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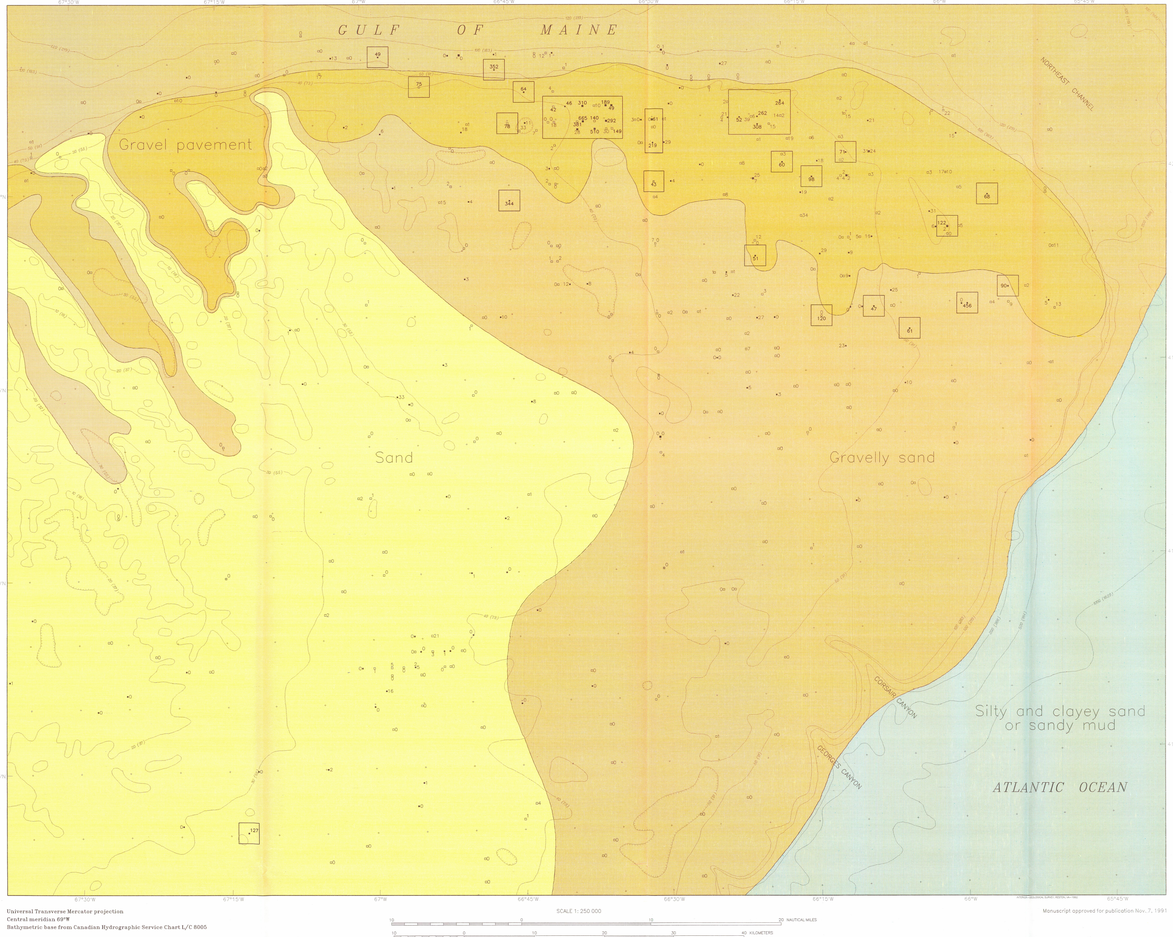
