NAFO Sci. Coun. Studies, 29: 3–12

Distribution of Juvenile Atlantic Cod (*Gadus morhua*) Relative to Available Habitat in Placentia Bay, Newfoundland

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Abstract

The availability of suitable habitat for, and the use of this habitat by, juvenile Atlantic cod (*Gadus morhua*) in Placentia Bay, Newfoundland during 1995 were investigated. Availability of habitat was established both by deep sea submersible (PISCES IV and SDL-1) and by a groundtruthed QTC View integrated acoustic seabed classification system. Habitat use of age 1 to 4 year old juvenile cod was conducted in April 1995 using submersibles. A total of 40 hours of "on-bottom" videotape, audiotape, and written records from 13 day dives and two night dives were analysed. Habitat types were characterized by depth, substrate particle size, bathymetric relief, and the presence or absence of macroalgae. The agreement between visual assessments of bottom type and those derived from echo sounder signals was good. Substrate selection by juvenile cod was age specific. Eighty percent of age 2–4 juvenile cod were found to be associated with areas of coarse substrate and high bathymetric relief (i.e., submarine cliffs). In contrast 59% of age 1 cod were found primarily in areas with a gravel substrate and low relief. Juvenile cod of neither age group exhibited selection for substrates with macroalgae cover. By integrating information on the substrate associations of juvenile cod with acoustically sampled bottom classification data over a broad area (15 nm^2), it was determined that the amount of suitable habitat for juvenile cod was a small portion of that available and the location of suitable habitat was age specific. Such information should refine the use of juvenile survey data and help to determine survey designs.

Key words: bottom classification, coastal bays, echo sounders, habitat selection, PISCES IV, SDL-1, QTC View, submersibles

Introduction

The 1995 Newfoundland Regional Groundfish Stock Assessment Review (Shelton 1996) suggested significant initiatives toward establishing a cross survey index of pre-recruit abundance for Atlantic cod (*Gadus morhua*). The survey measures considered for incorporation into this index were the nearshore "*Fleming*" survey (Schneider *et al.*, MS 1995), the demersal juvenile survey (Dalley and Anderson, MS 1995), and the pelagic 0-group survey (Anderson and Dalley, MS 1995). This cross survey approach was considered appropriate primarily because of the large variance inherent in data from each of these surveys and in the improved inference obtainable from multiple indicators of relative abundance.

Pelagic juvenile cod distribution can be considered to be primarily a function of the time, amount and location of spawning, water temperature, prevailing currents, and wind speed and direction. Active directional "input" by eggs and larvae can be assumed to be negligible. However, demersal cod distribution may be considered a function of location of settlement by pelagic stages and subsequent habitat selection after settling.

Although the degree to which juvenile pelagic cod may "select" a location to settle is not known, a great deal is known about the degree of substrate selection among demersal stages. From laboratory work (Gotceitas and Brown, 1993) and nearshore field studies (Tupper and Boutilier, 1995), it is known that 0-group cod actively select specific substrate types, and that these selections determine growth rate and survival. Once settled, demersal 0-group cod appear to select bottom habitats consisting of various combinations of particle size and macroalgae cover (Keats *et al.*, 1987) in response to the presence or absence of actively hunting predators (Gotceitas *et al.*, 1995), such as older age-classes of cod. Current research on the northeast coast, primarily inner Newman Sound in Bonavista Bay, is directed at addressing problems of habitat selection and use by 0-group cod in the nearshore environment (Anderson *et al.*, MS 1996; Gotceitas *et al.*, MS 1996).

Similar knowledge of the substrate selection by age 1-group and older juvenile cod has been more difficult to obtain. The main difficulty has been due to the greater depth range occupied by these individuals. However, the limited information which is available is consistent. Ultrasonic tagging studies show that age 3-group cod in Conception Bay exhibit strong selection of specific bottom types which differs with the time of day (Clark and Green, 1990). During the day, these cod are mobile in deeper water (≈30 m). At night, they return to rocky areas and remain relatively stationary. Recent work conducted in April 1995 using the submersibles PISCES IV and SDL-1, has revealed that age 1 to age 4 cod in Placentia Bay also exhibit strong associations with specific combinations of bathymetric relief and substrate particle sizes (Gregory and Anderson, 1997). Their study also demonstrated that 1-group and older juvenile cod utilize substrate differently. Age 2 to age 4 cod were found in areas of high bathymetric relief (cliffs) and/ or coarse substrate (rock and boulder). In contrast, age 1 individuals were found most abundantly over gravel substrates. Much of the above substrate combinations represent "untrawlable" and "acoustically challenging" bottom types.

It is clear that efforts to assess the relative abundance of demersal juvenile cod are hampered by poor knowledge of where trawlable bottom "intersects" with habitat which is suitable for juvenile cod. Much of the applied nature of this problem lies in the previous inability to identify bottom and habitat type as well as its use by cod, in advance of performing surveys. Despite this shortcoming, demersal juvenile surveys have shown distinct trends of abundance and distribution (Dalley and Anderson, 1997), which facilitate potential estimates of the ranked relative strengths of year-classes between years. Improved knowledge of the habitat requirements of juvenile cod can only help to improve the estimates of their abundance.

