Capelin in the northwest Atlantic

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1. Abstract

Capelin (*Mallotus villosus*) is considered to be one of the most important fish species in the northwest Atlantic because of its commercial importance and its position as a forage species. Aspects of capelin biology including distribution, spawning, migration patterns, stock discrimination, population biology, and its position in the trophic structure of the northwest Atlantic are reviewed. The offshore commercial capelin fishery began in 1972, peaked in 1976, and has declined since then. The pattern of the commercial fishery and its management are reviewed. The status of capelin stocks has been determined by a surplus-production model, acoustic techniques, and analytical models: and the results of the analytical models indicated that the strong 1973 year-class resulted in relatively high capelin abundance in the mid 1970s. The 1974–78 year-classes were relatively weak and the capelin biomass declined during the late 1970s. Fishing mortality rates calculated from the analytical models have been low for stocks in Northwest Atlantic Fisheries Organization divisions 2J3K and 3L suggesting that fishing did not contribute significantly to the decline. Heavy fishing pressure on the division 3N0 stock may have exaggerated the decline of this stock. Factors influencing the dynamics of capelin populations and the possible effects of fluctuations of capelin on its predators are reviewed. The research program in capelin is presented.

2. Résumé

Le capelan (*Mallotus villosus*) est considéré comme une des principales espèces de poissons du nord-ouest de l'Atlantique en raison de son importance commerciale et de sa qualité de fourrage. L'auteur reprend certains aspects de la biologie du capelan et traite aussi de la distribution, du frai, des schèmes migratoires, de la différenciation des stocks, de la biologie des populations et de la position du capelan dans la chaîne trophique du nord-ouest de l'Atlantique. La pêche hauturière commerciale du capelan, qui a débuté en 1972, a atteint un sommet en 1976 et a décliné depuis. L'auteur analyse la structure et la gestion de la pêche commerciale. La situation des populations a été déterminée grâce à un modèle de production excédentaire, à des techniques acoustiques et aussi à des modèles analytiques; les résultats obtenus avec les modèles analytiques montrent que le grand nombre de sujets dans la classe d'âge 1973 a donné lieu à une abondance relative de capelan au milieu des années 1970. Les quantités ont été relativement faibles dans les classes d'âges 1974 à 1978 et la biomasse du capelan a diminué vers la fin des années 1970. Les taux de mortalité causée par la pêche, calculés à l'aide des modèles analytiques, ont été faibles dans les stocks des divisions de la Northwest Atlantic Fisheries Organization 2J3K et 3L, ce qui indique que la pêche n'a pas concouru de façon appréciable à la baisse des populations. Une forte pression de la pêche sur le stock de la division 3N0 pourrait en avoir accentué le déclin. L'auteur revoit les facteurs qui influent sur la dynamique des populations de capelans et les effets possibles des fluctuations de l'effectif des populations sur les prédateurs de cette espèce. Il expose également le programme de recherche sur le capelan.

3, Introduction

It is probable that capelin (*Mallotus villosus*) is one of the most important fish species in the northwest Atlantic because of its commercial importance (1980 landed value $3.5 million) and its position as a forage species (Bailey *et al.* 1977, Winters and Carscadden 1978). The importance of capelin as a food species for other marine animals has long been recognized (Templeman 1948), but recently capelin has generated a great deal of interest both from the general public and the scientific community. This interest has arisen largely as a result of a commercial capelin fishery that developed in the early 1970s and the potential impact of this fishery on the capelin stocks themselves and on predator stocks, many of which are commercially important.

It is the purpose of this paper to review some aspects of capelin life history, the history of the commercial fishery and its management, the population dynamics of capelin, the possible impact of fluctuations of capelin on its predators, and the research program on capelin in the Newfoundland area.

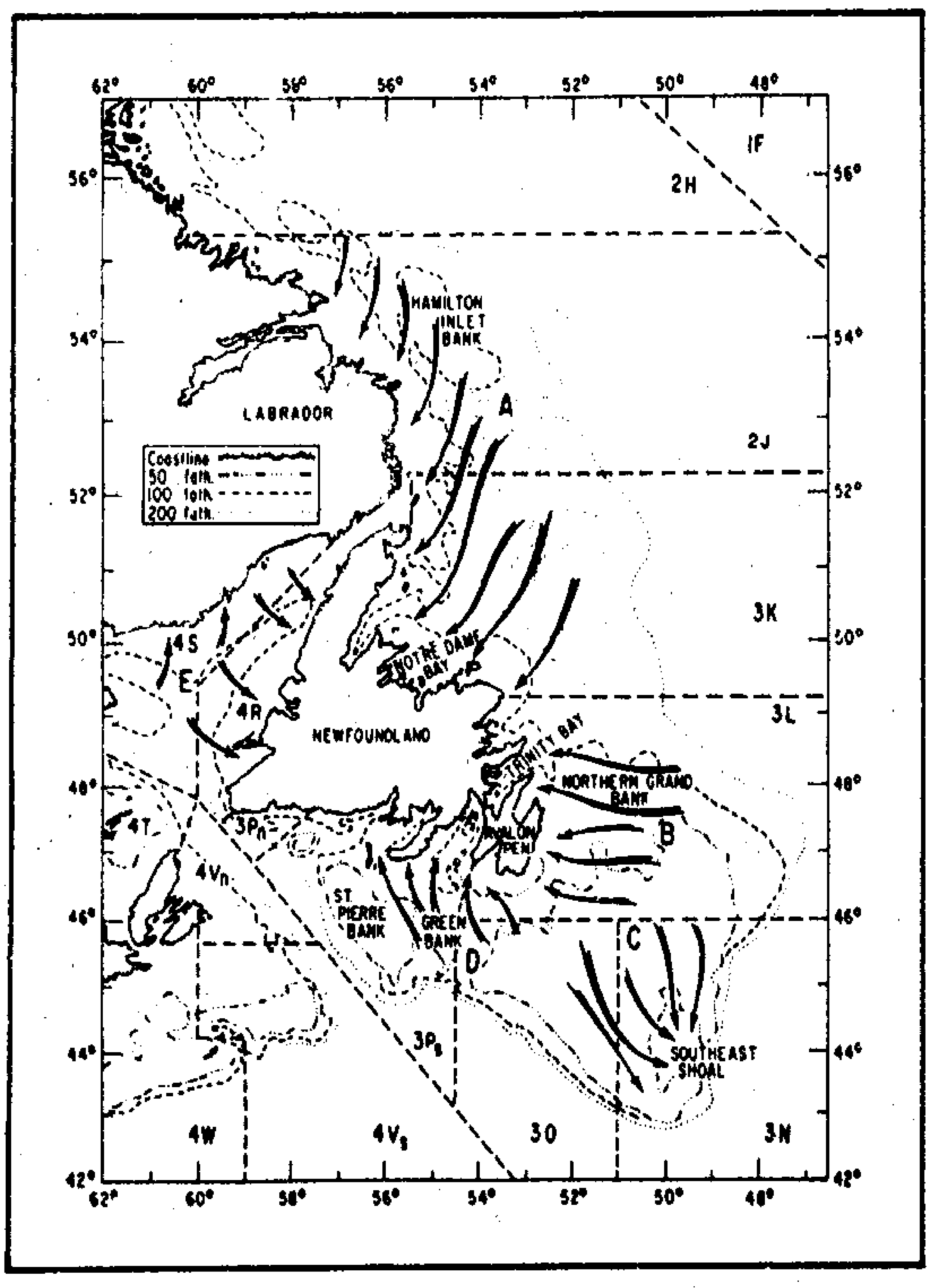
4. Life history

Capelin (or caplin) are small, silvery fish closely related to smelt. They are a cold water, pelagic, schooling species inhabiting arctic and subarctic seas in the Atlantic and Pacific oceans. In the eastern Atlantic, capelin occur from western Norway to northern Russia and are widely distributed throughout the Barents Sea. They are also abundant around Iceland and Greenland. On the east coast of North America, capelin occur from Hudson Bay to Nova Scotia, but are most abundant around Newfoundland and Labrador. In the Pacific, capelin occur from Alaska to Juan de Fuca Strait and from the Sea of Chukotsk to Japan and Korea (Jangaard 1974).

The relative distribution of capelin in the coastal zone varies seasonally but undoubtedly peaks in June and

July, when beach spawning occurs. At other times of the year, capelin can be found in large concentrations in the offshore waters. Although the distribution of young capelin is not well defined, the distribution and migration patterns of adults are better known and spawning stocks of capelin have been identified. There are five major stocks in the Newfoundland area: Labrador–Northeast Newfoundland stock, NAFO[1] div. 2J3K, (A); Northern Grand Banks – Avalon stock, NAFO div. 3L, (B); South Grand Banks (Southeast Shoal) stock, NAFO div. 3NO, (C); St. Pierre – Green Bank stock, NAFO div. 3Ps, (D); Gulf of St. Lawrence stock (E) (Fig. 1). Some of these major stocks (e.g. Labrador – Northeast Newfoundland and Gulf of St. Lawrence) may be composed of a number of substocks (Winters 1974*a*, Sharp *et al.* 1978). These stocks have been identified through the knowledge of seasonal distribution patterns and growth differences (Campbell and Winters 1973, Winters 1974*b*), meristic (Sharp *et al.* 1978, Carscadden and Misra 1980) and morphometric (Sharp *et al.* 1978) characters, and the fishing patterns of the commercial capelin fleet. Like most species of fish, there is some degree of stock overlap during some part of the life cycle. Because most of the commercial fishery occurred on only three of the stocks (div. 2J3K, div. 3L, and div. 3N0 stocks), subsequent discussion will be restricted to capelin occurring in these areas.