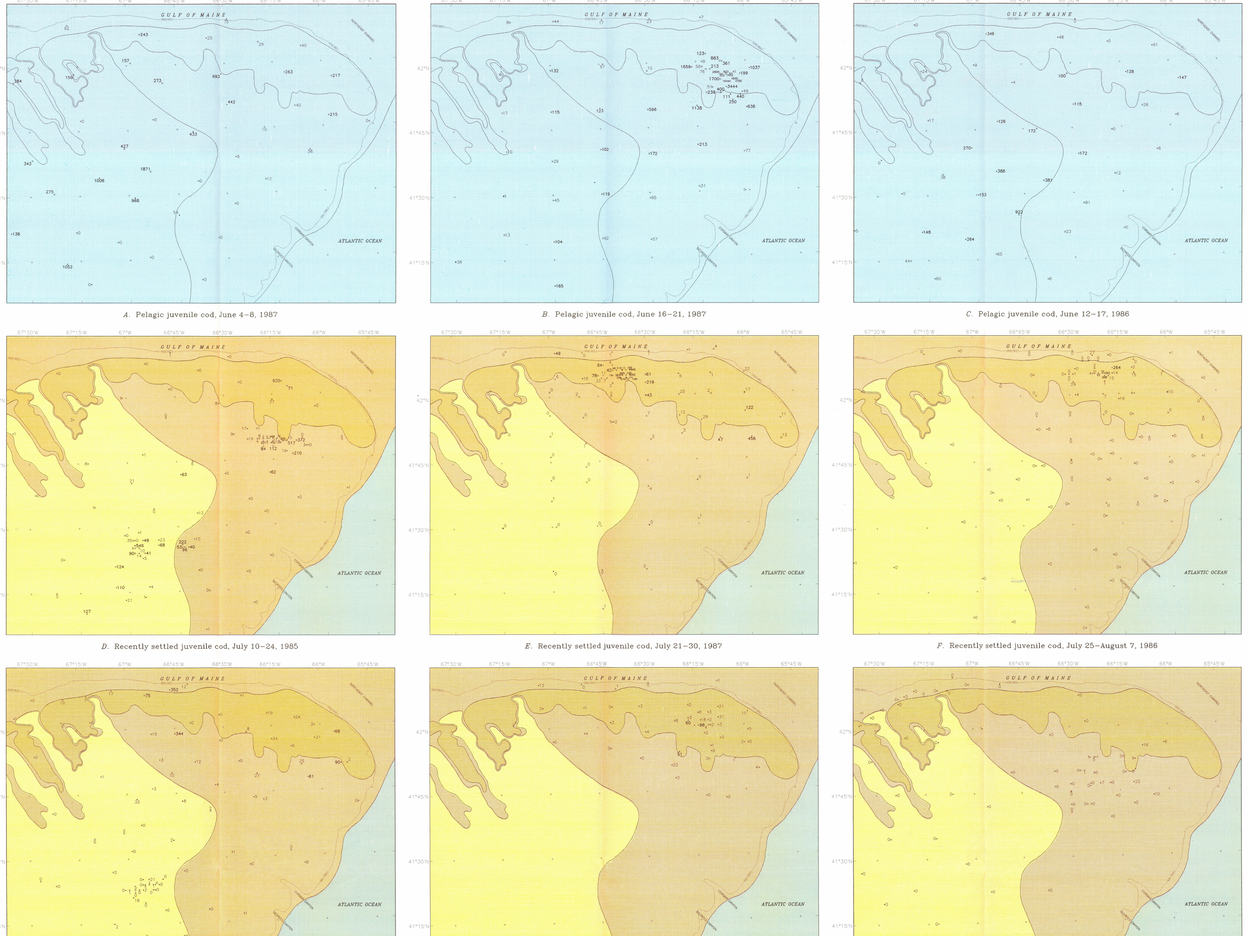
SHEET 1 OF 1