The efficient identification of habitat has only become feasible in the past few years. The development of seabed classification techniques (QTC View and RoxAnn) using ship echo sounders have introduced a cost effective and time efficient way to acoustically "sample" and classify juvenile cod habitat. In this paper one such method is described, using the QTC View. The habitat data obtained acoustically is then integrated with detailed information on the substrate associations of age 1-group and older juvenile cod obtained by using the submersibles. In an area of Placentia Bay, integrated results are applied to "predict" the distribution of juvenile cod. We suggest that such approaches would be valuable toward focusing research effort and improving on the ability to estimate the abundances of demersal juvenile cod in synoptic surveys.

Methods

The study area was located near Long Island and Haystack Bank at the head of Placentia Bay, Newfoundland Canada (47°37'N latitude and 54°04'W longitude – Fig. 1). Cormorant Cove, is located off the eastern shore of Long Island in the above area, and is approximately 2.0 km north to south, and 1.5 km east–west. The cove has a maximum depth of 112 m.

Submersible Survey

PISCES IV and SDL-1 are deep sea, free-diving submersibles capable of operating at depths of 2 000 m and 610 m, respectively. During the course of the study, dive operations were generally limited to depths shallower than 150 m. The two submersibles were maintained aboard the Canadian Navy submarine tender vessel, HMCS Cormorant. Nine daylight dives and one nighttime dive were conducted during 4–5 April, and 22–25 April 1995 and four daylight dives and one nighttime dive during 30 October–1 November 1995.

Videotape records were collected continuously while the submersibles were on the bottom. These records were used as the primary means of identifying substrate type. Observations of substrate, macroalgae cover and bathymetric relief were analyzed from the videotape in 1.0 minute increments. Substrate was classified into six categories by particle size (diameter): mud/silt (<0.1 cm); sand/gravel (0.1–2.0 cm), pebble/cobble (2.0–25 cm), rock (25–100 cm), boulder (>100 cm), and bedrock. Macroalgae (primarily Irish moss and kelp) density was classified into broad categories by percentage of the bottom cover: none (<1%) sparse (1–5%), moderate (6–25%), dense (>25%). Bathymetric relief was classified as high (>10° slope) or low (<10° slope).

The presence of juvenile and adult cod was recorded as the number observed in each 1.0

