15. ASSESSMENTS OF STOCK ABUNDANCE

Because of the short life span, variable recruitment and extremely high spawning mortality, sudden and sometimes drastic changes may be expected in the abundance of capelin stocks. Furthermore, the capelin is a schooling species and therefore belongs to the numerous stocks of fish that can yield high catch rates by a modern, sonar-guided purse seine fishery until practically the last school has been removed from the sea.

For these reasons, it is obviously of paramount importance to possess reliable information on the state and development of any heavily exploited stock of capelin. Otherwise, there is a real danger of eventually overfishing the stock to the extent of reduced recruitment, not to mention a recruitment failure. In the 1970s catches from the Icelandic stock of capelin increased dramatically (cf. Table 16.1). Thus, the winter catch increased from just under 200 thousand tonnes to about 450 thousand tonnes in the first half of the decade. In the latter half, a multi-national summer and autumn fishery began in the Iceland Sea between Greenland and Jan Mayen as well as off North and Northwest Iceland. This development resulted again in more than doubling of the catch from the 1975/76 season to that of 1978/79, when 1,195 thousand tonnes were removed from the fishable (spawning) stock in the July 1978 – March 1979 period.

In the latter half of the 1970s the need for reliable estimates of stock abundance, therefore, became progressively more pressing. For the reasons stated above, catch and effort data were of little value in assessing the state of the adult part of the stock. Furthermore, due to the high degree of selection by capelin purse-seines such catch data are quite useless for prognosis of future stock developments. In practical terms, the capelin seines only retain 2-group fish and older. In this and other cases of similar nature, fishery-independent stock assessment methods had to be applied in order to obtain information pertaining to current stock status and its future development.

In the past, when trying to assess the abundance of the different components of the Icelandic capelin stock, three methods have been applied. These are 0-group surveys, tagging and surveys of the juvenile and adult parts of the stock, using the technique of integrating echoes of acoustic signals.

15.1. The 0-group index

The distribution and abundance of 0-group capelin of the Icelandic stock has been recorded annually as a part of a general survey of 0-group fish in the Iceland – East-Greenland area since 1970. The survey methods and data handling were described by Vilhjálmsson and Friðgeirsson (1976). In short, the surveys are carried out along standard sections where measures of the numbers and species composition of 0-group fish are obtained through sampling the uppermost 50–70 m of the water column with a pelagic trawl having a fine meshed cod-end. The catch rates, in numbers of fish per unit distance trawled, are then plotted, taking into account the observed changes in acoustic records of echo abundance, on a map of the survey area. These values of 0-group abundance are then divided into several density strata and subareas and an abundance index calculated for each density stratum by weighing the average catch with the total area of that stratum. The indices thus obtained are then added to obtain the total for each subarea as well as the distribution area as a whole. As an indication of physical condition of the 0-group fish, records are kept of their size as well as the hydrography of the area (temperatures and salinities).

The 0-group surveys started in 1970 as a multinational effort in recruitment studies in the Iceland – East Greenland area at the initiative of the International Council for the Exploration of the

Sea (ICES). The results have been reported to ICES annually, although international participation ceased in 1977 (Vilhjálmsson and Friðgeirsson 1976; Anon. 1978–1981; Vilhjálmsson and Magnússon 1981–1986; Magnússon *et al.* 1987–1989; Magnússon and Sveinbjörnsson 1990, 1991, 1992).

With respect to the 0-group capelin, the above survey methods leave much to be desired. In the first place, the patchiness of the 0-group capelin distribution makes it difficult to obtain sufficient catch/effort data to get a reliable measure of inter-annual variations. And secondly, since the main target of the survey was not capelin but cod and haddock, the fishing gear chosen is better suited for catching those species than capelin. While the cod and haddock are caught in the cod-end in the usual manner, the 0-group capelin is almost exclusively found enmeshed in the large-meshed upper and central part of the trawl.

However, a comparison of the levels of 0-group capelin echo recordings with catches in the corresponding areas, indicates that the 0-group capelin catch, obtained in this way, gives a reasonble general picture of variations in the 0-group capelin distribution. The catch data should also represent a measure of annual changes in abundance, and an indication of the size distribution of the 0-group capelin. However, data obtained during the first 2 years of the series are less reliable, since the distribution area of the 0-group capelin could not be covered adequately due to mechanical break-downs and difficulties arising from variations in the timing of the work of some of the participating research vessels.

The total annual abundance indices of 0-group capelin in the period 1970–1993 are shown in Figure 15.1 and their distribution in the various areas is given in Appendix II.2, Table XI. After the rich years of 1972–1975 there was a sharp decline in the overall 0-group abundance, and in the following years it generally remained at a relatively low level compared to the 1972–1975 period. The highest and lowest index figures differ by about one order of magnitude. As expected, the largest deviations in abundance occur in the two outlying areas, *i.e.* off East-Greenland and off East Iceland while the annual abundance of 0-group capelin in the areas off North and West Iceland is much less variable (cf. Appendix II.2, Table XI).

It has been pointed out (Ástthórsson *et al.* 1983) that in the 1972–1982 period the relative changes in the 0-group indices of cod and haddock roughly followed the trend in zooplankton densities observed off South and West Iceland in the spring (May/June) of the same year. As shown in Figure 15.2 there appears to be no correlation between 0-group capelin and zooplankton, neither for the 1972–1982 period (Fig. 15.2a), nor the period 1983–1993 (Fig. 15.2b). This difference could be due to the fact that the main spawning of cod and haddock takes place at

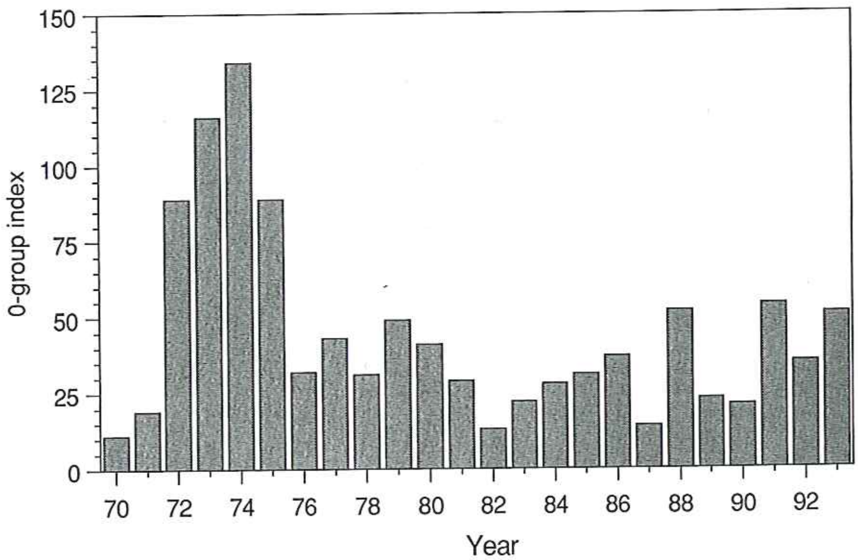

Figure 15.1. The 0-group indices of 1970–1992. See also Appendix II.1, Table XI.

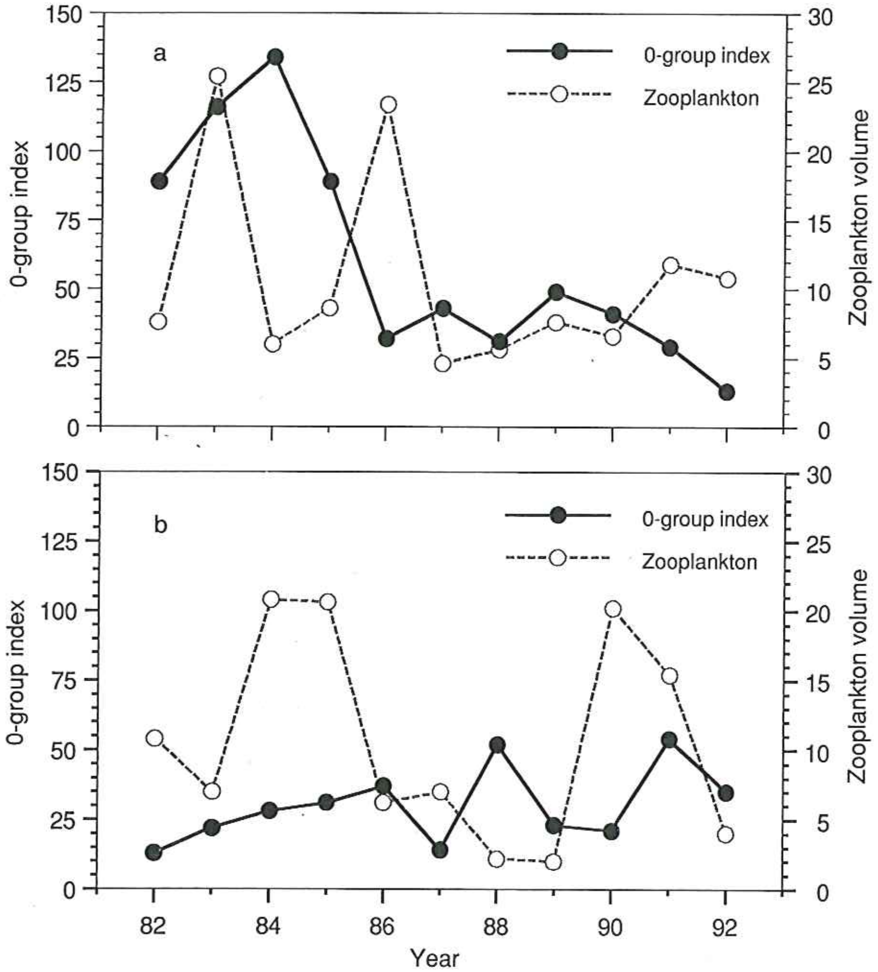

Figure 15.2. Comparison between the abundance of 0-group capelin and zooplankton densities off Southwest Iceland a) in spring 1972–1982 and b) in spring 1983–1992.

least one month later than that of capelin. The hatching of cod and haddock larvae, therefore, coincides more closely with the time of zooplankton observations than the earlier hatching of the bulk of the capelin. The survival of fish larvae must be determined, at least in part, by the availability of food at the end of the yolk-sac period and in the following months. But the mechanism is almost certainly complicated and variable from one year to another as explained in sections 6.4–6.7. Therefore, it is unlikely that general data on zooplankton abundance off Southwest Icland in May/June are adequate for explaining variations in survival rates of 0-group capelin, most of which were hatched about two months earlier.

The main purpose of assessing the abundance of 0-group fish was to obtain an estimate of the relative size of year classes among the various commercial fish species at Iceland as early as possible before the year classes are recruited to the fishery. In the case of the capelin, however, it did not become possible until in the late 1970s to compare the 0-group estimates of year class abundance with other methods of estimating year class size. It was in fact not until acoustic estimates of the fishable stock became available in the late 1970s that the validity of 0-group indices for forecasting recruitment could be tested. Figure 15.3 shows such a comparison between the abundance of the 1976–1988 year classes as measured at the 0-group stage on one hand and adult capelin abundance back-calculated from acoustic estimates on the other, taking account of fishing and natural mortalities. Clearly, there is no correlation between these two sets of data which describe year class abundance at different stages in the life cycle of the capelin.

If, on the other hand, the 1978–1993 0-group indices are plotted together with assessments of parent stock abundance, as projected from acoustic estimates by adjusting for fishing and natural mortalities, both plots show a similar overall trend for much of the period (Fig. 15.4). In spite of the occasional large deviations in the latter part of the period, resulting in a low correlation coefficient and marginal significance for this comparison ($R^2 = 0.23$, $P = 0.07$), the implication is that the inter-annual variation of the 0-group indices is in most cases probably due to changes in the biomass of the underlying spawning stock. Furthermore, in the high abundance 0-group years of 1972–1975 the catch from the respective spawning stocks never exceeded 450 thous. tonnes. With the advent of the summer and autumn fishery in the latter half of the 1970s, catches increased to about one million tonnes or more, and since then the fishery has almost certainly taken a much larger part of the spawning stock than in the 1972–1975 period. It thus ap-

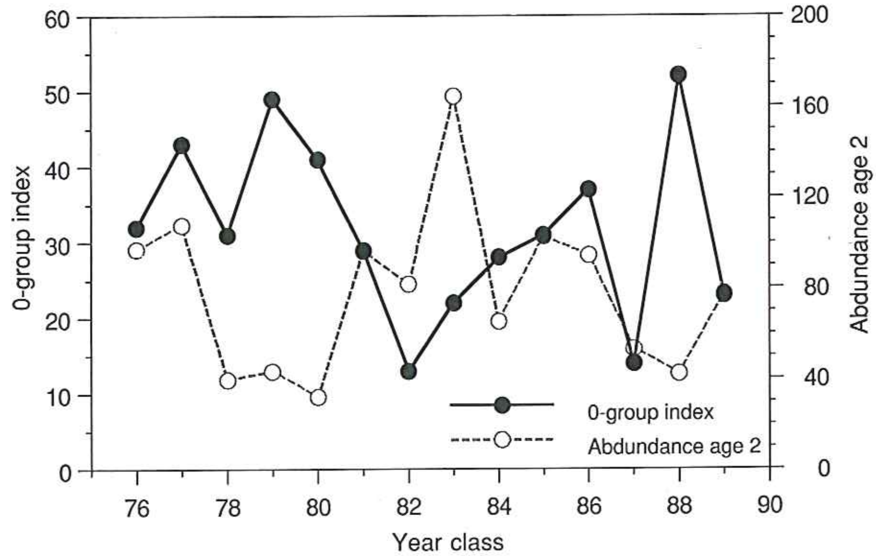

Figure 15.3. Comparison between the 0-group indices and the abundance of year classes 1976–1989.

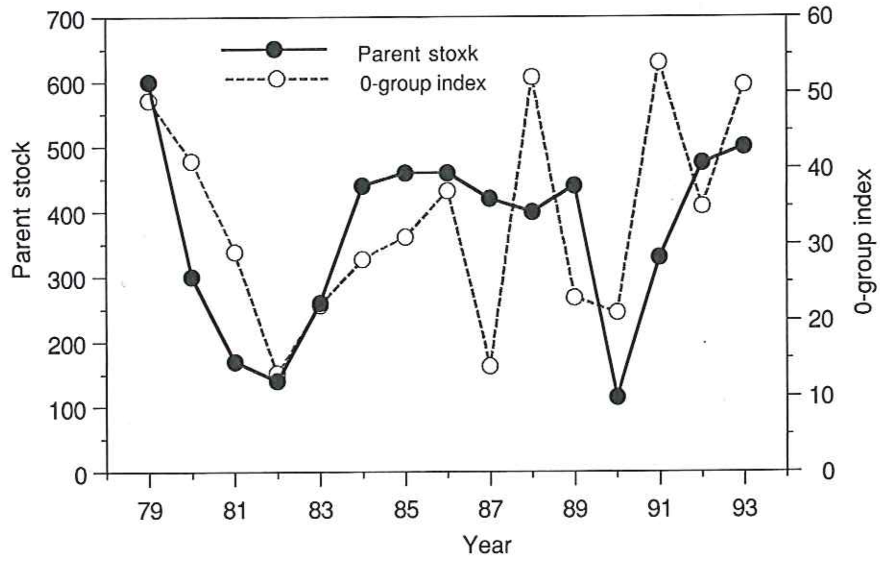

Figure 15.4. The relationship between parent stock size and the resulting 0-group abundance (indices) of 1979–1992.

pears likely that the actual spawning biomass was much larger in the years 1972–1975 than it has been ever since.

As will be described in detail later, estimates of year class abundance, obtained by acoustic assessment of 1-group capelin in autumn over the period 1981–1991, show a high degree of correlation with estimates of the same year classes as age groups 2 and 3, when the latter have been adjusted for catches and natural mortalities ($R^2 = 0.76$, $P < 0.01$). The available evidence, therefore, seems to indicate that the size of year classes in this capelin stock is ultimately determined at some point in time soon after the end of the 0-group stage. This conclusion is further discussed in section 15.6.4.

An additional support for the above conclusion is the fact, pointed out in earlier sections, that environmental conditions are much less stable in the North and East Icelandic areas than in the Atlantic water off South and West Iceland. It has indeed been found (Sveinbjörnsson and Helgason 1988) that taking account of environmental variables (salinity, temperature) off North and East Iceland in the following spring, together with the average size of the 0-group fish, enhanced the usefulness of 0-group indices for predicting year class size at age 3 in the Icelandic cod stock over the period 1973–1985. A multiple regression analysis does not improve much on the forecast value of 0-group indices of capelin. One of the reasons could simply be that the capelin 0-group indices have greater variance than do those of the cod. A more likely explanation is, however, that due to the much smaller size, and consequently inferior physical state of the 0-group capelin as well as the spatial heterogeneity of their distribution, it is much more difficult to relate the survival of 0-group capelin to environmental variables than is the survival of 0-group cod.

15.2. Tagging

In the early 1970s attempts were made to mark juvenile capelin with internal steel tags for obtaining some information on stock size. Because of the small size of these fish tagging mortality proved very high, and consequently tag returns were extremely low (Vilhjálmsson 1983).

In 1973 an attempt was made to tag mature capelin on board a purse seiner off East Iceland in January (Vilhjálmsson 1974b). The marking was done with internal steel tags which were recovered by means of electric magnets in the processing plants ashore. However, intensive fishery was concurrently taking place, and the survival from the various releases of tagged individuals belonging to the fishable stock were disproportionately low due to inadequate mixing of tagged fish with the population at large. Tag returns could, therefore, not be interpreted in terms of stock abundance, and the experiment failed.

In the period 15 July – 18 October 1978 a total of 18,304 maturing capelin were tagged in 75 releases on board commercial seiners fishing in deep waters off North Iceland and in the Jan Mayen area. Partly, the purpose of this experiment was, as before, to try to evaluate the size of the fishable stock (Vilhjálmsson and Reynisson 1979), while the main objective this time was to obtain information on the migrations of the stock (cf. section 13.3).

As it turned out, the survival rate of the tagged fish was drastically reduced after 26 liberations and remained on a comparatively low level after that. There are probably two main reasons for this. A sudden increase in food content while in the area off North Iceland in August resulted in difficulties in inserting tags without damaging the intestines. Later, the cold and windy weather in the Jan Mayen area in September, as well as off Northwest Iceland in October, obliged the tagging personnel to use gloves and so causing damage through descaling of the capelin due to inadvertent rough handling.

As a result, only returns from the first one-third of the 75 releases (5,057 fish) could be used for abundance estimation. On the basis of these returns and taking account of estimated tagging and natural mortalities, measured efficiency of magnets and the catches processed, the size of the fishable stock was calculated to be 1,230 thousand tonnes on 1 January 1979. This may be compared to the 1,350 thousand tonnes estimated by the acoustic method (Vilhjálmsson and Reynisson 1979).

It seems, therefore, that if carefully executed, tagging can give information on the size of the maturing or fishable stock. However, the final results do not become available until late in the fishing season or even not until it is over and are of little use for real-time management. Although potentially a useful tool for retrospective comparisons with other abundance estimates (acoustics), tagging of Icelandic capelin has not been continued.