Figure 1
Map showing major stocks and migration routes of mature capelin. Alpha-numeric designations (e.g. 2H, 2J, 3K, etc.) are NAFO divisions. A. Labrador – Northwest Newfoundland (NAFO div. 2J3K) stock. B. Northern Grand Banks – Avalon (NAFO div. 3L) stock. C. South Grand Banks (Southeast Shoal – div. 3N0) stock. D. St. Pierre – Green Bank (NAFO div. 3Ps) stock. E. Gulf of St. Lawrence stock. (Modified from Campbell and Winters 1973)



The Notre Dame Bay area is known to be an overwintering area for part of the Labrador – Northeast Newfoundland stock. It seems probable that capelin also overwinter in parts of NAFO subarea 2; capelin have been taken in research catches late in the year in this area and there is no known northward migration in the spring from div. 3K to the inshore spawning grounds in subarea 2. During June and July, mature capelin move inshore to spawn on beaches in northeastern Newfoundland and Labrador. After spawning, most fish die. The few spawning survivors move offshore in late summer and join immature fish to form feeding schools. Feeding is heavy from August to November and large schools are found in offshore waters from Labrador to northeast Newfoundland.

The northern Grand Bank – Avalon and Southeast Shoal stocks appear to mix and overwinter on the northern part of the Grand Banks (Campbell and Winters 1973, Carscadden and Misra 1980). During late winter and early spring the fish become active, form feeding schools, and begin a migration to the spawning grounds. The northern Grand Banks – Avalon stock moves inshore to spawn on Newfoundland beaches while the Southeast Shoal stock moves south over the Grand Banks to spawn on sandy substrate on the Southeast Shoal. Spawning in both areas occurs during June and July and post-spawning mortality is high at this time. Spawning survivors are believed to move to the northern Grand Banks area for feeding and overwintering.

There are differences in the timing of spawning in different areas. Spawning on the west and south coasts of Newfoundland usually begins in late May. Spawning time usually becomes later further to the north such that spawning in Labrador may not occur until August in some years (Templeman 1948). Spawning on the Southeast Shoal, the only known offshore spawning area for capelin, occurs in June and July.

The general environmental conditions necessary for spawning have been characterized. Capelin spawning inshore in Newfoundland and Labrador prefer water temperatures of 5.5–8.5°C and pebbles ranging in size from 0.5 to 2.5 cm in diameter (Templeman 1948). Spawning normally occurs at night or on dull cloudy days, although there are exceptions. On the Southeast Shoal, spawning occurs in a water depth of approximately 50 m where bottom temperatures are 2–4°C (Pitt 1958*a*).

Inshore spawning normally occurs for 4–6 weeks; most spawning occurs on the beaches, but if water temperatures on the beach become too high the fish will spawn in deeper water adjacent to the beaches. Deepwater spawning appears to be more common on the west coast of Newfoundland, apparently because the water temperatures near the beaches are too high by the time the capelin are ready to spawn (Templeman 1948). The extent of deepwater (nonbeach) spawning is probably very variable from year to year and other factors besides water temperature on the beach may exert an influence.

Capelin mature at 3 or 4 years of age with faster growing fish maturing earlier (Winters 1974*b*). In the

[1]Northwest Atlantic Fisheries Organization (formerly ICNAF, the International Commission for Northwest Atlantic Fisheries).

spawning populations, 3- and 4-year-olds usually predominate (Fig. 2), although other ages, including two, five, six, and seven do occur in varying proportions. Spawning mortality is high, usually greater than 80% (Carscadden and Miller 1980*a*).

There is no doubt that capelin are important as a forage fish in the Newfoundland area. There have been many feeding studies conducted on predators that indicate that at some time of the year, capelin are an important component of their diet. Perhaps the most extensively studied capelin predator is cod (*Gadus morhua*) and there are a number of studies (see Akenhead *et al.* 1982, Lilly 1981, Lilly *et al.* 1981 for reviews) that substantiate the observation that cod consume capelin. It is possible to describe the broad seasonal patterns of cod predation on capelin in div. 2J3KL and div. 3N0 and the following description is taken directly from Lilly *et al.* (1981).

> Predation is apparently most intense on the north slope of the Grand Bank in winter and spring, in the Avalon Channel and on the northwestern Grand Bank in spring, on the northern Grand Bank and inshore all along the coast in late spring and summer, and along the coastal shelfs of 2J3K and on the Hamilton Inlet Bank in late summer and autumn. The predation pattern is highly seasonal in the region of Hamilton Inlet Bank, but much less so on the northern Grand Bank. Predation by cod on capelin in 3N0 appears to be largely confined to spring and summer.

In spite of numerous feeding studies Lilly *et al.* (1981) point out that "there is no estimate, based on adequate seasonal and spatial sampling, of the contribution of capelin to the total food consumption of a single cod stock in a given year." However, several studies have estimated that for the Newfoundland area in general, capelin comprise about 30% of the cod's diet (Akenhead *et al.* 1982).

Although cod is the capelin predator that often evokes the most concern, other marine species feed heavily on capelin as well. Capelin accounts for 45–100% of the food of adult salmon (*Salmo salar*), depending on size, in Newfoundland coastal waters (Lear 1972). Greenland halibut (*Reinhardtius hippoglossoides*) in the length range of 20–80 cm feed heavily on capelin (Lear 1969) and American plaice (*Hippoglossoides platessoides*) (20–49 cm) in div. 3L depend on capelin for 14–38% of their food (Pitt 1973). Haddock (*Melanogrammus aeglefinus*), yellowtail flounder (*Limanda ferruginea*), winter flounder (*Pseudopleuronectes americanus*), skates, sea ravens, and a variety of other demersal species consume large quantities of capelin eggs and capelin during the spawning season (Pitt 1958*b*, Templeman 1968).

Marine mammals also feed heavily on capelin. Capelin are an important food for whales, including fin whales (*Balaenoptera physalus*) (Mitchell 1975), minke whales (*B. acutorostrata*), sei whales (*B. borealis*) (Sergeant 1963), and humpback whales (*Megaptera novaeangliae*) (Lien 1980), in the Newfoundland area. Sergeant (1973) has estimated that at least 25% of the diet of harp seals (*Pagophilus groenlandicus*) is capelin and other less abundant species of seals such as hooded (*Cystophora cristata*), grey (*Halichoerus grypus*), and harbour (*Phoca vitulina*) seals, also consume significant quantities of capelin.

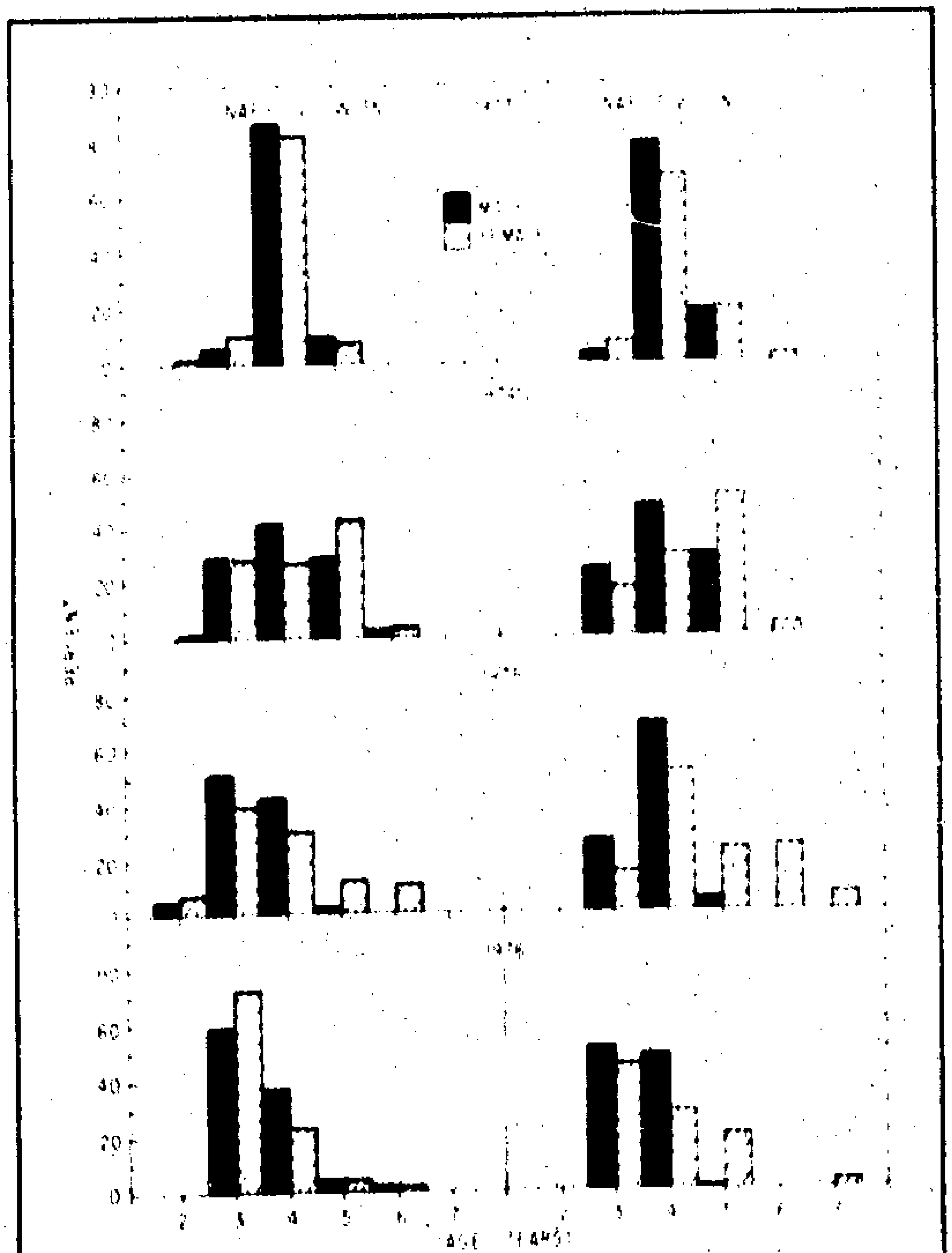
Seabirds are also capelin predators: murres (*Uria* spp.) (Tuck 1961), Atlantic Puffins (*Fratercula arctica*) (Nettleship 1972), Greater Shearwaters (*Puffinus gravis*) (Brown *et al.* 1981), Northern Gannets (*Morus bassanus*) (Montevecchi and Porter 1980), Black-legged Kittiwakes (*Rissa tridactyla*) (Maunder 1971, Winters and Carscadden 1978), and the *Larus* gulls (Pierotti 1979) all feed on capelin (see Brown and Nettleship, this volume, for details).