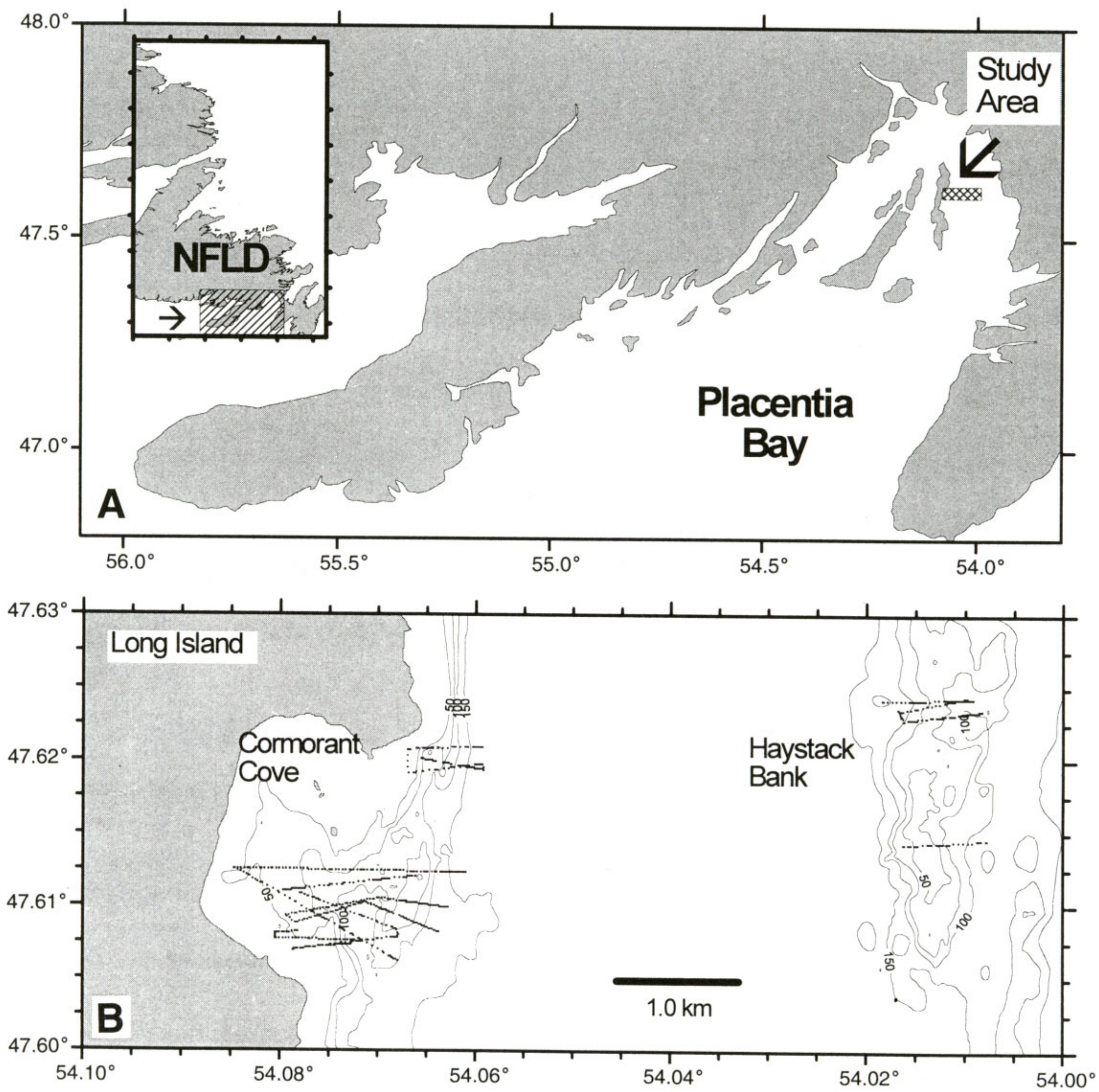

Fig. 1. (**A**) study area and (**B**) submersible dive tracks, in Placentia Bay Newfoundland, 21–25 April 1995 (bathymetry in m).

minute increment. Identification of age 1 juveniles and age 2–4 juveniles was based on size and coloration. Age 1 juveniles were approximately 10–12 cm long (total length), were mottled and brown to red in colour. Age 2–4 juveniles were longer than 15 cm and were more uniform in colour (usually grey or brown), but were not mottled. Size was estimated by using common bottom features (e.g. urchins, anemones, occasional bottles, cans and other debris) or by referencing background features against parts of the submersible.

QTC View Seabed Classification

The QTC View is an integrated acoustic signal processing system which analyses return echoes from a ship's echo sounder to describe the seabed. Each bottom return echo is digitally transformed and analyzed to provide 166 parameters describing signal shape and strength. These parameters are then reduced to three feature vectors (the first three principal components of a PCA). The signal processor then matches these three principal components (Q1, Q2 and Q3) to known "bottom signatures". These signatures are based on "calibration sites" with known bottom types, which have been identified *a priori* by the user. The resulting output is a classification of the seabed based on known bottom types.

In April 1995, the seabed in the Placentia Bay study area was visually sampled for the purpose of establishing calibration sites. This was done using the submersibles. These sites were then used to calibrate the QTC View to provide acoustic bottom classification signatures from the Simrad EQ100 echo sounder on board the *CSS Shamook* in October 1995.

Subsequent to collecting calibration data, the study area was systematically surveyed at a transect resolution of 0.1 naut. mile (maximum distance apart) in an east–west direction over a three day period in October 1995. Approximately 15 nm^2 of the seabed was acoustically sampled at this resolution, at intervals of 5 seconds at a survey speed of 4 knots. At 50 meters depth, the bottom "footprint" sampled by the echo sounder would have had an approximate radius of 4.4 m ($60m^2$).

Integrated Habitat and Distribution

In order to establish the utility of detailed knowledge of the use of habitat by juvenile cod, a preliminary analysis was conducted of the bottom classification data collected by the QTC View, weighted by the observations of habitat selection made from the submersible. This was accomplished as a multiplicative model of habitat choice (actual observations of presence and absence of juvenile cod and the expected observations based on habitat availability). The result was a weighted habitat index representing the likelihood of juvenile cod being present in a particular habitat type.

Results

Identification of Seabed Type by Submersible

The submersible survey established that the study area was heterogeneous with respect to bathymetric relief, substrate particle size, and presence of macroalgae (Fig. 2). Relief ranged from flat areas extending for several hundred meters to

