastern Newfoundland? What are their main prey types in this area? What is their main source of prey (planktonic, epiphytic or benthic)?

Materials and Methods

All samples were taken at Newman Sound, Terra Nova National Park, Bonavista Bay, Newfoundland (Fig. 1) between 17 May and 18 August, 1986. Juvenile cod collected during the day were obtained by shooting them with a spear gun through the vertebrae, behind the skull to minimize damage to the otoliths or stomach. All specimens were taken by one diver (DWK) and, by always spearing the fish closest to the diver, care was taken to avoid a size bias. Use of a tremmel net, a shrimp trawl, a
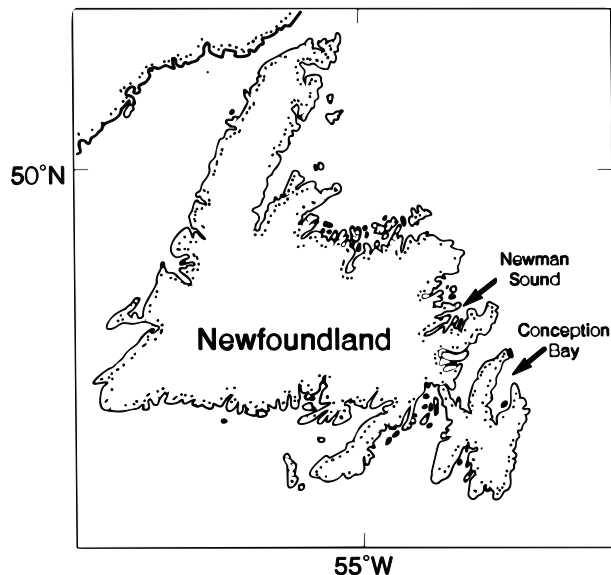
Fig. 1.   Map showing the location of the study site at Newman Sound, Bonavista Bay, and Conception Bay, Newfoundland.

beach seine, a small gill net and a hook and line all proved ineffective at catching juvenile cod. The tremmel net quickly filled up with cunners (*Tautogolabrus adspersus*), the cod could swim faster than we could tow the shrimp trawl, a beach seine cannot be worked on a rocky bottom, and hook and line was swamped with cunners. Spearing such small fish at night is impossible. The small cod are most docile at night, so they were forced to swim into a collecting bag using a diving light to guide them. Any differing size bias which may have been present between the two sampling methods (Table 1), were unlikely to affect the conclusion made here, especially since most samples were taken at night.

The following analysis was performed on each fish: fork length was measured to the nearest 1.0 mm, otoliths were removed for age determination,

TABLE 1.   Number of juvenile cod collected in different length classes integrated from two sample periods (number in parentheses is % of total sample for given time period).

Length (cm)	Time	
	0600–2230 hours	2300–0430 hours
60–80	7 (18)	34 (18)
85–100	4 (11)	64 (34)
105–120	15 (39)	70 (37)
125–140	10 (26)	14 (7)
145–160	2 (5)	6 (3)
Total	38	188