A. Pelagic juvenile cod, June 4–8, 1987

B. Pelagic juvenile cod, June 16–21, 1987

C. Pelagic juvenile cod, June 12–17, 1986

D. Recently settled juvenile cod, July 10–24, 1985

E. Recently settled juvenile cod, July 21–30, 1987

F. Recently settled juvenile cod, July 25–August 7, 1986

G. Recently settled juvenile cod, August 7–20, 1985

H. Recently settled juvenile cod, August 11–29, 1989

I. Recently settled juvenile cod, August 10–17, 1984

Figure 1. — A–C. Distribution and relative abundance of pelagic juvenile cod, sampled in June 1986 and June 1987. Abundance of pelagic juveniles is given in individuals per 1000 square meters of sea surface (figs. 1A, C), and as individuals per 30–min tow (fig. 1B). Samples containing 100 or more individuals are shown in boldface type. *D–I.* Distribution and relative abundance of recently settled juvenile cod, sampled in August 1984, July and August of 1985 and 1986, July 1987, and August 1989. Abundance is given in individuals per 30–min tow. Samples containing 40 or more individuals are shown in boldface type. For all maps, bathymetric contours are labelled in fathoms, followed by meters in parentheses.

MAP SHOWING DISTRIBUTION AND ABUNDANCE OF RECENTLY SETTLED JUVENILE COD DURING THE SEASONAL PERIOD JULY 21 – AUGUST 20, 1984–87, AND 1989

MAPS SHOWING THE DISTRIBUTION OF JUVENILE COD IN RELATION TO THE SEDIMENTARY ENVIRONMENT OF EASTERN GEORGES BANK

By

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INTRODUCTION

These maps show the distribution and abundance of juvenile cod (*Gadus morhua* L.) during the transition period from pelagic to demersal life in relation to the sedimentary environment on eastern Georges Bank. A large-scale map shows the five-year composite distribution and abundance of recently settled juvenile cod during the seasonal period late July to late August (1984–87 and 1989) on the sedimentary environment of eastern Georges Bank. Smaller maps show the relative distribution of pelagic juvenile cod observed in individual surveys made during June of 1986 and 1987, and six maps (figs. 1D–I) show the distribution of the demersal, or recently settled, juvenile cod observed in individual surveys conducted at various times during early July to late August of 1984–87 and 1989. The maps are designed to be used in conjunction with other maps in this series that depict the sedimentary environment and the sea floor topography of eastern Georges Bank (Valentine and others, in press a; Valentine and others, in press b).

Nine cruises, over a period of 5 years, collected sufficient data on pelagic and recently settled cod to show the relation of their distribution and abundance to the sedimentary environment. Each cruise commonly surveyed a broad region and also conducted intensive time–series sampling at selected stations. Juvenile cod less than 20 cm long were classified as 0–group fish (young of the year). Because juvenile cod exhibit diel behavior that affects their vulnerability to sampling gear (particularly bottom trawls), symbols are used to distinguish daytime catches (open square) and nighttime catches (closed square). Nighttime is defined as the period from one hour after sunset to one hour before sunrise. As a means of highlighting the locations of high concentrations of cod, samples containing either 100 or more pelagic juveniles or 40 or more recently settled juveniles are shown in boldface type. On the large–scale composite map, areas of high concentration of recently settled juveniles are outlined. Only the highest catch is shown for cases where multiple tows were made at the same station within a short time interval (several hours to several days).

METHODS

Pelagic juvenile cod were sampled by means of two types of gear. The first, a "multiple opening and closing net environmental sensing system" (MOCNESS) having a fixed mouth opening (10 square meters) and nets of 3–mm mesh size (Wiebe and others, 1985; Potter and others, 1990), was used on tow research vessel (RV) Albatross IV cruises (8603a, June 12–17, 1986; 8704a, June 4–8, 1987). Maximum depth of the MOCNESS tows was less than two meters off the bottom. At each station a single net was towed from the sea surface to the sea bed and back to the surface (resulting in a double–oblique profile of the water column) for a total of 30 min at 2 knots (3.7 km/h). The volume of water filtered was monitored electronically and averaged 19,000 cubic meters during a 30–min tow (Potter and others, 1990). MOCNESS catches were standardized to individuals per thousand meters of sea surface. The second type of gear, an "international young gadoid pelagic trawl" (IYGPT) was used on one RV Delaware II cruise (8705, June 16–21, 1987). The IYGPT has a larger, variable mouth opening (104 square meters) and has a graded mesh size (5–150 mm). The volume of water filtered is estimated to have averaged 338,000 cubic meters during a 30–min tow (Potter and others, 1990). The IYGPT was set to begin fishing within 3 to 11 meters of the bottom; each tow was stepped to fish at 20–m intervals to the surface and towed for 30 min at 3 to 3.5 knots (5.6 to 6.5 km/h). Some station catches represent tows during which the IYGPT sampled at only two levels, 10–20 m above the bottom and 20–30 m below the surface. IYGPT catches were standardized to individuals per 30–min tow. It is important to note that the abundances of pelagic juvenile cod shown in figures 1A–C are relative to the gear type used and are not directly comparable. Thus, the purpose of the maps is to show only the overall distribution of pelagic juveniles and the areas of high concentration.