4. The fishery and its management

It is only in the last decade that people have become significant predators of capelin although capelin have been taken during the spawning season for decades. It has been estimated that prior to the 1950s, 20 000–25 000 t of capelin were taken annually in Newfoundland for bait and fertilizer and to a lesser extent for food for dog teams (Templeman 1968, Barnes 1974). However, with the decline in the use of dog teams and in gardens and less demand for capelin as bait, inshore landings declined considerably. During the 1970s, interest in capelin as a commercial species increased with effort being concentrated in the offshore area in the early and mid 1970s and in the inshore area in the late 1970s.

In 1972, the first substantial offshore catches of about 70 000 t of capelin were reported. These catches increased rapidly, peaking in 1976 at about 370 000 t and declining since then. The catches were taken at different

Figure 2
Example of age-compositions of mature capelin populations from div. 3L and div. 3N, 1973–76



times of the year in different areas and details of the catches by areas (div. 3L, div. 3N0, and div. 2J3K) are given in Figures 3, 4, and 5.

The annual offshore capelin fishery normally began in March or April on fish, most of which were maturing and feeding, on the northern Grand Banks (div. 3L). Thus, fish from two stocks, the northern Grand Bank–Avalon stock and the Southeast Shoal stock, were fished at this time. Most of the vessels in this fishery were USSR midwater trawlers. The fishing fleet followed the capelin as they moved to their spawning grounds; however, once the inshore spawning component entered Canadian territorial waters, the fleet followed the Southeast Shoal (div. 3N0) capelin to their spawning grounds where the fishery on spawning capelin continued into July. Most of the vessels operating on the Southeast Shoal were USSR mid-water trawlers and Norwegian purse seiners.

The fishery in div. 3L developed very rapidly with the peak catch reported in 1974, followed by a gradual decline from 1975–80 (Fig. 3). In 1975, Canadian ports were closed to the USSR fishing fleet because Canadian authorities accused the Soviets of taking approximately double their quota in div. 3L. If true, the catch in 1975 in Figure 3 should be approximately 60 000 t. In addition, the "inshore" catch in 1974 is shown at approximately 8000 t, higher than the preceding and following years. This may be an anomaly caused by the grouping of the data; in the present grouping, Canadian catches were assumed to have been taken inshore. However in 1974, some catches were reported from large (500–999 GRT) purse seiners chartered by Canadian companies. Thus, the catches may have been taken offshore and the inshore catch estimates for 1974 may be overestimated and the offshore catch estimates underestimated. In general, the trend of catches for div. 3L since 1974 has been a decrease in the offshore portion and in increase in the inshore portion. Some unknown fraction of the div. 3L offshore catch may have been fish from the Southeast Shoal stock.

The catches (Fig. 4) of the Southeast Shoal stock (div. 3N0) rose rapidly from about 21 000 t in 1972 to a level of about 100 000 – 132 000 t for 4 years between 1973 and 1976 and dropped quickly to 47 000 t in 1977 and 5000 t in 1978. The fishery was closed in 1979 and has remained closed since then. It was the conclusion of scientists that "the intense commercial fishery on the spawning grounds in div. 3N may have substantially reduced the spawning stock size in recent years, and the possibility of recruitment overfishing should be taken into account" (Anon. 1979).

Each year when the fishery on the Southeast Shoal stopped with the cessation of capelin spawning, the attention of the fleet shifted to div. 2J and div. 3K in late August or early September. This fishery, which caught feeding capelin most of which would mature and spawn the following year, was prosecuted mainly by USSR midwater trawlers and continued until November or December.

The first large catch in the div. 2J3K capelin fishery was reported in 1972 at 46 000 t. Catches peaked in 1976 at about 216 000 t and declined after than to about 5000 t in

