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Recent Excursions of Capelin (*Mallotus villosus*) to Scotian Shelf and Flemish Cap During Anomalous Hydrographic Conditions

by

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SYMPOSIUM ON ANOMALOUS OCEANOGRAPHIC CONDITIONS

Introduction

Unusual occurrences of marine fish have been reported frequently in the scientific literature. If a few individuals have been sighted then simple straying from the normal habitat may be involved. If large quantities are involved a major shift in the species distribution may have occurred (see review in Mearns, 1987). A persistent change in distribution may indicate a range extension or establishment of a self-sustaining population in a new geographic area. It has been shown that large scale oceanographic processes (e.g. El Nino-South Oscillation) can alter the distribution and migration pattern of many marine fishes (Soule and Kleppel, 1987). This has led to the notion that whenever unusual occurrences of marine fishes are observed they reflect anomalous oceanographic conditions.

Some notable events in the commercial fisheries have occurred during the past century in the Northwest Atlantic suggesting an influence of anomalous ocean climate conditions. During the winter of 1877-78 unusually large schools of cod apparently immigrated from the Grand Banks (Div. 3NO) to the shores of the New England coast (Earll, 1880). This represents a migration on the order of 1000 km and may be related to anomalous oceanographic conditions. This linkage to oceanographic conditions is suggested because at about the same time (1882) enormous numbers of tilefish succumbed to cold water conditions occurring in the mid-Atlantic Bight (Cushing, 1982). More recently, cod and other groundfish in Div. 2J3KL (Fig. 1) have undergone large-scale changes in distribution towards deeper and more southerly portions of their stock ranges. Rose and deyoung (1993) speculated that the recent changes in cod distribution were due to widespread, below normal water temperatures and the distributional changes have in turn resulted in poor recruitment. These recent behavioral changes are not only confined to groundfishes on the Newfoundland and Labrador Shelves but appear also to have affected capelin, a small pelagic species and a major diet item of most commercially important groundfish species whose principal centre of distribution coincides with Div. 2J3KL (see Akenhead *et al.*, 1982). Since 1991, capelin spawning time has been delayed by up to one month (Nakashima and Slaney, 1994) and there has been a shift in distribution from Div. 2J areas further south (Lilly and Davis, 1993; Miller, 1994) similar to the groundfish distribution shifts. In addition, traditional abundance indices are now widely divergent, with offshore acoustic estimates, which measure recruitment, declining abruptly, and inshore indices, which monitor mature fish, remaining at about the same levels (Fig. 2). Capelin abundance was relatively high in the mid-1970s, low in the late-1970s and early-1980s, and during the mid-1980s high abundance levels were typical.

In the fisheries records capelin have occasionally been reported to occur in areas outside of their normal distributional range. For example, between 1965 and 1968, great quantities of capelin were recorded in the Bay of Fundy herring weir fishery and it was suggested they were reproducing successfully there (Tibbo and Humphreys, 1966; Jangaard, 1974). This occurrence of capelin in the Bay of Fundy coincided with a minima in ocean temperatures associated with a cooling trend from 1952 to 1967 (Fig. 3). Colton (1972) suggested that this cooling was a possible cause for the southward extension of capelin. In addition to the 1960s, substantial quantities of capelin occurred in the Bay of Fundy between 1915 and 1919 (Bigelow and Schroeder, 1953) and around 1903 (Huntsman, 1922). Both of these capelin observations occurred during periods of below normal water temperatures (Fig. 3).

In more northern waters in the Northwest Atlantic capelin have extended their range during either warming periods or through changes in the areal extent of the Labrador Current. Dunbar (1966) suggested that the occurrence of capelin in Ungava Bay in 1884 and 1959 indicated warming conditions. It is interesting to note that the 1884 occurrence of capelin in Ungava Bay has been linked to a warming period in that area but is about the same time that cod moved from Div. 3NO to New England and significant mortalities of tilefish occurred, ostensibly because of unusually cold conditions. Templeman

(1976) concluded that the unusual occurrence of capelin on the Flemish Cap in 1973 was associated with below normal water temperatures. Collectively, this information demonstrates a highly flexible distributional response of capelin to changing oceanographic conditions with the potential for rapid inhabitation of waters to the north, south, and east of their principal centre of distribution.

It appears that we are now witnessing a concurrent southward and eastward extension of capelin distribution, particularly on the eastern Scotian Shelf and Flemish Cap, respectively (Fig. 1). These latest events coincide with the occurrence of atmospheric and oceanic extremes in the Labrador Sea/ Newfoundland Shelf region and the Gulf of St. Lawrence. In general, cold air temperatures, heavy sea ice and cold water temperatures have prevailed in these regions during the past 3-5 years (Drinkwater, 1993). In this paper, we document these recent unusual occurrences of capelin on the eastern Scotian Shelf and Flemish Cap in the context of their historical occurrences in these areas and in relation to recent hydrographic events.

Materials and Methods

Data sources, detailed below, differed in the two study areas. In the Scotian Shelf area, biological and hydrographic data from research vessel surveys were the major sources of data. Other information came from records of by-catch in commercial fisheries and ichthyoplankton surveys.

For the Flemish Cap, biological data existed from historical research vessel surveys and from recent Spanish bottom trawl research surveys. Hydrographic data was available from research surveys. Historical by-catch data were available as well as detailed by-catch data from a new shrimp fishery that developed in 1993. Other information on capelin occurrence on the Flemish Cap was available from historical predator feeding studies and ichthyoplankton surveys.

Scotian Shelf

i) Study Area

The Scotian Shelf lies offshore of Nova Scotia and has a length of 700 km and a width, defined by the 200 m isobath, varying from 250 km at its eastern end to 150 km to the west. The average depth over the shelf is near 90 m. The complex topography includes several deep basins (>200 m) near mid-shelf and a series of shallow (less than 50 m) banks further offshore. A topographic ridge which includes Middle Bank separates the deeper shelf waters (> 100 m) in the northeast from those to the southwest. The Scotian Shelf is separated bathymetrically from the southern Newfoundland shelf by the Laurentian Channel and from the Gulf of Maine by the Northeast Channel. The residual circulation is dominated by the Nova Scotian Current, a southwestward flow whose axis lies 50-70 km offshore and whose strength varies seasonally from a winter maximum to a summer minimum (Drinkwater *et al.*, 1979). Anticyclonic circulation patterns have been observed over the banks where detailed current measurements have been taken, e.g. Browns Bank (Smith, 1989) and Western Bank (K. Thompson, personal communication). The density structure in summer in the western region consists of three layers, a near surface layer with salinities <32 and temperatures >5°C, a cold intermediate layer with salinities 32-33.5 and temperatures <5°C and a warm (>5°C), saline (>33.5) bottom layer. In winter the top two layers coalesce. In the eastern Scotian Shelf, there are only two layers in summer as the cold intermediate layer extends to the bottom.

ii) Research Vessel Surveys

Research vessel (RV) surveys of the Scotian Shelf have been conducted each spring since 1979 (NAFO Div. 4VsW) and each summer since 1970 (NAFO Div. 4VWX) by the Canadian Department of Fisheries and Oceans. Both sampling and data analysis protocols are well documented (Halliday and Koeller, 1981; Smith and Somerton, 1981). Because the codend of the bottom trawl is equipped with a 19 mm liner, by-catch of juvenile groundfish, pelagic fish, and small bodied fish species in general is common.

iii) By-catch in the Commercial Fisheries

There is no directed fishery for capelin on the Scotian Shelf but we examined *NAFO Statistical Bulletins 1972-90* for reports of capelin catches, which would have been reported as by-catches in other fisheries.

iv) Hydrographic Data

Biological sampling of capelin included estimation of size (length frequency), total weight and numbers in each tow. Capelin distributions were generated from individual sets and plotted using ACON Version 7.27 (Black, 1991). For each annual survey capelin abundance is expressed as stratified mean numbers per tow by division.

Hydrographic data were collected at the end of each trawling station during the research vessel surveys. Before 1990, water temperature and salinity data were obtained from water samples collected with a reversing bottle from near-bottom. Water temperatures were measured in 1990-93 using an internally recording Seabird model 19 (or 25) conductivity, temperature and depth (CTD) profiler. The near-bottom temperatures from each CTD profile were calibrated with the reversing thermometer estimates of temperature (Page and Losier, submitted).

Flemish Cap

i) Study Area

The Flemish Cap (NAFO Div. 3M) is a relatively small bank (about 52 n mi by 42 n mi bounded by the 200 m isobath) centred at about 47°N, 45°W (Fig. 1). It is separated from the northern Grand Banks to the west by the Flemish Channel (Pass) which is over 1000 m deep (Templeman, 1976).

Flemish Cap is influenced by two major current systems. Cold, low-salinity water from the Labrador Current flows from the west and splits into two branches at the northwest corner of Flemish Cap. A southward flowing branch moves through the Flemish Pass, between the Grand Bank and the Flemish Cap while the other branch flows east and then southeast around the northern and northeast slopes of the Flemish Cap. The North Atlantic Current, warmer and more saline than the Labrador Current, flows east-northeast across the southern slopes of the Flemish Cap. There is a weak anticyclonic gyre over the central portion of the Flemish Cap (Lilly, 1987).

ii) Research Vessel Surveys

The Flemish Cap has supported major fisheries for cod and redfish (Templeman, 1976; Lilly, 1987) and as a result it has been the site of research vessel surveys aimed at groundfish since the 1940s. Because of its geographic location, this area is in international waters and several countries have conducted these surveys. We review the results of these surveys as well as ichthyoplankton surveys in the area. In addition, we present capelin by-catch data from Spanish surveys conducted since 1988. The Spanish surveys have used a stratified random design (stratified by depth) with tow depths up to 720 m during late June to early August each year. Each survey has in excess of 100 (106-117) valid tows. The gear has remained unchanged and the trawl codend was 35 mm mesh (Vasquez, 1993). Numbers of capelin per tow and lengths of individual capelin were recorded. Distributions of capelin from the surveys were plotted using ACON Version 5.02 (Black, 1991). Tow duration was usually 30 min but because some tows deviated from this, we expressed capelin abundance as catch in numbers/hour.

iii) By-catch in Commercial Fisheries

As with the Scotian Shelf, there have been no directed fisheries for capelin but NAFO Statistical Bulletins were examined for reports of capelin by-catch.