15.3. Acoustic estimates of abundance

It is well known that in order to carry out successful acoustic evaluation of the abundance of any stock of fish, a comprehensive knowledge of its biology and, in particular, the migrations and general behaviour pattern of its various components must be obtained (cf. Johannesson and Mitson 1983). There are many reasons for this, the most obvious being:

a) The necessity of knowing the possible extent of the distribution area at various points in time.
b) The fact that the behaviour and distribution pattern of the fish may be almost constantly shifting.
c) That the varying admixture of other fish species or organisms, and even the ratio between year classes among the target species, may affect the results of such surveys.

Due to gear selection it is indeed often difficult to establish the effects of the last two variables. In addition, there are environmental variables such as weather, water depth and, in the present case, the extension of drift ice that have to be considered. The survey should, therefore, be timed in such a way that the effects of as many as possible of the above variables are at their minimum or at least as stable as can be expected.

It has been explained before how the adult capelin are often recorded by sonar in small but very dense schools in the near-surface layers during the main feeding season, and furthermore that they are often widely distributed and may be periodically located in ice-covered areas. As early as in the late 1970s, this phenomenon and its possible effect on acoustic abundance estimation had been recognized. This was first brought home during an Icelandic attempt to assess the abundance of the fishable stock in September 1978. At that time most of the fishable stock was recorded in a large area between Greenland and Jan Mayen as well as north of the island, mainly as single schools and often located in the immediate surface layers. The small and often very dense schools tended to keep to the immediate surface layers where they are easily seen on sonar but often above the range of the hull-mounted transducers of the echo-sounders. Such situations are totally inadequate for acoustic assessment of abundance and the experiment failed completely (Vilhjálmsson, 1979). As described in Appendix I.1, a survey of stock distribution and abundance was carried out in August 1979 and yielded an unrealistically low estimate of the abundance of the fishable stock (Vilhjálmsson *et al.* 1982).

Because of the southward migration from the northern feeding grounds, capelin usually occupy only part of their normal summer distribution area in October. Nevertheless, at that time of year a considerable part of the biomass may in some years be found almost anywhere within a large part of the maximum distribution area. It is also clear that the size of the distribution area of the maturing stock diminishes rapidly from October onwards, making more detailed surveying often possible in November and December. There are two main reasons why most of the autumn surveys have been carried out in October and not later in the year. One is the generally worsening weather and ice conditions near the end of the year. The other is the necessity to assess the fishable stock abundance as soon as possible to provide a basis for management advice on catch quotas.

As described in section 7.1 the maturing, fishable stock usually migrates in the beginning of the year in a clockwise direction to pass the east coast of Iceland and subsequently enter the south coast spawning grounds in late January and in February. The waters off East and Northeast Iceland are almost always ice-free at that time of the year and the spawning stock assembled, often in more or less continuous scattering layers, in a limited and well defined area that can be surveyed in detail in a matter of days. When these migrations have been located, quick and accurate estimates of abundance can be obtained in calm periods.

The winter surveys are also valuable for comparison with the abundance estimates based on autumn surveys of the year before, *i.e.* for estimation of natural mortality rates. As will be discussed in section 15.4.2, the winter surveys are in fact considered the most accurate means for measuring adult capelin abundance, and catch quotas have, therefore, always been adjusted on the basis of the winter estimates when these have been available and have differed from the autumn values. For management purposes such timing has, however, the obvious drawback that these surveys take place less than two months before the capelin spawn and the fishing season ends. In most cases the winter estimates have been obtained off East and Northeast Iceland in January and/or early February. However, as explained in Appendix I.1, various reasons have dictated that this could not always be done, in which cases the stock can be assessed in the shallow waters off the eastern south coast.

Apart from the adult stock assessments, estimates of immature capelin of age groups 1 and 2 (2 and 3 after 1 January) are usually obtained during the autumn and winter surveys. Furthermore, as already described, estimates of the 1-group capelin abundance have been obtained by August surveys of the distribution of 0-group fish in North Icelandic waters, in the area between Northwest Iceland and Greenland and in the northern Irminger Sea.

The series of annual estimates of the maturing or fishable stock in the autumn (winter) period dates back to the 1978/79 season. In addition, immature 1- and 2- (2- and 3-) group capelin have been registered during these surveys since 1979. August estimates of the immature 1-group capelin are also available from 1982. Many of these surveys have been carried out by cooperation of Icelandic and Norwegian research vessels.

15.3.1. The strategy

Acoustic surveys to study the movements and behaviour of capelin in the Iceland Sea and adjacent waters began in 1966 as a scouting and information service in connection with the development of an Icelandic winter capelin fishery at the south and west coasts. In the years that followed, intense activity of this kind took place in late winter (February – April) on the spawning grounds as well as off East and North Iceland in the months of December – February. In the mid-1970s scouting for capelin in summer and autumn began in connection with Icelandic fishing operations in the oceanic area of the central and northern Iceland Sea. By the late 1970s the information from these surveys, detailed catch statistics, intensive sampling of research and fishing vessel catches, and last but not least the long history of environmental research in Icelandic and adjacent waters had furnished the data on which a sound picture of the general biology, migrations and behaviour of the stock could be based. The data also provided information concerning external conditions for surveying.

Appendix I.1, contains a summary, charts of survey tracks and 3 density categories of capelin distribution for all capelin stock assessment surveys in autumn and winter in the period 1978–1993 (Figs. I–XLVII). Although the charts represent total recorded distribution of 1–3 group capelin and no attempt has been made to separate immature fish from the spawning stock, they mainly describe distribution af adult capelin biomass. The reason for this is the large difference in target strength between juvenile and adult fish. Exceptions are the westernmost parts of the distribution area south of 69–70°N, as well as the more coastal part of the shelf area off the central and western north coast and northeast of Iceland, where immature capelin tend to aggregate in more or less pure concentrations. In addition, 1-group capelin are sometimes recorded in deep waters off Northeast Iceland, especially in autumn.

Comparison of the charts clearly demonstrates the dynamic nature of this capelin stock, where the October distribution may in fact span almost the entire sea area between 30°W and 10°W from 66°N to 72°N with the east coast of Greenland acting as the western boundary in the northern parts of the area. Although juveniles may occur mixed with the adults in parts of the survey area, the contribution of this stock component to the total biomass estimate in such areas is relatively unimportant. This is due to the smaller size and much lower target strength of the juveniles, in particular the 1-group fish, as compared to adult capelin.

The highly mobile nature of the Icelandic capelin stock, its variable distribution and behaviour pattern from year to year and the ever changing environmental conditions, present large problems when measuring stock abundance. The success of this task under such conditions depends not only upon correctly timing the surveys, in view of past and present knowledge of stock movements and behaviour, but also on environmental surveying conditions. It has furthermore become evident long ago that the design of such surveys must allow for *in situ* adjustments to current situations, even to the extent of cancelling entire surveys or delaying them to a later date. The basic design of acoustic surveys of capelin abundance in the Iceland Sea and adjacent waters and the reasons behind it are as follows:

In general, the Icelandic capelin tend to be distributed in boundary zones between cold and relatively warm water masses, particularly in autumn and winter. With reference to the water circulation in the area (see Fig. 6.2), this implies that usually the capelin are distributed along the outer edge of the continental shelf off Northwest, North and East Iceland as well as north from there in the direction of the East-Greenland shelf. The advantage of running parallel transects at right angles to the general distribution of the biomass soon became apparent, since by such a procedure it is easier to locate the capelin and determine their distribution boundaries and thereby save survey time. In the first surveys this pattern was not strictly adhered to, but with few exceptions it has been followed since 1981. In the area south of 68°N transsects are, therefore, run at approximately right angles from the coasts of Iceland, while north of 68°N transsects are run in an east/west direction. Two slightly different strategies, one for the autumn surveys and another for the winter surveys, have been followed in measuring adult capelin stock abundance.

Experience has shown that spatial variations in the the maximum distribution of the maturing stock in autumn are so large that the possible distribution area can not be covered effectively because of the usual constraints imposed, mainly by variable weather conditions and drift ice. In order to cover the current distribution area within the time limits set by available vessel-time, a non-random survey track of parallel transects, arranged as described above and spaced about 15–20 naut. miles apart, has been adopted. Furthermore, in the light of information from past surveys and fishing activities, it is sometimes possible to determine the approximate area of stock distribution in advance. When this is not possible the usual procedure is somewhat different. After having located some part of the distribution area, usually between Northwest Iceland and Greenland, the necessary length of each transect can be determined in view of the existing hydrographic situation. This often allows the exclusion of parts of the area with a fair degree of confidence, and thus the running of the survey vessels for extended periods through waters of zero capelin registrations can be avoided. The time thus saved may then be used for running additional transects in areas of very high densities. Otherwise, the pre-determined survey procedure is maintained.

A different strategy is applied for the winter situation proper and is frequently used for the deep water area east and northeast of Iceland in the January/February period. Then the distribution of the maturing stock is often very restricted, densities high and the capelin migrating towards the spawning grounds at considerable speed. Furthermore, periods of good surveying conditions are often few, short and sometimes far between. Under these circumstances a rough pilot survey is usually run in order to establish the location(s) of the spawning stock. After that an abundance estimate can be obtained in a very short time and in more detail than would have been possible without this previous knowledge. In the earlier winter surveys a zig-zag pattern of transects was sometimes used. Like in the autumn surveys, this approach was soon abandoned in favour of parallel transects at approximately right angles to the biomass distribution. Once having found roughly the location of the spawning stock in winter, the predetermined space between transects is one half of that most frequently used in the autumn surveys, *i.e.* about 10 naut. miles but frequently reduced to 5 naut. miles in areas of high and uneven densities. The spacing of transsects during winter assessments of the much more evenly distributed immature stock component is, however, usually 15–20 naut. miles apart.

In addition, acoustic abundance estimates have occasionally been obtained in the shallow coastal waters off the eastern south coast. In this area the distribution has become very restricted and the density may be almost one order of magnitude greater that that of the more oceanic areas. On these occasions, parallel transsects are run at right angles to the coast as before, but the distance between them often shortened to no more than 2 naut. miles and the echo-integrating intervals to 0.5 naut. miles or less. Although such assessments can sometimes be very successful and carried out by two vessels in a matter of a few hours, they are often prevented by near-shore or near-surface distribution of the capelin and have, therefore, not been part of the standard assessment plan.

With respect to data evaluation by standard statistical methods, such strategic approach admittedly can not be subjected to the same testing as conventional surveys according to a random design. The Icelandic strategy relies heavily upon the ability of the scientific and technical staff to properly adjust the survey grid, based on previous knowledge, and judge the validity of the results. It is, therefore, for logical reasons subjective in nature. This was recognized from the beginning, as well as the fact that if such a strategy is to work, vessel time has to be flexible in order to accomodate extensions of survey time which may be neccessary to obtain valid estimates. However, as will be explained presently, it seems that in the case of the Icelandic capelin the above survey technique has paid off, and a strict random stratified approach would have failed on too many occasions.

The August estimates of 1-group capelin abundance are of a different nature. They are obtained as a by-product of the 0-group fish surveys of the Iceland-Greenland area. These surveys are run along standard transects, spaced at 20–25 naut. miles perpendicular to the coastline of East, North and Northwest Iceland (Appendix I.2, Figs. XLVIII–LVIII). The 0-group surveys cover the shelf area and adjacent waters, extending east of Iceland to 10°W, while the northern boundary has usually been at about 68°00–68°30′N. In the west, these surveys usually included the outer part of the Greenland shelf from south of Scoresby Sound to south of Ammasalik. On rare occasions Norwegian summer surveys of the Iceland Sea have recorded 1-group capelin north of 68°30′N.

15.3.2. Equipment, data acquisition and handling

The echo-integrating system, used in surveys of capelin abundance in the Iceland – Greenland – Jan Mayen area, is basically the same as that used for similar measurements of the Barents Sea capelin stock. A description of this system, its application and underlying theories, was given by Nakken and Dommasnes (1975) and later updated in detail by Dommasnes and Røttingen (1985). SIMRAD 38 kHz echo-sounders have been used in all instances. The older SIMRAD EK/QM integration system, which was used in the beginning of the series, had by 1983 been replaced by the newer SIMRAD ES400/QD system on board all vessels concerned. And the latter was in turn replaced by the SIMRAD EK 500/BI 500 echo-integrating system (Bodholt *et al.* 1989; Foote *et al.* 1991) in 1991.

Clearly, when adopting new instrumentation or measuring techniques, care must be taken to ensure continuing comparability of stock abundance estimates. In the first years of the surveys all recordings were referred to that of the Norwegian research vessel G. O. Sars through intercalibrations on plankton and 0-group capelin recordings at sea (Røttingen 1978; Vilhjálmsson *et al.* 1982). In this way the instrument constant, established by the Institute of Marine Research, Bergen, was transferred to the Icelandic Marine Research Institute. An example of the results of such an intercalibration is shown in Figure 15.5. The subsequent monitoring of instrument performance has been done by measurements of equivalent beam angles (Reynisson 1985, 1990). Furthermore, when new integration systems were commissioned, the old systems were run simultaneously until sufficient comparison had been obtained for relating the previously integrated abundance to that recorded with the new instrumentation. An example of the most recent comparison of this type is shown in Figure 15.6.

For each survey the performance of all acoustic systems has always gone through a fixed target calibration procedure (Foote *et al.* 1987). The integrated echo intensities are converted to fish densities by numbers, using a length dependent target strength of the form:

$$TS = 19.1 \log L - 74.5 \text{ dB}, \qquad (15.1)$$

where TS denotes the target strength in decibels (dB) and L the fish length in cm.

This target strength for capelin was established by scientists of the Institute of Marine Research, Bergen, Norway and represents an average of different types of measurements, which are believed to approximate that experienced under surveying conditions (Anon. 1985a; Dommasnes and Røttingen 1985). This average TS value is 10 dB lower than that given by Dalen *et al.* (1976) for the maximum target strength, measured for the dorsal aspect of capelin. The reason for not

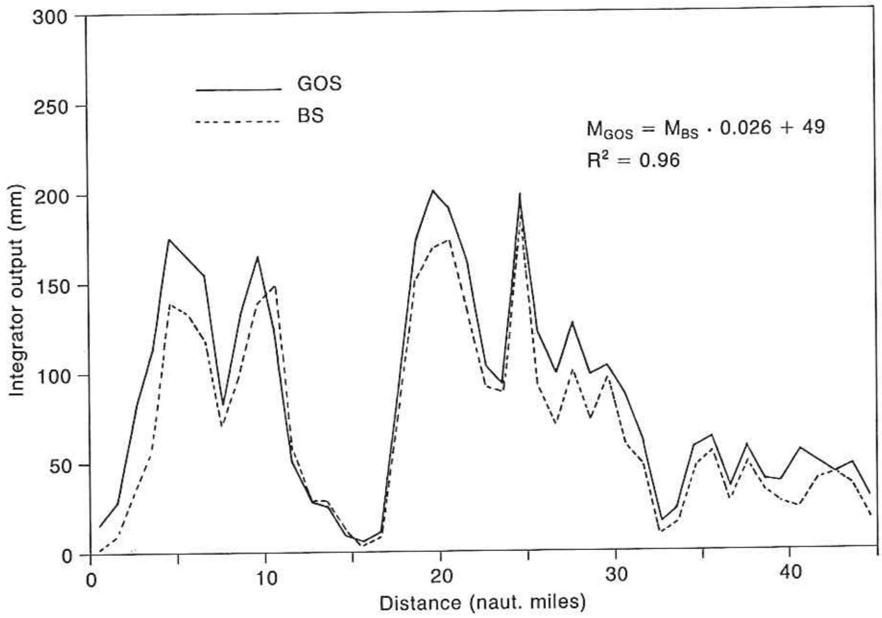

Figure 15.5. An intercalibration between r/v G. O. Sars and r/v Bjarni Sæmundsson, using a recording of a mixture of 0-group capelin and euphausiids in August 1979. (After Vilhjálmsson *et al.* 1983).

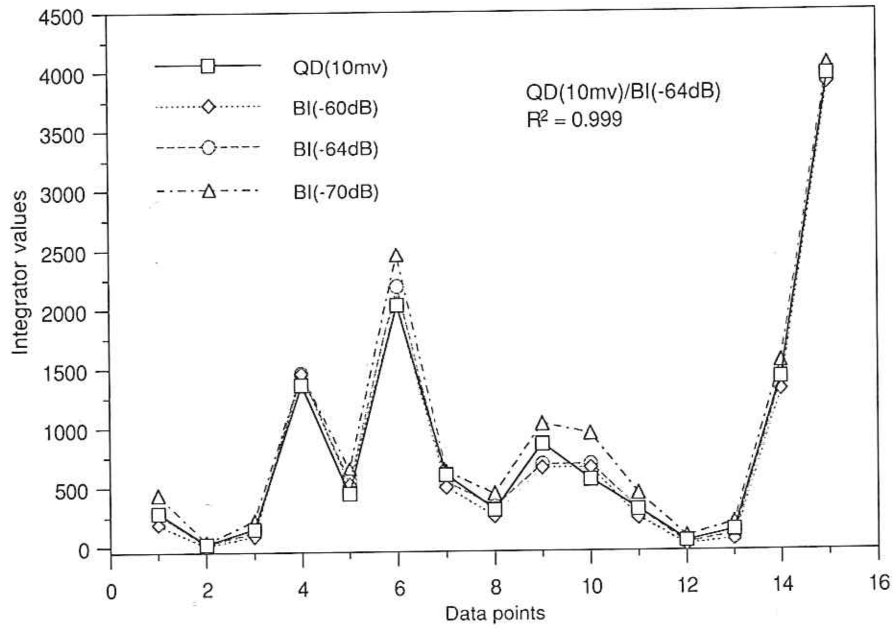

Figure 15.6. Comparison between EK400/QD and EK500/BI500 using different threshold values, January 1992. (For further explanation see text).

using the maximum dorsal aspect TS, is that in nature the fish do not meet the maximum dorsal aspect criterion at all times. On the contrary, their behaviour, *e.g.* during feeding, results in their pointing in various directions up and down in the water column and thus usually present an acoustic target of much reduced size.

During the surveys, echo intensities are registered continuously along the ship's tracks, usually spaced 10–20 naut. miles apart, as described earlier, and the values integrated and recorded as averages per naut. mile for every 5 naut. miles sailed. However, this distance as well as that between transsects may have to be shortened considerably when working under high density conditions and/or in shallow waters, as sometimes happens in winter. On such occasions, the sometimes uneven distribution of the capelin and their occurrence at shallow depths may necessitate shortening of inter-transect distances to 2 naut. miles and integration intervals to 0.5 naut.miles.

Fishing with a fine-meshed pelagic trawl (Dommasnes and Røttingen 1985) is done frequently in order to sample the size composition, obtain other biological data necessary (*e.g.* on age composition, sex ratio and weight distribution) and generally to establish the reasons for any changes in acoustic recordings. Paper records and, more recently, computer records of received echo-signals are scrutinized daily with reference to the catch composition and other information indicating their origin. Measured intensities of received echo-signals are then allotted to capelin and other sources on the basis of the catch composition and visual information from the echo records themselves.

At the end of a survey, the echo abundance of capelin measured by each participating vessel is plotted on a common map of survey tracks. Average values of echo-abundance for the various subareas (often 0.5° in latitude by 1° in longitude but smaller in areas of very high densities) are computed and the appropriate samples allocated to the various subareas. The resulting set of data is then run through a computer programme and converted to numbers of fish and biomass by length, age and maturity. Details of these computations were given by Dommasnes and Røttingen (1985).