Figure 3
Nominal catches (metric tons) of capelin in NAFO div. 3L, 1970–80

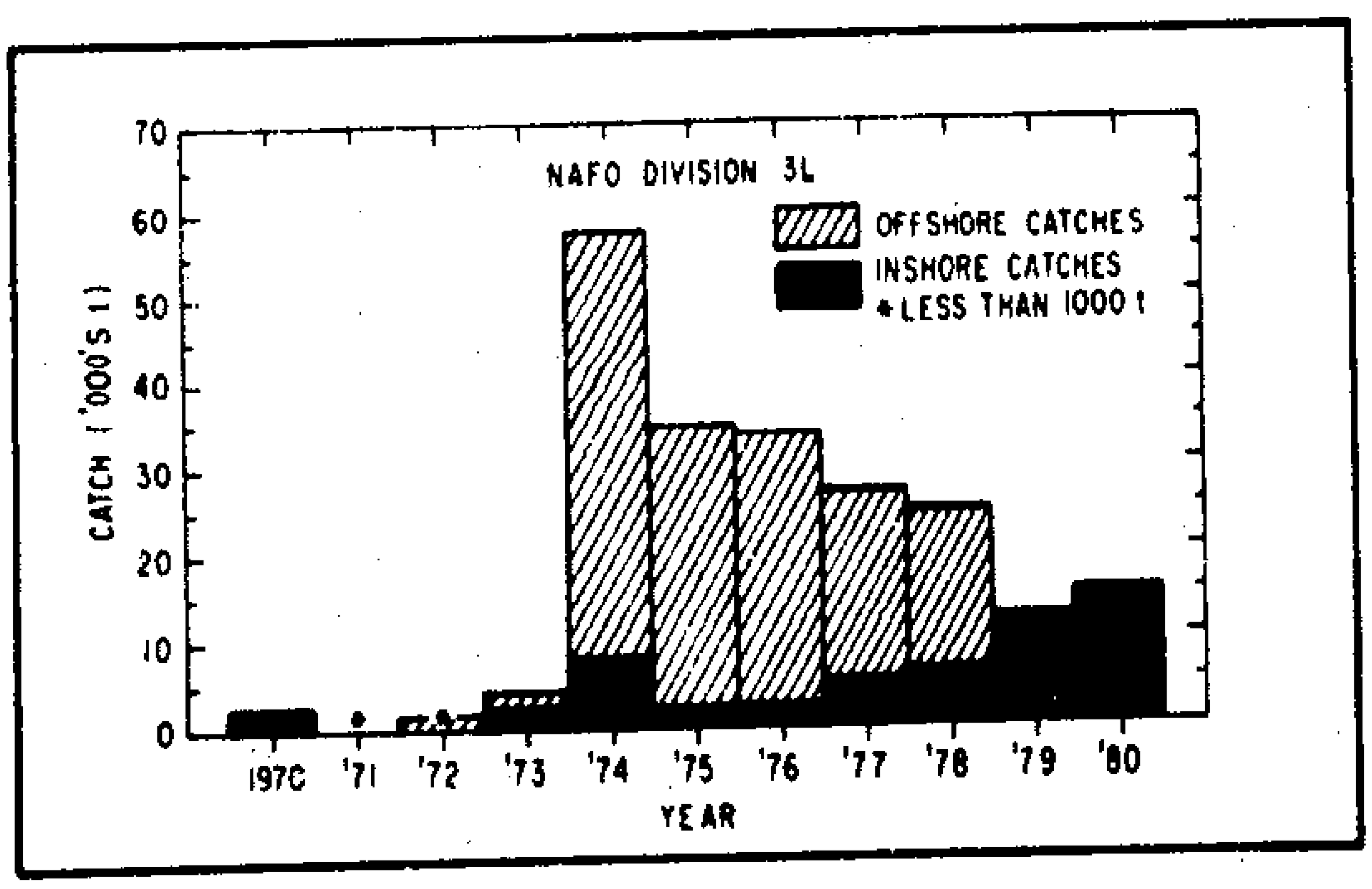


Figure 4
Nominal catches of capelin (metric tons) in NAFO div. 3N0, 1970–80

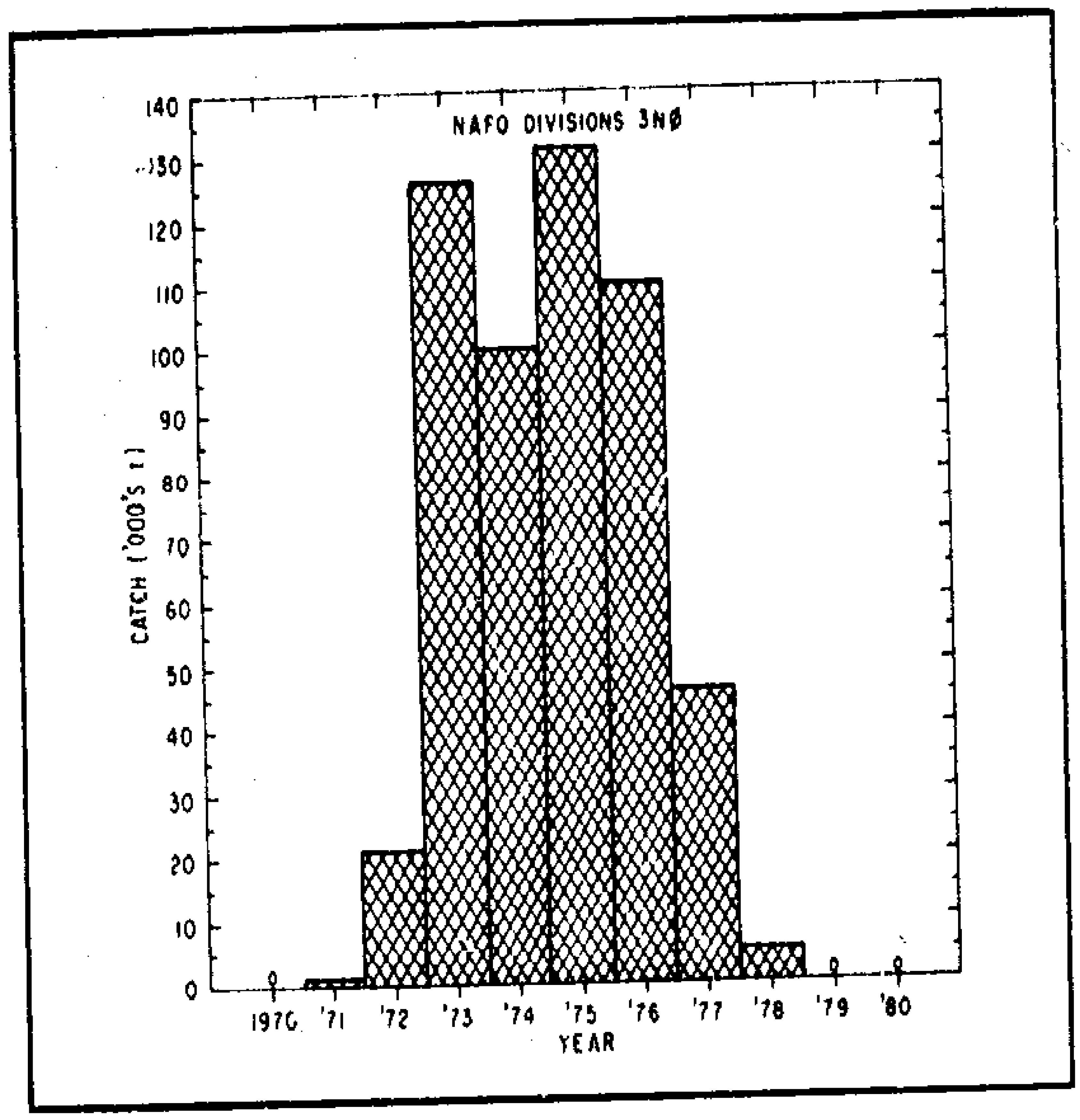
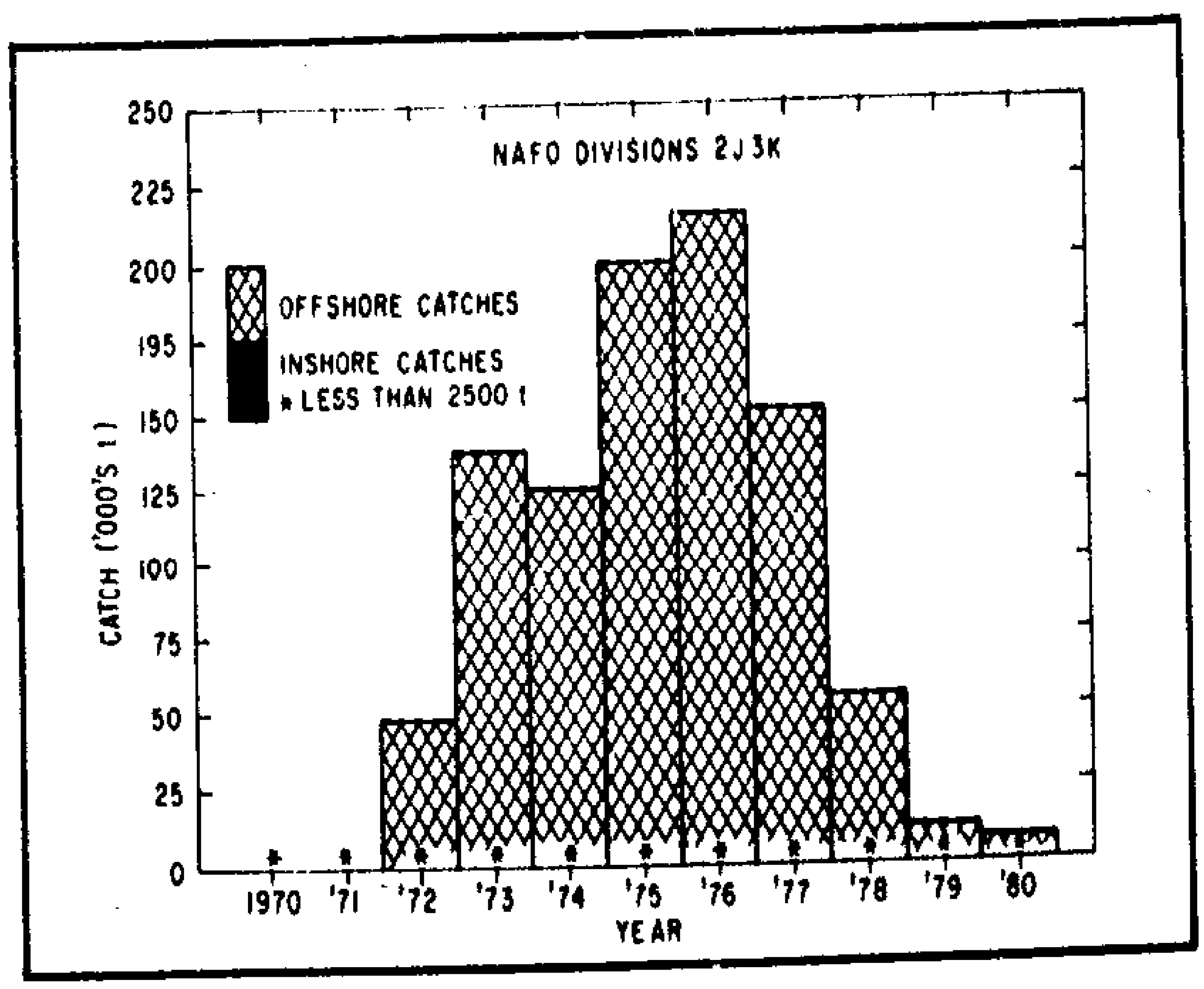


Figure 5
Nominal catches (metric tons) of capelin in NAFO div. 2J3K, 1970–80



1980. During 1970–80, inshore catches remained at a low level below 2500 t (Fig. 5).

The management of capelin came under jurisdiction of ICNAF, and later NAFO, until Canada extended its fisheries jurisdiction to 200 miles (1 Jan. 1977). At this time, the div. 2J3K stock came solely under Canadian management because it occurred completely within Canadian jurisdiction although Canada has continued to request that biological advice be provided through NAFO. The div. 3L and div. 3N0 stocks overlap the Canadian zone and biological advice and management recommendations have continued under the auspices of NAFO. The biological advice provided for the management of capelin has, with few exceptions, bceen adopted by the fisheries managers in NAFO and in Canada and as a result, the biological advice and some of the rationale for that advice is provided below.

The biological advice, provided through ICNAF and later NAFO, was initially requested because of the increasing commercial offshore fishery during the early 1970s. The first advice concerning the total allowable catch (TAC) of capelin pertained to 1974 when it was recommended by the Standing Committee on Research and Statistics (STACRES) of ICNAF that the catch should not exceed 250 000 t. The following year (1975) it was recommended that the TAC could be increased to 500 000 t and maintained for 3 years. Furthermore, it was noted that the fishery should be restricted to mature capelin approaching and during the spawning season, and countries participating in the fishery should conduct surveys of both the adult and juvenile stock to monitor the effect of the fishery. Also in 1975, a crude estimate of relative stock size resulted in a recommendation that 300 000 t could be allocated to the northern area (div. 2J3K) and 200 000 t to the southern area (div. 3LN0Ps). A further subdivision of the southern TAC, based on various biological factors, was also recommended at that time:

> Consideration was given to the question of further subdivision of the TAC on the basis of existing knowledge of stock differentiation. It was concluded that further subdivision of the northern TAC was not practical at the moment due to insufficient knowledge of stock separation in this area. In the south, however, there is evidence to suggest that the fishery in Div. 3L may operate on several separate spawning components which spawn later inshore in Div. 3L, on the Southeast Shoal, and possibly in Subdiv. 3Ps. In 1974, Div. 3L supported a large fishery, while the catch in Subdiv. 3Ps was small. To preclude rapid development of a fishery on a possibly small stock in Subdiv. 3Ps, STACRES advises that an amount of 10 000 tons from the southern TAC be reserved as a maximum permissible catch from Subdiv. 3Ps, with the proviso that any part of this amount could be taken in Div. 3N0 if not taken in the former area. For the southern area as a whole, it was concluded that it would be desirable for the fishery to be concentrated as much as possible on the concentrations of mature capelin in Div. 3N0 to minimize potential adverse effects on capelin and other species. If this were practical, it would avoid the possibility of overfishing any one of the spawning components present in Div. 3L earlier in the season, and, for the inshore spawning stock, it would avoid the possibility of adversely affecting inshore migration and feeding success of the Div. 3L cod. If the principle of directing the southern fishery toward the spawning concentrations is accepted by the Commission, this objective could be achieved by further subdivision of the southern TAC. For example, it could be achieved by setting an upper limit for the Div. 3L fishery of 50 000 tons, with the proviso that any part of this amount not taken in Div. 3L could be taken in Div. 3N0.
>
> To summarize, the management regime in the southern area would then consist of an overall maximum TAC of 200 000 tons, no more than 10 000 tons of which could be taken in Subdiv. 3Ps and no more than 50 000 tons of which could be taken in Div. 3L. If these maxima were not achieved in Subdiv. 3Ps and Div. 3L, the uncaught amounts could be added to the catches in Div. 3N0. (Anon. 1975)

The biological advice remained essentially unchanged until 1979 when evidence of poor recruitment in the capelin population resulted in a recommendation of reductions in the TACs. STACRES advised that the 1979 TAC in div. 3LN0 should be 16 000 t and to protect the spawning stock in div. 3N and during its migration through div. 3N0, there should be no commercial fishery for capelin in div. 3N0. This meant that 16 000 t could be taken only in div. 3L. It was agreed by the NAFO commissioners that there would be no offshore fishery for capelin in div. 3L and Canada claimed only 10 000 t to be taken inshore. Therefore the TAC for capelin in div. 3L in 1979 was essentially 10 000 t. In the northern stock, it was recommended that the 1979 TAC be reduced from 300 000 to 75 000 t. The recruitment prognosis remained poor in 1980 and the biological advice remained unchanged for the stocks in div. 3LN0 that is, a TAC of 16 000 t with no fishing in div. 3N0. In the north, the advice was to close the fishery or allow a small nominal TAC. It was noted that a small fishery of 10 000–15 000 t in the north would allow scientists to better assess the status of the stock in 1980 and to quantify the advice for the next year. An experimental fishery with a TAC of 5000 t was conducted in fall 1980 to provide data for assessment purposes. In 1981 there was some evidence of improvement in the southern area and based on the exploitation rate that had been recommended in 1980 and 1981, a TAC of 30 000 t to be taken in div. 3L was recommended while the div. 3N0 fishery should remain closed. In the northern area, there was conflicting evidence in the scientific data and as a result, the advice remained unchanged from the 1980 advice; that is, that the fishery remain closed or a small nominal fishery of 10 000–15 000 t be allowed. An experimental fishery with a TAC of 10 000 t operated in div. 2J3K during fall 1981.