During April 1993, a shrimp fishery developed on the Flemish Cap. Data for individual tows collected on Canadian shrimp vessels during May, June and July by fisheries observers included date, time, location, duration, depth of tow and by-catch weight by species. Capelin occurred in the by-catch and samples were frozen for later detailed biological sampling in the laboratory. At that time, data such as length, sex, maturity, and ovary weight were collected.

iv) Hydrographic Data

Hydrographic data have been collected during research vessel surveys by DFO personnel for several years. Data collected during July 1993 were recently published by Colbourne (1993) who compared these data to the historical time series.

Results

Scotian Shelf

i) Research Vessel Surveys

The spring and summer RV surveys both show a progressive increase in capelin abundance in Div. 4VW during the past six years (Fig. 4) with recent capelin catch rates during the summer survey among the highest ever observed. Throughout the remainder of the survey series capelin were not abundant except for the early-1970s when catch rates exhibited a minor peak (Fig. 4).

This recent episode of increased capelin abundance appears to be confined to the offshore waters of the eastern Scotian Shelf, as revealed by the spring and summer RV surveys (Fig. 5). Very few capelin were encountered in the Bay of Fundy during the summer surveys and there have been no reports of capelin occurring in the herring weir fishery after 1968 (W. Dougherty and C. Monaghan, DFO port technicians, Biological Station, St. Andrews, New Brunswick, E0G 2X0, pers. comm.). It appears, therefore, that the present capelin invasion is not as extensive as in the past (e.g. 1960s as described by Tibbo and Humphreys, 1966), with the leading edge of the current distribution coinciding with the boundary between Division 4W and 4V. Because there were no offshore surveys of the entire Scotian Shelf before 1970 we do not know whether capelin were as abundant offshore as they were during the mid-1960s in the Bay of Fundy.

The composite size frequency distribution of capelin revealed that the majority of the fish captured ranged in size from 14 to 16 cm (Fig. 6). Based on age readings conducted by Tibbo and Humphreys (1966) of capelin from the Bay of Fundy and capelin in other areas (Winters, 1982), capelin ≥14 cm are 2+ years old. The occurrence of capelin both smaller than 14 cm and larger than 16 cm suggests that several age groups were co-occurring in this geographic area.

ii) By-catch in Commercial Fisheries

There were no capelin catches reported to NAFO for Div. 4VWX between 1972-90. However, one ton of capelin was reported caught in Div. 5ZE in May 1973 and one ton of capelin in Div. 5ZW in July 1973. Both areas are further south off the U.S. coast. The timing of these by-catches is the same as the minor peak in capelin by-catch in the summer RV surveys on the Scotian Shelf (Fig. 4) and the same year as the unusual by-catch of capelin on the Flemish Cap (see below).

iii) Other Information

Numerous 0-group capelin (20-40 mm) were taken during October-December 1991 and 1992 (L. Fortier, Laval University, Ste. Foy, P.Q., pers. comm.) as part of monthly sampling conducted by the Ocean Production Enhancement Network in Div. 4W using a rectangular midwater trawl (1.6 mm mesh). These capelin may have originated on the eastern Scotian Shelf through local spawning. Capelin in this size range dominated midwater trawl collections on the Southeast Shoal of the Grand Banks during November of 1987, 1988, and 1989 (K. T. Frank, unpubl. data) and these larvae were known to have originated from the resident spawning stock.

iv) Temperature Trends

As during previous southward extensions of capelin into Nova Scotian waters, recent water temperatures have been below normal and near record low levels. In Div. 4Vs, where recent capelin catch rates are highest (Fig. 4), near-bottom water temperatures have been declining since 1985 with average temperatures <2°C between 1989 and 1991 (Fig. 7). A similar temperature trend was evident in Div. 4Vn but near-bottom water temperatures did not drop below 2°C in recent years (Fig. 7). It should also be noted that the declining temperature trend seen during the early-1970s (Fig. 7) coincided with a minor peak in capelin abundance (Fig. 4). Cooling is evident in Div. 4W but recent near-bottom temperatures may still be too warm for successful occupation of these waters by capelin (Fig. 7). The recent cooling of the near-bottom waters in Div. 4Vs and 4Vn was not apparent in Div. 4X (Fig. 7), which includes the southwestern Scotian Shelf and Bay of Fundy.

However, it is interesting to note that the bottom temperatures in Div. 4X during the early- 1970s are about the same as the late-1980s and well above the near-bottom temperatures in Div. 4Vs. Div. 4X is immediately adjacent to Div. 5ZE where the 1973 by-catch of capelin was reported. This 1973 occurrence of capelin in southern waters may have been less closely related to water temperatures but the absence of persistent colder water may have prevented their long-term occupation of the area.

Flemish Cap

i) Research Vessel Surveys

Canadian and USSR bottom trawl research vessel surveys conducted between 1949 and 1985 reported no capelin by-catches (Fig. 8). This is not a result of using inappropriate gear since the same gear used in other areas successfully caught capelin (USSR: Borovkov *et al.*, 1989; Canada: Lilly and Davis, 1993 and other records available at DFO, St. John's).

Spanish bottom trawl surveys initiated in 1988 did not catch capelin during 1988-91 but in 1992 and 1993, 74 and 447 individuals respectively were caught. Capelin occurred over the north central part of Flemish Cap with most catches occurring in water depths less than 300 m and fewer catches in the 300-600 m depth range (Fig. 9).

Length frequencies from the Spanish survey were similar between 1992 and 1993 (Fig. 10) with most fish >14 cm and in the 15-17 cm size range. The similarities of the length compositions over the two years indicates that different year-classes were recruiting into the population in the Flemish Cap area.

ii) By-catch in the Commercial Fishery

By-catches of capelin in the Flemish Cap, as reported to NAFO, are unusual. In 1973, 317 tons of capelin were reported as by-catch in a redfish fishery. Templeman (1976) attributed this occurrence of capelin to unusually cold water on the Flemish Cap that year.

No other catches of capelin have been reported until 1990, 1991 and 1992 (preliminary data for these years) when 14 t, 6 t, and 6 t respectively were reported.

During the shrimp fishery on the Flemish Cap which began in 1993, capelin occurred in 173 (95% of the 183 observed sets in May, 485 (65%) of the 742 observed sets in June and 137 (77%) of the 178 observed sets in July. The shrimp fishery occurred mostly in the 300-400 m depth zone (Anon., 1993) and capelin catches occurred throughout the shrimp fishery (Fig. 11). In both May and July, capelin were distributed along the western and northwestern edge of the Flemish Cap spanning over 1° of latitude (approximately 110 km). In June, the distribution was more extensive in a dome shape covering the western, northern and eastern flanks of the Flemish Cap and spanning more than 1° of latitude (approximately 110 km) and 2° of longitude (approximately 140 km). Most of the catches were small, less than 1 kg/hr.

Length frequencies were similar in all months with most fish >14 cm (Fig. 12). Capelin of age 4 comprised over 80% of the samples with the remainder being ages 5 and 3. The length frequency distribution was similar to the distribution from the Spanish data (Fig. 10). The small mesh shrimp gear probably would have retained smaller capelin, indicating that smaller capelin were not accessible to the gear, either because they were not in the Flemish Cap area or not near the bottom.

We compared roe content (weight of roe expressed as % of total body weight) of Flemish Cap capelin to roe content of capelin collected between March and July on the Grand Banks and on the spawning grounds of the Southeast Shoal (Fig. 13). This comparison shows that gonads were developing at the same rate as gonads of capelin from other areas. The roe content of capelin at about Day 180 and later were 25% or greater and represent fish in spawning condition.

iii) Other Information

From our examination of the literature, we estimate that in excess of 25,000 cod stomachs from the Flemish Cap have been examined between 1978 and 1990 by Canadian, Soviet and Spanish scientists. These studies cover most months (although not in one year) yet no capelin have been recorded as prey (Fig. 14). Similar results have been reported from examinations of over 2000 American plaice stomachs.

In contrast, capelin have been recorded as prey of redfish and Greenland halibut, although such records are uncommon. Noskov *et al.* (1963) reported that in summer 1962, concentrations of redfish were found on the northwestern and northeastern slopes of the Flemish Cap between 300 and 450 m. These redfish were reportedly feeding heavily on amphipods, shrimp, capelin and lantern anchovy but no quantitative estimates of stomach contents were provided. In a study of feeding by Greenland halibut in Flemish Pass in 1992, capelin were found occasionally (<1% frequency of occurrence) in predators taken in less than 1000 m (Rodriguez-Marin *et al.*, 1993). The actual feeding location may not have been in Div. 3M but rather Div. 3L since the study covered both Divisions and the data were combined. Capelin are common in Div. 3L.

The Flemish Cap had been the site of several ichthyoplankton surveys by the USSR: March-April 1959-63, 1966 and 1970 (Serebryakov 1978) and spring and early summer 1978-81, 1983 (Serebryakov *et al.*, 1987). Data from the 1959-70 series are aggregated but the authors reported catching 21 capelin "fry" during these years. However, at least 6 of the 41 stations occurred in and west of the Flemish Pass with at least one station on the Grand Banks. Capelin in the area of these stations would not be an unusual occurrence. Without further details, the occurrence of capelin fry on Flemish Cap based on the 1959-70 surveys must be classed as doubtful. During the 1978-83 surveys, stations were restricted to east of the Flemish Pass. One capelin larva was caught during March 1980.