and stomachs were preserved in 70% ethanol. For age readings, otoliths were broken transversely and examined under either transmitted or reflected light, or both. Stomach contents were examined under a dissecting microscope. A rank scale was used to analyze stomach contents (Keats *et al.*, 1987; Keats and Steele, 1990), because we were primarily interested in determining where the fish obtained their prey, and because of the small size of both the cod stomachs and the prey which they contained. Fullness was estimated on a scale of 0 (empty) to 4 (distended), the degree of digestion on a scale of 1 (fresh) to 4 (well digested remains, identifiable only to general taxonomic groups). Food items were classified into three categories: planktonic (calanoid copepods, carid shrimp zooea, cirriped cyprids, fish eggs and larvae, *Oikopleura* sp., hyperiid amphipods and medusae), epiphytic (associated with fleshy macroalgae; harpacticoid copepods and several gammarid amphipods) or benthic (found on the bottom rather than on the algae; gastropod molluscs, carid shrimp, bottom-living mysids, several gammarid amphipods, cumaceans and annelids). The classification of food items into the pelagic, epiphytic or benthic categories, are based on personal observations and unpublished studies of the prey taxa. The stomach contents were sorted under a dissecting microscope, and the proportion each food type formed of the total volume was estimated on a scale of 1 to 10. For example, if there were two food types with equal amounts then each was scored as a 5, but if one type was estimated to be nine times the volume of the other, the former would be scored as 9 and the other as 1. If only one type of food was found, it was scored as 10. The importance of each type of food was then calculated as the rank of relative volume times the fullness rank of the stomach. Results are expressed both as frequency of occurrence (i.e. percentage of fish containing that type of food), and as importance (i.e. by summing the individual importance values, and calculating the percentage each makes of the total). To examine changes in diet with size, the fish were divided into five size categories (30–55, 56–95, 96–125, 126–165, 166–235 mm), chosen to provide a reasonable number of specimens in each category, and to facilitate comparison with our previous data (Keats *et al.*, 1987).

Results

Diel feeding pattern

The limited data available from mid-day suggested that feeding continued throughout the day, so that all measures of total contents were highest in early evening (Fig. 2). Little or no feeding took place at night, as the mean degree of digestion of food in juvenile cod stomachs increased through the night, being greatest in the early morning (Fig.
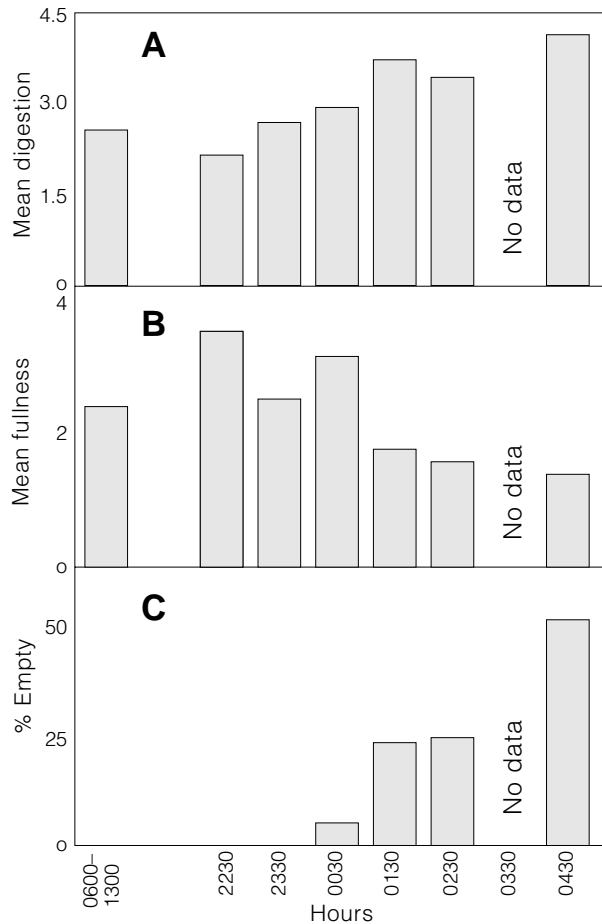
Fig. 2. Mean degree of digestion (**A**), mean fullness (**B**), and percent with empty stomachs (**C**) at different times of the day for juvenile cod from Bonavista Bay, Newfoundland.

2A). The mean volume of stomach contents decreased through the night, and was lowest in the early morning (Fig. 2B). The percentage empty stomachs also increased through the night, being highest in the early morning (Fig. 2C).

Prey type

Most fish examined contained food (Table 2). Crustaceans were the most important prey in all size groups of cod examined, and calanoid copepods were the most important crustaceans by both percent occurrence (Table 2) and relative importance (Table 3). Amphipods and cyprid larvae had a fairly high incidence of occurrence, but were relatively unimportant overall. The only obvious change in prey type with increasing size was a higher incidence of *Oikopleura* sp. and medusae in the larger fish. However, this may have been a reflection of the small sample size for the larger individuals. It is unlikely that any significant prey items were missed

as there was very little unidentifiable material in the cod stomachs (Table 3).