Recently settled juvenile cod were sampled using bottom trawl gear. The 36 Yankee bottom trawl (Azarovitz, 1981) was used on five RV Delaware II cruises (8407, August 10–17, 1984; 8505, July 10–24, 1985; 8506, August 7–20, 1985; 8605, July 25–August 7, 1986; 8707, July 21–30, 1987) and on a RV Chapman cruise (8903, August 2–11, 1989). The trawl was towed for 30 min at 3.5 knots (6.5 km/h). The height and width of the mouth opening was 3.2 x 10.4 m, and the net had a graded, stretched mesh (13–127 mm). Standard roller gear (40.6 cm diameter) was used on RV Delaware II cruises 8605 and 8707, and on RV Chapman cruise 8903. In place of the standard rollers, the chain sweep was covered with rubber disks (14.4 cm in diameter, and referred to as "cookies") on RV Delaware II cruises 8407, 8505, and 8506. However, on extremely rough ground or at several stations, the roller gear was substituted for the "cookies" and trawl duration shortened to 15–20 min. Bottom trawl catches of recently settled juveniles were standardized to individuals per 30–min tow.

Because various pelagic and bottom trawl gear were used on the cruises, some comments concerning the comparability of the data collected by the samplers are necessary. A comparison of the effectiveness of the samplers used for the capture of 0–group pelagic cod on Georges Bank was made in June 1986 (Potter and others, 1990). Based on a predictive model that utilizes the ratio of mesh–width to fish head–width, the smallest cod caught are estimated to be 15–16 mm, 25–26 mm, and 31–35 mm in length for MOCNESS, IYGPT, and 36 Yankee trawls, respectively. Comparison of a series of paired trawls using IYGPT gear showed the lower size limit of retention to be 25 mm by day and 35 mm by night. The upper size limit of pelagic cod retained by the MOCNESS and IYGPT gear could not be determined, but the IYGPT trawl tends to catch larger individuals (both by day and by night) than the MOCNESS. Standardized abundance estimates are comparable for the MOCNESS and IYGPT catches made during the day, but are higher for the MOCNESS during the night, indicating undersampling of the cod by the IYGPT at night. The MOCNESS can sample safely closer to the bottom than the IYGPT (0.5 m versus 3–11 m). Those members of the pelagic cod population that inhabit the water column near the sea floor apparently rise somewhat higher off the bottom at night and are caught by the MOCNESS but not the IGYPT.

Vertical distribution studies indicate that as juvenile cod approach the transition stage from pelagic to demersal life, they are found deeper in the water column at body length increases (Lough and Potter, 1991). In the case of recently settled juvenile cod (3–13 cm in length), observations from research submersibles in August 1986 and July 1987 documented the cod within 0.5 m of the bottom during the day, whereas at sunset part of the population rose 1–5 m off the bottom and drifted with the current. A comparison of standardized research bottom–trawl catches with counts made from the submersible along the same tracks showed the extent of undersampling by the bottom trawl. For 4–cm modal–size cod (1987), daytime trawl abundance estimates were at least an order of magnitude lower than those based on submersible counts; nighttime estimates did not differ significantly. With regard to larger juveniles of 7–cm modal length (1986) that are more demersally oriented, very few fish were caught during daytime bottom trawls, and abundance estimates based on nighttime trawls were at least an order of magnitude lower than those based on submersible counts (Lough and others, 1989). The larger juveniles appear to stay closer to the bottom both day and night, and, consequently, they are less vulnerable to the bottom trawl that may pass over them. Preliminary results of Colson and others (1985) show that more juveniles (4–5 cm in length) were caught by means of the bottom trawl whose chain sweep was covered with "cookies" than with larger roller gear.