Hydrographic Conditions

The Flemish Cap has been the site of hydrographic sampling for several years and results up to summer 1993 were presented by Colbourne (1993). On the western side of the Flemish Cap (area FC 1 in Colbourne, 1993), cold periods occurred throughout the 1970s, mid–1980s and the late–1980s and early–1990s (Fig. 15). Temperature anomalies in the upper water layers of less than 200 m persisted from 1971 to 1977 but temperature anomalies deeper than 200 m were insignificant. Temperature anomalies in the upper layers between 1978 and 1984 were variable but generally positive. Intense negative anomalies in the top 100 m began in 1985, moderated briefly in 1987, and then persisted up until summer of 1993. The temperature patterns for this area on the Flemish Cap were similar to the patterns exhibited over the continental shelf at the same depth ranges. the patterns of temperature anomalies for the upper 100 m (Fig. 15) are very similar over the shallow central part of the Flemish Cap (Area FC 4) as well (Colbourne, 1993). Over the whole area of the Flemish Cap water temperatures, especially in the top 100 m, were decreasing from 1988 until 1993 when they were up to 2°C below normal. These anomalies coincided with the severe meteorological and ice conditions in the Northwest Atlantic (Colbourne, 1993).

Discussion

The data we have presented indicate that the occurrence of capelin on either eastern Scotian Shelf or Flemish Cap is uncommon. The recent upsurge of capelin in these areas began in the late–1980s for Scotian Shelf and early–1990s for Flemish Cap and has persisted until 1993 (preliminary data for 1994 indicate a continuation of this pattern into 1994 on the Scotian Shelf). These unusual distribution patterns have occurred at a time of extreme oceanographic and meteorological conditions over the eastern Scotian Shelf, Gulf of St. Lawrence, Grand Banks and Labrador Shelf. Furthermore, the occurrence of capelin in these areas during the recent past (e.g. 1973 on Flemish Cap and early–1960s for the Scotian Shelf/Bay of Fundy) has occurred during other cold periods. On the other hand, capelin have not been recorded in these areas during times of average or above-average temperatures. There has been at least one clearly identified cold period, the mid-1980s, when the appearance of capelin in either of these two areas was minor. During this time period, capelin in survey tows on Scotian Shelf appeared in low numbers (Fig. 4) and did not appear in any data records from Flemish Cap. Based on the available evidence, we conclude that capelin are generally rare in both areas, do not occur there during periods of average or above-average temperatures, and occur only during periods of below normal temperatures. Although the latter situation appears to be a requisite condition it does not guarantee the occurrence of capelin in either of the two areas. The occurrence of capelin in these areas during anomalous temperatures may depend on more than temperature and may be, for example, an interaction between temperature and population abundance.

It is apparent that capelin can quickly respond to changing environmental conditions and that this species has the capacity to rapidly colonize locations outside of its normal geographic range. This may be a unique life history characteristic of capelin. We believe that the time series of data presented here rules out the possibility of resurgence of local populations given the prolonged absence of capelin at various times on either the Scotian Shelf or Flemish Cap. Rather, the recent situation appears to be due to transport or migration of capelin into these areas (at an undetermined life stage) and eventual establishment of a reproducing population. This interpretation is consistent with that of Tibbo and Humphreys (1966) for the Bay of Fundy capelin episode in the mid-1960s.

The origin(s) of the source population(s) and the life stages at which colonization occurred are not known. For the Scotian Shelf group, the capelin could have originated either from the Gulf of St. Lawrence or St. Pierre Bank. The Gulf of St. Lawrence is, however, a more likely origin for this group. Although Jeffers (1931) noted several occurrences of capelin in the Bay of Fundy and the Nova Scotia coast during the late-1800s and early-1900s, he concluded that the southern limit of capelin in that area was Louisbourg on the Cape Breton coast and even in that area, capelin spawning was sporadic. Capelin are common in the Gulf of St. Lawrence as far south as northern Cape Breton Island and in years with below average temperatures, capelin schools occasionally occur in the southern Gulf, Chaleur Bay and around Prince Edward Island (Jangaard, 1974).

We cannot eliminate the possibility that capelin on the Scotian Shelf originated from St. Pierre Bank. The ocean currents would promote larval drift from that area although the deep (~500 m) Laurentian Channel might be assumed to be a barrier to active migration of older fish.

For the Flemish Cap, capelin almost certainly originated from the Northeast Newfoundland Shelf/Grand Banks area. The branch of the Labrador Current that splits to flow down the west side of the Flemish Cap and across the northern part of the Cap would afford a mechanism to transport larvae from the northern Grand Banks. Capelin larvae leave the Newfoundland beaches and nearshore areas within a few weeks or months of hatching and by late fall and early winter can be found widely distributed across the northern Grand Banks. Thus, biological and physical opportunities exist for larval dispersal from the Grand Banks onto the Flemish Cap. Based on our data, this phenomenon would occur only during cold periods suggesting an increasing influence of the Labrador Current to the east. However, it is also possible that juvenile and/or adult capelin actively migrated from the Grand Banks to the Flemish Cap. A cooling of Flemish Cap water, concurrent with a general cooling over the Northwest Atlantic, might be the only change necessary to permit temporary colonization by capelin.

The length frequency data from both the Scotian Shelf and Flemish Cap indicate that the fish were older, mature fish. In the Scotian Shelf area, the presence of quantities of larval capelin is a strong indicator of spawning in the area. On the Flemish Cap, the presence of very ripe fish in late June and early July 1993 suggests that spawning likely occurred. It is possible however that maturing fish detected earlier would have migrated west to the inshore spawning areas or to the spawning area on the southern Grand Banks (Carscadden *et al.*, 1989). The presence of these capelin on the Flemish Cap could explain, in part, the dramatic decline in estimates of abundance of immature and maturing capelin from May acoustic surveys observed beginning in 1991, declines which were not witnessed in the inshore spawning areas. In a discussion of this observation, Shackell *et al.* (1994) suggested that a delay in maturation of capelin, mediated by cold ocean temperatures, delayed the migration of capelin into the acoustic survey area. This delay of the migration into the survey area was compounded by the fact that the annual survey was fixed in time. It was suggested that some capelin were either in and around the ice and inaccessible to acoustic survey gear (a suggestion that was supported by anecdotal evidence) or elsewhere outside the survey area. The occurrence of capelin on the Flemish Cap, which is well to the east of the historical survey area (easterly survey boundary about 49°W), at the same time as the acoustic survey, is consistent with the above explanation. Our observations on the maturation schedule of capelin on the Flemish Cap (Fig. 13) did not indicate delayed maturation. However, this observed normal maturation rate and late spawning inshore during 1993 are not inconsistent because of the greater migration distance that capelin would have faced from the Flemish Cap.

As we have shown, capelin seem to be able to redistribute themselves relatively rapidly over an extensive geographical area in response to changing environmental conditions. During the same time period, the distributions of some groundfish species in the Newfoundland Shelf/Grand Banks area have also changed although we know of no evidence to indicate that this shift has been as extensive (i.e. as far as the Flemish Cap) as that of capelin. For the Scotian Shelf area, we examined the results from the research vessel surveys and noted that few Arctic/boreal species had responded similarly as capelin to the recent, and past, cold water conditions in that region. Out of several species considered (see Simon *et al.* 1994 for a complete description), two showed a temporal pattern of abundance similar to capelin: Greenland halibut, *Reinhardtius hippoglossoides* and checker eelpout, *Lycodes vahlii* (Fig. 16). Peak catch rates of Greenland halibut and checker eelpout were observed during the mid-1970s and during the 1990s, both of which correspond to periods of below normal water temperature on the eastern Scotian Shelf (Fig. 7). Although not shown, the distributional pattern of these two species is confined to the eastern Scotian Shelf, closely resembling the patterns depicted in Figure 5 for capelin. It should also be noted that the first occurrence of Greenland halibut in the Bay of Fundy was recorded in 1968 by Barrett (1968) and Boyar (1964) reported its occurrence off Boothbay Harbour in 1963, both records being associated with times of below normal water temperatures in the area of capture and with the major cooling event of the Scotian Shelf and the Gulf of Maine during the mid-1960s (Fig. 3).

The limited number of species whose geographic distribution changes extensively on ecological time scales may ultimately be linked to the physiological capacity of the species. As Colton (1972) noted during the 1952 to 1967 cooling event of the continental shelf waters from Nova Scotia to Long Island, the distributional patterns of several groundfish species did not change extensively and it was suggested that spawning area and bottom type were the principal habitat requirements for species such as yellowtail flounder and haddock. Seasonal production of blood anti-freeze proteins among certain species (cod, winter flounder, eelpout) may allow individuals to remain in nearshore waters during winter time where water temperature drop below 0°C such as in the southern Gulf of St. Lawrence and coastal Newfoundland (Goddard *et al.*, 1992).

Capelin are a major diet item of cod in several geographic areas (e.g. Newfoundland: Lilly, 1991; Iceland: Magnusson and Palsson, 1989; Norway: Hamre, 1991). One would expect, therefore, that the resident cod stocks in the two target areas would benefit from the influx of new and abundant prey. The available evidence suggests that this has not occurred. In the Scotian Shelf, cod abundance has declined dramatically and weight at age (an index of condition) shows a temporal decline since the mid-1980s (Frank *et al.*, 1994). This situation can be attributed, in part, to excessive exploitation but we cannot rule out concurrent effects due to changes *in the physical environment.* On the Flemish Cap, the evidence is more direct. Feeding studies between 1982 and 1992 indicate cod were not feeding on capelin (Casas and Paz, 1994).