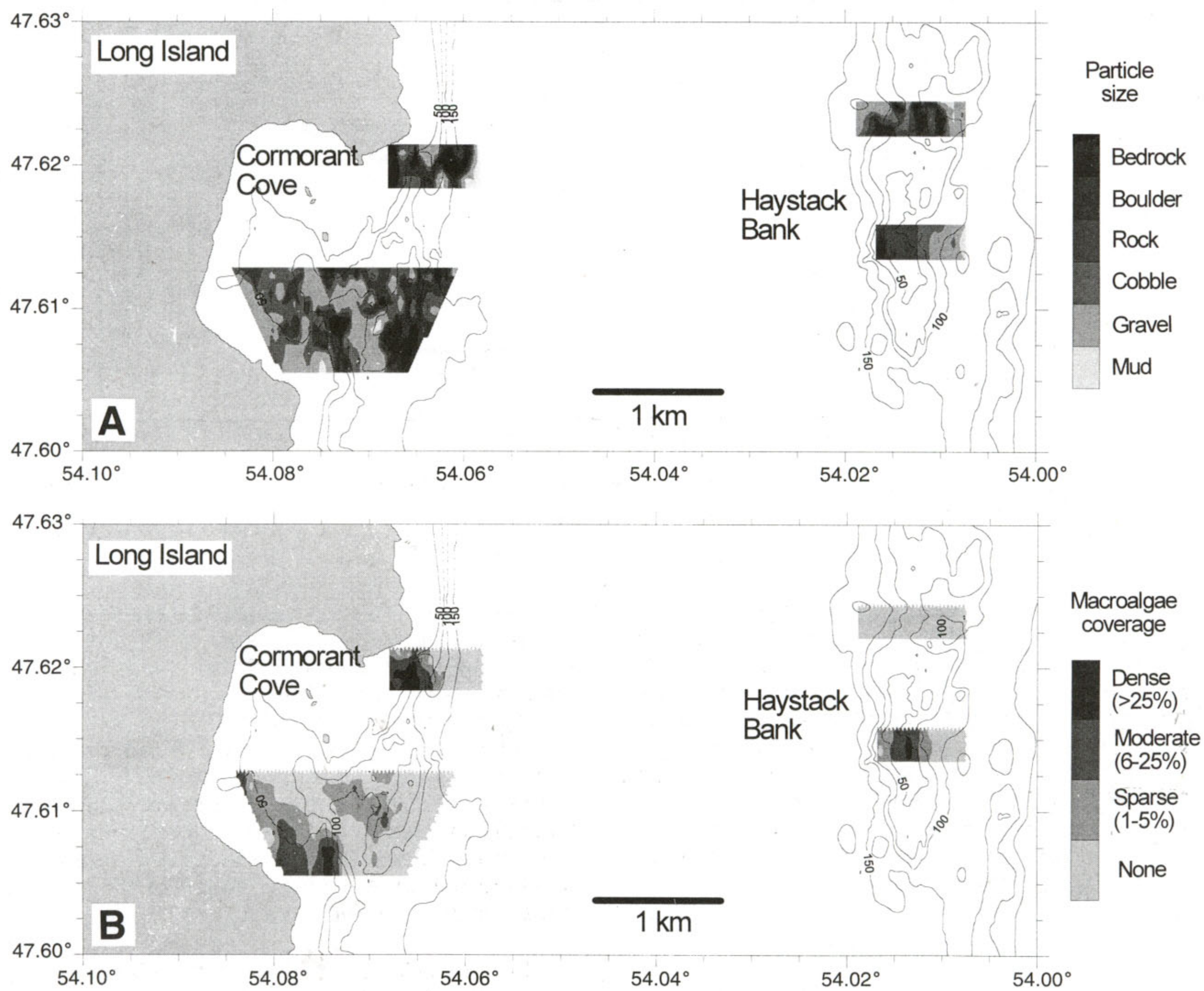

Fig. 2. (**A**) Substrate particle size (see text) and (**B**) percentage of macroalgae coverage, within the immediate vicinity of the four dive areas, and bathymetry of the study area, 19 April 1995.

cliffs rising 50 m from the sea floor. Within the immediate vicinity of the dive areas (two areas in Cormorant Cove and two areas on Haystack Bank), the bottom substrate varied in composition from mud/silt (<0.1 cm diameter) to bedrock. Areas of high relief ran in several series of cliffs and ridges oriented roughly parallel to shore. Much of the cobble, rock and boulder were found at the base and tops of these ridges and cliffs, which themselves consisted of bedrock. In much of the low relief areas, the substrate was dominated by gravel/sand deposits (0.1–2.0 cm diameter) with a fine layer of mud/silt. Substrate deeper than 200 m in this area was generally dominated by mud/silt. Macroalgae, including Irish moss (*Chondrus crispus*) and kelp (*Laminaria digitata* and *Agarum cribrosum*), was generally found at depths <40 m and in several locations approached 100% coverage of the bottom.

Classification of Seabed Type by QTC View

The QTC View trackplot of the study area (Fig. 3) matched the expectations from the submersible observations very well in the low particle size end (mud/silt – cobble). Coarser substrate types – rock, boulder and bedrock – were distinguishable from finer substrates, but not from one another using the calibration sites in the study area. In large part, this was due to the large degree of "contamination" among these substrate types throughout the study area. "Pure" substrate types at the large end of the particle size spectrum were not of sufficient area to be used as calibration sites. However, we have since found, that these signals can be post-processed to extract such information if required. For this study, such a procedure was not necessary. We also found that we could discriminate macroalgae "signatures" from the return echo signals. This degree of discrimination was not anticipated prior to our work in October.

Abundance of Juvenile Cod

Individual juvenile cod ranged in age from 1 to 4 years. Age 1 juveniles and age 2–4 juveniles were found throughout the study area (Fig. 4). Most juvenile cod were seen at depths greater than 60 m (Fig. 5).

Juvenile cod were not significantly associated with the presence of macroalgae (Fig. 6). On the contrary, the data suggested that age 1 cod neither associated with, nor avoided, macroalgae. Age 2–4 juveniles were significantly less frequent in areas with moderate to dense macroalgae than would be expected by chance (Chi-square = 4.63; $p < 0.05$; d.f. = 1; n = 50).