Within their usual distribution area, the Icelandic capelin are by far the largest contributor to echo recordings, and echoes due to other species or false bottom are as a rule easily recognized and removed. Since most of the work is in deep water, bottom interference is usually not a problem. Therefore, when capelin distribution and behaviour is at all suitable for acoustic assessment of abundance, there seem to be two main sources of error. The first is connected with interference by aeration below the hull-mounted transducers, caused by wind and wave action (Dalen and Løvik 1976), and the second is due to selectivity of the fishing gear used to obtain samples of the size composition of the capelin and other biological data.

The effects of reduced strength of capelin echo signals due to the blocking of sound by aeration, are difficult to judge and correct for. Although this sometimes has to be attempted, the general rule has been to halt surveying when wind force exceeds 24 knots and never survey high-density areas in winds stronger than 18 knots. As mentioned earlier, gear selection favours the older and larger fish, and 1-group capelin will, therefore, be under-represented when mixed concentrations are sampled. Since the total echo intensities are divided between the various size categories (fish lengths) on the basis of the trawl samples, the adult stock component will be over-estimated and the juveniles under-estimated under such conditions. Again, the errors are difficult to quantify. But due to the much lower target strength of the 1-group as compared to the older part of the stock, the under-estimation will be much more serious in the case of the 1-group than the over-estimation of the older capelin. A third problem is interference by drift ice, rendering parts of the distribution area inaccessible. Such situations are, however, easier to recognize. They have certainly been encountered, and in fact they have invalidated whole surveys in the past.

15.4. Estimates of the abundance of adult capelin

15.4.1. Surveys in the 1978/79–1992/93 seasons

In the past 15 years, much effort in the form of manpower, vessel time and equipment has been expended in order to assess the abundance of adult, fishable capelin in the area between Iceland, Greenland and Jan Mayen and to monitor the effects of the large scale fishery which was conducted in most years during this period.

Familiarity with the design and execution of acoustic assessment surveys is a prerequsite for attempting to assess the historic performance of such work. For this reason, a fairly detailed account of the progress of each survey, its findings and contemporary judgements of surveying conditions and results, is given in Appendix I.1. A complete list of unpublished survey reports, available at the Marine Research Institute, Reykjavík and/or the Institute of Marine Research, Bergen, is given in Appendix I.3. The resulting abundance estimates in numbers and biomass at age are given in Appendix II.2, Tables XII and XIII. Charts of the distribution of capelin recorded during the autumn and winter assessment surveys are contained in Appendix I.1, Figures I – XLVII. An abstract of this research activity is as follows:

The abundance of the adult or fishable part of the Icelandic capelin stock was first assessed by acoustic methods in late October 1978. Because of an intense scouting activity and due to previous information supplied by the fishing fleet, it was clear that at the time of the survey practically all of the adult stock was assembled in a limited area in the region of the Iceland-Greenland Channel. The assessment was repeated two more times resulting in similar estimates of abundance on two occasions. A storm prevented the completion of the third estimate.

In 1979 the Norwegian Institute of Marine Research, Bergen joined the Icelandic Marine Research Institute in assessing adult capelin abundance in the Iceland-Greenland-Jan Mayen area. The first joint survey was carried out in July–August of that year and failed to register but part of the stock, in all probability because of near-surface distribution. This is also true for a joint survey in September–October of that year. After this experience the autumn surveys have usually been carried out in October and repeated in November when conditions were found to be inadequate due to fish distribution and behaviour and/or drift ice. Lately, the main autumn survey has been further delayed and carried out in late October and November in order to reduce the risk of having to repeat autumn stock assessments. Norwegian participation in the autumn surveys continued uninterrupted until 1984. After that Norwegian research activity in the above area has been centred around capelin migrations and hydrographic measurements in the Iceland Sea in summer (July–August).

As mentioned in a previous section, an estimate of adult capelin abundance can usually be obtained in January/February, when that part of the stock has segregated from the juveniles and is distributed in areas of relatively small geographical extension. From the beginning of these surveys in the winter of 1979 until the mid-1980s it was considered necessary to re-assess this part of the stock for comparison with the autumn estimate(s) and the large catches, often taken in the period mid-October until the end of January. Since 1979 such mid-winter assessments have indeed been carried out annually, with the exception of 1986 and 1988, when it was not considered necessary due to the late but apparently reliable estimates of stock abundance obtained in the fall of 1985 and 1987. Furthermore, the January survey of 1993 failed to register but part of the spawning migration because of adverse weather conditions. In some cases, the winter assessments also included repetitive surveys of parts or all of the spawning migrations as tests of precision.

15.4.2. Reliability of the acoustic estimates of adult capelin

Acoustic surveys of the Icelandic capelin stock were started in order to supply urgently needed information on stock abundance, current exploitation rate and to forecast stock developments. As described in section 15.3.1, the sampling schemes used in these surveys do not, strictly speaking, conform with the demands of elementary sampling theory. Nevertheless, it is believed that the scheme adopted is sound, since it is designed in such a way that the essential features of the distribution are satisfactorily covered, as established by the observed distribution in most years. The judgement of whether survey conditions, with regard to weather, ice cover and fish behaviour, have been satisfactory or not, must in each case lie with the personnel carrying out the survey. The resulting estimates of abundance are, therefore, bound to be somewhat subjective and difficult to test fully with regard to normal statistical procedures. Furthermore, there are no other methods of absolute stock abundance assessment to which acoustic estimates of capelin abundance can be compared, and thus the "true" size of the stock remains unknown. However, there is information available which allows us to judge with some confidence the performance of the acoustic method, as applied to this stock, and the accuracy of the abundance estimates which have been obtained.

During some of the first assessments, time was taken to carry out repetitive estimates of abundance in order to obtain a measure of precision when working under apparently comparable conditions (Vilhjálmsson and Reynisson 1979; Vilhjálmsson *et al.* 1982). Thus, the maturing stock was successfully surveyed two times in late September 1978, while a third survey had to be abandoned due to rapidly worsening weather condi-

Table 15.1. Comparison of the results of repeated acoustic surveys of the same stock component. Numbers in billions and weights in thousands of tonnes. Catches between repeats were negligible.

Northwest Iceland

16/10–29/10 1978	*Age 2*		*Age 3*		*Total*		*% deviation from average*
	N	*W*	*N*	*W*	*N*	*W*	
Survey 1	58.3	1,142.7	13.5	344.3	71.8	1,487.0	−4.1
Survey 2	63.4	1,242.6	14.6	372.3	78.0	1,614.9	+4.1
Average	60.8	1,192.7	14.1	358.4	74.9	1,551.0	

East Iceland

01/02–07/02 1979	*Age 3*		*Age 4*		*Total*		*% deviation from average*
	N	*W*	*N*	*W*	*N*	*W*	
Survey 1	21.3	428.1	5.0	121.4	26.3	549.5	−4.4
Survey 2	22.0	442.8	5.2	125.6	27.2	568.4	−1.1
Survey 3	23.5	472.1	5.5	133.9	29.0	606.0	+5.5
Average	22.3	447.6	5.2	127.0	27.5	574.6	

Northwest Iceland

08/02–18/02 1979	*Age 3*		*Age 4*		*Total*		*% deviation from average*
	N	*W*	*N*	*W*	*N*	*W*	
Survey 1	20,9	424.3	4.6	110.9	25.5	535.2	−6.2
Survey 2	22.7	460.8	6.0	144.6	28.7	605.4	+6.2
Average	21,8	442.6	5.3	127.8	27.1	570.3	

tions in its last stages. During this experiment, the stock was concentrated within a relatively small area, but the capelin were almost exclusively registered as schools of varying densities and sizes. A second experiment was carried out in the first week of February 1979 on that part of the maturing stock which had migrated to the area east of Iceland. This time it proved possible to complete three surveys covering the narrow distribution area at the shelf edge, from the southern east coast north to the latitude of the Langanes promontory. In the southern part of the area there were dense schools alternating with scattering layers, while farther north the capelin occurred only as scattering layers. This distribution pattern did not change throughout this second experiment. The third experiment took place at the shelf edge off the Vestfirðir peninsula, where two surveys were carried out in the second and third week of February 1979, thus with a time difference of a few days. During the first survey in this area, the adult capelin occurred both as schools and scattering layers and were to some extent mixed with juveniles. The contribution of juveniles to the total echo abundance was estimated on the basis of a number of samples, taken with a fine meshed pelagic trawl. The remaining adult capelin was then divided into age groups as usually. During the second survey, however, the adult capelin had migrated some 30 naut. miles to the southwest, while the juveniles had remained in much the same position as before. In the new position the adult stock was recorded as a dense and continuous scattering layer, and the estimate did not have to be adjusted for an admixture of juveniles. Both of these surveys were carried out under good weather conditions. There was no schooling in the near-surface layers during any of these experiments, nor were there noted any abnormalities in the behaviour of the capelin that obviously would have influenced the outcome of the surveys in one way or another.

The three groups of repeated stock size estimates, in numbers and biomass by age groups, as well as percentage deviations from the respective means, are given in Table 15.1. This brings out that the observed deviations are in the range of 1.1–6.2% of the respective means. Although these experiments are too few for meaningful statistical testing, the results indicate convincingly that any repeated estimate of stock abun-

Table 15.2. Comparison of valid autumn/winter acoustic estimates of adult stock abundance by number. N_1 denotes autumn stock estimate, C is catch in numbers between stock estimates, $N_{2calc} = (N_1-(C \cdot e^{M/2})) \cdot e^{-M}$ and N_{2est} is the winter stock estimate.

Dates	N_1	C	N_{2calc}	N_{2est}
01/11/78–01/02/79 . . .	74.9	12.4	55.6	54.7
01/11/79–01/02/80 . . .	59.2	9.4	44.4	45.5
01/11/80–01/02/81 . . .	24.3	7.6	14.7	15.4
01/12/81–01/02/82 . . .	12.5	3.3	8.5	8.2
01/11/82–01/02/83 . . .	16.6	0.0	14.9	15.5
01/11/83–15/02/84 . . .	64.3	13.1	45.5	43.2
01/11/84–01/02/85 . . .	42.5	7.3	31.3	32.7
01/11/86–01/02/87 . . .	50.0	16.1	29.6	45.2
01/11/88-15-01/89 . . .	70.5	20.2	43.4	46.6
10/12/90–01/02/91 . . .	19.3	1.0	17.1	24.5
01/12/91–15/01/92 . . .	56.1	4.5	48.8	61.1

dance should fall within ±10–12% of the previous one, given similar surveying conditions with regard to track density, weather and fish behaviour.

For practical reasons, this type of experimentation was unfortunately discontinued. Repeated surveys of the adult capelin stock, or parts of it, have of course been carried out since 1979, as described in Appendix I.1. But in all cases, the time interval between surveys has been considerably longer than in the experiments just described. Furthermore, an ongoing and often intensive fishery as well as changes in external conditions, could have introduced additional uncertainties. Although many of these repetitions gave very similar results, when adjustments had been made for catches taken during the time between them (cf. Table 15.2), they can not, for these reasons, be used for measuring precision in the same way as the experiments from 1978 and 1979.

Together, the descriptions of individual surveys given in Appendix I.1 should provide a good general picture of changes in adult capelin distribution and behaviour over the period August – February. Quite apart from external variables, such as weather and the extension of drift ice, fish distribution and behaviour may affect the reliability of acoustic assessments of stock abundance to a considerable degree. Thus, surveys during the feeding period in summer and early autumn have almost always failed to register but part of the stock, and some of the autumn surveys were immediately recognized as being of dubious validity due to the behaviour of the capelin. The ideal situation would of course be such that the target species were distributed fairly evenly within a limited and well defined area, which then could be surveyed in sufficient detail within reasonable time limits. Although surveying conditions have usually become adequate by autumn, this has not always been the case, as described in Appendix I.1. During the autumn surveys, the stock has for example sometimes shown an unfavourably wide distribution, and parts of it exhibited a behaviour pattern reminiscent of the feeding season. Unsuitable behaviour patterns, for acoustic surveying of stock abundance have usually been recognized while conducting the survey. Although such stock assessments have been repeated, there are a few cases when, in retrospect, suspected unsuitable conditions have just been noted in general terms in the survey reports, but the abundance estimates otherwise accepted as basis for setting interim total allowable catch quotas (TACs), to be revised, if warranted by later assessment in winter.

Apart from difficulties, mainly associated with stormy weather, surveying conditions in the months of January and February have been by far the most stable over the years. This conclusion is supported by the fact that the mature stock has by then assembled and started the spawning migrations, which are easy to locate, and usually behave in a more or less predictable manner. An exception, however, is the transition area between the cold and warm water masses off Southeast Iceland, where the capelin tend to scatter in such a manner that their abundance is not easily assessed. For these reasons, the January/February surveys of the maturing stock abundance, carried out off East and Northeast Iceland, and occasionally off the eastern part of the south coast and Southeast Iceland, have been considered the most reliable ones, indicating the true size of this part of the stock in the years when they have been obtained. Thus, when at variance with the autumn survey results, the winter estimates have always been chosen as the basis for final decision on the total allowable catch for the current season.

Out of 15 seasons in the period 1978/79 – 1992/93 there are 14 autumn estimates, which at the time were accepted as valid and used for setting catch quotas or otherwise to manage the fishery. As described in Appendix I.1 , the single exception is the autumn of 1989 when, in spite of several attempts, the stock could never be assessed

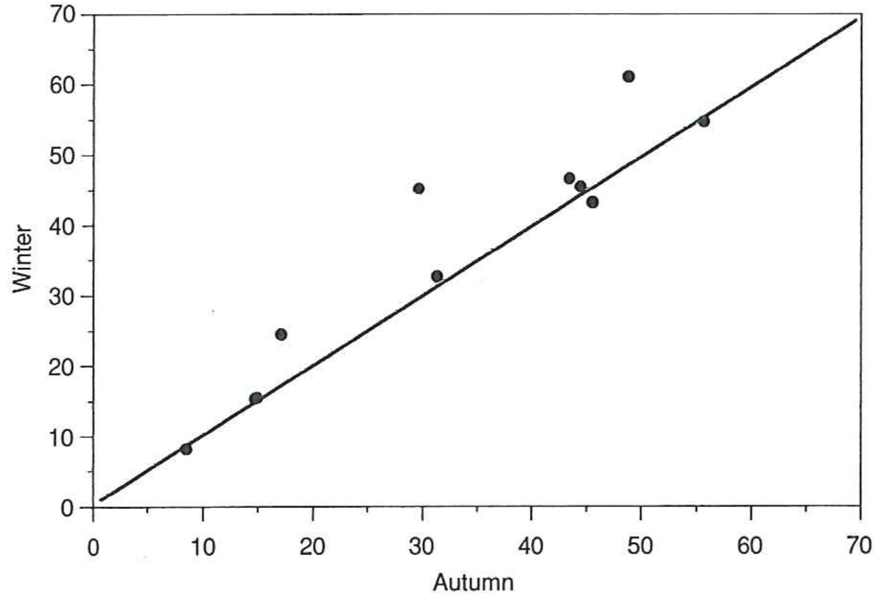

Figure 15.7. The relationship between "valid" autumn and winter acoustic stock abundance estimates in the 1978/79–1991/92 seasons.

due to extensive drift ice. The maturing stock was not assessed in the winters of 1986 and 1988. In addition, the 1989 winter estimate was obtained under conditions that were not altogether satisfactory, and the winter 1993 estimate could not be completed, as described in Appendix I.1. The remaining 11 pairs of autumn/winter acoustic measurements of stock abundance, that at the time of assessment were accepted as valid and subsequently used in advising on catch quotas, have been made comparable by accounting for catches and natural mortality between the measurements. The basis for these calculations, the resulting estimate of total adult stock abundance and the new stock estimate is given by numbers in Table 15.2.

A simple linear regression of the winter estimate onto the autumn estimate yields the result that the slope and intercept are not significantly different from 1 and 0, respectively. Furthermore, the point estimates are also so close to 1 and 0 that in practical terms the difference is negligible. This indicates that each pair can be thought of as a duplicate measurement of the same quantity, namely the true acoustically surveyable abundance in the season. The full set of paired measurements is plotted in Figure 15.7 along with the line having a slope of 1 and an intercept of 0.

The variance is estimated from the duplicate measurements. Since a standard error is most naturally thought of as a percentage, the data were log-transformed before fitting a model of the form

$$\log(y_{ij}) = \mu_i + \varepsilon_{ij} \qquad (15.2)$$

where y_{ij} denotes the two ($j = 1,2$) measurements in season i, μ_i the logarithm of the true abundance in season i, and ε_{ij} denotes the measurement error on log-scale.

This model is a simple analysis of variance and yields an estimated standard deviation of each measurement. After log-transforming the data the analysis of variance yields an $R^2 = 0.9993$, since almost all of the variability in the entire data set can be explained by the assumption that the two measurements in each season are estimating an underlying mean. The residual standard error is 0.131, indicating that the coefficient of variation of the measurements is about 13%.

It is seen, however, that there are some anomalies in the data set. In particular, in the basic regression, data point 1986/87 is an outlier with a studentized residual of $t = 2.75$. Data point 1991/92 also has an uncomfortably high residual from the regression line. The full list of diagnostics is given in Table 15.3.

If data point 1986/87, which is an obvious outlier, is dropped from the regression model, it is found that data point 1991/92 is a severe outlier with a studentized residual of 3.76. Dropping this

Table 15.3. The analysis of variance diagnostics of the sets of data ($N_{2calc} - N_{2est}$) given in Table 15.2.

Data pairs	*Error*	*Studentized residuals*
78/79	−4.73	−0.92
79/80	−2.58	−0.44
80/81	−2.60	−0.46
81/82	−3.53	−0.67
82/83	−2.71	0.48
83/84	−6.00	−1.09
84/85	−2.12	−0.35
86/87	12.11	2.75
88/89	−0.47	−0.08
90/91	4.06	0.72
91/92	8.56	1.74

data point results in data point 1990/91 becoming an outlier with a studentized residual of 3.48. Dropping these three data points results in an analysis of variance model in which the remaining standard error is 0.031, *i.e.* the estimated coefficient of variation is about 3%. Although the dropping of measurements is of some concern, it seems that the 3 anomalous observations are different from the remaining 8 pairs, in that on these three occasions the autumn surveys were suspect due to abnormal fish behaviour in comparison to the other eight cases. This is further emphasized by the log ratio of first to second measurement as shown in Fig. 15.8.

The most reasonable explanation of these features of the data seems to be that when measurements are successful and the stock is covered, the coefficient of variation is below 5%, while in some years there are problems with the fall measurements in that only part of the stock is "covered". In the latter case there is of course a potential for any amount of underestimation. In many cases, however, it will be known that problems in stock estimation have occurred.