Finally, how long will capelin persist on the Scotian Shelf and Flemish Cap? Their presence is clearly linked to the cooling trends in both areas and we would expect capelin to continue in these areas as long as water temperatures remain below normal. Given the recent warming of some of the deep basins in and around the Scotian Shelf (Cabot Strait and Emerald Basin) due to the presumed changes in the slope water characteristics (see Drinkwater, 1993), it is entirely possible that the capelin population will shortly disappear. However, preliminary results from the spring and summer 1994 research vessel surveys on the Scotian Shelf indicate the presence of small (about 5.0 cm) capelin in the spring and larger adult capelin in the summer. In the eastern Newfoundland area, severe winter air and water temperatures persisted during late-1993 and early-1994. Based on this persistent cold trend, we would expect the presence of capelin on the Flemish Cap to continue into 1994 at least.

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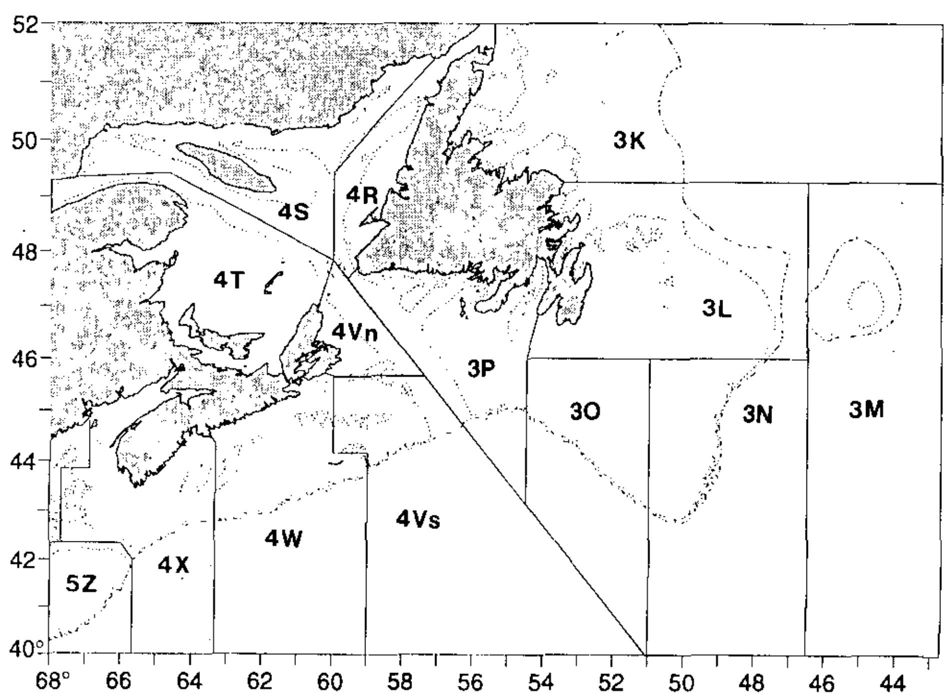


Fig. 1. Map of Northwest Atlantic showing NAFO Subareas and Divisions.

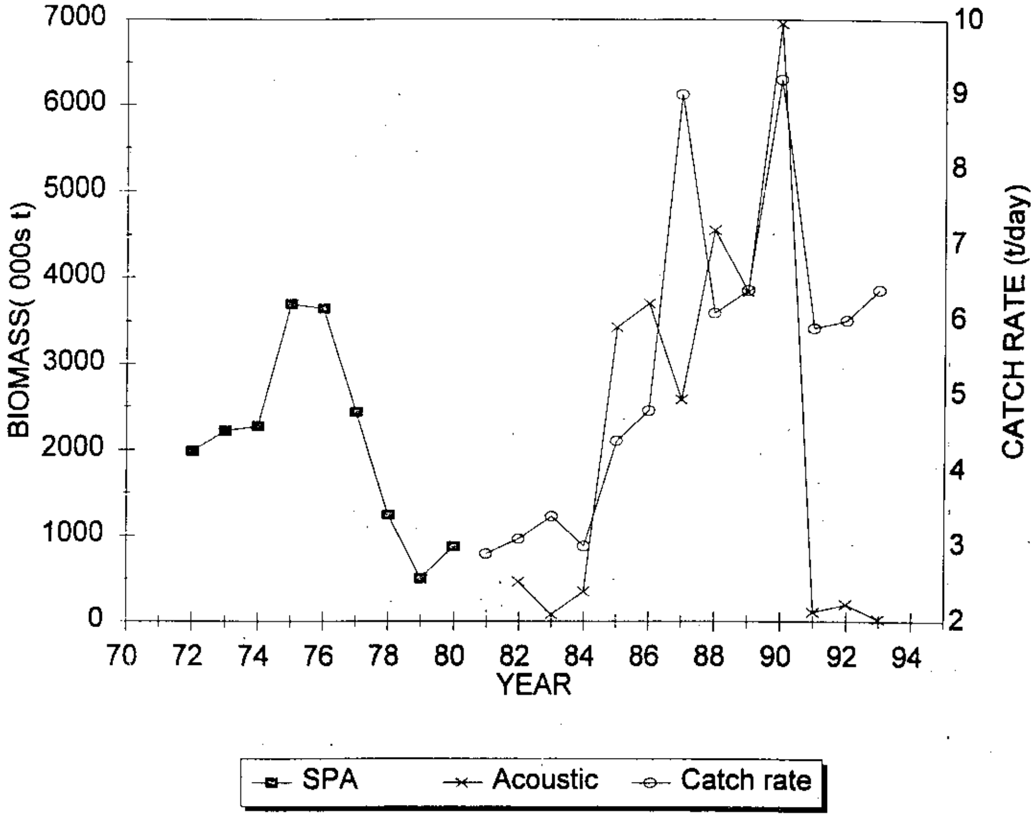


Fig. 2. Trends in abundance of Div. 3L capelin from 1970 to present. Note dramatic decline in acoustic estimates after 1991 compared to near-average catch rate values. SPA = sequential population analysis from Table 7, Carscadden and Miller (1981); acoustic estimates for Div. 3L, spring 1982-92, fall 1993 from Miller (1992, 1993); catch rates from Nakashima (1994).

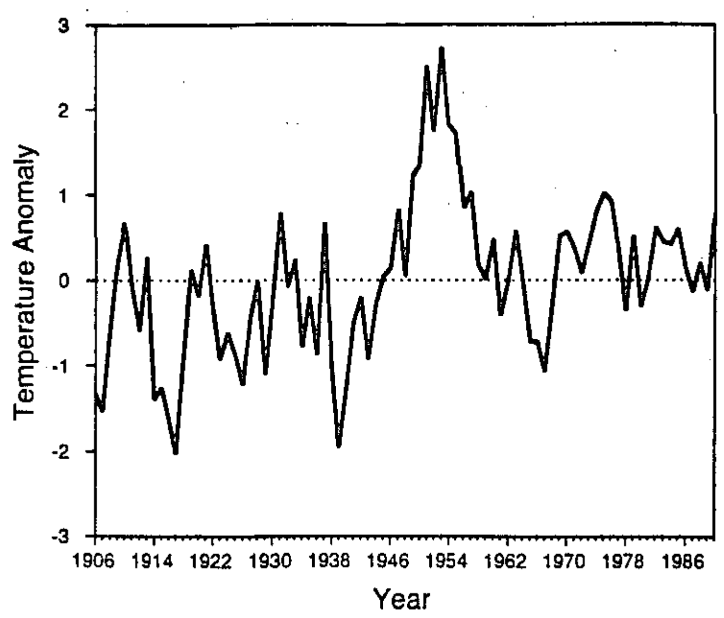


Fig. 3. Annual mean sea surface temperature anomalies from Boothbay Harbor, Maine. Long-term annual mean temperature calculated for the period 1906-90. This data series is generally representative of the low frequency temperature trends across the Gulf of Maine and Scotian Shelf (Petrie and Drinkwater, 1993).