Prey source

An analysis of the source of the prey items (i.e. planktonic, epiphytic or benthic) revealed that the juvenile cod of all size groups primarily fed on plankton (Table 4). Of minor importance were epiphytes and benthic prey. A comparison with samples of juvenile cod taken during 1983 in Conception Bay (data from Keats *et al.*, 1987), revealed that the fish sampled in 1986 in Bonavista Bay (in this study) persisted on a pelagic diet to a much greater degree as they grew larger than did fish sampled during the same season in Conception Bay in 1983 (Fig. 3).

Size and growth

Analysis of the size frequency distributions showed a mode consistently moving to the right indicating that growth occurred throughout the study period (Fig. 4). By late July and early August the first young-of-the-year had appeared. Calculations based on mean size at each time suggested a growth rate of 0.62 mm-per-day for age-group-1 fish in summer.

Discussion

Time of feeding

The results presented here strongly suggest that the nocturnal migration into shallow water by juvenile cod (Keats, 1990) does not take place for feeding. Feeding evidently takes place during the daytime, which is consistent with the observations of Keats *et al.* (1987) in Conception Bay, Newfoundland.

This diurnal feeding, followed by night-time quiescence in shallow water, in the primarily age-group-1 cod studied here contrasts markedly with the results of sonic tagging studies on older, larger juveniles in Conception Bay (Clark and Green, 1990). Age-group-3 cod were active nocturnally in shallow, warmer water, but rested during the day in deeper, colder water in summer (Clark and Green, 1990). The diel activity pattern of these older juveniles was reversed in autumn, following the breakdown of the thermocline.

Other studies have also suggested that juvenile cod feed at night, rather than during the daytime. Settled age-group-1 cod were reported to rest near the bottom during the day, and to feed in the water column near the bottom at night on Georges Bank (Lough *et al.,* 1989). In Swedish waters individuals

TABLE 2.   Percent occurrence of prey taxa in stomachs of 5 size-groups of juvenile cod from Bonavista Bay.

Taxon	Size group (mm)				
	30–55	56–95	96–125	126–165	166–235
Crustacea	100	96	98	75	29
Harpactacoidea	30	17	2	0	0
Calanoidea	85	89	84	58	14
Shrimp larvae	25	30	22	25	14
Shrimp adults	0	0	0	5	14
Cyprid larvae	5	13	16	30	14
Amphipods	5	14	18	13	0
1. *Ischyrocerus anguipes*	5	0	1	0	0
2. *Apherusa megalops*	0	2	0	0	0
3. *Bathymedon obtusifrons*	0	1	1	0	0
4. *Pontogeneia inermis*	0	1	2	0	0
5. *Crophium bonelli*	0	4	2	0	0
6. *Calliopius laeviusculus*	0	0	1	0	0
7. *Photis* sp.	0	0	1	0	0
8. *Metopella carinata*	0	0	2	0	0
9. *Phoxocephalus inflatus*	0	0	1	0	0
10. Hyperiid amphipods	0	1	6	8	0
Cumacea	0	2	3	0	0
Mysidea	0	0	6	8	14
Gastropoda	0	2	0	0	0
Pteropoda	0	0	6	5	0
Polychaeta	5	4	9	5	0
Fish eggs & larvae	5	4	14	5	0
Medusae	0	1	1	8	14
Oikopleura sp.	0	2	8	13	43
No. Examined	24	128	121	24	7
% with food	96	98	91	100	100

in the size range 150–370 mm fed mainly between dusk and dawn (Pihl, 1982). Data from Kiel Bay, suggested that age-group-0 and -3 cod fed mainly around sunset and sunrise (Arntz, 1973). Pelagic age-group-0 cod fed at night in the northern North Sea (Robb, 1981). These conflicting results suggest a flexibility in diel activity patterns, perhaps related to what Eriksson (1978) has termed "flexibility in fulfilling ecological needs in a semi-opportunistic way".