In all the three anomalous cases it was indeed noted that the autumn surveys had probably underestimated stock abundance to some degree. In 1985 this was attributed to schooling in the near-surface layer off the Vestfirðir peninsula, which is a readily recognizable phenomenon, although its effect is usually difficult, and sometimes quite impossible, to quantify. The other two cases were of a completely different nature. Thus, it was suggested in the November 1990 survey report that the unusual distribution of almost all of the adult stock together with juvenile capelin in the relatively shallow North and East Icelandic shelf area might in some way have resulted in a changed behaviour pattern that was not suitable for acoustic estimation af abundance. The November 1991 distribution followed

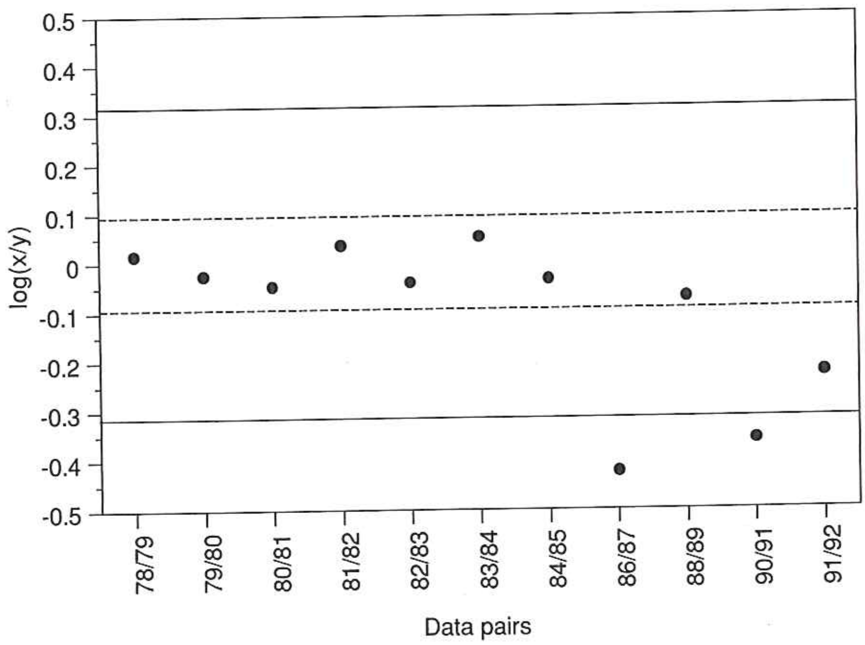

Figure 15.8. The log-ratio of first to second measurements of "valid" stock abundance estimates in 1978/79–1991/92. The confidence intervals correspond to two standard deviations. The larger confidence interval is based on all 11 data pairs, whereas the inner interval is based on the 8 "valid" pairs.

much the same pattern, and on both occasions the adult capelin were at times found to be feeding on euphausiids.

As described in Appendix I.1, the adult part of the capelin stock also had an anomalous summer distribution in 1989–1991 and, partly in 1992, in that it did not migrate to feed in the central and northern Iceland Sea. It is therefore possible that in these years the fat content of the maturing part of the stock was lower than usual in the fall, and that the capelin had to make up for this deficiency by feeding fairly intensively through the autumn and early winter period. That this may have been so, is supported by the fact that the fat content in the 1991 and 1992 January and February catches was about 1–2 percent higher than the long term average. The only food available in quantity to capelin in these waters in the autumn/winter period, consists of euphausiids which have considerable swimming powers and exhibit a violent escape reaction when disturbed. If capelin are actively feeding on euphausiids, they will, therefore, have to chase their prey, and it is suggested that under such circumstances they probably present a much more unstable and weaker acoustic target than when at rest. To detect such conditions when they occur, and judge their effect on an acoustic abundance estimate, would require comparative information from several years on feeding intensity and stomach contents. For the Icelandic capelin stock such information is not yet available. However, feeding intensity generally tends to decline as the capelin approach their spawning time. Therefore, it is fairly certain that this problem, if it exists, will be less severe during stock assessments in January than in October and November.

As described in section 15.3.2 and discussed in the paragraph above, the reliability of acoustic estimates is critically dependent upon a target strength (TS) for capelin that is correct for each situation. With flexibility in vessel time and using a strategic survey technique, it has with few exceptions proven possible to obtain consistent abundance estimates of the maturing or fishable part of the Icelandic capelin stock, both in the autumn as well as in winter. Although these estimates need not describe absolute stock size in numbers, and consequently, also in weight, the evidence seems overwhelming that they describe true variations in stock abundance in a relative sense during the period in which these estimates were obtained. The periodic recurrence of anomalous conditions is, however, unavoidable. Until methods of actually measuring surveying conditions have been developed, the reliability of each estimate will continue to depend on the judgement of the personnel responible for their execution.

15.5. Estimates of juvenile 1- and 2-group capelin abundance

15.5.1. Autumn estimates

The first stock assessment survey, carried out in late October 1978, was specifically aimed at the maturing, fishable stock and practically no immature capelin were recorded. During the joint Icelandic-Norwegian survey in late September – early October in the following year, however, 1-group capelin were recorded, mainly over the Greenland shelf in the westernmost part of the survey area. Although these capelin were recorded in comparatively low numbers, the question arose whether it would be possible to obtain some measure of the abundance of immature 1- and 2-group capelin in the autumn surveys. At the time, there was a complete lack of suitable data to forecast recruitment and such information was, therefore, sorely needed.

It proved difficult to obtain credible estimates of juvenile 1- and 2-group capelin abundance in autumn. This part of the stock was then mainly recorded in the western part of the area, between Northwest Iceland and Greenland, as well as in the more coastal areas off North and Northwest Iceland. However, in 1980 and 1981 juvenile 1- and 2-group capelin were also recorded in unrealistically low numbers in comparison to later assessments. In 1982–1984 the recorded distribution of juveniles remained similar, and although their numbers increased somewhat in comparison to previous years, the measured abundance still was unrealistic (cf. Appendix II.2, Tables XII and XIV).

In the years that followed, the juvenile 1- and 2-group stock component continued to be recorded in the more coastal part of the survey area north and northwest of Iceland as well as in the area over the Iceland-Greenland Ridge and in the Iceland-Greenland Channel. Since 1985, however, a part of the recordings of juvenile capelin also derived from the area off Northeast Iceland.

Abundance estimates of juvenile 1- and 2-group capelin, obtained in autumn surveys of stock abundance, are given in Appendix II.2, Table XIV. Comparison with estimates of the same year classes in the following autumns (cf. Appendix II.2, Table XII) clearly reveals that the juvenile stock component must be grossly underrated at this time of the year. There are two obvious reasons why this might have been so. As mentioned earlier, gear selection, favouring the older and larger fish, leads to an underestimate that is particularly serious in the case of the 1-group. This is due to the fact that like the 0-group, 1-group capelin does not seem to be herded by the wings and the upper, large meshed part of the trawl, into the cod-end to the same degree as the older fish. When occurring together with older stock components, some of the echo abundance derived from the 1-group will, therefore, inevitably be allocated to the larger fish on the basis of size composition in the catch. Although Icelandic experiments to determine the selectivity of capelin trawls have been inconclusive, the results strongly point to selection in favour of the older and larger fish. Furthermore, Norwegian experiments to determine the escape from capelin trawls indicate a strong selection in favour of larger fish when trawls are set on mixed concentrations (Larsen 1984; Dommasnes and Røttingen 1985).

The other reason for the low abundance of 1- and 2-group capelin in autumn surveys might in some cases be their distribution outside the survey area. Parts of this stock component have often been recorded in the vicinity of and over the Greenland shelf from west of the Northwest peninsula of Iceland to the Scoresby Sound area. Parts of this area have sometimes become covered by drift ice in the latter half of October and, therefore, inaccessible to shipborne surveying. This is indeed noted in many autumn survey reports, the worst case being that of October 1987 when all age groups were certainly underestimated to a large degree because of ice. Furthermore, because of the wider distribution range of the immature 2-group capelin as compared to their younger counterpart (1-group), the former would even more often tend to go undetected in ice-covered areas during the autumn surveys.

Estimates of year class strength, back-calculated from acoustic estimates of mature fish as shown in Table 15.4, catches and natural mortalities, are available and given in Table 15.5 for the year classes corresponding to the estimates of 1- and 2-group immature capelin from surveys in the 1980–1992 period (year classes 1979–1989). Simple regressions of the measured abundance of immature 1-group capelin on the calculated total abundance of 2-group recruits on one hand, and a regression of autumn estimates of immature 2-group capelin on the calculated number of 3-group recruits to the maturing stock on the other, indicate a significant correlation, with $R^2 = 0.73$ and 0.80 respectively and $P < 0.01$ in both cases. While the intercept is not significantly different from 0 in either case, year class abundance is, however, underestimated by a factor of 1.5 in the first instance and 4.3 in the second. However, the "true" underestimation is even

Table 15.4. Back-calculations of year class abundance to 1 August at ages 2 and 3. The examples refer to surveys in January and an even distribution of catches. M denotes natural mortality of 0.035/month. N_2, N_3 og N_4 denote measured or calculated numbers at ages 2, 3 and 4. N_{mat} denotes numbers of mature capelin and N_{imm} denotes numbers of immatures. Other denotations are explained in the text.

	Months | *A* | *S* | *O* | *N* | *D* | *J* | *F* | *M* | *A* | *M* | *J* | *J* | *A* | *S* | *O* | *N* | *D* | *J* | *F* |
N_2 mature	$N_{2mat} = N_{3mat} \cdot e^{6M} + C \cdot e_{3M}$
N_2 immature	$N_{2imm} = N_{4mat} \cdot e^{18M} + C \cdot e^{15M}$
N_3 mature	$N_{3mat} = N_{4mat} \cdot e^{6M} + C \cdot e^{3M}$

Table 15.5. The calculated numbers of capelin (billions) of year classes 1976–1989 before the fishing season (1 August) divided according to age and maturity.

Year class	*Age 2* Immature	Mature	Total	*Age 3* Mature
1976	15.3	81.9	97.2	10.1
1977	16.4	91.3	107.7	10.3
1978	4.2	35.4	39.6	2.8
1979	3.6	39.7	43.3	2.4
1980	15.0	17.1	32.1	9.8
1981	42.5	53.7	96.2	27.9
1982	40.9	40.7	81.6	27.0
1983	100.0	64.6	164.6	65.8
1984	29.4	35.6	65.0	20.1
1985	37.2	65.4	102.6	24.5
1986	24.0	70.3	94.3	15.8
1987	10.3	42.8	53.1	6.8
1988	10.1	31.9	42.0	6.7
1989	9.7	67.7	77.4	6.4

more severe since this comparison does not include natural mortality. Assuming the same natural mortality rate as used for the adult stock, which must be considered an absolute minimum, the above factors of underestimation would have to be scaled upwards by about 40%. Although the high correlation suggests a systematic trend in the same direction, the severe underestimation must be kept in mind, and this makes it necessary to excercise great care when using such estimates for forecasting year class strength. This will be further discussed in chapter 17.

It has been suggested that the more severe underestimation in the autumn stock assessment surveys of the immature 2-group capelin, as compared to the 1-group, may result from difficulties in determining the maturity stage of capelin belonging to this age group. This problem has long been recognized in capelin assessments of the Barents Sea capelin which are carried out in September, *i.e.* 1–2 months earlier than at Iceland (Forberg 1982, 1983; Forberg and Tjelmeland 1985). But if this is the case, it means that the autumn surveys must have overestimated the maturing part of the 2-group capelin by at least 5–10% in number and 10–15% by weight as compared to the winter estimates. This is contrary to the observation that the age distribution in the maturing stock, recorded in autumn and winter, is usually much the same (section 14.6). Furthermore, the number of maturing capelin, recorded in autumn surveys on one hand and in winter surveys in the following year on the other, are generally in good agreement when catches and natural mortalities in the period between the corresponding estimates have been accounted for (section 15.4.2).

The implication of a systematic error in the acoustic estimates of the juvenile 1-group capelin abundance, and in part the underestimation of the 2-group juveniles as well, suggests that there may be other important reasons for the autumn abundance underestimation of these stock components besides the presence of these capelin outside the survey area or because of gear selection. Some of the causes of systematic underestimation of the juvenile stock component might in theory be the following:

1) The threshold value, which is used in the integration software system in order to filter out unwanted contributions from ambient noise and scatterers such as plankton, might be too high. This, however, does not seem to be likely since capelin are practically never caught when fishing in areas containing such diffuse recordings. The echo abundance thus lost could, therefore, only amount to a small fraction of the total.
2) The length dependent acoustic target strength of capelin might be too high for the lower end of the size scale. The results of *in situ* target strength measurements of capelin (Halldórsson and Reynisson 1983) do not, however, support this proposition.
3) The 1- and 2-group immature capelin might behave differently from the adult stock in autumn and often be positioned so that they give a weaker reflection of the sound beam relative to the older fish. Considering the stronger schooling behaviour, generally exhibited by the older capelin in comparison to the juveniles, which tend to occur in less dense and irregular aggregations, this explaination seems likely.
4) In the shelf area north and northeast of Iceland the juvenile capelin are usually distributed in the autumn period in the near-bottom layer during the daylight hours. The bottom-offset feature of the echo sounder, used in order to avoid integrating disturbances due to smaller bottom irregularities and groundfish, would of course also exclude that part of the

juvenile capelin found in the 1 metre or so of the water column, next to the bottom. Since surveying continues uninterupted throughout the day, losses due to near-bottom distribution would be of a similar magnitude in most surveys and might be considerable.

Some of the possible causes of underestimating juvenile capelin abundance are speculative and need further study. But for the time being, the last two suggestions do seem the most plausible ones to account for the systematic underestimation of juvenile capelin in Icelandic waters in autumn.

15.5.2. Winter estimates

Except in 1988, when no winter surveying took place, serious attempts to assess juvenile capelin abundance date back to 1983. As described in Appendix I.1, these surveys have taken place in January and/or February, usually as a continuation of assessments of the mature stock. In the 1970s immature capelin were sometimes recorded in quantities off Northeast and East Iceland at this time of the year, but in the 1980s and the early 1990s most of the juvenile stock was recorded off the north coast as well as north and northwest of the Vestfirðir peninsula.

With the possible exception of 1986, when much of the immature stock was located off East and Northeast Iceland and off the central north coast, these surveys encountered the same difficulties in the 1980s and 1990s, *i.e.* a capelin distribution in areas partly covered by ice. Thus, most of the juveniles had during these years a much more westerly distribution than in the 1970s, and it was clear that parts of this stock component were often under ice in the westernmost part of the survey area. Difficult weather conditions are also noted in almost all survey reports except those of 1986 and 1992.

The abundance of immature 2- and 3- group capelin, by number and biomass, assessed in the winter surveys in 1983–1992, is given in Appendix II.2, Table XV. As in the autumn surveys, there is a tendency to underestimate the juvenile component. In this case the main reason is clearly often due to the inaccessibility of these capelin and not due to gear selection, since most of the adult stock has separated from the juveniles at the time of the winter surveys. This conclusion is further supported by the weak correlation between these and subsequent estimates of the same stock components. It follows, therefore, that in general the winter period is unsuitable for assessing the juvenile stock component although very useful estimates may be obtained in individual years, such as in 1986, when the 1985 autumn survey had failed to register but a part of the large numbers of immature capelin of the very rich 1983 year class.

15.5.3. Estimates in summer

As explained in a previous section, two main criteria must be honoured in order to obtain reliable estimates of the abundance of 1-group capelin by the acoustic method. In the first place, the distribution area as well as the fish themselves have to be accessible in good weather, and the admixture of older stock components should be at its minimum. On the basis of information from previous acoustic capelin surveys, as well as from the fishery, it seemed clear that these criteria would be best met in late summer. Then the feeding migrations of the adult stock to more northern latitudes in the Iceland Sea would be at their maximum, drift ice in the area of the Iceland-Greenland Channel and the Iceland-Greenland Ridge rapidly receding, and the most usual distribution of the 1-group in the area off Northwest, North and Northeast Iceland, therefore, easily accessible.

Attempts to estimate the abundance of 1-group capelin in summer began with a pilot survey in 1982, which was carried out by extending the usual August 0-group survey of the North Icelandic area farther to the north and northwest. In 1983 the 0-group survey pattern was formally extended to incorporate the 1-group capelin as far as possible, and from then on has remained the same. As described in section 15.3.1 its main features are parallel transects at right angles to the Icelandic coastline and spaced about 20 naut. miles apart. Methods of data acquisition and handling are the same as used in other surveys of capelin abundance. Survey tracks and 1-group capelin distribution south of 68°30′N in August 1982–1992 are given in Appendix I.2, Figures XLVIII–LVIII.

In gerneral, the August surveys confirmed that the 1-group capelin were distributed northeast and north of Iceland in August and sometimes also in the Iceland-Greenland Channel and over the Iceland-Greenland Ridge. At this time of year the 1-group usually appear as scattering layers rather than dense schools, and near-surface schooling has generally not presented much of a problem. Data from autumn surveys indicate a migration to the west and northwest in the fall. As expected, most of the maturing stock appears to be distributed at more northern latitudes than the juveniles in August, and problems in allocating echo signals to age groups are, therefore, much less obvious than in the autumn period. The estimates of 1-group capelin abundance, measured during the August 1982–1992 surveys, are given in Appendix II.2, Table XVI.

The August estimates of 1-group capelin abundance may be compared to abundance estimates of the same year classes as total numbers of 2-group recruits calculated from autumn or winter assessments, catches and natural mortality rates (Table 15.5). The resulting comparison yields an $R^2 = 0.41$, which is not significant, even with the exceptionally large 1983 year class included. Obviously, the August estimation of 1-group capelin abundance has failed to meet its goal of forecasting year class abundance one year later.

The reasons for the failure of the August estimates are not clear. The results obtained in the first few years of the series were indeed promising. And the underestimations of the 1984, 1985 and 1986 year classes could be explained by Norwegian observations which showed that part of these year classes were distributed outside the Icelandic survey area. After 1987 no such obvious reason for the failure of the August surveys of 1-group capelin abundance can be found. As just mentioned, this might in the first place be due to some of these capelin being distributed outside the survey area. Alternately, the 1-group may in part be inaccessible to acoustic assessment due to a behaviour pattern resulting in reduced target strength as suggested in section 15.5.1, or because of near-bottom distribution for some of the time during the summer months. In any case, it is clear that the biology, distribution and behaviour of this age group was not known in sufficient detail when the August surveys were designed. Information of this nature is still incomplete. It is, therefore, not possible to say with certainty whether the August surveys should be redesigned or discontinued altogether.

15.6. Variations in stock abundance

It was described in section 15.4 how a series of acoustic abundance estimates of the adult part of the capelin stock, both in number and weight by age, have been obtained during the period 1978–1992. Furthermore, it was established, through comparison of successive within-season estimates, that for each fishing season (August – March) there is at least one valid stock abundance estimate available and that in a number of seasons two or more such estimates have been successful. The comparison also indicated that this assessment method, as used with regard to the Icelandic capelin, is measuring actual stock abundance rather than giving relative stock sizes.

However, as explained in section 14.10, investigations on removal rates of capelin by the Icelandic cod stock as predator, suggest that the natural mortality of capelin may be higher than that required to account for differences in successive in-season accoustic estimates of abundance. In that case, the acoustic method would to some extent be underestimating stock abundance. But in either case, all the evidence suggests that for each fishing season we have obtained estimates of capelin stock abundance that are consistent and valid for comparative purposes and for projections of future stock developments.

Naturally, these in-season estimates tell us only what the abundance level of the stock was at the points in time when they were obtained, usually after some or even major parts of the original stock had been removed by the fishery or would be taken later. To obtain improved estimates, *e.g.* of year class size or stock abundance at the beginning and in the end of each fishing season, additional information is needed in the form of detailed catch statistics as well as knowledge of current stock structure and such biological variables as natural mortality rates, including spawning mortality, and changes in weight at age with time.