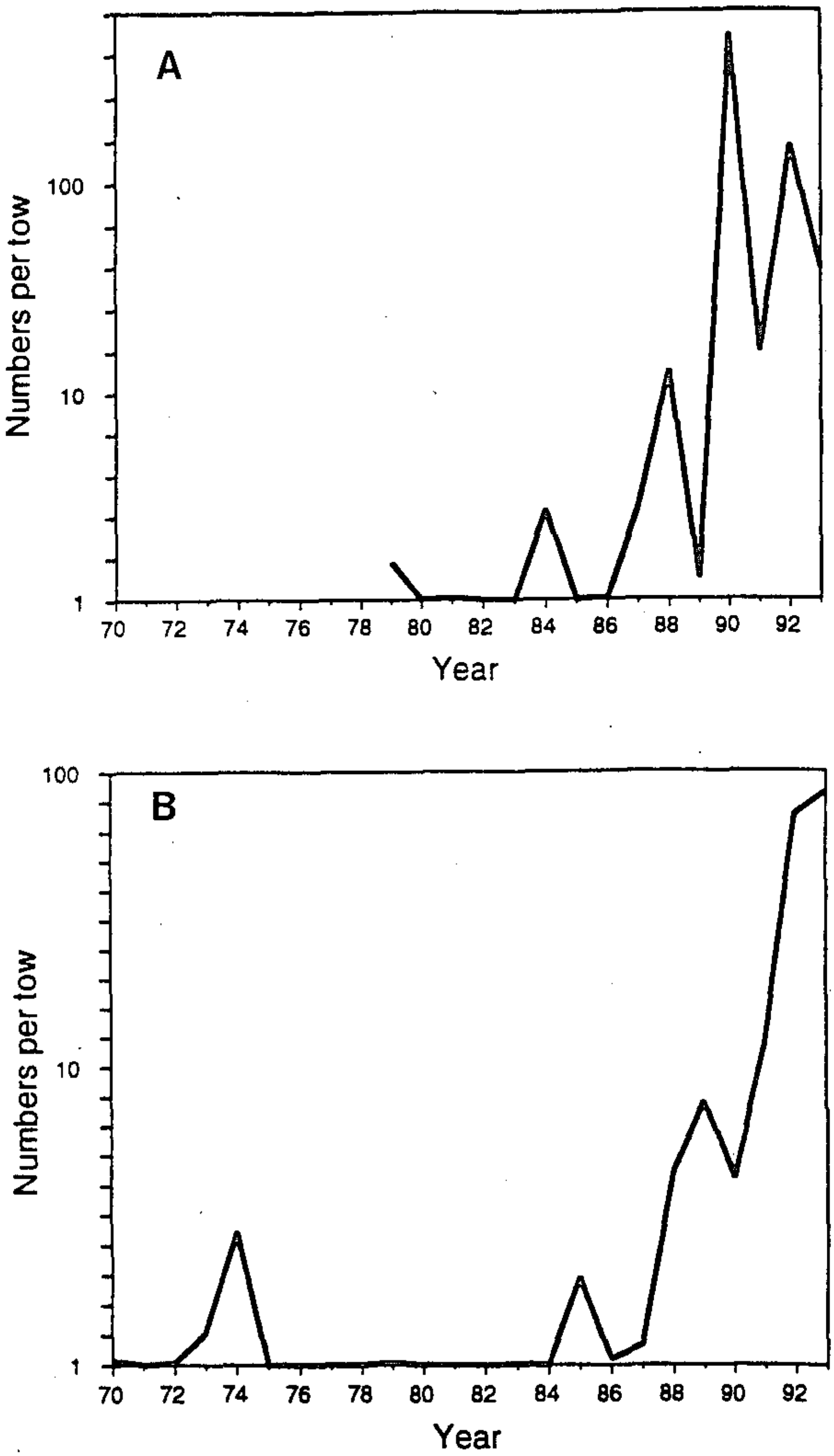
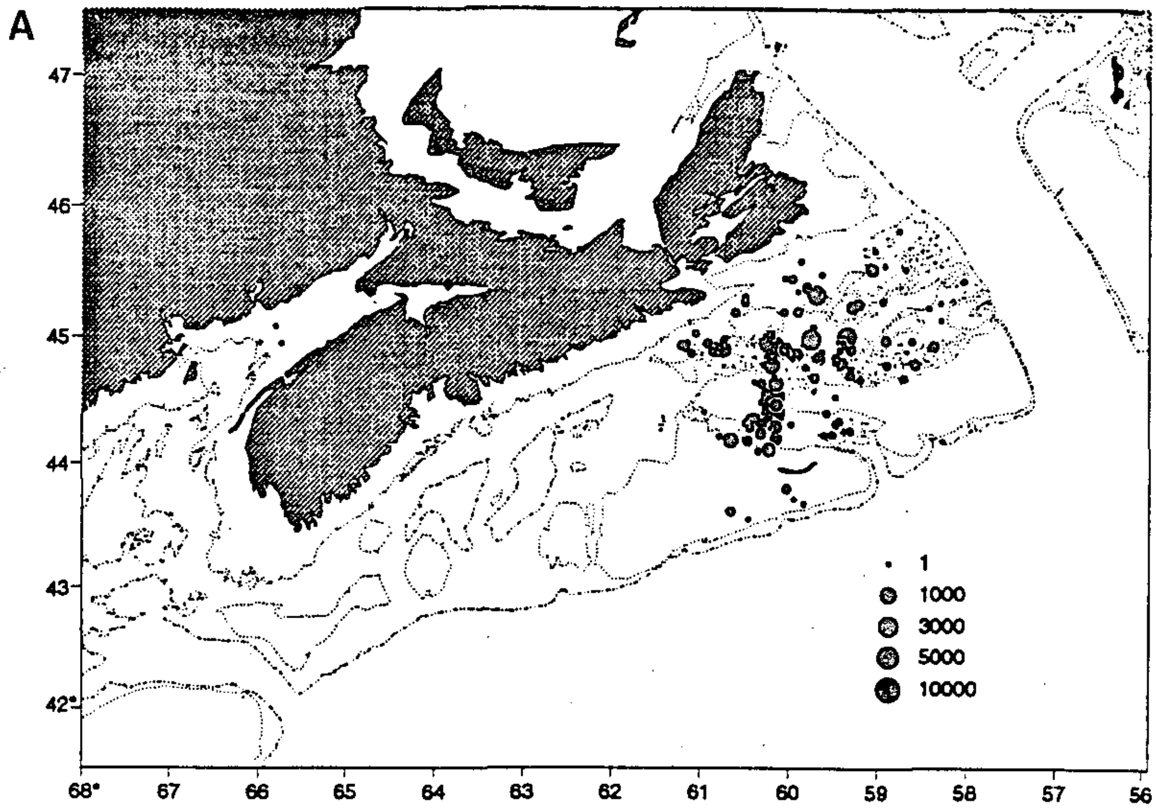


Fig. 4. Mean numbers per tow of capelin for Div. 4VW during spring (A) and summer (B) RV surveys. Note that these catch rates represent only the eastern half of the Scotian Shelf because generally no capelin were collected in Div. 4X.



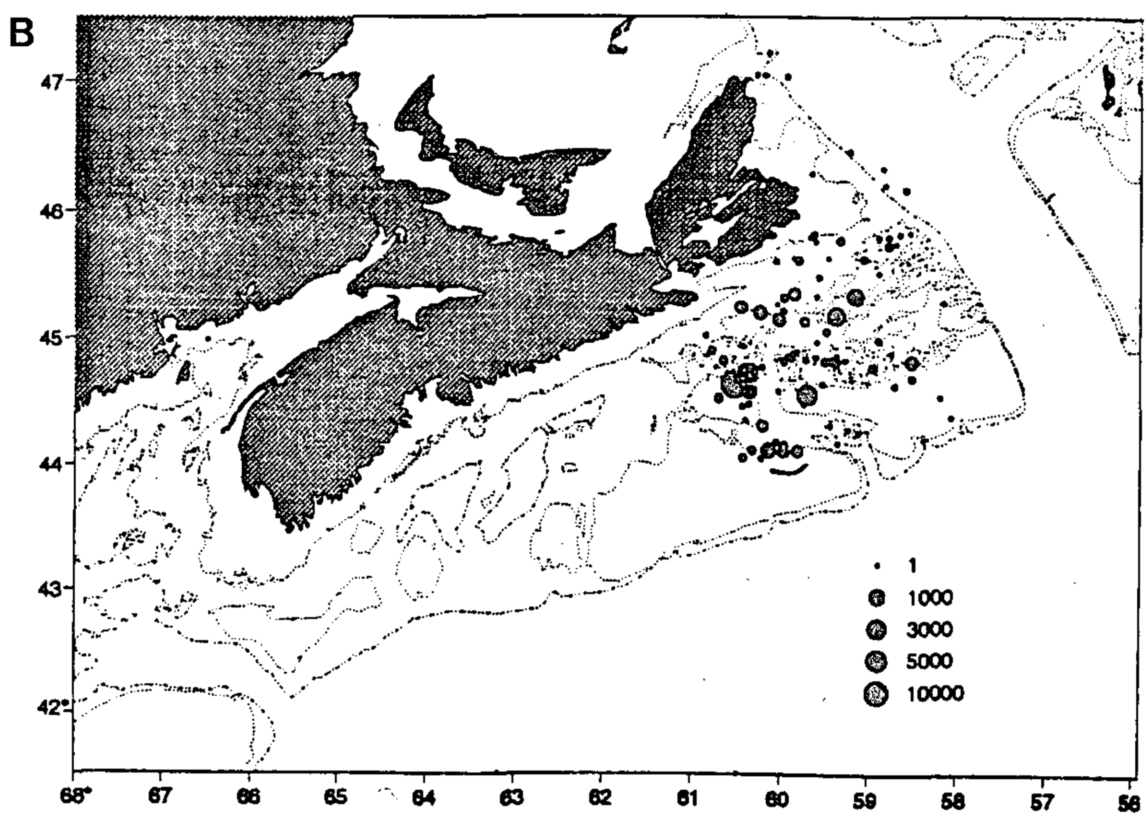


Fig. 5. Geographic distribution of capelin on the Scotian Shelf depicted as expanding symbols of capelin catch per tow from the spring (A) and summer (B) RV surveys for all years combined. Note that the spring RV survey did not include Div. 4X.

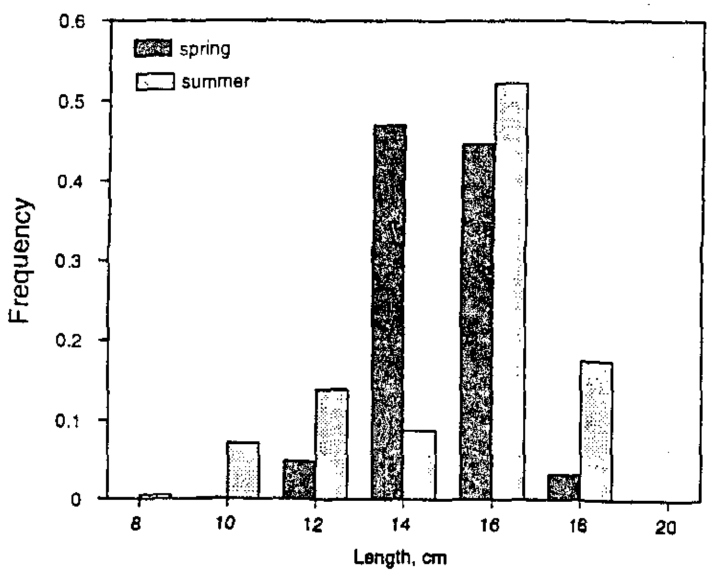


Fig. 6. Length frequency distribution of capelin for all spring and summer RV surveys combined.