The presence of juvenile cod was significantly associated with specific combinations of substrate types and bathymetric relief (Fig. 7) and these associations were age specific (Chi-square $p < 0.001$; d.f. = 4; n = 83).

Integrated Habitat and Distribution Data

The results of the weighted habitat use index (Fig. 8) clearly indicated two main aspects of juvenile cod distribution within the study area in

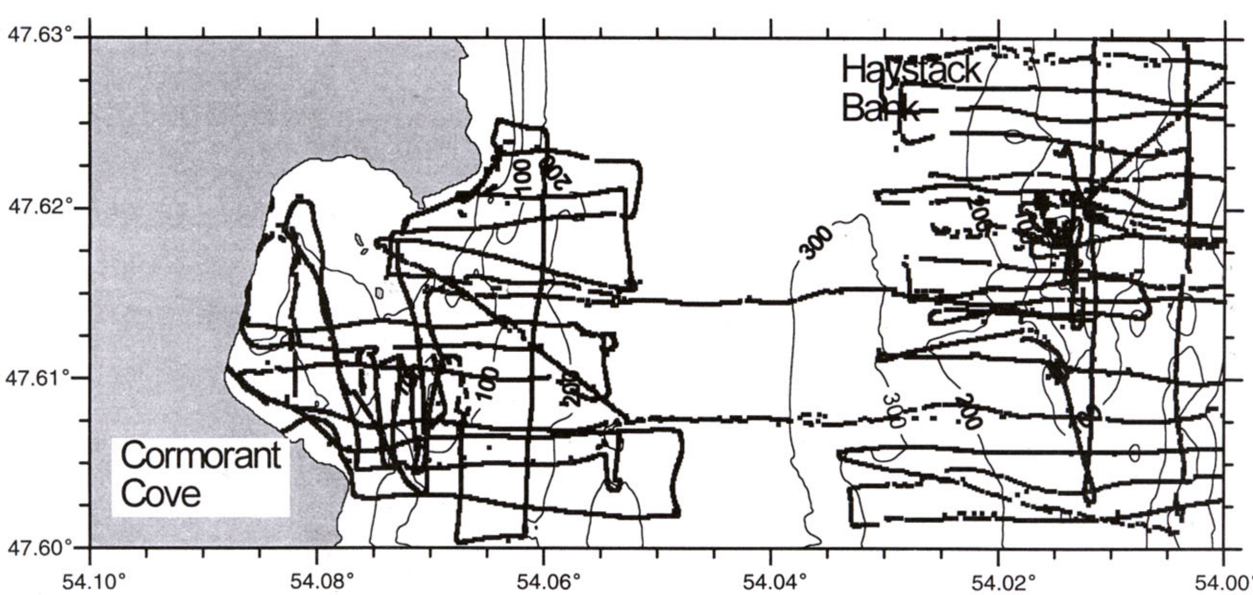

Fig. 3. QTC View track plot of Cormorant Cove and Haystack Bank, Placentia Bay, October 1995.

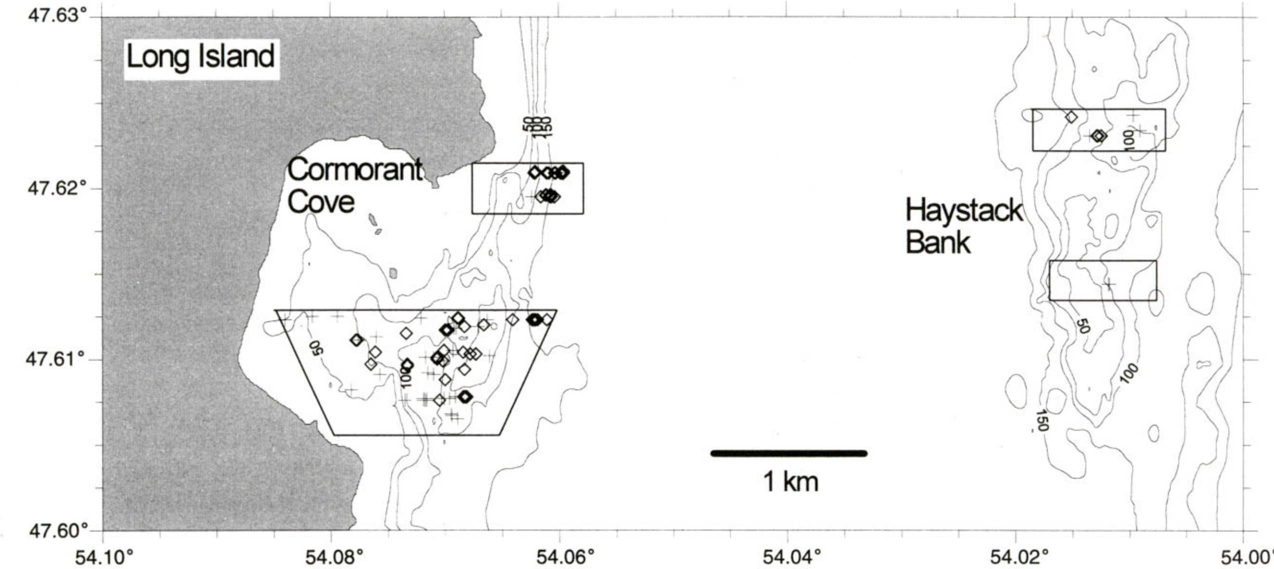

Fig. 4. Location of observations of individual young (+ age 1) and old (◊ age 2–4) juvenile cod in Cormorant Cove and Haystack Bank, April 1995, as confirmed by videotape analysis.