SEDIMENTARY ENVIRONMENT

Georges Bank is a shallow part of the continental margin that is separated from the mainland by deeper waters of the Gulf of Maine. At present the bank receives no sediment from the continent. Sediment texture, current speed and direction, and bottom topography are the principal factors that interact to produce the sedimentary environment of eastern Georges Bank. The sea floor is covered by glacial sediment transported from source rocks in New England, New Brunswick, and Nova Scotia during late Pleistocene time (Schlee, 1972; Schlee and Pratt, 1970). This sediment originally ranged in texture from mud to gravel (including boulders), but it has been reworked and eroded to some extent since flooding by the rising sea, following the retreat of the glaciers.

Circulation on the bank is dominated by semidiurnal tidal flow (strongly oriented northwest–southeast), by storm currents of varying directions, and by a mean gyre that flows clockwise around the bank and that has a particularly strong flow from west to east along the northern edge (Butman and Beardsley, 1987; Jordan, 1962; Moody and others, 1984). Plankton (for example, phyto– and zooplankters, bivalve larvae; fish eggs and larvae) and juvenile fish (both pelagic and recently settled) are transported by these currents. Many of these organisms spend part of their life cycle drifting around the bank in the residual current gyre. The gyre has a mean speed of approximately 10 cm/s (0.5 km/h) and takes about 3 months to complete a circuit of the bank (Bumpus, 1973; Lough and others, 1982; and others, 1982). Sediment transport is effected chiefly by the bottom tidal currents, which reach speeds of more than 40 cm/s in some areas, and by less frequent storm currents, which reach greater speeds. As a result of winnowing by these currents, fine sediment (silt and clay) has been removed from the sea bed; sand continues to be transported off the bank, while the gravel remains.

The action of the currents on the glacial sediment has formed several dominant textural patterns on eastern Georges Bank which are discussed by Valentine and others (in press b). In the shallow western part of the map area, tidal currents have formed large sand ridges that are aligned northwest–southeast. A continuous sheet of sand extends to the east and southeast from the shoals into deeper parts of the bank. A large gravel deposit stretches for approximately 150 km along the northern bank edge and occupies an area of more than 3000 square kilometers. It is a lag gravel pavement of dominantly pebble size (0.4–6.4 cm in diameter) that has resulted from the winnowing of sand and finer sediment by bottom currents. The pavement marks an area where coarse sediment was deposited directly from glacial ice. The gravel also supports the most diverse benthic fauna on the bank (Wigley, 1958, 1961, 1968). South of the pavement, sand dunes, gravelly sand, and small patches of gravel all occur within a 10 km–wide band that represents a transitional area between the gravel and a broadly defined region of gravelly sand to the south. Gravelly sand is present on the northern slope of the bank, on the floor of Northeast Channel, and in the southeastern part of the bank south of the area where the shoal sand ridges. In deeper water, the southeastern bank slope is covered by silty sand which becomes finer to seaward as the silt and clay content increase with increasing water depth.

As a result of ongoing erosion, the sand ridges are diminishing in size as sand is transported northward into the Gulf of Maine and southward toward the shelf edge. The gravel patch is growing westward along the northern edge, and the gravelly sand that lies between the sand ridges and elsewhere is expanding to cover a larger part of the bank. Inevitably, the sea floor of Georges Bank will become coarser–grained overall.

DISTRIBUTION OF JUVENILE COD

Atlantic cod historically has been an important species in the New England fishery because of its abundance and wide distribution (Azarovitz and Grosslein, 1987). The cod found on Georges Bank are considered a separate stock from those in the Gulf of Maine and southern New England region (Brown, 1987). Cod spawn widely over Georges Bank throughout most of the year, but peak spawning occurs in February and March and is concentrated on the southeastern part of the bank (Sherman and others, 1984). Eggs spawned on eastern Georges Bank generally float south and west in the residual clockwise circulation and hatch in two to three weeks. By May, the pelagic larvae tend to be concentrated along the southern bank margin, georgraphically between the 55–m and 91–m isobaths, but by June, they are spread over most of the bank (Lough and Bolz, 1989). The greatest transition from pelagic to demersal life occurs by the time the juvenile fish are 4 to 6 cm in length, or at about 3 months of age (Koeller and others, 1986; Lough and Potter, 1991). From late July to late August, they appear to be primarily demersal, and the juveniles are abundant only on the large gravel patch on southeastern Georges Bank (Lough and others, 1989).