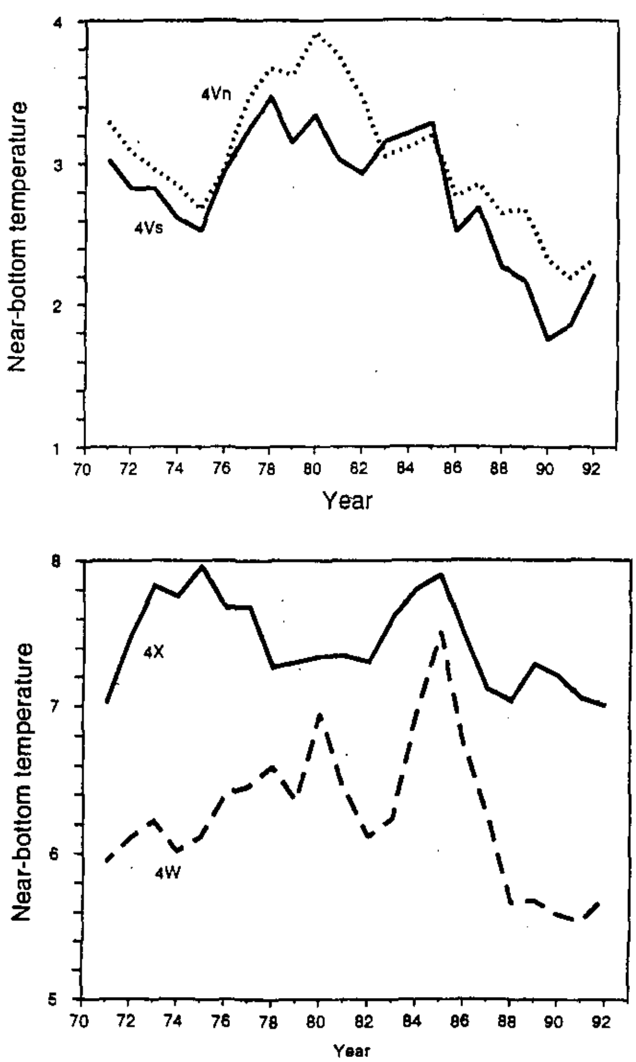


Fig. 7. Average, near-bottom temperatures from the summer RV survey in Div. 4Vn, 4Vs, 4W and 4X. Data were smoothed using a three-year running mean.

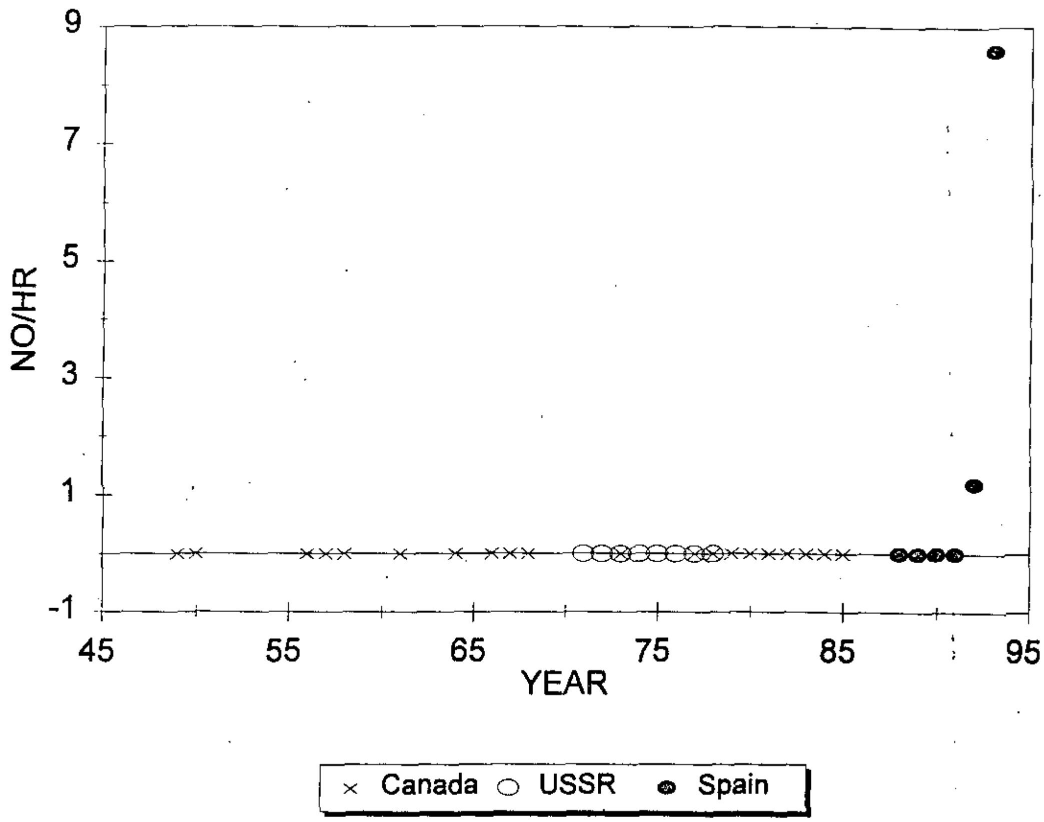


Fig. 8. Capelin abundance trends based on research vessel surveys conducted by Canada, USSR and Spain on Flemish Cap (Div. 3M).

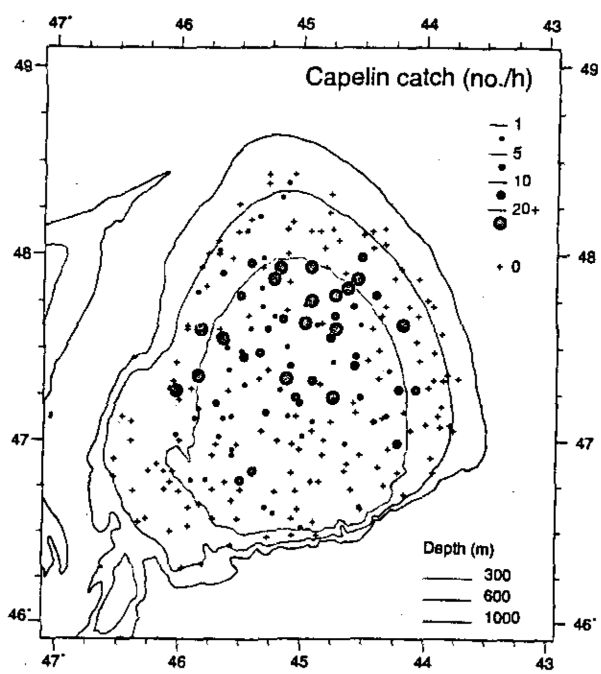


Fig. 9. Geographic distribution of capelin depicted as expanding symbols of catch per tow in Div. 3M from RV surveys conducted by Spain in 1992 and 1993.

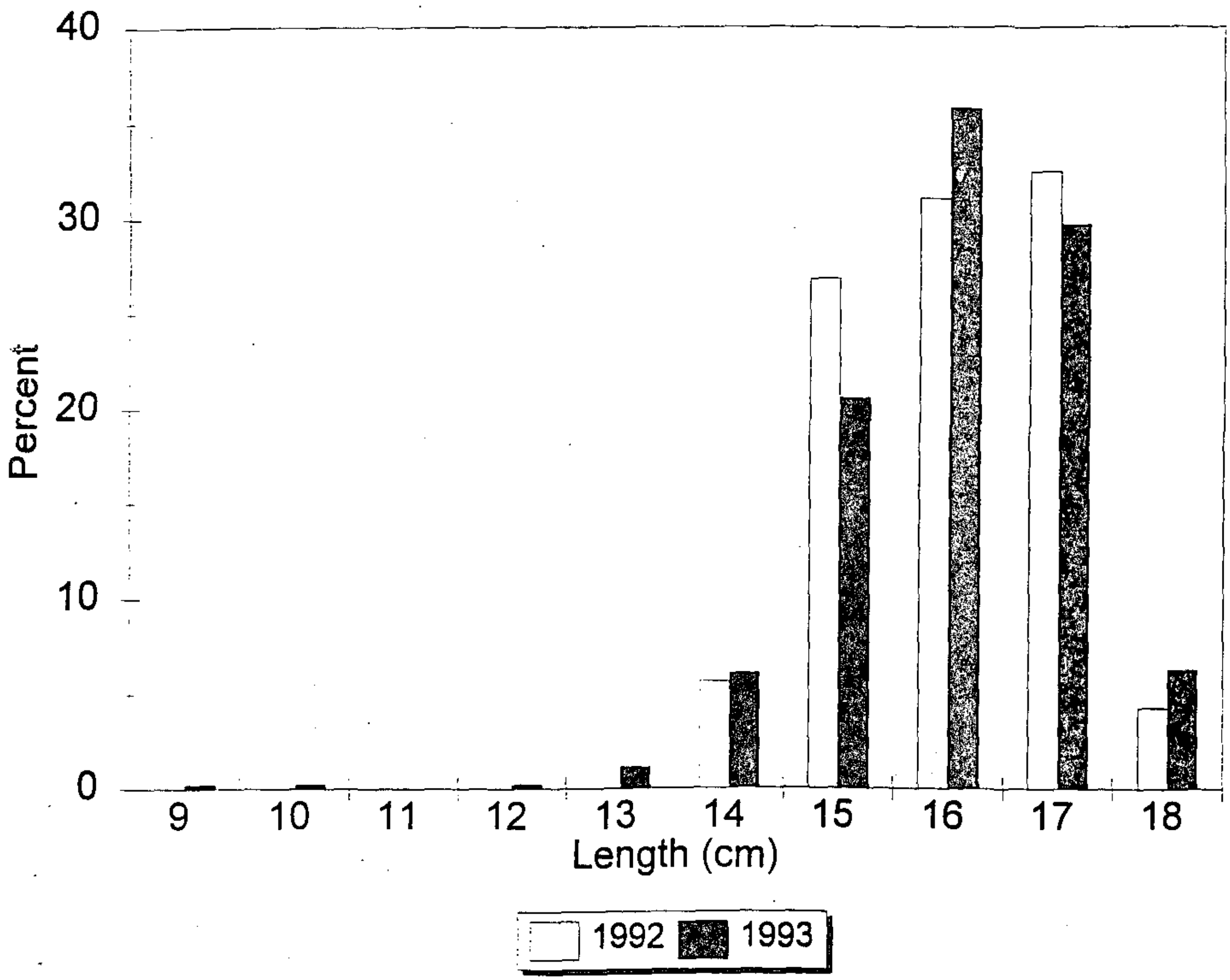


Fig. 10. Length frequency distribution of capelin from 1992 and 1993 RV surveys of Div. 3M.