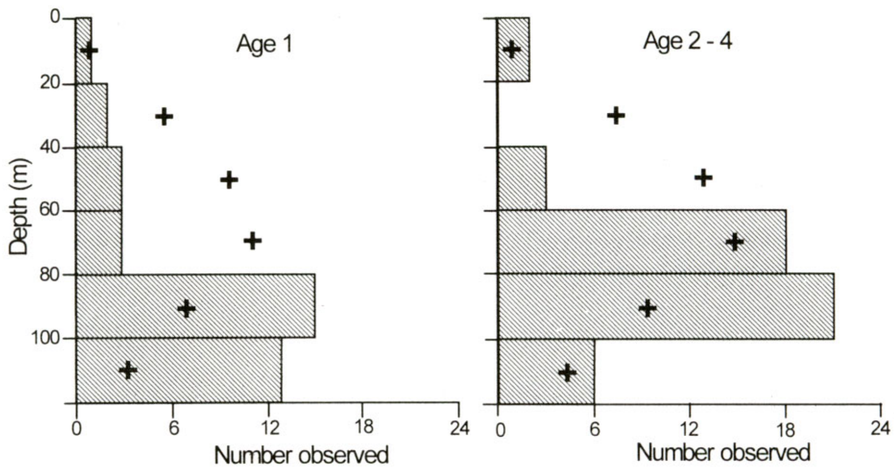

Fig. 5. Depth distribution of young (age 1) and old (age 2–4) juvenile cod in Cormorant Cove and on Haystack Bank, April 1995 (+ expected number of juvenile cod if their distribution was proportional to the frequency of occurrence of the depth stratum identified in the submersible survey).

Placentia Bay. First, of the habitat of all types available in the study area, only a small amount of it appeared to be suitable for juvenile cod. Second, although age 1 and age 2–4 cod tend to occupy the same general areas within the study area, the areas where they were most predominant exhibited only a modest degree of spatial overlap.

Discussion

Juvenile cod were observed throughout most of the range of depths traversed by the submersibles to a depth of 130 m, but they occurred most abundantly at 60–120 m. In Placentia Bay, age 1 and age 2–4 cod co-occurred laterally and

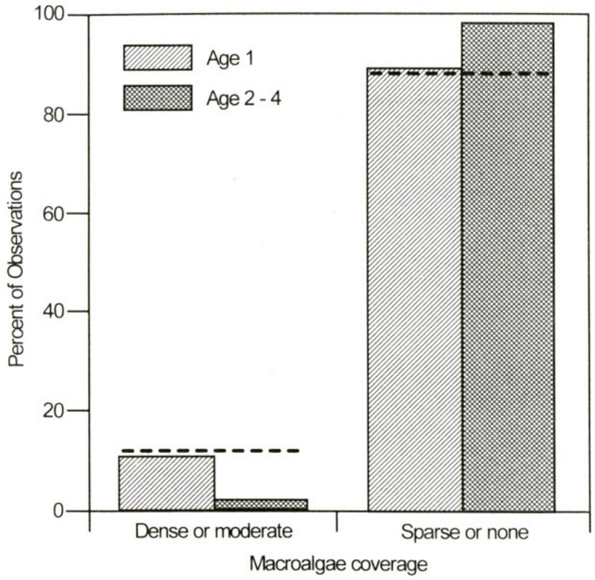

Fig. 6. Percent frequency of occurrence of young (age 1) and old (age 2–4) juvenile cod in areas of sparse/none and moderate/dense bottom coverage of macroalgae (kelp, *Laminaria digitata* or *Agarum cribrosum*, and Irish moss, *Chondrus crispus*), Cormorant Cove and Haystack Bank, April 1995 (— expected number of juvenile cod if their distribution was proportional to the frequency of occurrence of the algae coverage category identified in the submersible survey).

vertically within the study area. The depth range of juvenile cod distribution was also consistent with previous observations on shallow offshore banks (Lough *et al.*, 1989, Wigley and Serchuk, 1992, Walsh *et al.*, 1995). Observations of the distribution and substrate use of individual juvenile cod have generally been from shallow depths, less than 20 m (Keats *et al.*, 1987, Keats, 1990). However, juvenile cod (age 0–2) appear to occur regularly as deep as 100 m in coastal bays of Newfoundland and offshore onto the shelf (Dalley and Anderson, 1997). By tracking acoustically tagged cod inshore, Svendsen (1995) observed that large age 1 juveniles (21–27 cm) inhabit depths ranging from 10–30 m inshore. In a tagging experiment, Pihl and Ulmestrand (1993) found that most age 1 cod were recaptured in less than 10 meters of water, close to shore. Nearshore studies (Methven and Bajdik, 1994) have shown that age 0+ cod are numerous in depths less than 5 m nearshore, but that abundance generally decreases from late summer to late autumn. Few older individuals were found within 70 m of shore in either of these studies. These observations suggest that age 0+ cod move deeper as they grow. Age 1 individuals in spring 1995, would have been age 0+ individuals the previous autumn. Therefore, our observations also support the contention that young cod move into deeper water over time.