Pelagic juvenile cod are widespread over eastern Georges Bank in early to mid–June (figs. 1A–C), but the abundance distribution is very uneven. At a sampling density of 18 to 22 km apart (1986, 1987), stations were usually more than 100 km or more individuals apart (straight line distance), and stretched across the bank above all sedimentary environments. All three surveys in 1986 and 1987 show pelagic juveniles to be present in low numbers over the southeastern part of the bank. The abundance of the two surveys in 1987 (figs. 1A, and 1B) reveals that the high concentration of pelagic juveniles in the June 4–8 period had coalesced and dispersed somewhat over the following week, but the distribution of the adult and residual currents.

Recently settled juvenile cod are present on the bank in the middle of July. The maps showing their distribution and abundance in the July–to–August period are arranged from left to right chronologically by season, not by year (figs. 1D–I). An exception is made for figure 1G, which is placed beneath figure 1D (rather than under 1F) so that data collected in July and August of the same year can be compared easily. Note that bottom trawl catches are not directly comparable because more cod are caught at night than during the day and because of variation in the type of roller gear used.

The earliest recently settled survey (fig. 1D) of recently settled juvenile cod occurred from July 10–24, 1985 (Delaware II cruise 8505). A broad survey of eastern Georges Bank during the early part of the cruise (July 10–19) revealed a patchy distribution of cod. Dense aggregations of juveniles were present in a variety of sedimentary environments. In two areas (lat. 42° 25′ N, long 66° 55′ W, 41° 49′ N, 66° 15′ W) these aggregations were documented by sampling over a period of 5 to 9 days. The general distribution pattern for the month (July, 1985) resembled an ellipse extending from southwest to northeast (somewhat comparable to distribution patterns of pelagic juveniles observed a month earlier in the 1986 and 1987 season; fig. 1A–C). During the latter part of the cruise (July 22–23), a trawl from the more southern area of concentration captured only 5 individuals, which suggests the number of individuals there had declined by late July; by contrast, a trawl from the more northern area of concentration captured 120 individuals and confirmed the continued presence of this aggregation. Later in the same year, a survey from August 7 to 20 (fig. 1G) recorded large aggregations of juvenile cod in or near the gravel patch (fig. 1G) and in the area of the sand ridges in the southern part of the bank. Most of the southern area described above, which had supported a large aggregation of juveniles in the July 10–19 period captured few individuals in the August 7–20 period (compare figs. 1D and 1G).

In 1987 (fig. 1E), sampling conducted from July 21 to 30 (Delaware II cruise 8707) juvenile cod are strikingly absent from most of eastern Georges Bank, but several dense aggregations were present in the gravel patch and just to the south of it. In the gravel patch, sampling was intensive in a large aggregation (located by trawling) where coordinated submersible and trawler surveys were carried out; a second aggregation was present near the eastern end of the bank.

In 1986 (fig. 1F), sampling took place from July 25 to August 7 (Delaware II cruise 8605). As was the case in 1987, sampling was intensive in an area selected for submersible and trawler surveys. The distribution of juvenile cod is similar to that encountered in 1987 (fig. 1E), but in 1986 sampling occurred somewhat later in the year, and only one aggregation of cod was identified.

In 1989 (fig. 1H), samples were collected from August 2 to 11 (Chapman cruise 8903), and a limited number of stations were visited. As in 1985 and 1987, trawling was conducted to locate aggregations of juvenile cod so that joint submersible and trawler surveys could be made. On the basis of prior experience, the gravel patch was made the focus of sampling, and two aggregations were identified, one in the gravel patch and one on its southern margin. Juvenile cod were sparse in most of the area 10 to 15 km south of the gravel patch (lat. 41° 30′ N) and even further to the south where cod were present or were poorly represented in the late July to late August period in 1984, 1985, 1986, and 1987 was not surveyed.