The structure of the Icelandic capelin stock and its biological characteristics, relevant to calculations of year class and stock abundance, are described and discussed in chapter 14. The catch in number by year classes, seasons and months is given in Appendix II.3 and Tables XVII–XIX, respectively. On the basis of the available information on the general biology of this stock the following assumptions can be made:

1. All capelin belonging to this stock spawn only once and die thereafter. Nevertheless, as described in section 14.11, it seems that a part of the spawning stock, mostly if not only consisting of females, may survive and spawn again. The evidence is, however, indirect and suggests variable survival rates. In all probability the contribution of repeat-spawners is, for practical purposes, negligible.
2. There is no spawning of 2-group fish. However, as also described in section 14.6, this is not strictly true. Almost every year there are records of the spawning of 2-group capelin, but these spawners have always been a small proportion of the total annual spawning stock by number and a negligible part by weight.
3. Only part of each year class spawns as 3-group fish. The remainder spawns at age 4.
4. In the last 25 years there has never been a significant contribution of age group 5 to the spawning stock.
5. An average monthly natural mortality rate of M = 0.035 is used for the adult part of the stock. As indicated in Table 14.8, natural mortality may vary from year to year. However, there is as yet no known way in which to estimate these variations accurately and hence the adoption of a working average figure.

15.6.1. Year class abundance

As described in chapter 14 the Icelandic capelin are recruited to the fishery as age 2 adults on 1 August (the appoximate beginning of the summer season). From the discussion presented in the previous section, the closest approximation of the total year class abundance by number, is obtained in the following way:

1. The basis for these calculations are the best (cf. section 15.4.2) acoustic assessments of the number of mature 2-group capelin in autumn, or 3-group if the survey data used were collected in January/February, as often has been the case. The measured number is then back-calculated through some 3 to 6 months, as the case may be, to the beginning of the season (1 August), adjusting for catches and the monthly natural mortality rate. This calculation gives numbers of maturing 2-group capelin recruiting to the fishable stock.
2. It has proven impossible to obtain directly comparable estimates of the immature 2- (3-) group part of the year classes. Therefore, an acoustic estimate of the numbers of maturing 3- (4-) group fish in the following season (one year later) has to be used and back-calculated in the same way as for the mature 2-group, but over a period of 15 to 18 months in this case. Addition of the back-calculated abundance of the two year class components then gives the total number of 2-group recruits (mature + immature capelin) of that year class on 1 August.

For illustrating the way in which year class abundance by number has been calculated from the acoustic estimates of the the abundance of maturing capelin, we use Pope's (1972) formula;

$$N_1 = N_2 \cdot e^{M} + C \cdot e^{M/2} \qquad (15.3)$$

where N_1 denotes back-calculated number at age, N_2 is the measured number of maturing capelin at that age, C the catch in number of the age group, M denotes the natural mortality rate multiplied by time in months, and M/2 is one half of the natural mortality rate over the same time, assuming an even spread of the catch.

The above calculations are further explained in Table 15.4. The resulting estimates of the total abundance of the 1976–1989 year classes as 2-group recruits (mature + immature capelin) and at age 3 are given by number in Table 15.5. The division of the number of 2-group recruits into mature and immature components is also given.

Estimates of the abundance of 1-group capelin by number, obtained in August and October/November, are available for the year classes 1981–1991 in the former case and 1979–1991 in the latter (cf. section 15.5). Almost all of these estimates have indicated an abundance which was far below that found by calculations of the type explained above. For reasons explained in the next paragraph, the calculated abundance must be considered a minimum for the 1-group stage. Although there is a conflict between the August estimates of 1-group abundance and those of the older parts of the stock, especially in later years, there is a significant correlation between the autumn estimates of the 1-group capelin and those of the same year classes as 2-group recruits. Thus, when the autumn estimates of the 1-group are regressed on the estimated total number in the same year classes as 2-group recruits, the resulting $R^2 = 0.73$ is highly significant ($P < 0.01$), with the slope and intercept being 1.7 and -3.8 respectively. Since the 1-group is not taken by the fishery, it should, in theory, be possible to calculate the abundance of this age group from total estimates of 2-group recruits on the assumption that natural mortality was known.

Due to the small size and inferior swimming ability of the 1-group compared to older capelin, as well as its frequent location within the distribution area of known predator species, the 1-group is a very easy and available prey. Furthermore, as explained in section 13, the 2- and 3-group capelin are often distributed outside the range of major predator species like the cod, for long periods of time. Therefore, the survival rate of 1-group capelin should be lower than that of the older parts of the stock. However, as discussed in section 14.10 the natural mortality of the adult capelin does not seem to have varied greatly in the period 1978–1989. Furthermore, the correlation between the abundance estimates of year classes, at age 1 on one hand and at age 2 on the other, suggests that the natural mortality rate of these age groups is the same or has changed in a similar manner over the past years. It must be left to future research to reconcile these differences. In the meantime, the best approximation to the true number of capelin, as age group 1 in the various year classes, seems to be to back-calculate year class abundance using the estimated monthly adult natural mortality rate of $M = 0.035$.

15.6.2. The stock biomass on 1 August and 1 January

Having obtained a valid estimate of stock abundance in numbers, by age groups and maturity stages, it is possible, using the average monthly natural mortality rate and catch in number, to project abundance to any point in time from the beginning of a fishing season to spawning time in March of the following year. We use the same method of projection as described in 15.6.1 when projecting backward in time, while for forward projections we rearrange equation 15.3:

$$N_2 = (N_1 - C \cdot e^{-M/2}) \cdot e^{-M} \qquad (15.4)$$

where the denotations are identical to those for equation 15.3.

However, as described in the previous section, this applies only to the adult or fishable part of the stock. The final estimate of the "true" abundance of the immature part of the 2- (3-) group capelin is not obtained until in the following year. Therefore, in spite of real time assessments, the estimate of the total abundance of mature 2- and 3-group and immature 2-group capelin, for example with reference to 1 August of a given year, does not become available until some 15 to 18 months later.

To obtain stock biomass we only need to multiply the number of capelin in each age and maturity group by the average weight for each group respectively and then sum up the total of all groups. In spite of the sometimes large annual changes in growth rates, this is of course easy to do for biomass estimates in the period October – March. We then have at least one and usually two valid stock assessments in number and biomass by age, maturity and length groups, from which mean weights can either be read directly or calculated using length/weight relationships as will be described in section 17.3.

Backward projections beyond October are more problematic. As described in earlier sections, it is difficult, if not impossible, to assess adult stock abundance, even in a relative sense, during the height of the feeding season in summer. Furthermore, annual changes in growth conditions are not necessarily the same in all parts of the feeding area, and disproportionate sampling of capelin within the area may, therefore, give misleading results (Vilhjálmsson 1977). In the absence of valid total stock estimates from the summer period, divided into mature and immature fish, an average growth increment for immature 2-group and maturing 2- and 3-group capelin in the August – October period, has been

Table 15.6. The calculated number (billions) of capelin before the beginning of the fishery on 1 August 1978–1992 by age and maturity. The total number (billions) and weight (thous. tonnes) of the immature and maturing (fishable) stock components are also given.

Age/maturity	*1978*	*1979*	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*
1 juvenile	163.9	60.3	65.9	49.1	147.3	125.1	252.1	99.1
2 immature	15.3	16.4	4.2	3.6	15.0	42.5	40.9	100.0
2 mature	81.9	91.3	35.4	39.7	17.1	53.7	40.7	64.6
3 mature	29.1	10.1	10.8	2.8	2.3	9.8	27.9	27.0
4 mature	0.4	0.3	+	+	+	0.1	0.4	0.4
Number immat. . .	179.2	76.7	70.1	52.8	162.3	167.6	293.0	199.1
Number mature . .	111.4	101.7	46.2	42.5	19.4	63.6	69.0	92.0
Weight immat. . . .	790	337	298	228	650	882	1,343	1,358
Weight mature . . .	2,147	1,482	932	743	307	985	1,270	1,417

Age/maturity	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
1 juvenile	157.1	143.5	80.8	64.2	117.8	148.5*	–
2 immature	29.4	37.2	24.0	10.3	10.1	9.7	26.9*
2 mature	35.6	65.4	70.3	42.8	31.9	67.7	70.7
3 mature	65.8	20.1	24.5	15.8	6.8	6.7	6.4
4 mature	0.7	0.1	0.4	+	+	+	+
Number immat. . .	176.5	180.7	104.8	74.5	127.9	158.2*	–
Number mature . .	102.1	85.6	95.2	58.6	38.7	74.4	77.1
Weight immat. . . .	812	832	469	307	562	843*	–
Weight mature . . .	2,116	1,540	1,528	1,072	680	1,146	1,136

* Preliminary

calculated from all data available for the last 15 years (cf. section 14.2). The resulting estimates are 3.2 g, 2.3 g and 2.1 g, respectively for these stock components, which then must be subtracted from the average weights in the relevant autumn assessment in order to obtain an estimate of the mean weight on 1 August.

As described earlier, estimates of the "true" abundance of capelin at the 1-group stage are not available. In order to demonstrate variations in the availability of 1-group capelin to predators, their biomass has been computed from the back-calculated abundance of 2-group capelin in the year before, assuming the same natural mortality rate as that used for the older parts of the stock. However, this part of the stock has been registered during surveys of stock abundance in August, October/November and, sometimes, also in January/February of the past decade or so. The annual changes in mean weights of the 1-group at these times of the year are, therefore, quite well known.

The numbers of capelin, calculated in this way and divided on age groups and maturity stage, are given in Tables 15.6 and 15.7 for 1 August 1978–1992 and for 1 January 1979–1993, respectively. Corresponding biomass estimates are given in Tables 15.8 and 15.9.

15.6.3. The remaining spawning stock

Having a reliable stock abundance estimate and records of catches in weight and number to work from, one may proceed to calculate the amount of capelin which remained to spawn each season. For each age group we use Pope's (1972) formula as given in section 15.6.1. As before, we only need to multiply the number of capelin in each age group by the average weight in order to obtain an estimate of biomass.

Apart from the winters of 1986, 1988 and 1993, estimates of adult stock abundance have been obtained annually in January/February in the 1979–1993 period and used in calculations of the remaining spawning stock in number and biomass. In the three exceptional cases, the calculations are based on estimates from late autumn (October/November) of the year before and on mean

Table 15.7. The calculated number (billions) of capelin on 1 January 1979–1993 by age and maturity. The total number (billions) and weight (thous. tonnes) of the immature and maturing (fishable) stock components and the remaining spawning stock (sp.st.) by number and weight are also given.

Age/maturity	*Year* 1979	1980	1981	1982	1983	1984	1985	1986
2 juvenile	137.6	50.6	55.3	41.2	123.7	105.0	211.6	83.2
3 immature	12.8	13.8	3.5	3.0	12.6	35.7	34.3	83.9
3 mature	51.8	53.4	16.3	8.0	14.3	39.8	25.2	34.5
4 mature	14.8	3.6	4.9	0.5	2.0	7.6	15.6	10.5
5 mature	0.3	0.2	+	+	+	0.1	0.3	0.2
Number immat.	150.9	64.4	58.8	44.2	136.3	140.7	245.9	167.1
Number mature	65.6	57.2	21.2	8.5	16.3	47.5	41.1	45.2
Weight immat.	1,028	502	527	292	685	984	1,467	1,414
Weight mature	1,358	980	471	171	315	966	913	1,059
Number sp.st.	29.0	17.5	7.7	6.8	13.5	21.6	20.7	19.6
Weight sp.st.	600	300	170	140	260	440	460	460

Age/maturity	*Year* 1987	1988	1989	1990	1991	1992	1993
2 juvenile	131.9	120.5	67.8	53.9	98.9	124.8*	–
3 immature	25.6	31.2	20.1	8.6	8.6	8.1	–
3 mature	22.1	34.1	48.8	31.2	22.3	54.8	46.5
4 mature	37.0	11.7	16.0	12.1	4.5	5.3	3.5
5 mature	0.2	+	0.3	+	+	+	+
Number immat.	157.5	151.3	87.9	62.5	107.5	132.9*	–
Number mature	59.1	45.8	64.8	43.3	26.8	60.1	50.0
Weight immat.	1,003	1,083	434	291	501	695*	–
Weight mature	1,355	993	1,298	904	544	1,106	1,017
Number sp.st.	18.3	18.5	22.0	5.5	16.3	25.8	23.6
Weight sp.st.	420	400	440	115	330	475	499

* Preliminary

weights in the catch during January/February in the following year. As explained in section 15.4.2, the most reliable stock abundance estimates are obtained in winter. Furthermore, the short time that elapses between the winter estimates until spawning, minimizes errors resulting from variations in mortality, other than those due to the fishery. Therefore, the estimated abundance of capelin remaining to spawn each year, which is given in number and biomass by age in Table 15.10, should be relatively accurate.

It is known, however, that among the spawners there is an extra increase in weight during the period immediately preceding the spawning process. This increment is difficult to quantify since ripe fish tend to lose some of their gonad contents in the sampling process. Therefore, the weight used when calculating the remaining spawning stock, is that read from the winter assessments some 3–5 weeks before spawning, and in such cases when no winter assessment were available, from mean weights in catches sampled in January and the first half of February. In consequence, the calculated remaining spawning stock abundance is systematically underestimated by a small margin (<5%).

15.6.4. Discussion of changes in stock abundance

In the past 15 fishing seasons, 1978/79–1992/93, during which comparable and accurate assessments of capelin abundance have been obtained, we have observed large variations in year class size. Because of the very short life span of the capelin, these variations are, naturally, reflected in adult stock biomass which in all cases but one has been determined to a very large degree by the size of the recruiting year class (2-group) as shown in Figure 15.9. The exception is the 1986/

Table 15.8. The calculated biomass of capelin (thous. tonnes) by age and maturity before the beginning of the fishery on 1 August 1978–1992. Based on projections from autumn and winter acoustic abundance estimates of stock in numbers, catches and a monthly natural mortality rate of M = 0.035.

	Year							
Age/maturity	*1978*	*1979*	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*
1 juvenile	639	235	257	192	501	500	908	377
2 immature	151	102	41	36	149	382	435	981
2 mature	1,428	1,267	668	678	251	770	572	891
3 mature	709	208	264	65	56	212	688	614
4 mature	10	7	+	+	+	3	10	12
Total immature . . .	790	337	298	228	650	882	1343	1,358
Total mature	2,147	1,482	932	743	307	985	1,270	1,417

	Year						
Age/maturity	*1986*	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*
1 juvenile	518	431	210	218	471	758*	–
2 immature	294	401	259	89	91	85	231*
2 mature	573	1042	970	685	514	983	1,004
3 mature	1,523	495	548	387	166	163	132
4 mature	20	3	10	+	+	+	+
Total immature . . .	812	832	469	307	562	843*	–
Total mature	2,116	1,540	1,528	1,072	680	1,146	1,136

* Preliminary

Table 15.9. The calculated biomass of capelin (thous. tonnes) on 1 January 1979–1993 by age and maturity. Based on projections from autumn and winter acoustic abundance estimates of stock in numbers, catches and a monthly natural mortality rate of M = 0.035.

	Year							
Age/maturity	*1979*	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*
2 juvenile	841	314	476	254	535	595	1045	499
3 immature	187	188	51	38	150	389	422	915
3 mature	989	897	337	157	265	768	481	773
4 mature	361	83	134	14	50	196	424	286
5 mature	8	5	+	+	+	2	8	6
Weight immature .	1,028	502	527	292	685	984	1,467	1,414
Weight mature . . .	1,358	980	471	171	315	966	913	1,059

	Year						
Age/maturity	*1987*	*1988*	*1989*	*1990*	*1991*	*1992*	*1993*
2 juvenile	693	649	225	207	398	587*	–
3 immature	310	434	209	84	103	108	181*
3 mature	424	668	908	580	432	981	914
4 mature	925	325	382	3324	112	125	103
5 mature	6	+	8	+	+	+	+
Weight immature .	1,003	1,083	434	291	501	695*	–
Weight mature . . .	1,355	993	1,298	904	544	1,106	1,017

* Preliminary

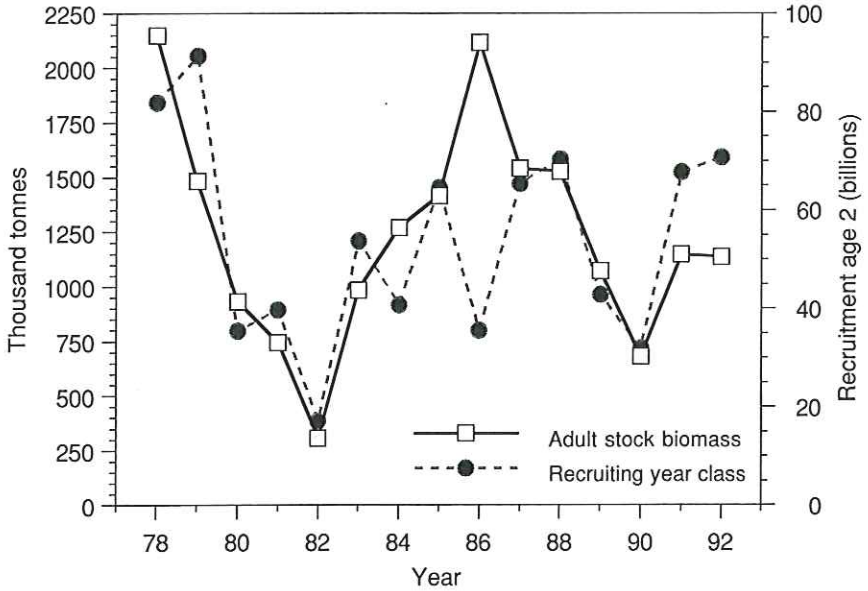

Figure 15.9. The relationship between the biomass of adult capelin and the size of the recruiting year class (2-group) by number in the years 1978–1992.

87 season, when the very large 1983 year class was still responsible for about 60 percent of the maturing fishable stock by numbers and almost 70 percent by weight.

In the period referred to, considerable changes have been recorded in that part of the North Atlantic occupied by this capelin stock, in particular in the shelf area off North Iceland and the southern part of the Iceland Sea. As described in earlier sections, these environmental changes have had great influence on distribution and migration patterns as well as the growth of the capelin. Thus, deviations in weight at age have been considerable, or in the order of 15% above or 10% below the 1980–1991 mean, for both mature and immature capelin. The annual changes in feeding conditions alone may, therefore, cause considerable variations in the stock biomass of 2-group and older capelin.

Environmental changes, especially in the north Icelandic area, may also be the cause of the large variations observed in the abundance of individual year classes by number. Thus, there is no apparent relationship between numbers of 0-group capelin in mid-summer and the abundance of the same year classes as measured later in their life (cf. section 15.1). Furthermore, there is a highly significant correlation ($R^2 = 0.73$, $P = 0.01$) between the measured abundance of 1-group capelin in autumn and the abundance of 2-group capelin one year later. This indicates that the final year class abundance is determined by environmental variables in the North Icelandic area, during the fall, winter and spring transition period, between the 0- and 1-group stage which is spent in these waters.

Unfortunately, the available data are not detailed enough for a more exact determination of the critical time in the life of the Icelandic capelin when the size of a year class is finally established. As could be expected, Pálsson's (1974) study of the diet of 50 mm 0-group capelin indicated that capelin larvae take mostly the smaller copepod species, such as *Oithona* and *Acartia* as well as juvenile copepods. The 0-group capelin add little to their size until the following summer, and in the meantime they must depend on small food items in the plankton. It is unlikely that quantitative measurements of the total zooplankton volume correlate with the mid-summer abundance of 1-group capelin. The reason may simply be that volumetric measurements of the overall zooplankton abundance mainly reflect variations in the biomass of the larger species and not in that of the smaller members of the planktonic community. Although the life cycles of most of the relevant zooplankton communities are fairly well known, inter-annual changes in the timing of zooplankton production have not been monitored as a matter of routine. Such studies are very time consuming and costly but will be necessary to answer questions pertaining to the variable survival rates of cohorts of other species which are dependent upon zooplankton communities for their success.