In general terms, because of the uncertainties involved in the scientific data, the known poor recruitment to the capelin stocks in recent years, and the importance of capelin as a food for other marine species, a conservative exploitation rate of 10% has been recommended since 1979. By comparison, the annual catch (ranging between 1 149 000 and 2 940 000 t) from the Barents Sea capelin stock exceeded 20% of the estimated stock size between 1974 and 1980 (Anon. 1982).

The assessment techniques that formed the basis for the biological advice detailed above have undergone considerable evolution, expansion, and improvements since the mid 1970s, but in general, the international capelin fishery developed faster than the scientific base. There had been some studies on the biology of capelin (e.g. Templeman 1948; Pitt 1958*a*, 1958*b*; Winters 1966, 1970*a*, 1970*b*) but detailed information on population dynamics of capelin, especially biomass estimates, was not available during the early 1970s. Since 1974, there have been three general methods of assessing the capelin stocks; a surplus production model, acoustic estimation, and analytical models.

The use of the three assessment methods has shown a trend over time. During the early phase of the fishery, acoustic estimates and the surplus-production model were the only sources of information. Both types of estimates were recognized as being crude but they were accepted as indications of the magnitude of the capelin resource. The surplus-production model was used only in the early years of capelin assessments whereas the acoustic method has been used since 1974. Eventually the acoustic estimates were used only as indications of relative abundance. As the fishery continued through the 1970s, there were enough data accumulated to develop the sequential-capelin-abundance models. In the most recent years, these models have been used as the most reliable indications of stock status and as a starting point for projections. Ironically, these models have depended on the fishery as a data source and the results from the models have been largely responsible for the advice to reduce the total allowable catch.

The surplus-production model was first developed in 1973 (Campbell and Winters 1973) and expanded in 1975 (Winters 1975, later revised by Winters and Carscadden 1978). Although it is extremely crude, the model was used to provide biological advice and was intended to provide a first estimate of potential long-term annual yield of capelin. It was recognized that many species of marine fish, mammals, and seabirds fed extensively on capelin. Since it was known that the stocks of many of these predators had declined during the 1950s and 1960s, it was assumed that there would be capelin available to a commercial fishery in the 1970s that previously would have been necessary to sustain the predator stocks. Three predators, cod, whales, and seals, were chosen for this analysis because there were estimates of both abundance and of capelin consumption (albeit crude in some cases) available for these animals. It was estimated that annual capelin consumption by cod between the mid 1950s and mid 1960s, when adjusted for density-dependent changes in cod growth, declined from 3.97 million metric tons to 3.0 million metric tons, releasing 0.97 million metric tons of capelin. Estimates of feeding by harp seals suggested that consumption of capelin had declined from 432 000 to 300 000 t due to the attrition in the seal population. Therefore the surplus production of capelin released by the decline in the harp-seal population was 132 000 t. For fin whales, the annual consumption of capelin was estimated to have declined from 360 000 to 250 000 t releasing 110 000 t of surplus production of capelin. The surplus production of capelin released by the decline in the population of minke whales was estimated to be 15 000 t. The total excess production of capelin released by the decline in the abundance of its major predators (cod, seals, and whales) and available for utilization by people was estimated to be about 1.25 million metric tons.

It was noted (Winters 1975, Winters and Carscadden 1978) that these calculations were extremely crude and relied on a number of untested assumptions. Furthermore, this estimate was an average, and considerable variation in stock size and potential catch could be expected due to the large recruitment variations known to occur in capelin (Gjosaeter 1972). The authors (Winters 1975, Winters and Carscadden 1978) suggested that the TAC should not exceed the lower limit of fluctuation in spawning stock size. In this case, the TAC should not exceed 20% of the 1.25 million metric tons of surplus capelin or 250 000 t. In a later study of cod feeding, Minet and Perodou (1978) estimated that cod in div. 2J3KL3Pn4RS consumed 2.24 to 3.8 million metric tons of capelin annually in the years 1965–69, a figure that was in reasonable agreement with that of Winters (1975) and Winters and Carscadden (1978).

Acoustic estimates have been produced primarily by Soviet and Canadian scientists although one early estimate (Dragesund and Monstad 1973) was produced from an exploratory survey by the Norwegians. All of the acoustic estimates have been derived using vertical echo sounders and integration of the voltage of the returned signal (echo integration) — a technique commonly used to estimate abundance of schooling fishes such as capelin in the Barents Sea (Dommasnes 1977) and blue whiting (Anon. 1981) in European waters. In the northwest Atlantic, the Soviets have the longest time series of acoustic estimates of capelin, beginning in 1974 in the northern area (div. 2J3K) and 1975 in the southern area (div. 3LNO). The Canadian estimates are more recent, with the first estimate in the northern area coming from a 1977 survey and in the southern area from a 1979 survey.

Biomass estimates derived from the Soviet and Canadian acoustic surveys are shown in Tables 1 and 2 respectively. It is not possible to discuss the details of each survey here but it should be noted that there are factors, both physical and biological, that affect the results of these

Table 1
Biomass estimates of capelin (metric tons) from Soviet surveys in div. 2J3K and div. 3LNO, 1974–80 (from Bakanev 1981)

Year/stock	2J3K	3LNO
1974	1 334 000	—
1975	981 800	1 050 000
1976	748 900	680 000
1977	505 700	1 000 000*
1978	59 000	230 000
1979	14 500	483 000
1980	20 200	††

*Up to 1977, mainly surveyed mature stock in div. 3NO; after 1977, mainly surveyed in div. 3L where mixtures of mature and immature capelin and sandlance occur.
†Few mature capelin, immature capelin mixed with sandlance — no biomass estimate possible.

Table 2
Standardized acoustic biomass estimates (metric tons) for capelin from Canadian acoustic surveys (from Miller and Carscadden 1981)

Year/stock	2J3K	3L	3NO	3LNO
1977	41 500	—	—	—
1978	14 000	—	—	—
1979	10 400	37 400	4 600	42 000
1980	—	16 700	9 900	26 600
	—	(2 600)*	(1 300)*	(3 900)*

*Adult portion in 1980. Most adults in div. 3L have already migrated to spawning grounds at time of the survey.

surveys and such factors are usually discussed in each survey report (all in ICNAF/NAFO research document series). Hence, the original reports should be consulted for the authors' assessments of the reliability of the estimate and how such factors affected the final estimate. In spite of this note of caution, it is obvious that the results from the Soviet surveys (Table 1) indicate a decline in capelin stocks, especially in the northern stocks. Although the Canadian time-series (Table 2) is shorter, the results from these surveys also show a decline in capelin stocks in recent years.

The results of the Soviet and Canadian surveys are not directly comparable. The results are often conducted at different times of the year and usually cover somewhat different areas. The equipment used by the two countries and calibration techniques differ markedly. For instance, the Canadian method involves a calibration of the acoustic system using a calibrated hydrophone. In some of the Soviet surveys (e.g. Ermolchev *et al.* 1979, 1980) the echo integration of capelin was calibrated by echo counting while in others (e.g. Bakanev *et al.* 1976, Klochkov *et al.* 1977) the calibration consisted of comparison of the echo signal to density estimates calculated from photographs of capelin obtained by lowering a camera into capelin schools. These differences may have contributed to differences in the estimates; however, it is not clear why the Canadian estimates are so much lower than the USSR estimates. Although not comparable between countries, the biomass estimates have generally been accepted as internally comparable.

It should be emphasized that although the Canadian acoustic estimates are given in metric tons, they are used only as relative estimates, not as absolute values and as such, they are regarded only as trend indicators. Furthermore, in recent years, the Soviet acoustic estimates have been used mainly to indicate trends in abundance rather than as absolute estimates of abundance.

The decision to use the Canadian acoustic estimates as relative estimates arose for two reasons. First, there were relatively few measurements of target strength available for capelin: the target-strength values are critical for biomass estimation, and errors in target strength can create serious errors in the final biomass estimate. There was no information available on swimming angle of capelin in the field and it is known that target strength can change radically with swimming angle of the fish (Nakken and Olsen 1977). Second, there was a reluctance on the part of other scientists to accept estimates derived from acoustics, a relatively new technology to most, as valid indications of stock status. Thus, the conservative approach of using the acoustic estimates as relative was adopted.

Like all survey techniques, hydroacoustics has both advantages and disadvantages, and these are summarized in Table 3 in comparison to other techniques. Because of the biology of capelin, hydroacoustic surveys, augmented by mid-water and bottom trawling to provide information on biology and species composition, appears to be the most effective way to provide indices of abundance from surveys for capelin.

Most of the analytical analyses employed have been developed and used since 1978 and except for two (Gulimov and Kovalev 1957, Seliverstov and Serebrov 1979) all have involved sequential population analysis. The high natural mortality in capelin, especially the mortality incurred during spawning (Winters and Campbell 1974) prevented the use of standard sequential population analyses such as virtual population (Gulland 1965) or cohort analysis (Pope 1972). As a result, new sequential-capelin-abundance models (SCAM) were developed to use pertinent biological and fisheries information and provide a historical perspective of the dynamics of capelin in the Newfoundland area (Carscadden *et al.* 1978, Carscadden and Miller 1979, Miller and Carscadden 1979, Carscadden and Miller 1980*a*, Carscadden and Miller 1981, Carscadden *et al.* 1981).