Whatever the implications of these conflicting results, there is no doubt that the pattern which we observed here is real. Juvenile cod were rarely encountered in shallow water during the daytime, but were found in all habitats sampled at night (Keats, MS 1986; 1990). They were remarkably evenly distributed at night, and the coefficient of variation of transect samples was relatively low (Keats, MS 1986; 1990). Except around sunset when they were arriving in shallow water, and sunrise when they were departing, they were seldom observed to be moving at night if not disturbed (Keats, unpublished observations).

Habitat use

Studies of diel changes in habitat have also given conflicting results. Juvenile cod (included age-group-0, but mainly age-group-1) were abundant in seaweed beds in the daytime in Conception Bay (Keats *et al.*, 1987). No such strong relationship with algae during the day existed in Newman Sound (Keats, MS 1986), although juvenile cod were occasionally observed in seaweed beds. Juvenile cod were only abundant in shallow water at night in Newman Sound (Keats, 1990). As mentioned, age-group-3 cod seem to spend the day resting in deeper, colder water, and move into shallow water at night (Clark and Green, 1990). The

TABLE 3. Relative importance of prey taxa in stomachs of 5 size-groups of juvenile cod from Bonavista Bay.

| Taxon	Size group (mm)				
	30–55	56–95	96–125	126–165	166–235
Crustacea	99.1	95.2	83.4	87.7	22
Harpactacoidea	10.7	6.2	0.6	0	0
Calanoidea	74.3	71.4	61.6	64.1	1.5
Shrimp larvae	13.0	11.1	9.2	5.8	7.5
Shrimp adults	0	0	0	6.8	10.0
Cyprid larvae	0.4	2.1	5.8	8.6	1.5
Amphipods	0.6	3.3	2.3	0.9	0
Cumacea	0	1.1	0.6	0	0
Mysidea	0	0	3.2	1.5	1.5
Gastropoda	0	0.5	0	0	0
Pteropoda	0	0	0.7	0	0
Polychaeta	0.4	1.2	4.4	0.6	0
Fish eggs & larvae	0.4	0.6	6.2	0.4	10.1
Medusae	0	0	0	1.9	20.1
Oikopleura sp.	0	0.7	4.3	7.5	42.7
Unidentifiable	0	1.6	1.4	2.9	5.0
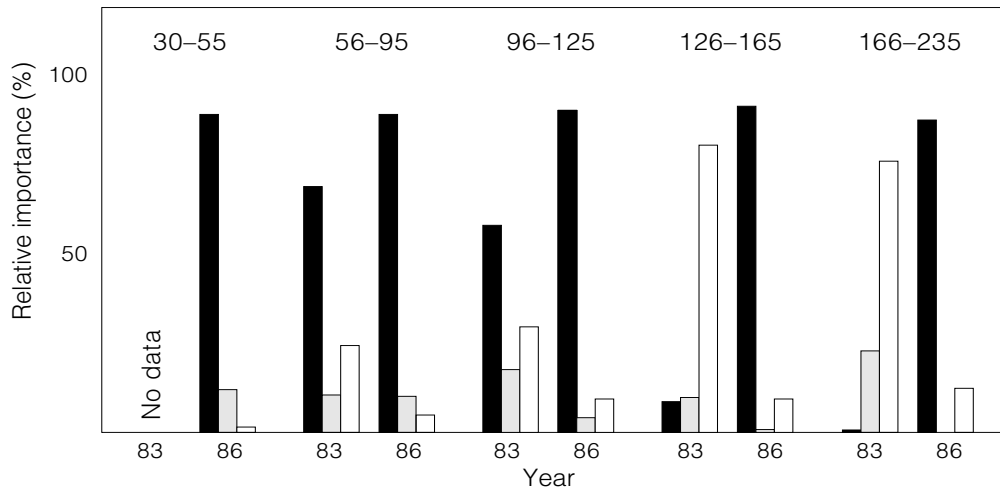
Fig. 3.   Relative importance of pelagic (solid), epiphytic (stippled) and benthic (open) prey in the stomachs of juvenile cod from Conception Bay (1983 data from Keats *et al.*, 1987), and Bonavista Bay (1986 data). Numbers above the histograms indicate the size group (mm) of the juvenile cod.

nocturnal feeding at Sweden occurred when the juveniles moved into a shallow bay at dusk, and moved out again at dawn (Pihl, 1982). No diel migration was reported in Kiel Bay (Arntz, 1973; Zarkeschwari, 1978). These observations again suggest flexibility in patterns of habitat use.