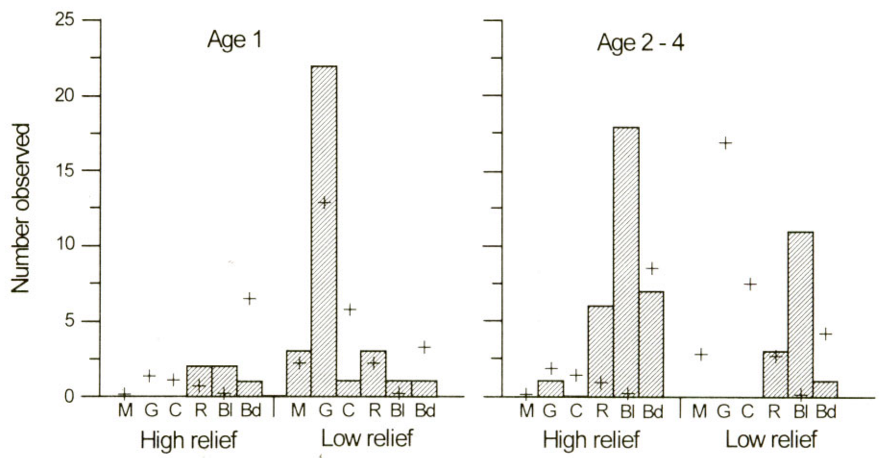

Fig. 7. Frequency of observations of young (age 1) and old (age 2–4) juvenile cod in areas of bottom habitat in Cormorant Cove and Haystack Bank, April 1995, as defined by bathymetric relief and substrate particle size (substrate categories; M – mud/silt, G – gravel/sand, C – cobble/pebble, R – rock, Bl – boulder, Bd – bedrock; + expected number of juvenile cod if their distribution was proportional to the frequency of occurrence of the substrate and bathymetry conditions identified in the submersible survey).