These models are similar to virtual population analysis and cohort analysis both in their design and mechanics. They attempt to calculate for any year-class its age-specific size and fishing mortality rate based on such input parameters as catch-at-age and natural mortality rate. Like cohort

Table 3
Advantages and disadvantages of various survey methods used in fisheries research (from Ulltang 1977)

Method	Applicability	Discrimination between species	Result obtained: Variance	Result obtained: Potential bias	Time-spatial coverage	Craft and equipment	Operation cost	Time for data processing
Fishing survey	Demersal and to some extent pelagic fish	Excellent	Large	Small	Limited	Vessel and fishing gear	High	More or less long
Acoustic survey	Pelagic and to some extent demersal fish	Poor	Small	More or less large	Good	Vessel and acoustic instrument	Low*	Short
Sighting survey	Pelagic fish	Poor	Large	Large	Good	Aircraft or vessel	Variable	Short
Eggs and larval survey	Demersal and pelagic fish	Excellent†	Large	Large	Limited	Vessel and collector	High	Long, laboratory work
Tagging	Demersal and pelagic fish	Excellent	Highly variable‡	Highly variable, often large		Vessel and fishing gear for releasing, fishery and eventual equipment for recovery	Variable	More or less long

*Cost of acoustic instruments is rather high and not included in the operation cost.
†Except in cases where the eggs or larvae of different species cannot be reliably identified. This is a bigger problem for eggs, particularly in early development stages, than for larvae.
‡Is directly related to number of recaptures.

analysis, some method of estimating fishing mortality in the most recent year is necessary and in all cases to date, commercial catch rates have been used to calibrate the models and so provide an estimate of terminal fishing mortality. The models differ from cohort and virtual population analysis in that some temporal partitioning occurs and the different mortality rates (i.e. high spawning mortality rate at one time of the year and natural mortality rate at other times) are applied to the population estimates at the appropriate time of the year within the model. Because recruitment to the mature portion of the population is essentially equivalent to maturation rate and the fishery operates primarily on mature fish it was necessary to incorporate annual age-specific maturation rates into the models as well.

These models are quite detailed and require a large body of data from the fishery and sometimes from research cruises. Catches from the commercial fishery are broken down into age-classes using length, weight, and age data collected from the fishery. Estimates of spawning mortality (Carscadden and Miller 1980*a*) and maturation rate (Winters *et al.* 1980) have been calculated and are necessary for the models. The models have to be calibrated in some way; we have used catch-per-unit-effort data but other indices of abundance, such as estimates from a hydroacoustic survey could also be used. In the SCAM 2J3K, estimates of selection by the fishery are necessary and these have been derived from comparisons of age-composition of the capelin taken by the commercial fishery and by research vessels.

The models have undergone various modifications in their development and use. For instance the SCAM for the div. 2J3K capelin stock (SCAM 2J3K) has changed little since its development in 1979 (Miller and Carscadden 1979; Carscadden and Miller 1980*a*, 1981). On the other hand, SCAMs for the southern area have changed dramatically such that the earliest version (Carscadden *et al.* 1978) and a later version (Carscadden and Miller 1979) have not been used recently. These earlier versions have been dropped because of the cessation of commercial fisheries in the areas of interest. In the most recent assessment of the capelin stocks (February 1981) two versions of the models — SCAM 2J3K (Carscadden and Miller 1981) and SCAM 3L (Carscadden *et al.* 1981) were used. The results of these models, showing trends in biomass and historical catches, are given in Figures 6 and 7. It is obvious that the catches have been low in relation to the biomass estimates resulting from these models.

Unfortunately these models do have some drawbacks. Sequential population models (cohort, virtual population analysis) are useful because, due to the nature of the mathematics, the further back in time the calculations are carried, the less sensitive are the population estimates to the input fishing mortality. In addition, these models are potentially more useful with species that have a number of age-classes in the population and natural mortality rates that are equal to or lower than the fishing mortality rates. Since capelin have relatively few age-classes, high natural mortality rates, and a relatively short history of fishing on a large scale, the sequential-capelin-abundance models converge less quickly than models using multi-age species with a longer fishery. The models have also been found to be very sensitive to the input parameters of age-specific maturity and age-specific spawning mortality. Like all sequential population models they are fishery-oriented, that is, much of the basic data is derived from the fishery itself. In a

Figure 6
Exploitable capelin biomass (metric tons), estimated using sequential-capelin-abundance models, and catches in div. 2J3K, 1972–80

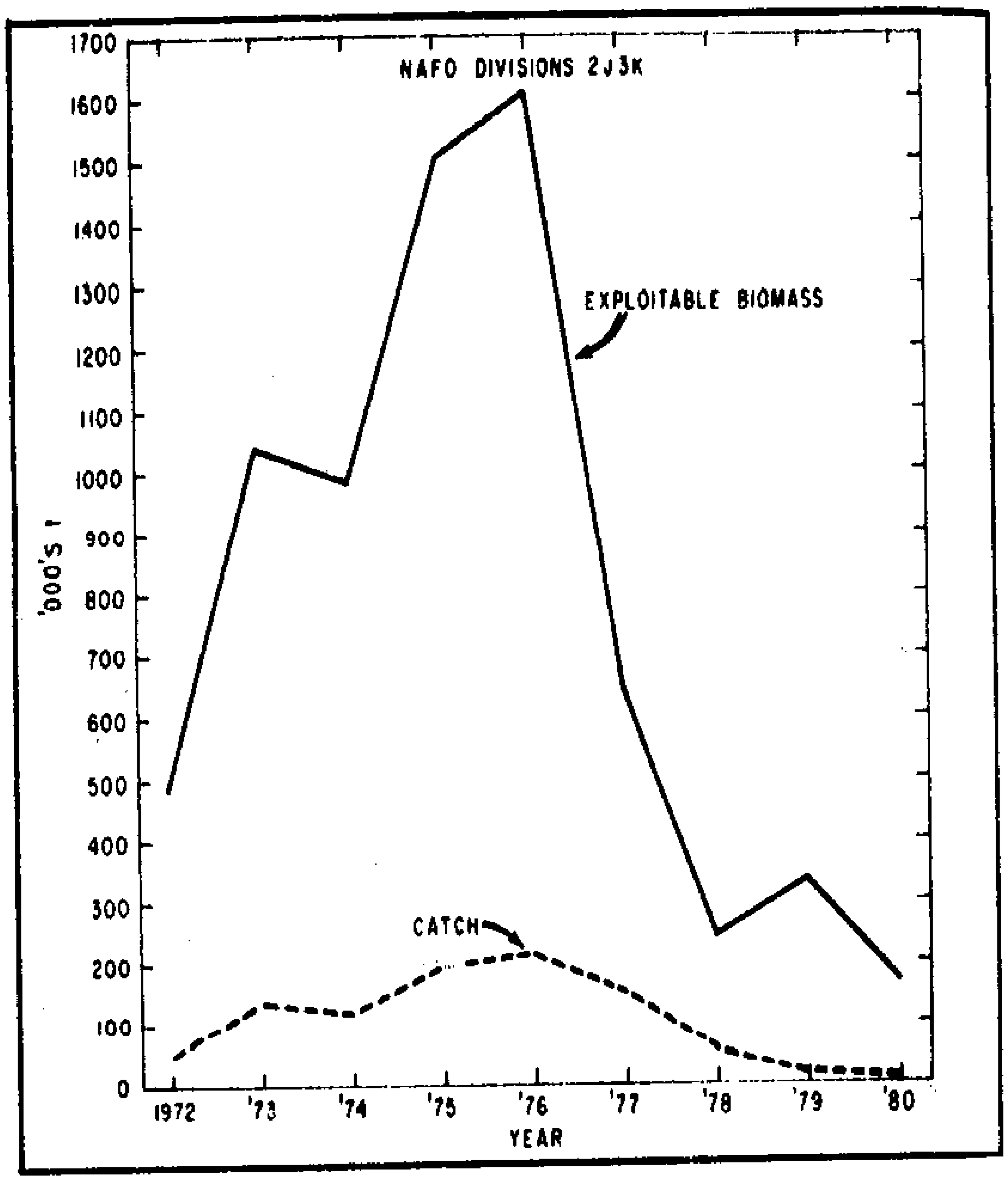
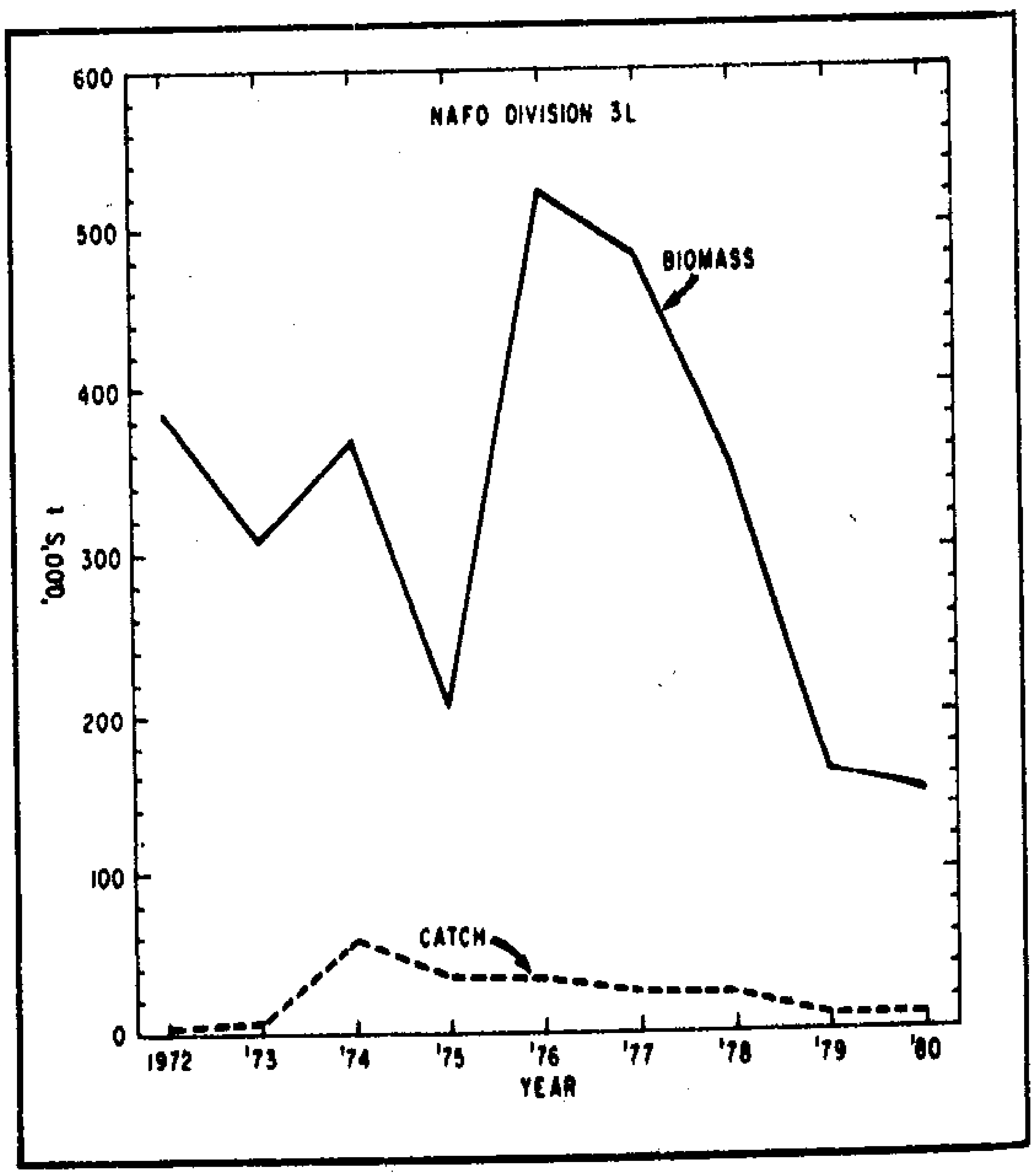