As described in detail in chapters 16 and 17, the stock has also been heavily fished in the period 1978/79–1992/93. This is reflected in the remaining spawning stock abundance which has varied between about 100,000 and 600,000 tonnes in 1979–1993 as stated in the previous section (cf. Table 15.10). Therefore, the task at hand is to try to determine the relative role of man and nature in governing these variations in the capelin abundance.

Figure 15.10 shows the biomass of capelin remaining to spawn in the spring of 1979–1992 and the resulting year class abundance as 2-group recruits by number (cf. Tables 17.1 and 17.2). From this comparison it is evident that the small spawning stocks, left by the fishery in 1981 and 1982, yielded the fairly large year classes responsible for the quick recovery of the stock in the 1983/84 and 1984/85 seasons. Furthermore, in spite of the available evidence pointing to a very low remaining spawning stock in 1989, that year class has turned out to be of a good average size. Conversely, low abundance year classes have resulted from large spawning stocks, *e.g.* in 1979 and 1988.

In section 15.1 it was explained how the number of 0-group capelin appears to be related to parent stock biomass, and as stated above there is no apparent relationship between the number of 0-group capelin and the final year class size as calculated from acoustic estimates of adult stock abundance. The conclusion must therefore be that the adult capelin stock abundance, specifically in the 1978/79–1992/93 period, has first and foremost been determined by natural events and has not been influenced to a measurable degree by the large-scale fishery.

It is well known that the abundance of pelagic fish stocks, which generally are plankton feeders and, therefore, near the beginning of the food chain in the oceans, tends to fluctuate greatly due to rapid changes in feeding conditions resulting in extreme variations in year class size. As expected, this is especially true of short lived species such as capelin.

Recently, Jakobsson (1992) reviewed the variability of some exploited fish stocks in relation to climatic changes in the North Atlantic. This review included a number of both pelagic and demersal stocks which in the past decades have been under varying stress, both from the fishery and natural causes. However, from his many and varied examples Jakobsson concluded that when, and only when, enough spawning products were at hand, had nature been able to remedy damages, no matter whether caused by itself or by man. Thus, the small spawning stocks of capelin in 1981, 1982 and 1989 could well have resulted in reduced recruitment or recruitment failure under

Table 15.10. The remaining spawning stock by number (billions) and weight (thous. tonnes) by age in the years 1979–1993. Numbers are in billions and weight in thousand tonnes.

	Age 3		*Age 4*		*Age 5*		*Total*	
Year	*N*	*W*	*N*	*W*	*N*	*W*	*N*	*W*
1979	22.9	463	5.3	132	0.2	5	30.2	600
1980	16.6	252	2.0	48	+	+	18.6	300
1981	5.7	120	1.8	50	+	+	7.5	170
1982	7.2	129	0.4	11	–	–	11.5	140
1983	11.8	218	1.7	42	–	–	13.5	260
1984	17.7	341	3.8	99	+	+	21.5	440
1985	13.5	258	7.4	200	0.1	2	21.0	460
1986	14.0	302	5.6	153	0.2	5	19.8	460
1987	7.1	136	11.3	281	0.1	3	18.5	420
1988	14.6	291	3.9	109	–	–	18.5	400
1989	18.6	310	5.5	130	–	–	24.1	440
1990*	3.9	72	1.6	42	+	1	5.5	115
1991	12.9	260	2.5	70	–	–	15.4	330
1992	23.7	425	2.1	50	–	–	25.8	475
1993	21.9	430	2.5	70	–	–	24.4	500

* Assessment suspect due to weather and fish behaviour

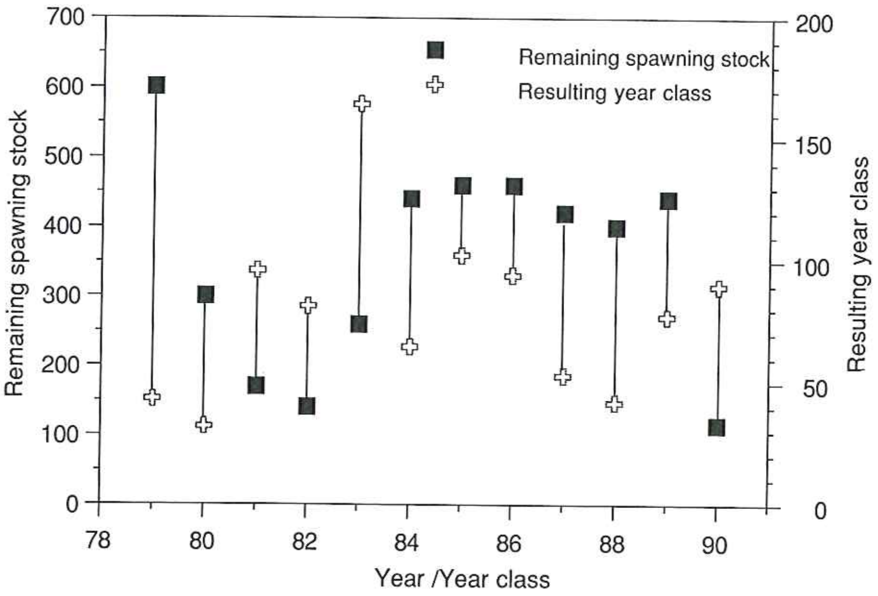

Figure 15.10. The relationship between the biomass of capelin, remaining to spawn in the years 1979–1989, and the resulting year class abundance by number at age 2.

other natural conditions, or that still larger year classes would have been produced if more capelin had been allowed to spawn under the same natural conditions.

It must be pointed out that in the case of the Icelandic capelin stock, the period of observations is relatively short in biological terms, and the findings, however well defined, should therefore not lead us to the fallacy of drawing any final conclusions. From the above data and discussion, this author only allows himself to conclude that while the year class abundance in the Icelandic capelin stock is by and large determined by environmental conditions during the first winter and spring of its life, the feeding conditions in the following year may also play a significant role in some cases. Furthermore, the lack of evidence of a tangible relationship between spawning stock biomass and recruitment in the Icelandic capelin stock, does not preclude the existence of such a relationship in other circumstances than those which we have experienced in the known past. In the long run it can, therefore, not be considered a safe practice to fish the spawning stock down to the very low levels of 1981, 1982 and 1988.

16. THE FISHERY

As mentioned in an earlier section, it used to be customary in some Icelandic communities to collect capelin stranded on the beach in the spawning season. This was reported from Eyjafjörður on the central north coast as early as 1757 by Ólafsson (1772), who also stated that in no other Icelandic locality was capelin used for human consumption at the time. But this was to change, and in the 19th century capelin was collected for human consumption as well as for animal feed elsewhere, both on the north coast and in the south of Iceland (Kristjánsson 1980, 1985).

Directed fishing for capelin does not, however, have a long history in Iceland. Kristjánsson (1985) states that in 1896 capelin were taken with scoops in Hafnir on the Reykjanes peninsula for use as bait. As far as can be ascertained, a small beach-seine fishery was conducted in fjords on the north coast around the turn of the century (K. Jónsson, personal communication). This fishery was dependent upon local and variable spring spawning capelin migrations and, consequently, was somewhat sporadic. The main purpose was to obtain bait for the longline or handline fishing of cod. Similarly, capelin seem to have been taken for this purpose on the east coast when available by the same or similar means (Sæmundsson 1899).

Elsewhere, beach-seining for capelin as bait was generally not practiced in Iceland until later. Thus, a bait fishery of capelin was begun at Hornafjörður on the southeast coast in the early 1920s (Steinsson 1944) and soon became common practice in that area. At Southwest Iceland, however, the use of capelin as bait did not become commonplace until in the late 1930s (Jakobsson 1969), the fish being taken by fishing vessels in small scoops and seines as well as from the beach. The catch taken in the bait fishery never amounted to more than a few hundred tonnes per year.

In the 1950s, technical innovations in fish finding equipment and the seining of schooling pelagic species soon resulted in the extension of the Icelandic herring season and huge increases in catches. The new fish finding techniques also made it possible to obtain a rough idea of fish abundance and availability, and it was soon realized that capelin could be caught in large amounts during the spawning season.

16.1. The winter season

In the winter of 1958 the Technical Laboratory of the Icelandic Fisheries Association initiated an experimental capelin fishery for the production of meal and oil. The main purpose was to determine what sort of raw material the capelin were and whether the existing reduction factories could handle this raw material in a satisfactory fashion. On the whole, the results were considered promising and indicated that a fishery could be started with certain reforms and adjustments of the existing processing plants (Thorbjarnarson 1961).

Nevertheless, it was not until the mid-1960s that an Icelandic capelin fishery for the production of meal and oil was started (Fig. 16.1). This was a purse seine fishery conducted by the local herring fleet outside the traditional herring season. Details of this fishery are given in the annual reports of the Icelandic Capelin Board (Anon. 1973, 1974, 1976a, 1977, 1979b, 1980a, 1981a, 1982b; Jónasson 1985–1993) the Icelandic fisheries bulletin Ægir (Jónasson 1991, 1992) as well as in reports of the Atlanto-Scandian Herring and Capelin Working Group of ICES (Anon. 1982–1993). The outline of the developments of this fishery in the 1964–1983 period, given by Vilhjálmsson (1983), will be reproduced below and brought up to date. Catches in weight by years, seasons and participating fleets in the period 1964–1993 are given in Table 16.1. Catches in numbers by age and season in 1978–1993 are given in Appendix II.3, Tables XVII–XVIII and by months in Table XIX.

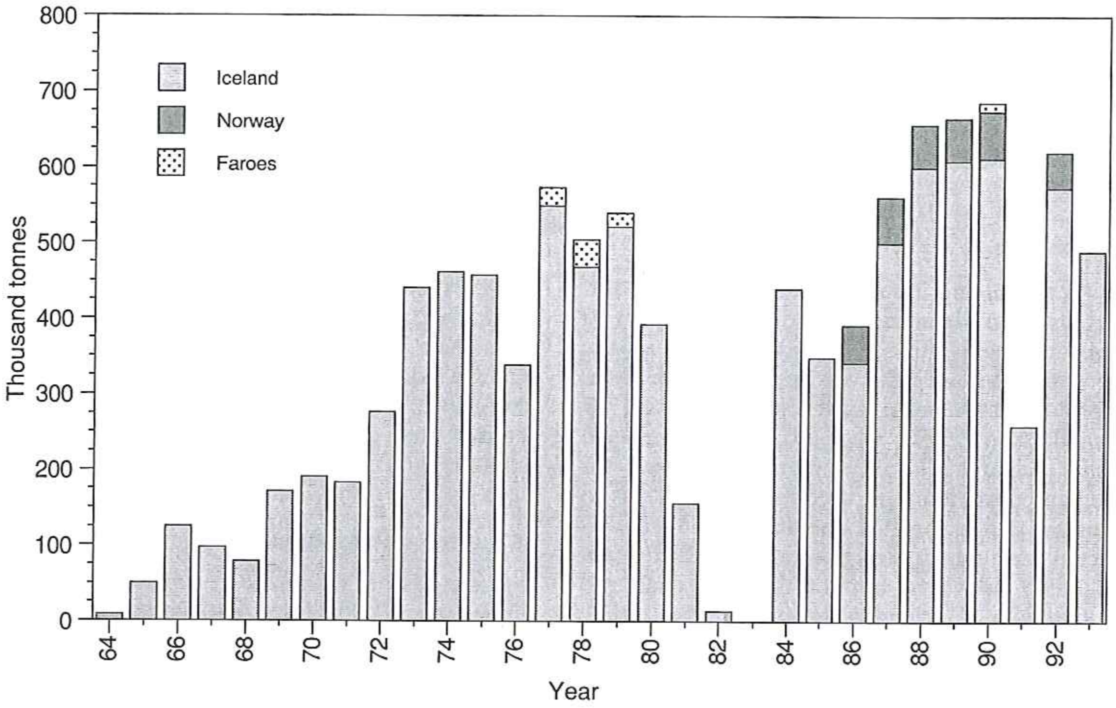

Figure 16.1. The total international catch of capelin in the winter seasons of 1964–1993.

The Icelandic winter fishery of pre-spawning and spawning capelin started in a modest way in 1964 when a few herring seiners landed 8.6 thousand tonnes for reduction. In view of the limited participation, this small beginning was, however, considered a success and aroused considerable interest. In 1965 the number of participating vessels was, therefore, much larger, and the catch increased to almost 50 thous. tonnes.

In the beginning, the winter capelin fishery did not start until late February, and consequently took place off the western part of the south coast and southwest of Iceland only. However, with the depletion of the Atlanto-Scandian herring stocks in the 1960s and the later decimation of the North Sea herring stocks, the Icelandic capelin fishery gained momentum and importance. It became customary for the fleet to go out as soon as the first spawning migration was located off the eastern south coast, and by 1969 almost all the Icelandic herring fleet had become involved in the winter capelin fishery. This, together with the earlier start of the season, resulted in the total catch reaching 170 thous. tonnes in 1969.

In the 1970 and 1971 seasons the catch amounted to 190,000 and 198,000 tonnes, respectively. The duration of the coastal phase of the winter capelin season is largely determined by the time difference between the arrival of the first and last spawning migrations, since each migration usually spends only 3–4 weeks in the warm coastal waters before the capelin spawn and die. The very early appearance of the first spawning migration in 1972, together with an obviously large spawning stock that arrived on the south coast grounds over an unusually long period of time, resulted in a record catch of 276,500 tonnes in the 1972 season. By then it had become clear that in the short winter season, the shore-based processing facilities were a limiting factor. Therefore, if no arrangements were made to induce the transport of capelin to factories outside the immediate vicinity of the fishing area, the total capelin catch would probably range between 200,000 and 300,000 tonnes at most.

Before the 1973 winter season a coordinating body, the Capelin Board, was established in order to synchronize fishing and production. This was mainly accomplished by dividing the fishing grounds into several price zones and allocating higher prices for longer trips. Funds for this purpose were contributed by the fishery as well as the industry in proportion to catches and production. The total catch in the 1973 season amounted to 440,000 tonnes, an increase of more than 100 percent, as compared to the average for the previous three years. Although the season started this year in deep waters off Southeast Iceland already in the fourth week of January and lasted into April, there is no doubt that the operations of the Capelin Board were responsible for a major part of this large increase.

By the late 1970s the increased size of the capelin boats and radical changes in the fishery, which will be described below, had reduced the need for a central authority for directing landings of the catch. In 1979 the prize zone system was discontinued, and from then on the Capelin Board functioned as an information centre for available landing spaces and waiting time in the various ports where the factories were located. With the ever increasing size of the vessels fishing for capelin and the continuing reduction in their numbers (from 136 vessels with a carrying capacity between 250 and 350 tonnes in 1974, to 45 vessels, each capable of carrying from 600 to 1600 tonnes in 1990), the need for such an information service diminished greatly. The Capelin Board was, therefore, disbanded in 1990, and its role of keeping catch statistics taken over by the Ministry of Fisheries.

As described in an earlier section, a scouting survey located the 1969 spawning migration in deep waters east of Iceland in late January. At the time, the capelin were assembled in large, dense schools that came close to the surface at night and would have been readily available for purse seining. A report to this effect (Jakobsson and Vilhjálmsson 1970) attracted much attention, and in 1970 practically all of the Icelandic capelin fleet headed for this area in January, following the location of the migration off the northern east coast by a research vessel in the middle of the month. However, the capelin soon dispersed and did not reassemble until they arrived in the warmer waters at the southeast coast about five weeks later. Practically no catches were taken in the intervening period.

After this dismal experience, the capelin skippers were understandably reluctant to repeat the experiment in the following years. The next attempt to catch capelin off East Iceland in winter was, therefore, not made until 1973 when the season started while the capelin were still located off the southern east coast. This time the offshore fishery was successful, and since then the winter season has begun in January, except when stock abundance has made it necessary to impose catch restrictions. Such restrictions were imposed to a varying degree in the winter seasons of 1980–1986 as well as in 1991. The relatively low winter catch in 1976 was, on the other hand, due to a strike by the fishing fleet over a price dispute (Figure 16.1).

The winter fishery of capelin takes place exclusively within the Icelandic economic zone and is conducted by vessels using purse seines. For a while in the early 1970s several skippers also experimented fishing for capelin with pelagic trawls. The main purpose was to investigate whether capelin could be fished by this gear when schooling below the range of capelin seines or when the fish were distributed in concentrations too scattered for seining. Although it proved possible to oblain good catches by pelagic trawling, it soon became obvious that the prerequisite for high density was much the same with regard to trawling as for seining. This is not surprising, since in both cases the catch was sold for the same low-price product and, therefore, had to be obtained quickly and in large quantities. Furthermore, periods when capelin were not available to the seiners became progressively shorter with increasing size and depth of that type of fishing gear, and it became ever more obvious that the two types of gear were difficult or even impossible to operate in the same area. The trawl lost out in this competition, being much more cumbersome to handle, and in addition the trawler skippers had to give the right of way to the stationary purse seiners.

As shown in Figure 16.1, the winter fishery has always been predominently Icelandic. However, in the period 1977–1979 Faroese vessels were allocated small quotas in this fishery as part of an agreement between the two countries on Faroese fishing in Icelandic waters. Similarly, from 1986 onward, Norway obtained the right to fish capelin off North and East Iceland in January – February as part of a bilateral Icelandic-Norwegian agreement on the utilization and quota sharing of capelin in the Iceland – Greenland – Jan Mayen area. In 1989 Greenland became part of the above agreement, and in the winter of 1990, Faroese vessels, operating on Greenlandic licence, were again allowed to fish capelin off East Iceland.

Apart from the initial 1970 experiment, the winter fishery of capelin in offshore areas east and northeast of Iceland has generally been successful when catch restrictions have not been in force. Using the modern type large seines, designed for the summer and autumn fishery, catches in January alone have ranged between 133,000 and 210,000 tonnes in the 1987–1990 period. But even so, the failure of the initial 1970 experiment when capelin were too sparsely distributed and below the range of purse seining, is not, however, an isolated case. Only 65,000 tonnes were caught in January 1992, and the results would, for the same reasons, probably have been even more disappointing if fishing had been allowed in January 1991. In the latter case, however, capelin abundance was much lower. Furthermore, the capelin were very dispersed during their southward migration through the deeper offshore area east of Iceland in the winter of 1993. It was mainly for this reason that the winter 1993 fishery could not begin until the first spawning migration reached the relatively shallow area some 30–50 naut. miles off the southeast coast.

16.2. The summer and autumn fishery

In the 1960s extensive acoustic surveys were conducted in the area between Iceland, Greenland and Jan Mayen in order to locate feeding migrations of the Atlanto-Scandian herring. During these surveys, research and fishing vessels often located large concentrations of capelin in deep waters north of Iceland as well as southwest of Jan Mayen (Jakobsson 1978, 1980). In August and September 1969 the Marine Research Institute chartered a 250 GRT herring/capelin boat for studying capelin distribution and behaviour in these waters and conducting experimental fishing with a purse seine. While considerable concentrations of capelin were located 80–120 naut. miles north of the Vestfirðir peninsula and the western north coast of Iceland, catches were generally small and only amounted to a few hundred tonnes in all. In retrospect, the main reason was that most of the schools were located at depths exceeding 15–20 m below the surface. At the time, conventional capelin seines were so shallow that they could only fish schools that were practically at the surface, such as frequently is the case in the coastal winter fishery.