TABLE 4.   Percentage importance (calculated form amount X fullness) of pelagic, epiphytic and benthic prey items for each of the 5 size-groups of juvenile cod examined from Bonavista Bay.

Taxon	Size group (mm)				
	30–55	56–95	96–125	126–165	166–235
Pelagic					
Calanoidea	74.4	73.1	62.0	62.6	1.6
Shrimp larvae	13.0	11.4	9.2	5.7	7.9
Cyprid larvae	0.4	2.2	5.8	8.4	1.6
Hyperiid amphipods	0	0.3	0.8	0.9	0
Pteropoda	0	0	0.7	0	0
Fish eggs & larvae	0.4	0.7	6.2	0.4	10.6
Medusae	0	0	0	5.1	21.2
Oikopleura	0	0.7	4.1	7.7	45.0
Total Pelagic	88.3	88.4	88.8	90.8	87.9
Epiphytic					
Harpactacoida	10.7	6.4	0.6	0	0
Amphipoda	0.6	2.3	1.8	0.6	0
Total epiphytic	11.3	8.7	2.4	0.6	0
Benthic					
Amphipoda	0	0.1	0.7	0	0
Cumacea	0	1.0	0.6	0	0
Mysidae	0	0	3.2	1.5	1.6
Shrimp adults	0	0	0	6.6	10.6
Gastropoda	0	0.5	0	0	0
Polychaeta	0.4	1.0	4.3	0.6	0
Total benthic	0.4	2.6	8.8	8.7	12.2

It is difficult to resolve these conflicting results, although it seems evident that juvenile cod have a flexible diel cycle of feeding activity and habitat utilization. Clark and Green (1990, p. 1435) stated that "whether these differences in behaviour are due to ontogenetic, seasonal and/or population differences is unknown." One possible explanation relates to the possible predation of older stages on younger stages.

Cod are cannibalistic, and larger juveniles (e.g. age-group-3) can feed on smaller juveniles (e.g. age-group-1), and adults can feed on all younger groups (Schroeder, 1930). Given their cannibalistic nature, it would be adaptive for the smaller stages (age-group-0 and -1) to segregate from the larger stages (age-group-3 and -4, and adults). Further-more, it would be adaptive for the larger juveniles to segregate from the adults. This segregation could occur in space, by habitat or depth, and in time, by season or time of day. Segregation of cod of differ-ent ages is well known. For example, older cod (aged 10–20 years) apparently remain in a very deep water layers which is warmer than the water at intermediate depths (Templeman, 1966). Younger adults and older juveniles evidently overwinter in this deeper water, and move into shallow water in spring. In the inshore area of the southern Gulf of St. Lawrence, groups of cod of adjacent ages were found together consistently from year-to-year (e.g. 2–3, 4–5, 6–8, 9–11 year old groups), but not neces-sarily in the same geographical area (Tremblay and Sinclair, 1985). Flexibility in this segregation could explain these apparently conflicting results. For the present, however, these ideas must remain in the realm of speculation, and other hypotheses may be equally plausible.