Figure 7
Total (ages 3, 4 and 5) capelin biomass (metric tons) 1 Jan. each year, estimated using sequential-capelin-abundance models and catches in NAFO div. 3L, 1972–78



dynamic fishery, which the capelin fishery has been, this has resulted in some limitations in their use, especially in recent years. The fact that the capelin fishery in its early years was a foreign fishery operating in international waters caused some difficulties in data collection as well and, in some cases, we have been forced to use data with little or no knowledge of the scientific basis of its collection.

In spite of these disadvantages, the models do have several advantages. They make use of a vast body of fisheries-related data that might otherwise not be used. They have provided a historical perspective of capelin population dynamics — in some cases, in years when no other estimates were available.

5. Population dynamics and the impact on predators

The sequential-capelin-abundance models have provided the most valuable insights into the population dynamics of capelin. For instance, year-class strength in div. 2J3K, measured as 2-year-olds, has varied such that the strongest year-class (1973) was over 30 times the strength of the weakest year-class (1975 and 1976); yet because of a number of age-classes (five in the div. 2J3K analysis), the largest calculated biomass (1975) was only seven times the smallest biomass (1980) (Table 4). The trends in biomass in two stocks, the div. 2J3K stock and the div. 3L stock, indicate that because of the presence of the strong 1973 year-class in the total capelin population the biomass peaked in the mid 1970s. However, five consecutive year-classes (1974–78) have been relatively weak resulting in low capelin biomasses.

The pattern of large variations in abundance of year-classes is typical of pelagic fish species. For instance, MacCall (this volume) reported that anchovy abundance off southern California varied over 30-fold in 30 years and that the Peruvian anchoveta and the sardines in Peru and California were also variable in abundance. Herring also exhibit variable year-class strengths. In the southern Gulf of St. Lawrence herring stock, two exceptionally strong year-classes (1958 and 1959) appeared after a fungus (*Ichthyosporidium hoferi*) had caused large mortalities (Winters 1976). Other relatively good year-classes in this stock in recent years were the 1967, 1968, and 1974 year-classes while all other year-classes have been lower in abundance. In the recent series of year-classes (1967–78), the weakest and strongest vary by a factor of seven (Cleary 1981).

In many pelagic stocks, the natural fluctuations in abundance are often complicated by the presence of fishing mortality and in some cases (e.g. Norwegian spring-spawning herring [Dragesund *et al.* 1980]) fishing mortality may be affecting recruitment. Based on the analyses using the sequential-capelin-abundance models, fishing has not been the cause of the decline for the div. 2J3K (Carscadden and Miller 1981) and div. 3L (Carscadden *et al.* 1981) stocks. Fishing mortality rates calculated from these analyses have generally been below 0.1. As has already been noted, it was the opinion of ICNAF scientists that the stock spawning on the Southeast Shoal may well have been fished too heavily.

It would appear that the capelin biomass fluctuations detected in recent years have been due to natural variation in year-class strength although the causes of this variation are not understood. Frank and Leggett (1981*a*, 1981*b*) have been studying factors affecting egg and larval mortality on a capelin spawning beach in Newfoundland since 1978. The time between egg deposition on the beach and hatching in the gravel was influenced by average incubation temperature; this incubation temperature varied between years and between cohorts in a single year and between low, mid, and high-tide locations on the beach. Water temperature, maximum and minimum air temperatures, and hours of sunlight all determined the average incubation temperatures. The interacting effects of egg density, water temperatures, maximum and minimum air temperature, hours of sunlight, rainfall, and tidal amplitude explained over 70% of the temporal and spatial variance in egg mortality. The climatic and hydrographic variables that influence egg mortality vary only slightly over most of the major spawning sites in eastern Newfoundland and southern Labrador areas, and the authors suggest that synchronous changes in these variables may contribute to the year-to-year fluctuations in capelin year-class strength (Frank and Leggett 1981*b*).

Frank and Leggett (1981*a*) have also reported that the emergence of larval capelin from beach gravel was correlated with onshore wind-induced wave action. There was a positive correlation between density of larvae in the beach gravel and length of time separating the occurrence of onshore winds. As residence time in the gravel increased, the physical condition of the larvae deteriorated. The authors suggest that year-to-year difference in wind patterns could contribute to the large annual variation in year-class strength in capelin. However, it is obvious that wind events were not the only factors affecting survival of capelin because two strong year-classes (the 1969 and 1973 year-classes) have been strong in all areas of the northwest Atlantic, including the spawning areas in deeper water on the west coast of Newfoundland (1973 year-class only because of lack of data for 1969) and the Southeast Shoal, where the effects of winds on the spawning substrate would be expected to be minimal (Frank and Leggett 1981*a*).

Table 4
Total numbers of capelin at age (billions of fish) and total biomass (metric tons) on 1 January estimated for div. 2J3K capelin stock using SCAM (Carscadden and Miller 1981). Total population at start of year ($\times 10^{-3}$) is given

	Year								
Age/years	**1972**	**1973**	**1974**	**1975**	**1976**	**1977**	**1978**	**1979**	**1980**
2	52 194 912	53 032 533	42 059 585	224 422 999	22 247 628	7 700 815	6 425 579	18 012 101	62 534 457
3	60 542 688	38 449 570	38 045 602	30 193 482	160 977 185	15 730 672	5 555 650	4 524 932	13 005 768
4	24 492 397	37 609 906	24 454 739	21 822 845	16 310 735	81 765 801	8 667 393	3 068 657	2 954 761
5	2 426 912	7 844 461	15 202 730	10 328 566	4 527 922	3 625 181	26 937 567	2 838 022	520 224
6	433 255	494 393	1 620 667	3 842 337	1 417 383	496 787	1 031 350	5 215 569	474 083
Total biomass	1 987 294	2 220 153	2 274 123	3 697 127	3 641 572	2 435 473	1 238 245	500 920	869 536

It is possible that predation has some influence on year-class variation in capelin and Dawe *et al.* (1981) investigated the effect of inshore predation by squid (*Illex illecebrosus*) on the abundance of capelin using correlation analysis. There was a negative correlation between abundance of squid and year-class strength (ages 0 and 1) of div. 2J3K capelin. However, the authors noted that there were a number of problems with their analysis, usually related to the unavailability of proper data to evaluate their hypothesis. For instance, there are no quantitative studies on squid feeding and although squid appear to have the potential to have a significant impact on prey species, the biomass of the prey species cannot be calculated because it is not known if squid prey on larvae, 0-group, 1-group, or older fish. The authors were forced to use estimates of year-class size at ages two, three, or four as indicators of abundance of age groups zero and one since neither estimates of abundance of the younger age groups nor estimates of natural mortality were available. The analysis may have been confounded by temporal trends since the time-series for capelin was only 8 years. Interestingly, in 1979 squid abundance was very high (Dawe *et al.* 1981) and the 1979 year-class of capelin appears to be very abundant (see following section). Thus, this correlation may disappear with the addition of the 1979 point.

Based on a feeding study of capelin in the Gulf of St. Lawrence, Vesin *et al.* (1981) advanced a different interpretation for the observation that in some years squid abundance was high when capelin abundance was low. They estimated that with the decline of capelin in the Newfoundland area in the late 1970s, substantial quantities of zooplankton would be released to other predators. This led them to speculate that this release of zooplankton may be important in regulating changes in year-class of other species, notably arctic cod (*Boreogadus saida*) and squid (*Illex illecebrosus*). Except for the estimates of surplus zooplankton, no quantitative analyses were presented to support the hypothesis.