In 1984 (fig. 1I), sampling occurred from August 10 to 17 (Delaware II cruise 8407). Juvenile cod were absent in most of the region. The highest catches were in the southeastern part of the gravel patch and just to the south of it. Cod were sparse or absent in the remainder of the map area, although sampling was not uniform on this cruise, and the gravel patch was not sampled adequately.

The large–scale map shows the composite distribution and abundance of recently settled juvenile cod on eastern Georges Bank in late July to late August (1984–87 and 1989). During the seasonal period that extends from July 21 to August 20 (late July to late August), at this time of the year, juvenile cod are by far most heavily concentrated on the gravel patch and to some extent on a variably textured bottom of gravel, sandy gravel, and sand that lies within a 5– to 10–km–wide band along the southern margin of the gravel patch. Juvenile cod aggregations that occur earlier in the season (early to middle July) well to south of the gravel patch (lat 41° 25′ N, fig 1D) are not included in this compilation because they appear not to persist into late July and early August (excepting one station where 127 juveniles were sampled on July 22 at lat 41° 10′ N, long 67° 13′ W, fig 1D).

SEDIMENTARY ENVIRONMENT AND SURVIVAL OF RECENTLY SETTLED JUVENILE COD

Pelagic juvenile cod are, by June, widespread in the water column over eastern Georges Bank; by mid–July they become demersally oriented and are present on bottom types ranging in texture from mud to gravel. By contrast, in late July to early August the recently settled juveniles are abundant only on the large gravel deposit on the northern edge of the bank and within a 5– to 10–km–wide band of highly variable texture to the south of the gravel. They are sparse or absent from the large areas of sand and gravelly sand that cover most of eastern Georges Bank. Recently settled juvenile cod, during the daytime, tend to remain close to the bottom facing into and stemming the strong tidal current; they rise off the bottom during nighttime, irregularly paced to feed, and drift with the current. As a result of their diel behavior, the flow of tidal currents, and the west–to–east residual current, cod on the northern edge will be transported from west to east, but will remain on the gravel for many weeks (depending on the initial location of their settlement onto the gravel). The timing of the events outlined above may vary somewhat from year to year due to variation in the time of peak spawning, in water temperature, in current speed and direction, and in the occurrence of storms. However, the seasonal pattern of pelagic juvenile cod transport, settlement to the bottom, and the presence or absence of demersal cod in certain regions of the bank is clear; it supports the hypothesis that the gravel–gravelly sand bottom observations from submersibles have documented that the cod are difficult to discern on the biologically rich gravel substrate, but are easily visible on the relatively barren sandy bottom. Thus, survival of the juveniles on the gravel is enhanced by their ability to avoid predators, and by the availability of plentiful food. The maps presented here, based on data collected over five seasons, document a strong correlation between the sedimentary environment and the presence and absence of recently settled juvenile cod. Sediment type, current patterns, fish behavior, and food preference and availability all are important factors that determine the survival of juvenile cod on eastern Georges Bank.

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This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

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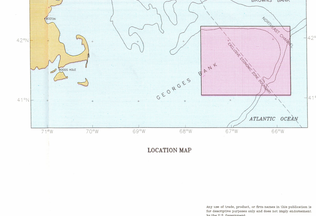
EXPLANATION

- Pelagic juvenile cod (figs. 1A–C)
- Water column
- Recently settled juvenile cod (figs. 1D–I; and 1:250,000 map)
- Gravel pavement
- Gravelly sand
- Sand
- Silty and clayey sand or sandy mud
- Location of juvenile cod collected during daytime
- Location of juvenile cod collected during nighttime
- 25 Number of juvenile cod
- Sample sites yielding 40 or more recently settled juvenile cod during seasonal period July 21 – August 20, 1984–87, and 1989.



LOCATION MAP

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