Prey and predation

All size groups of juvenile cod examined in this study fed primarily on planktonic crustaceans, mainly copepods.   This contrasts with the trend of in-creased benthic feeding with increased size re-ported from Conception Bay in 1983 (Keats *et al.*, 1987), and from offshore waters of Iceland (Palsson, 1983). The dietary composition of cod is apparently determined largely by availability (Daan, 1978),
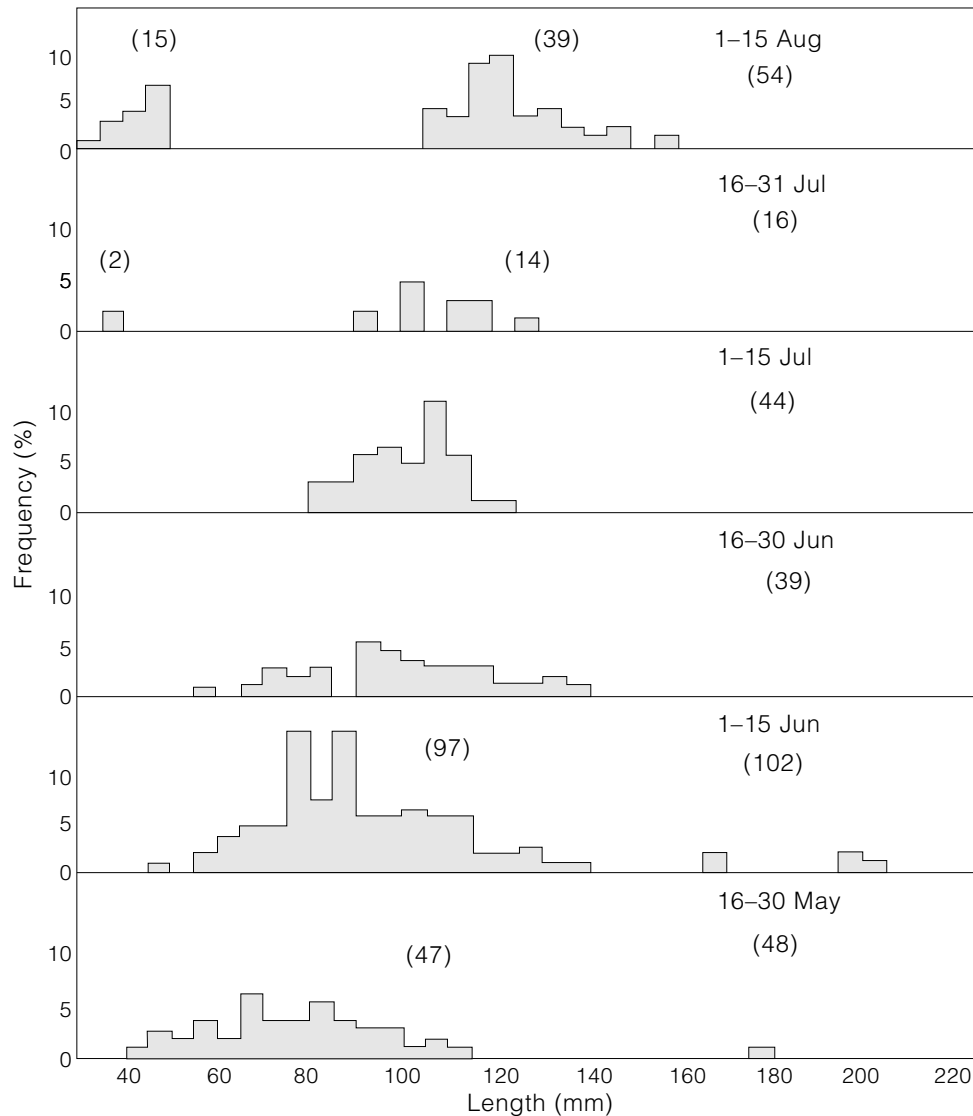
Fig. 4.   Size frequency distributions for the juvenile cod sampled from Bonavista Bay, Newfoundland. Numbers in parentheses indicate the number of individuals in each sample.

which could explain these differences. If this is so, then it seems likely that the impact of juvenile cod on small benthic invertebrates would be patchy in space and time. Since juvenile cod are often very abundant, such variable predation on the benthos could contribute to patchiness of benthic invertebrate populations in space and time. This possibility requires experimental evaluation.

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