The decline in capelin in recent years, has caused a great deal of concern regarding the effects this decline will have on predator stocks. Because of its importance to the Newfoundland fishery and economy and the anecdotal observations that cod follow capelin inshore (Akenhead *et al.* 1982) the effects of capelin fluctuations on populations of cod have been questioned. Although there have been no studies designed to accurately quantify the importance of capelin to cod, one study (Akenhead *et al.* 1982) did attempt to investigate the effects of fluctuations of capelin biomass on cod growth and on the inshore cod fishery using data already at hand. There was no statistically significant effect of capelin biomass on cod growth detected in this study. However, after making corrections for the biomass of cod, the authors did detect significant relationships between cod-trap catches and capelin biomass as well as between total inshore-gear catches and both capelin biomass and water temperature. Unfortunately, because of considerable uncertainty in the data, including the lack of proper data in some cases, the authors concluded that "the present analysis provides no useful evidence for testing the importance of capelin to cod but does suggest areas of concentration of future research." Furthermore, the authors concluded with the following statement:

> A lack of detailed data also hinders examination of the importance of capelin to the inshore cod fishery. Although cod and capelin tend to arrive in inshore waters at about the same time, suggesting that cod may actively follow the capelin toward shore, there is also anecdotal evidence that either species may arrive inshore unaccompanied by the other, and that the arrival of cod is also closely related to the warming of inshore waters. Elucidation of these relationships requires a site-specific study of the inshore migration, in which the abundance and movement of both cod and capelin can be related to changes in oceanography.

Recently, the failure of the 1977 smolt-class of salmon prompted Carter (1979, 1980) to state that the decline of capelin due to overfishing caused the failure of this smolt-class. It appeared that an unusually high mortality of this smolt-class had occurred during its first winter at sea (Reddin and Carscadden 1981). There were virtually no feeding data available to indicate whether capelin were important in the diet of salmon during their first sea-winter, but the size of young capelin in relation to smolts suggested that they would be suitable prey. Assuming that capelin were eaten by salmon, Reddin and Carscadden (1981) showed, using correlation analysis, that in some cases there were statistically significant relationships between salmon catches and abundance of young capelin. However, the authors noted that these relationships might degenerate with additional data since most of the relationships were significant only because of the 1977 smolt-class. Indeed, when the analyses were repeated (Carscadden and Reddin 1982) using data updated by one year, none of the relationships was statistically significant.

The analyses of the cod–capelin and salmon–capelin relationships failed to produce unequivocal proof of the dependence of the predator on capelin. In both analyses, the data available were not collected to test the postulated relationships, thereby making the results suspect, or in some instances, the proper data were not available. For instance, cod-trap catches were assumed to be an indicator of inshore cod abundance which further assumes that fishing effort has not changed over the time period in question. A better indicator would have been catch per unit effort which accounts for changes in effort from year to year; unfortunately, effort data were not available. In both studies, it was assumed that the predators were dependent on capelin and a change in the abundance of capelin would result in a change in the dynamics of the predator. However, the diet of both cod (Akenhead *et al.* 1982) and adult salmon (Reddin and Carscadden 1981) is spatially and temporally variable and in the absence of capelin, both species could probably feed on other prey if available. In this case, an absence of capelin probably would not result in starvation of the predator nor an immediate drop in abundance. Instead, a reliance on other prey or less prey might result in slower growth and/or reduced fecundity, if in fact there was a detrimental effect at all. Such effects would be subtle and long-term, making them more difficult to detect. During the late 1970s when capelin abundance had declined, arctic cod (*Boreogadus saida*) populations appeared to have increased in northern Newfoundland and Labrador (unpubl. data) while sandlance (*Ammodytes dubius*) (G. Winters, pers. comm.) and squid (*Illex illecebrosus*) (Dawe *et al.* 1981) increased in the Grand Banks area. All of these species would be potential prey for capelin predators.

The decline of capelin in the late 1970s has also been implicated in the increase of damage to fishing gear resulting from whale collisions (Lien 1980). Although the relationship was not established statistically, Lien (1980) suggested that a decline of the offshore capelin stock resulted in increased migration of whales to the inshore area. Sightings of humpback whales increased along the northeast coast of Newfoundland from 1974 to 1979 and sightings decreased along the south coast in 1978 and 1979 and Lien (1980) attributed this to the fact that the northern capelin stock had not declined as much as the southern capelin stocks. This postulated relationship may not be as direct as Lien suggests since in 1979 the northern stock (div. 2J3K) dropped to about one-fifth of the 1976 biomass (Fig. 6), while the southern stock had dropped to about one-third in the same period (Fig. 7). The estimates for the southern stock do not include capelin from div. 3N0 and div. 3P. However, Lien (1980) suggested that other factors have contributed to an increase in collisions of whales with fishing gear: these were an increase in the whale population, an increase in fishing effort, and an attitudinal change on the part of fisherpeople resulting in increased reporting of collisions.

Seabirds are known to feed on capelin and Brown and Nettleship (this volume) have expressed concern for seabirds, especially Atlantic Puffins, as a result of the recent decline in the capelin population. These authors note that puffins will feed heavily on capelin during the puffin breeding season when the fledging success is related to the food supply. It would seem reasonable to expect that the effects of fluctuations in capelin biomass would be more readily apparent in a predator such as puffin than a predator such as cod which apparently has a more varied diet. In fact, seabirds do exhibit wide annual variations in breeding performance and this, in combination with their life-history characteristics such as long life span, late maturity, and low reproductive rates, makes the identification of factors responsible for changes in the populations of these seabirds difficult (Nettleship 1977).

In general, although considerable concern has been expressed for the well-being of capelin predators when capelin abundance is low, it is impossible with the present data base to predict what, if any, the effects on predators would be. This is partly explained by the lack of detailed, long-term quantitative feeding data (for the fish and marine mammals, at least) which would permit a more quantitative definition of the importance of capelin to its predators. Little is known of the biology and population dynamics of potential alternate sources of prey, arctic cod and sandlance for instance, and what the effects of increased predation of these animals would be in the event of low capelin abundance. Furthermore, the natural factors affecting the abundance and behaviour of capelin predators are not understood, although there is probably a complex of environmental and biological factors operating rather than a single one such as abundance of capelin.

6. The future

It is impossible to make predictions regarding the long-term trends in capelin population dynamics. Presently, biological advice for management purposes is being provided either 1 year in advance of or early in the fishery year. The large annual variations in year-class strength and the short life cycle of the species make predictions over a longer period very uncertain. Research vessel cruises conducted by Canada (Miller and Carscadden 1981, unpubl. data) and the USSR (Bakanev 1981) have detected large concentrations of young capelin composed of the 1979 year-class in the area of the northern Grand Banks. If this year-class proves to be large (and it appears that it is) then the abundance of spawning capelin inshore in 1982 (as 3-year-olds) and possibly 1983 (as 4-year-olds) will be large. Such a phenomenon would be interesting because this large year-class would have resulted from the spawning of an adult biomass that was estimated to be one of the lowest in our time-series (see Fig. 6 and 7). Of particular interest in coming years will be the response of the Southeast Shoal population where overfishing has been implicated in its decline in comparison to spawning stocks where fishing does not seem to have been deleterious. Whether the 1979 year-class proves to be large or not, the results of the analyses to date suggest that any changes in the capelin stocks will be largely dependent on the environment rather than on the presence or absence of a conservative and controlled fishery.

The first stage in the management of capelin fishery is the provision of biological advice from the research biologists. At the present time, the capelin research revolves almost exclusively around estimation of biomass, both inshore and offshore, and attempts to estimate incoming year-class strengths. The changing pattern of the commercial fishery has made the use of the SCAMs more and more difficult, particularly regarding the calibration of the terminal fishing mortality estimates. There is a heavy commitment to offshore acoustic surveys using a newly developed microprocessor-based hydroacoustic data-acquisition system. Our research vessels will have onboard HP1000 computer systems and it is our intention to analyse much of the data collected on these acoustic cruises onboard the vessel using specially-written echo-integration programs. Our experience in the last 3 years in div. 3LNO suggests that it will be possible not only to provide an abundance index of capelin moving inshore to spawn in div. 3L and spawning in div. 3N0, but also to estimate an abundance index for juveniles in div. 3L. The annual fall hydroacoustic survey in div. 2J3K provides an index of abundance of maturing capelin as well as information on juveniles.

There is a need for additional research on target-strength measurements of capelin, especially the factors such as depth, biological condition, and so on, that affect target strength. Through the use of underwater photographs of capelin (Carscadden and Miller 1980*b*), information on swimming angle distribution of fish is being collected and eventually these data will be used to refine acoustic estimates.

The recently developed inshore fishery is being monitored as closely as possible. Emphasis is being placed on collection of log-book data and biological data from all sectors of the fishery. Particular emphasis is being placed on Trinity Bay, an important capelin and cod area. Extra effort on the inshore capelin fishery will be expended in this bay because a detailed study on the early life history of herring and capelin will be initiated here in 1982. In addition, a pilot project was conducted in 1981 to determine the feasibility of detecting schools of capelin in inshore areas by aerial survey. This technique appears promising and expanded surveys using professional aerial survey personnel are planned for 1982.

One larval survey is now being conducted each year in an effort to estimate year-class strengths of capelin as 0-group fish. This survey has been conducted for 3 years but the first 2 years were largely unsuccessful because of vessel and weather problems. However, the cruises have permitted an evaluation of techniques and equipment and the 1981 survey will probably be considered the first in the time-series. By their nature, such surveys require a long time-series to test their results with estimates of adult stock size.

Because of the necessity of monitoring the current fisheries and providing biological advice to managers on total allowable catches, and so on, very little research on biology of capelin is being conducted, although many gaps in our knowledge exist. The exceptions to this are the studies planned in Trinity Bay, and studies on eggs and newly emerged larvae (Frank and Leggett 1981*a*, 1981*b*) now being conducted in Conception Bay by personnel from McGill University.

No studies are being conducted to test the effects of fluctuations of capelin abundance on the dynamics of cod or other predators. Such studies are attractive but require careful planning and large commitments of personnel and funds over a number of years. At present, extensive collections of stomachs of several predators (cod, Greenland halibut, American plaice, harp seals) of capelin are being accumulated and examined and these should improve our understanding of the time, place, and intensity of interactions between capelin and its predators.

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