A summer capelin fishery was not attempted again until 1975. In that year three capelin boats and a research vessel again tried to locate and fish capelin off the western north coast of Iceland (Jakobsson 1976). By then considerable developments had taken place in the Icelandic capelin fleet. Larger vessels were being commissioned, and due to the oceanic winter fishery off North and East Iceland in January and February, which by then was well established, the purse seines had become both larger and deeper. Nevertheless, this attempt failed. There was much drift ice off the Vestfirðir peninsula as well as the western north coast of Iceland in July and August of 1975. The only concentrations available to seining were located in the western Húnaflói Deep but consisted of juvenile 1-group capelin and only a few loads were taken.

Continued scouting by a research vessel in September 1975 recorded only scattered capelin north of the Vestfirðir peninsula and the western north coast of Iceland. And it was not until in October – November 1975 that fishable concentrations were located during a short survey some 120–140 naut. miles north and northeast of Vestfirðir. However, winter storms had by then set in, and fishing on these concentrations was never attempted.

Due to the unusually difficult ice conditions, the 1975 experiment was regarded inconclusive, and it was decided that another attempt should be made in 1976 (Vilhjálmsson 1976, 1977). In order to secure conclusive results as far as possible, the Icelandic Ministry of Fisheries chartered four commercial capelin boats, selected on the basis of their size, equipment and previous performance, to work with a research vessel in the period from late June to August. Roughly, the financial arrangement was that the Ministry of Fisheries would pay the difference between the value of the catch and the cost of the operation.

The research vessel began scouting for capelin off the Vestfirðir peninsula on 23 June 1976 and quickly located fishable concentrations at the ice edge north of the peninsula. However, when the first two fishing boats arrived about one week later, the drift ice was in the process of closing this area. On the other hand, search farther to the east and northeast soon revealed the presence of large concentrations of adult capelin at

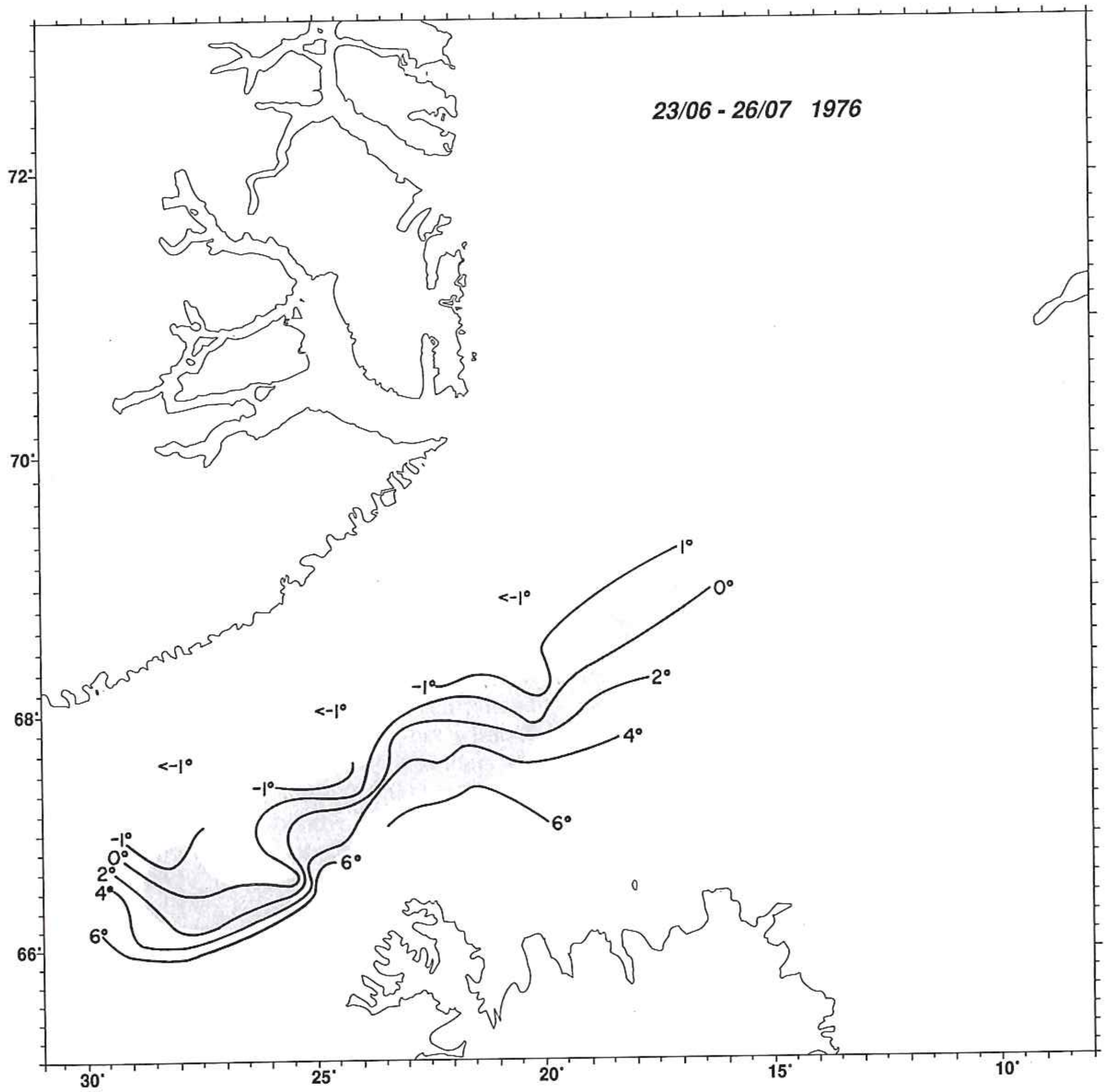

Figure 16.2. The distribution of capelin and sea temperature at 50 m depth in the June – July 1976.

about 120–130 naut. miles north of the central north coast of Iceland and fishing could begin. Further scouting failed to locate any capelin north of 69°N and east of 17°W. The distribution area of the capelin and sea temperature at 50 m depth in the period 23 June – 26 July 1976 are shown in Figure 16.2.

By mid-July the charter vessels had taken several individual loads of 500–1300 tonnes each, and the first capelin fishing boats began to arrive. Around that time, the capelin began a slow migration to the southwest, and in the latter half of July and in August the fishery mainly took place at or just off the shelf edge to the north and northwest of the Vestfirðir peninsula.

In September most of the boats left the capelin grounds to fish for herring in the North Sea area, and at the end of the month only 5 vessels remained fishing for capelin off the Vestfirðir peninsula. The distribution of capelin and sea temperature were then as shown in Figure 16.3. In October and November the capelin assembled in large, dense schools in the central area of the Iceland-Greenland Ridge, mainly between

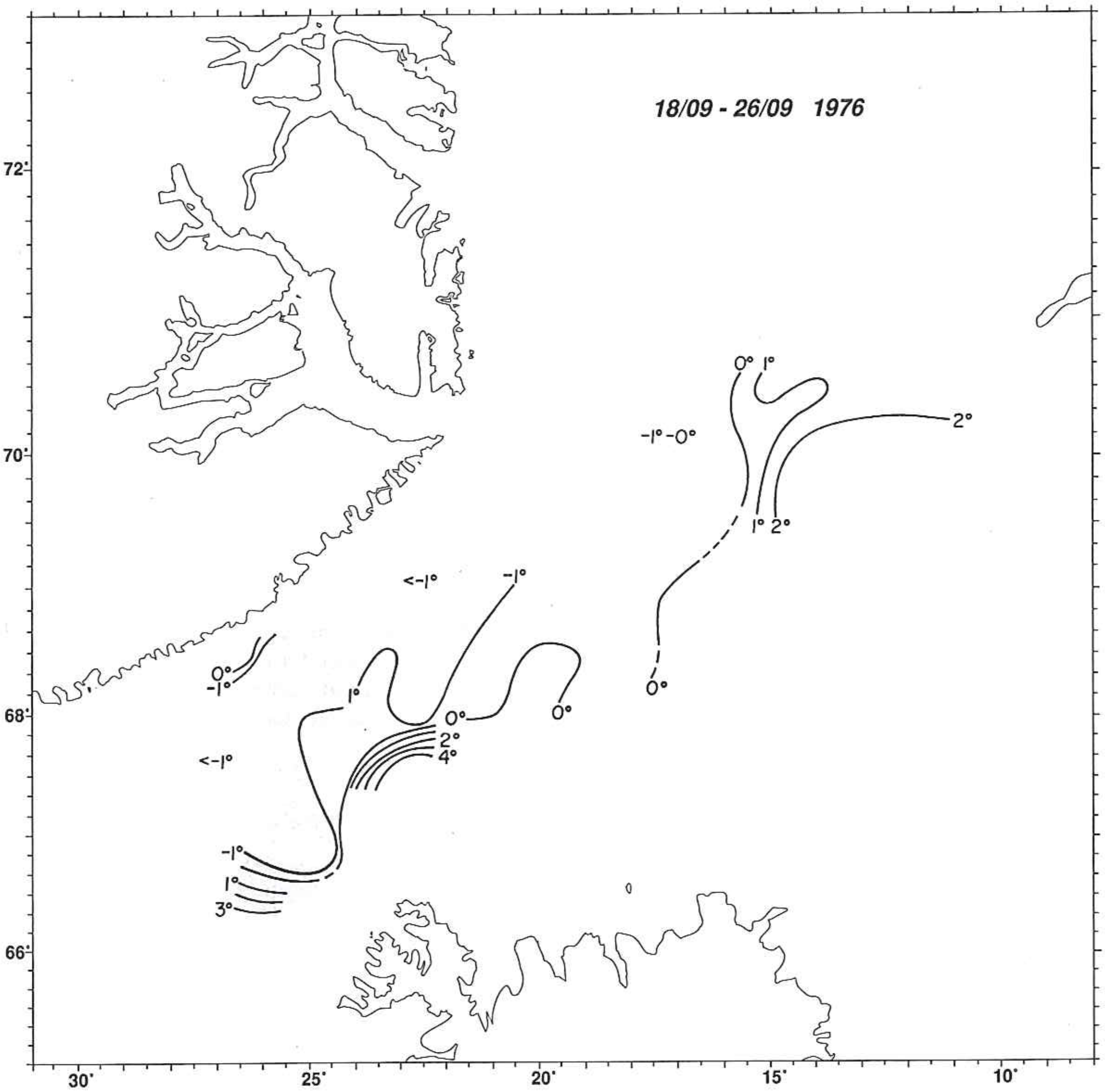

Figure 16.3. The distribution of capelin and sea temperature at 20 m depth in September 1976.

66°15′N and 67°00′N, where good catches were consistently taken by the remaining boats.

In late October and November the number of fishing boats increased again and catch rates remained reasonably high when weather permitted fishing operations. Altogether, 29 boats took part in this first summer capelin fishing season in the oceanic area between Iceland, Greenland and Jan Mayen, which continued until 20 December. Because of their relatively shallow, coastal type capelin seines, some of the vessels, however, did not do very well. Nevertheless, the fishery was on the whole profitable, and the Ministry of Fisheries never had to compensate the four charter vessels that were engaged to start the fishery. The total catch in the period July – December 1976 amounted to 114,400 tonnes (Fig. 16.4).

In view of the success of the Icelandic summer fishery in 1976 and the existence of occasional reports of capelin in the area west of Jan Mayen in the 1960s, a vessel, chartered by the Norwegian Directorate of Fisheries, as well as a number of Norwegian capelin boats on their way home from

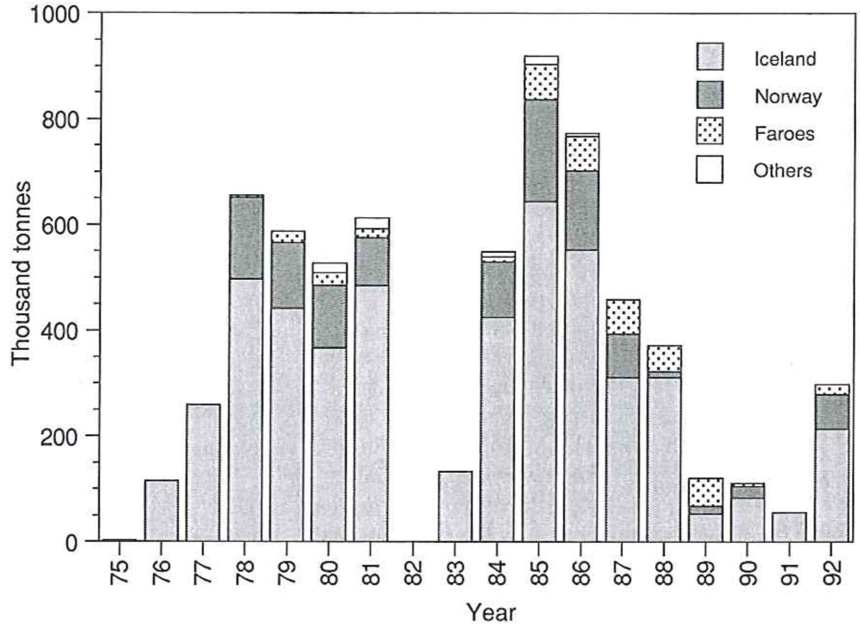

Figure 16.4. The total international catch of capelin in the summer/autumn season of 1975–1992.

a fishery on the banks off Newfoundland and Labrador, searched for capelin in the central and northern Iceland Sea in July 1977, but without success (Sangolt 1977). In 1977 the Icelanders, on the other hand, caught about 260,000 tonnes of capelin in deep waters off the Vestfirðir peninsula and off the western north coast of Iceland, south of 68°30′N, from mid-July until the end of the year.

In the following year, the central and northern Iceland Sea was again searched by chartered Norwegian fishing vessels, this time in August and September (Nilsen 1978). This scouting effort revealed the presence of capelin to the west and northwest of Jan Mayen around mid-August, where a Norwegian fishery soon began. Figure 16.5 shows the Norwegian fishing areas in late August and in September 1978 together with the length and age distribution of the capelin. In the weeks that followed, these capelin slowly migrated to the northwest and north of the island. Good catches were made fairly constantly in the area, until in the latter half of September when the capelin scattered before beginning their return migration back south towards Iceland. In September the Norwegians were joined by Icelandic as well as some Faroese vessels in the Jan Mayen area, where these parties took a total catch of 210,000 tonnes in the summer of 1978. The total catch of the season was 650 thous. tonnes (Fig. 16.4).

In the following period, 1979–1987, Norwegian, Faroese and for a while some Danish vessels conducted a successful capelin fishery in the area between Jan Mayen and Greenland in the months of July – September. Exceptions were the years of 1982 and 1983 when a fishing ban had to be imposed due to low stock abundance. The Icelanders, on the other hand, mainly fished within their own economic zone, and although Icelandic fishing vessels occasionally visited the Jan Mayen area, their landings from that fishery were insignificant in comparison to their total catch of capelin (Fig. 16.4).

As mentioned in an earlier section, the capelin had an exceptionally westerly distribution in 1988, and practically no capelin could be located in the Jan Mayen zone. Since Norwegian vessels were not allowed to fish west of the equi-distance line between Jan Mayen and Greenland, their 1988 summer fishery was a failure yielding only a catch of 11,500 tonnes. The same is in part true for the Icelandic summer and autumn fishery in 1988. Until late October the fishable stock remained almost entirely within the Greenlandic exclusive economic zone and, thus, was also out of bounds with respect to the Icelandic capelin fleet. In consequence, over 90% of the Icelandic

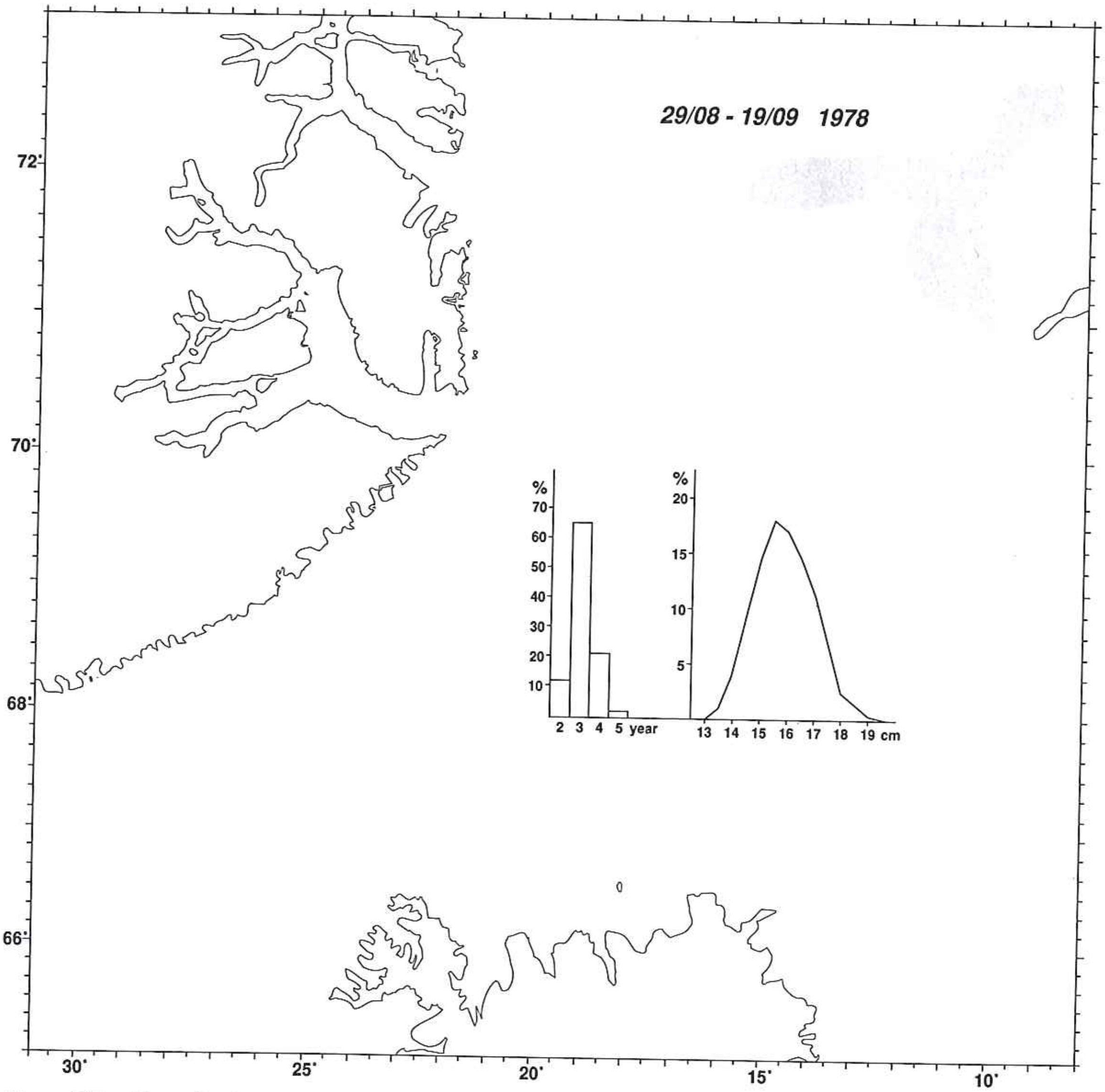

Figure 16.5. Norwegian fishing areas in August and September 1978 and the size and age distribution of capelin in the catch. (After Nilsen 1978).

catch of 311,400 tonnes in the 1988 summer/autumn season was taken in November and December. About ten Faroese vessels, operating on Greenlandic licence, had, on the other hand, a fairly successful season with a total catch of 48,500 tonnes in the summer and autumn of 1988.