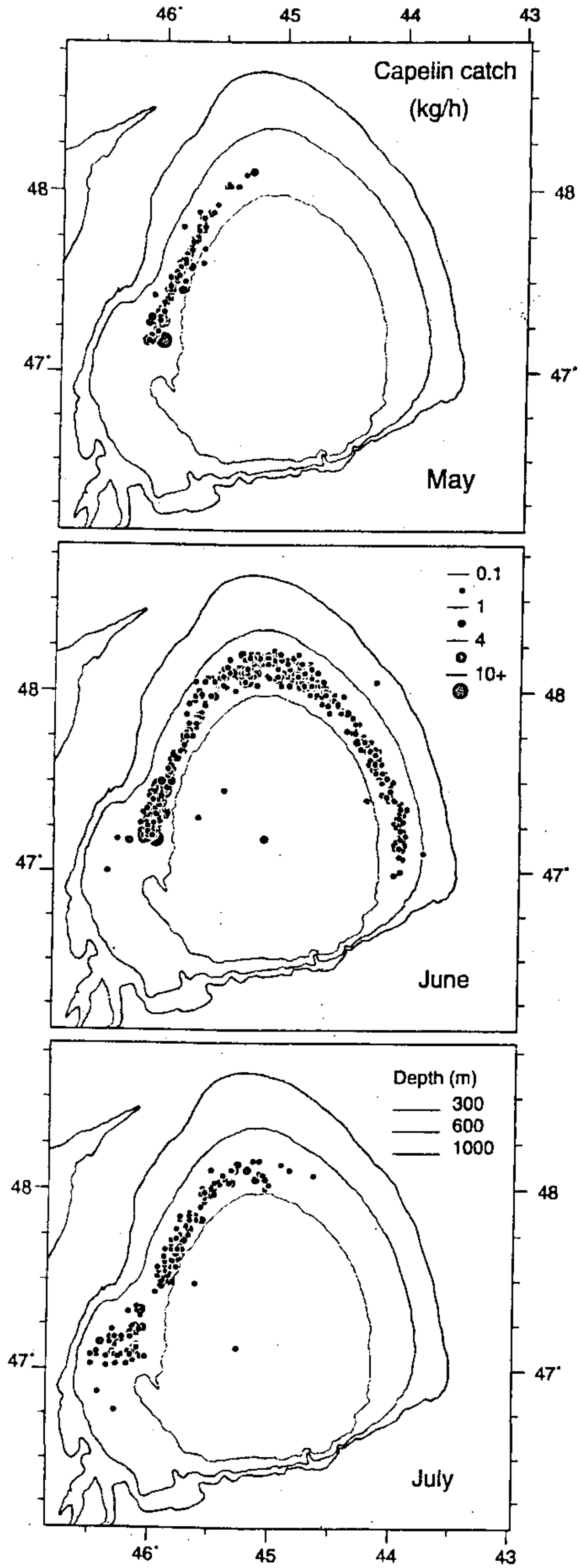


Fig. 11. Geographic distribution of capelin during May, June and July based on incidental catches from the shrimp fishery in Div. 3M during 1993.

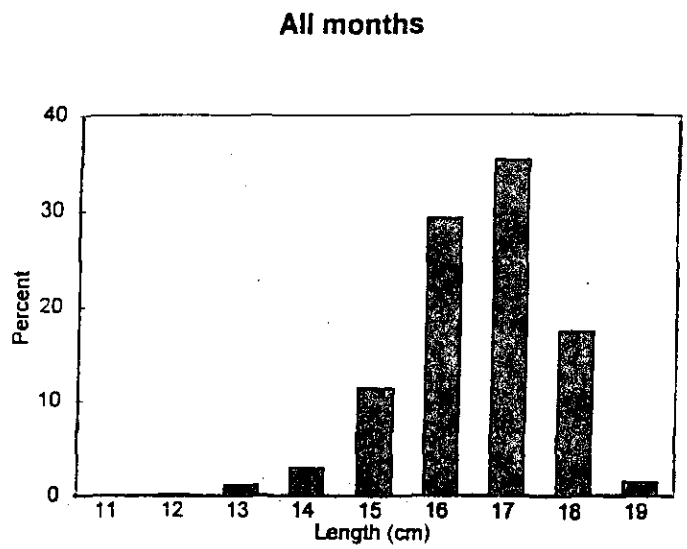


Fig. 12. Length frequency of capelin from the 1993 shrimp fishery in Div. 3M.

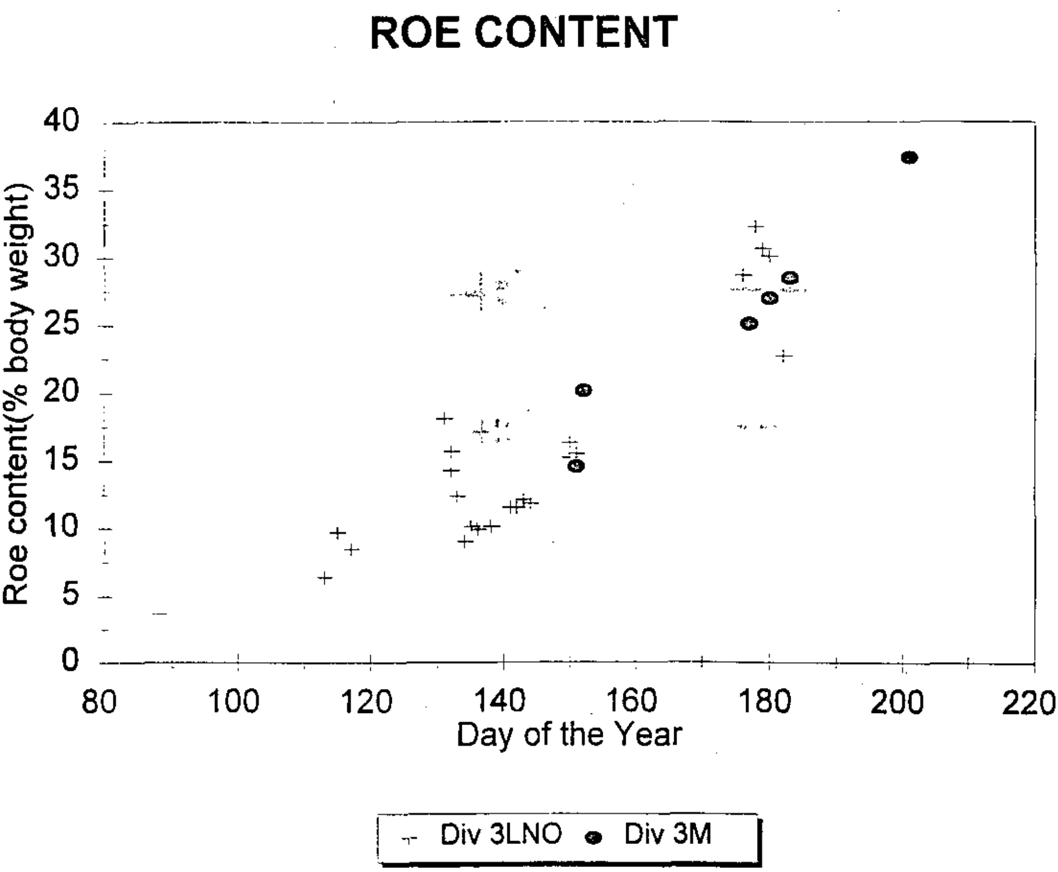


Fig. 13. Ratio of gonad weight to total body weight of capelin from Div. 3LNO and 3M.