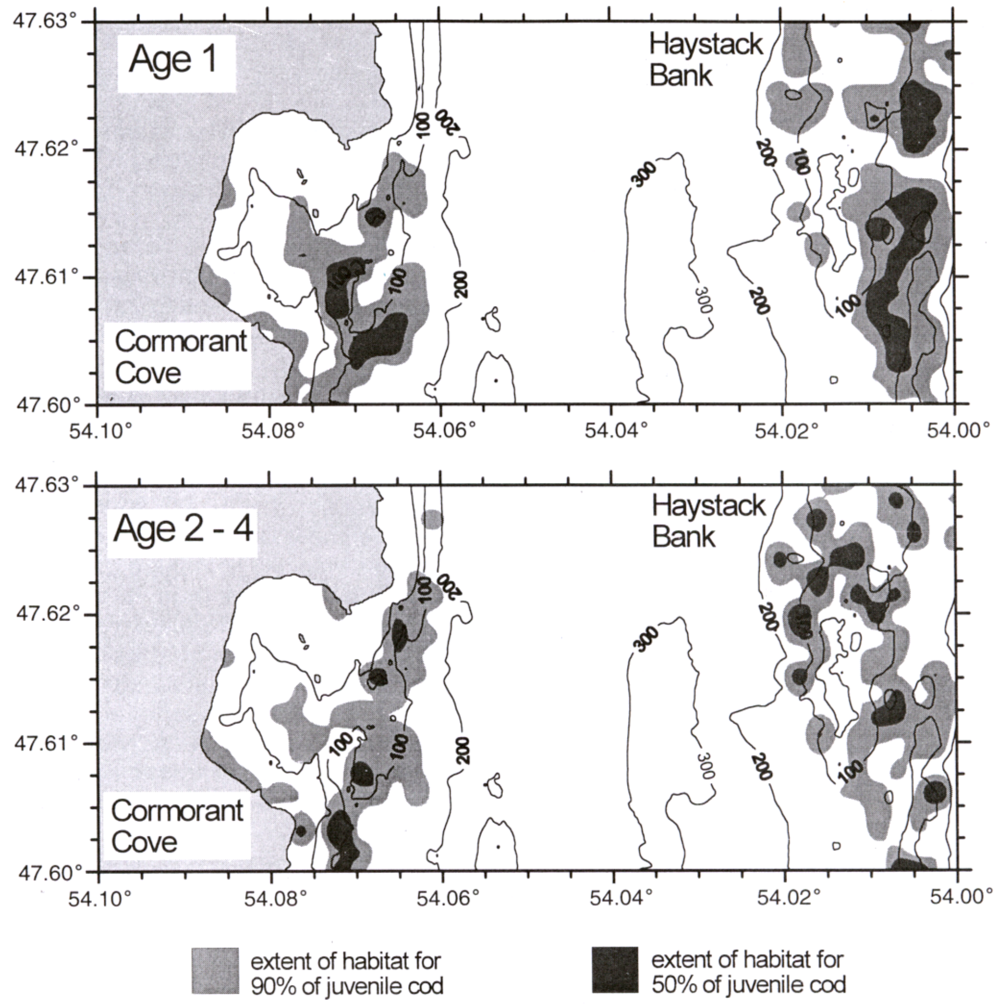

Fig. 8. Distribution of suitable habitat for age 1 and age 2–4 juvenile cod in spring, based on QTC View classification of habitat type weighted by observations of the habitat associations of juvenile cod made during submersible operations in Placentia Bay, April 1995.

Laboratory studies have shown that age 0 and 1 juvenile cod exhibit preferences for specific types of substrates based either on particle size or the presence of vegetation (Gotceitas and Brown, 1993, Gotceitas *et al*., 1995; Fraser *et al*., 1996). In these studies, it has also been shown the presence or absence of a predator (an older conspecific) can alter these preferences. Substrate preference is a potent force shaping the distributions and survival juvenile cod (Lough *et al*., 1989; Gotceitas and Brown, 1993; Tupper and Boutilier, 1995). Our results corroborated these findings. Older juveniles in this study were rarely present over gravel substrate, but were associated instead with areas of high bathymetric relief and coarser substrates (rock and boulder). In contrast, age 1 cod were observed predominantly over gravel substrates, similar to observations by Lough *et al*. (1989).

A priori, we had expected to see more juvenile cod in association with macroalgae cover than in its absence. However, the results demonstrated that macroalgae is neither avoided or preferred by age 1–4 juvenile cod. Keats *et al*. (1987) showed that fleshy macroalgae was a preferred habitat of juvenile cod (age 0–2) in shallow (<20 m) nearshore areas, during autumn. In the laboratory, Gotceitas *et al.* (1995) showed that the presence of kelp, as well as cobble, increases the survival of age 0+ cod in the presence of an actively foraging predator. These authors also demonstrated that macroalgae cover is only preferred in the presence, but not in the absence of, such a predator. It is possible that there were either few predators in the study area or that those present were inactive during our studies. Only three adult cod were observed during this study. All were inactive when encountered. The lack of a significant correlation between the presence of macroalgae and presence of juvenile cod suggests that juveniles associate with macroalgae only during the summer and autumn. It is not clear from published accounts whether juvenile cod use macroalgae primarily for feeding or for predator avoidance. However, it does appear clear from our results that macroalgae is not used for cover from predators during April, in Placentia Bay. The study area was heterogeneous with respect to substrate particle size and bathymetric relief. All substrate-relief combinations, with the exception of mud, were within ~200 m of each other. Therefore, there is little doubt that young and old juvenile cod actively selected the habitat where they were observed.

In this study, it is demonstrated that age 1–4 juvenile cod exhibit age-specific associations with substrate. From their patterns of activity in relation to cover, these fish appeared likely to be using specific substrate characteristics for protection from predators (Gregory and Anderson, 1997). These activity patterns also appeared to change with age, suggesting that the behaviourial mechanisms of predator avoidance for cod are also age-specific. These observations were consistent with those of other researchers working on young Atlantic cod in nearshore and offshore waters as well as the laboratory, but represent the first accounts of changes in substrate selection and use of available cover by juvenile cod, with age. The results suggest that substrate which is ideal for one age group of cod may be completely inappropriate for another.

These findings have significant ramifications on the design of research surveys for demersal juvenile cod and for the subsequent interpretation of collected data. Juvenile cod in Placentia Bay were associated within a specific range of habitat category combinations. Weighting these category combinations by the observations of individuals within them can provide an index of relative importance of that particular combination to juvenile cod. Knowing this, better informed decisions can be made of how relative abundances of juvenile cod obtained from specific sites in trawl and acoustic sampling surveys should be interpreted. For example, high numbers of age 1 cod in a "preferred" habitat would be expected. The same numbers captured in areas "not preferred" would suggest something completely different, e.g. it may be concluded that juvenile cod abundances were high in the general area, not necessarily just that site. Similar examples could be easily constructed inferring conclusions in the opposite direction. The ramifications of such findings on guiding sampling effort in research surveys is even more readily apparent – we would know where to look in the first place.

Acknowledgements

This study was financially supported by an award from the Environmental Innovations Program of Environment Canada and by the Interim Funding Research Program (DFO). Arnold Murphy, Eugene MacDonald, Gerard Conan, Dan Porter and Greg Redmond of DFO contributed invaluable scientific observations, enthusiasm and technical support. We also appreciated technical conversations with Bill Collins at Quester Tangent Corporation. We extend our gratitude to the Commanding Officer, LCDR John Creber, and the crew of the HMCS Cormorant and the pilots of PISCES IV and SDL-1 submersibles. This paper is Ocean Sciences Centre contribution number 280.

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