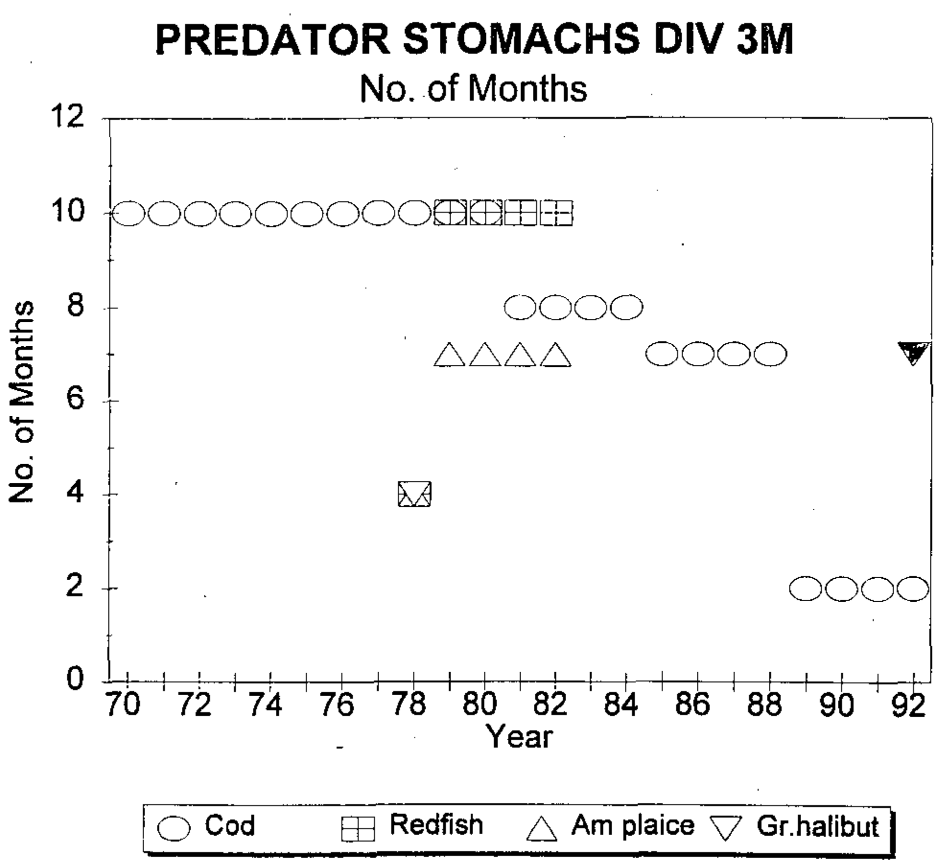


Fig. 14. Number of months in each year (1970-1992) in which predator stomachs were collected in Div. 3M to analyze feeding patterns. Literature sources were Noshov *et al.* (1963), Turuk and Postolaky (1980), Turuk (1981), Konstantinov *et al.* (1985), Albikovskaya and Gerasimova (1989), Paz *et al.* (1989), Paz *et al.* (1991), Rodriquez-Marin *et al.* (1993) and Casas and Paz (1994). Predators include cod, redfish, American plaice, and Greenland halibut.

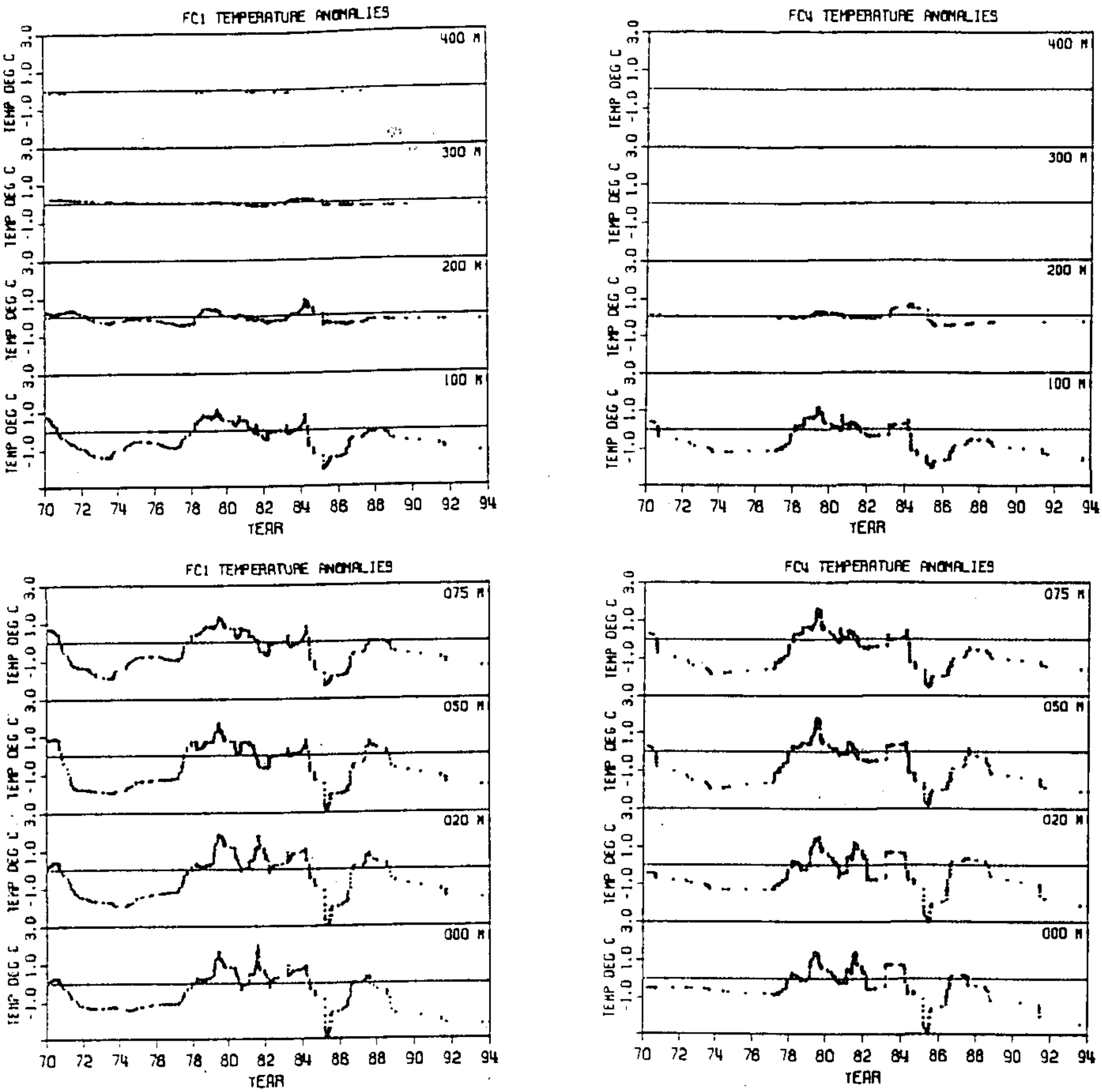
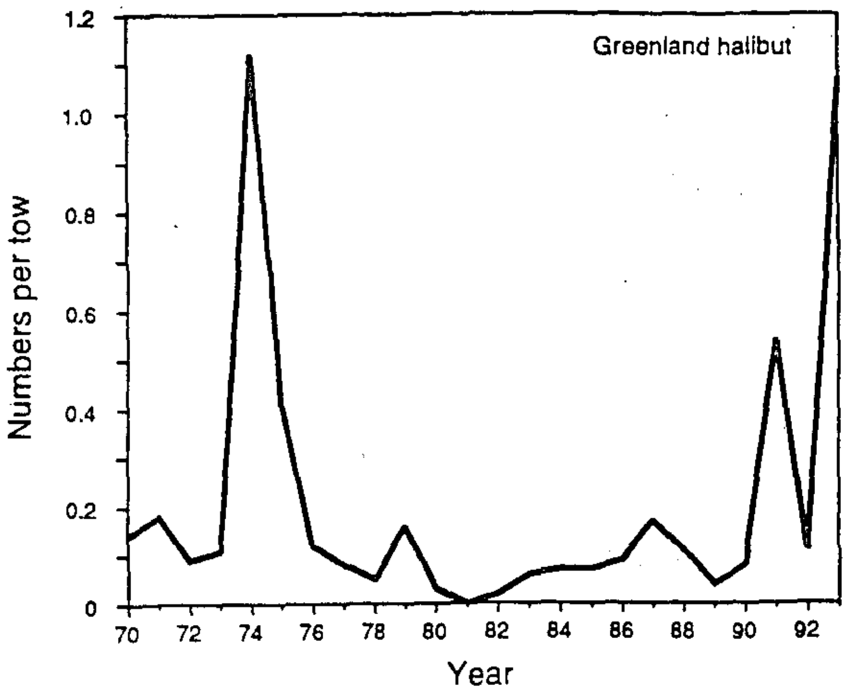


Fig. 15. Annual temperature from western (Area FC1) and central (Area FC4) Flemish Cap during 1970 to present (taken from Colbourne 1993).



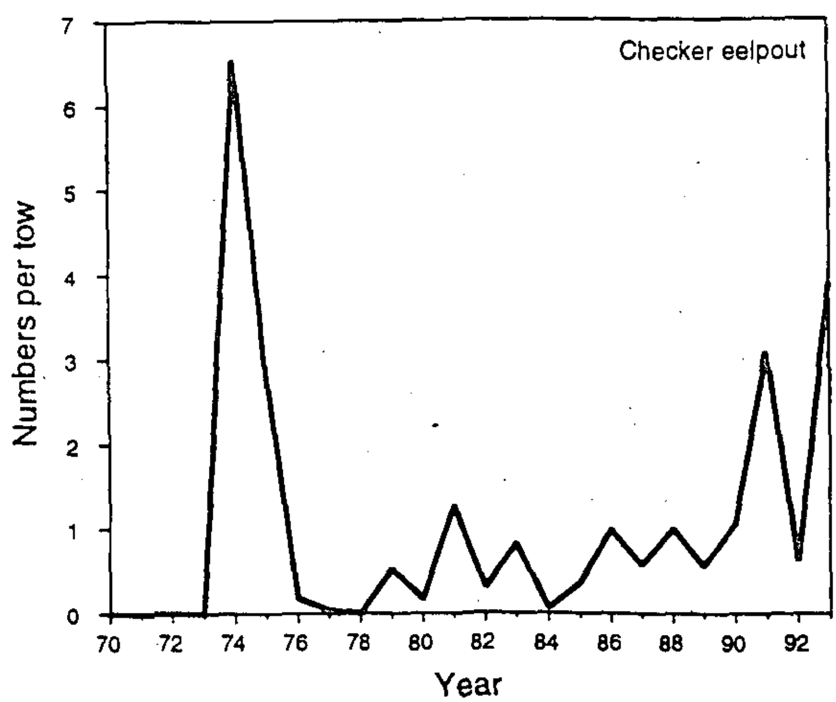


Fig. 16. Mean numbers per tow of Greenland halibut and checker eelpout for Div. 4VW during RV summer surveys on the Scotian Shelf.