On the basis of the high abundance of 1-group capelin, recorded in the 1988 August survey, the fishable stock of the 1989/90 season was expected to be abundant. Prior to the beginning of the summer fishery, an agreement had been reached between Greenland, Iceland and Norway on fishing rights of these nations anywhere in the capelin distribution area within limits set by catch quotas. Furthermore, for protecting the juvenile part of the stock it was agreed that large parts of the shelf area off North and Northeast Iceland should remain closed to the summer and autumn fishery. In spite of this, the summer/autumn fishery of 1990 was an even more dismal failure than that of the previous year (Fig. 16.4). There was extensive drift ice in the area between Iceland and Greenland as well as in the southern Iceland Sea. Practically no capelin could be located in open waters until December, probably because they did not, as in 1988, migrate to feed in the central and northern Iceland Sea in the summer of 1989. Apart from 1982 and 1983, when all fishing of capelin was banned, the catch in the summer/autumn 1989 season is the lowest on record for this phase of the fishery, since it was begun in the 1970s. However, when the spawning migration had reached the area off Northeast and East Iceland in early January, catch rates improved greatly and continued at a high level until the end of the winter season in March 1990 (cf. Appendix II.3, Table XIX).

The summer and autumn fishery was also a failure in 1990 (Fig. 16.4). In late July, scouting by Norwegian fishing vessels located commercial concentrations in a small area some 110 nautical miles north of Melrakkaslétta (NE-Iceland), where Norwegian and Faroese vessels took about 22,000 and 2,700 tonnes respectively in the first half of August. Extensive scouting by a Norwegian research vessel in the area south of 72°N, did not reveal any capelin concentrations north of 68°30′N. And on 11 August Norwegian and Faroese fishing operations ceased since no further capelin concentrations could be located. Due to the Norwegian and Faroese experience, the Icelandic fleet did not begin fishing for capelin until October 1990. However, catch rates were low and the fishable stock was mixed with juveniles. This resulted in the area off the western north coast of Iceland soon being closed to the fishery. The total international catch in the 1990 summer and autumn season amounted to only 111,200 tonnes when all fishing was temporarily suspended in late December on account of low acoustic stock abundance estimates. The fishery was not opened again until after repeated acoustic assessments of stock abundance in January and early February 1991, when the total allowable catch for the whole of the 1990/91 season was set at 300,000 tonnes of which only 180 thous. tonnes remained to be taken.

All information available prior to the 1991 summer season, pointed to a low abundance of the fishable stock. The fishery was, therefore, not opened until late October after acoustic surveys of stock abundance had been carried out. Norwegian research vessels surveyed the central and northern Iceland Sea in August 1991 but found no capelin north of 69°N. Like in 1990, most of the fishable stock was distributed together with juveniles off the western north coast of Iceland in the period October – December. Consequently, that area was closed to capelin fishing until the end of the year, and the autumn fishery yielded only 56,000 tonnes over the two month period November – December 1991 (Fig. 16.4). In accordance with the results of the January 1992 assessment survey, the total allowable catch (TAC) for the 1991/92 season was set at 740,000 tonnes. As in the previous year, catch rates were low in January 1992 due to the scattered distribution of the capelin in the area east of Iceland. However, after the spawning migrations arrived in the shallower waters off the southeast coast in late January, catch rates improved greatly and remained high when weather permitted until mid-March. In spite of the the arrival of small migrations of late spawners at the southeast coast as well as in the Breiðafjörður area in March, catch rates dropped to practically zero around the middle of the month. The total catch of 682,000 tonnes, taken in the 1991/92 season, was thus about 60,000 tonnes short of the TAC, the main reason being the scattered distribution and low catch rates in the period October 1991 – January 1992.

In accordance with the predicted TAC of some 820,000 tonnes for the 1992/93 season and a precautionary rule of allocating no more than ⅔ for the summer and autumn fishery, a preliminary TAC of 500,000 tonnes was set for July – November 1992. The fishery started in the area some 100–120 naut. miles north of Melrakkaslétta (68°20′–68°30′N, 16°25′W). In July and the first half of August, Icelandic, Norwegian and Faroese vessels continued to fish capelin in the Iceland Sea off the eastern north coast of Iceland, gradually moving northward with the north migrating capelin. In the latter half of August this capelin retraced its former route, south to the shelf edge north of Melrakkaslétta, whereupon it turned west to mix with the rest of the maturing stock and immature capelin off the western north coast of Iceland. Like in the previous years, the fishable stock remained in an extremely scattered condition and mixed with immature capelin from September 1992 until the end of the year. For this reason, and because extensive areas were closed to the fishery due to high proportion of juveniles,

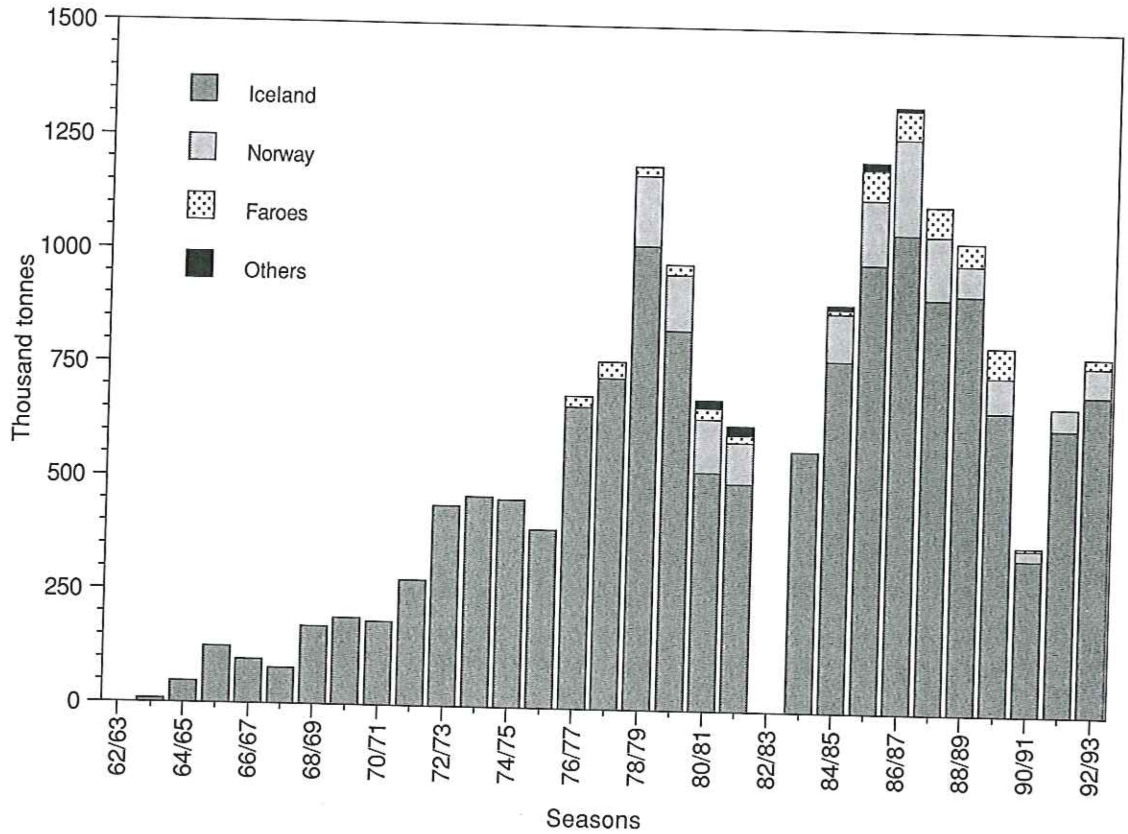

Figure 16.6. The total international catch of capelin in the fishing seasons of 1964/65–1992/93.

catch rates remained low for most of the time in this period. Therefore, the total catch during July – December 1992 amounted only to 307,000 tonnes (Fig. 16.4). Because higher mean weights were observed in the January 1993 survey than had been predicted from the October 1992 survey, the total TAC for the 1992/93 season was raised to 900,000 tonnes. However, the situation in the winter of 1993 was almost an exact replica of that of the previous year. Thus, no catches could be taken east of Iceland in January, and the winter fishery did not begin until the first part of the main spawning migration arrived in the shallower waters off Southeast Iceland. In spite of very difficult weather conditions, catch rates remained high throughout February and in the first half of March 1993. But for the same reason, catch rates fell off sharply thereafter, since calm weather is a prerequisite for effective fishing of post-spawning capelin concentrations. The winter capelin catch of 1993 amounted to 486,000 tonnes, and the total catch in the 1992/93 season thus fell about 110,000 tonnes short of the allocated TAC.

The total capelin catch by all participating fleets in the 1964/65–1992/93 seasons is shown in Figure 16.6. The details of these catch statistics are given in Table 16.1.

16.3. Discussion

In the 17 years of summer and autumn fishery for the Icelandic capelin, we have, therefore, seen very large fluctuations, where periods of large catches have alternated with periods of poor fishing. While the low in the summer/autumn fishery in the early 1980s is obviously associated with reduced capelin abundance, the failure of the summer, and also in part the autumn fishery in 1987–1990, can only in part be explained by shortage of capelin. As mentioned above, the extreme western distribution of capelin in 1987, and their failure to migrate to the central and northern Iceland Sea in 1988, placed them out of reach of both the Icelandic and Norwegian fishing fleets until late autumn. In the summer and autumn of 1989 ice prevented fishing operations between Northwest Iceland and Greenland as well as in the southern Iceland Sea much of the time. At the same time, however, stock abundance was declining and continued to do so in 1990. This, together with scattered distribution of the capelin, resulted in totally unsuitable summer and autumn fishing conditions in these two years. Since the same behaviour pattern was also observed in the period October – December 1991, and indeed in January 1992 also, it seems most likely that if a summer fishery had been attempted, it would also have failed in 1991.

As described above, part of the maturing stock started a northward feeding migration in the central Iceland Sea in 1992, only to return from that area already during the latter half of August. While remaining in the northern area, these capelin yielded good catches, but from then on the situation became similar to that of the 2–3 previous years. A description of observed variations in migration patterns and routes, and the possible reasons for these changes, are given in chapter 13. In summary, it seems that a prerequisite for a successful summer, autumn and, in part an early winter fishery also, is that a large part of the maturing, fishable stock migrates to feed in the Iceland Sea in summer. Experience shows that good catches can usually be taken in this area during the height of the feeding season. Later, when these capelin arrive in the shelf area off North and Northwest Iceland, their fat content is high and there is little need for continued feeding activity. Such capelin will therefore form dense concentrations which are easily fished. Conversely, when all or most of the maturing, fishable stock has to feed in or near the north Icelandic shelf area, there probably is a shortage

Table 16.1. The international capelin catch 1964–1993 (thous. tonnes)

	Winter season			*Summer- and autumn season*				
Year	*Iceland*	*Norway*	*Faroes*	*Iceland*	*Norway*	*Faroes*	*Others*	*Total*
1964	8.6	–	–	–	–	–	–	8.6
1965	49.7	–	–	–	–	–	–	49.7
1966	124.5	–	–	–	–	–	–	124.5
1967	97.2	–	–	–	–	–	–	97.2
1968	78.1	–	–	–	–	–	–	78.1
1969	170.6	–	–	–	–	–	–	170.6
1970	190.8	–	–	–	–	–	–	190.8
1971	182.9	–	–	–	–	–	–	182.9
1972	276.5	–	–	–	–	–	–	276.5
1973	440.9	–	–	–	–	–	–	440.9
1974	461.9	–	–	–	–	–	–	461.9
1975	457.1	–	–	3.1	–	–	–	460.2
1976	338.7	–	–	114.4	–	–	–	453.1
1977	549.2	–	24.3	259.7	–	–	–	833.2
1978	468.4	–	36.2	497.5	154.1	3.4	–	1,159.6
1979	521.7	–	18.2	442.0	124.0	22.0	–	1,127.9
1980	392.1	–	–	367.4	118.7	24.2	17.3	919.7
1981	156.0	–	–	484.6	91.4	16.2	20.8	769.0
1982	13.2	–	–	–	–	–	–	13.2
1983	–	–	–	133.4	–	–	–	133.4
1984	439.6	–	–	425.2	104.6	10.2	8.5	988.1
1985	348.5	–	–	644.8	193.0	65.9	16.0	1,268.2
1986	341.8	50.0	–	552.5	149.7	65.4	5.3	1,164.7
1987	500.6	59.9	–	311.3	82.1	65.2	–	1,019.1
1988	600.6	56.6	–	311.4	11.5	48.5	–	1,028.6
1989	609.1	56.0	–	53.9	14.4	52.7	–	786,1
1990	612.0	62.5	12.3	83.7	21.9	5.6	–	798.0
1991	258.4	–	–	56.0	–	–	–	314.4
1992	573.5	47.6	–	213.4	65.3	18.9	0.5	919.2
1993	489.1	–	–					

of food which the capelin compensates for by continued active feeding in autumn and winter. The main food category, available at that time of year, is euphausiids. This type of prey is much more active than the copepods, which are the main food item during the summertime. When feeding on euphausiids, the capelin, therefore, tend to be distributed in more scattered concentrations than would be expected when they are feeding on copepods or when they are in a condition of rest.

On the other hand, the winter fishery proper is based on schools of pre-spawning capelin after they have arrived in the shallow waters off the south and west coats of Iceland. In these waters the behaviour of the capelin is very predictable in comparison to that in the more oceanic areas, and they are in general easily fished. The success of the winter fishery depends, therefore, mainly on the number of migrations (stock abundance) and weather condition.

Due to the naturally occurring variations in year class size among the Icelandic capelin and variations in stock distribution and behaviour, caused by changes of the environment, periodic variations of stock abundance and availability of capelin to the fishery will continue to recur in future as they have in the past. As described in section 7.1.3, the spawning of capelin in a small area off the eastern part of the south coast in 1970 was associated with an obviously small spawning stock. Since 1978, acoustic assessments of capelin abundance have recorded one veritable stock collapse in the early 1980s and a large decline of capelin abundance in 1989–1991. The available information, therefore, suggests that there might be a periodicity of major variations in stock abundance, occurring at intervals of about 8–10 years. However, due to the short time series of stock assessments it is clearly not possible to ascertain whether major variations in stock abundance and distribution will continue to occur at such regular intervals, or whether the observed variations are the result of irregular adverse physical and/or biological changes of the environment. As described in chapters 6 and 13 such adverse conditions indeed occurred in the late 1960s, 1979 and 1988.

17. MANAGEMENT OF THE CAPELIN FISHERY

17.1. Minimun landing size, mesh size and closed areas

Initially, regulatory measures were purely precautionary in nature (Vilhjálmsson 1983). In Iceland there was a closed season in spring and summer from 1973–1978, lasting from 2 to 4 months. In 1979 the closed season was extended to last until 20 August, and in 1980 until 5 September. In 1981 Icelandic vessels were allowed to fish capelin from 10 August in the oceanic area north of 68°N and east of 21°W. From the mid-1980s, after the capelin stock had recovered from its collapse earlier in the decade, the summer fishing season has usually been opened in mid-July although fishing operations have not always begun at such an early date, especially not in the case of the Icelandic fleet. However, large areas south of 68°N have in most years since 1984 been closed to all capelin fishing during the summer months.

The purpose of the above restrictions was to protect the juvenile 1- and 2-group stock from the fishery, as well as the slower-growing part of the maturing 2-group capelin in the southern and southwestern parts of their distribution area, at the time when their growth rate is fastest. A directed seine fishery of 1-group capelin is almost out of question, since most of that stock component will escape through the mesh commonly used in capelin seines. In the shelf area off Northeast, North and Northwest Iceland as well as over the Iceland-Greenland Ridge, juvenile 1- and 2-group capelin may, however, be found together with the maturing, fishable stock. Much damage can then occur by catching small and immature 2-group capelin, as well as by 1-group mortalities, caused by repeated escapes when setting the fishing gear on concentrations consisting of a mixture of age groups. In a relative sense, such damage becomes less likely in autumn with the arrival of that part of the maturing stock which feeds in higher latitudes in summer. The adult capelin most frequently tend to aggregate near the outer limits of the juvenile distribution area off North and Northwest Iceland in autumn, where schools of adults can often be distinguished from juvenile capelin aggregations due to the higher densities and more pronounced migration of the adults.

In 1975 a minimum landing size of 12 cm was introduced in the Icelandic capelin fishery, with a minimum mesh size of 19.6 mm. In order to improve the release ratio of small juvenile capelin, Iceland increased the minimum mesh size to 21 mm in 1981. There is no doubt that minimum mesh size in purse seines is effective in preventing the catch of juvenile 1-group capelin while retaining the older age groups, without causing excessive enmeshing of any part of the stock (Vilhjálmsson 1983). This is supported by the fact that complaints of excessive enmeshing from skippers of Icelandic capelin boats are rare. The reason is simply the large difference in girth, between the 1-group on one hand and the 2-group and older capelin on the other.

Therefore, 1-group capelin have seldom been numerous in the autumn catch (cf. Appendix II.3, Tables XVII and XIX). An exception to this is the autumn 1980 season. At that time there was much ice off the western north coast of Iceland as well as off the Vestfirðir peninsula, resulting in restricted access to the adult, fishable stock. The Icelandic capelin fleet was, therefore, obliged to fish mixed concentrations of maturing and juvenile capelin, and considerable numbers of 1-group fish of the 1979 year class were caught and landed due to the unusually high growth rate among this age group during the summer of 1980. Due to the mixed nature of practically all fishable capelin concentrations in the autumn and early winter of 1989–1992, the problem of immature 1- (2-) group capelin being taken with the older components during that part of the fishing season, recurred although on a smaller scale than in 1980.

17.2. Multinational agreements on fishing rights

Due to the extensive summer migrations of the Icelandic capelin, the fishable part of the stock may at times be located in any or all of the exclusive economic zones of Iceland, Greenland and Norway (Jan Mayen). After the successful Norwegian capelin fishery in the central and northern Iceland Sea in 1978 and again in 1979, a dialogue was initiated between the two nations in order to establish a reasonable division of allowable catches from the stock. In May 1980 Iceland and Norway reached an agreement to the effect that these nations would share the catch quota in the ratio 85 and 15 percent respectively. It was also agreed that Icelandic vessels could fish the same amount of capelin as Norway in the Jan Mayen zone, but must take the remainder within the economic zone of Iceland (Jónasson 1989).

As described in detail by Jónasson (1989a), there followed a series of meetings of a committee, consisting of representatives from Iceland, Norway and the member states of the European Economic Community (EEC), which was then acting on behalf of Greenland/Denmark, in order to determine a reasonable sharing between the three parties of the capelin fishery and access to the stock. To help establish a platform for these discussions, a sub-committee of scientists was set up, its chief mandate being to draw a general picture of geographic stock distribution and access to the fishery at various times of the year with respect to the exclusive economic zones of the three parties concerned. The scientific sub-committee submitted its report, based on the available data, in May 1983 (Anon. 1983). In the light of new data, the original 1983 report was revised by a working group of biologists from the same parties and brought up to date in May 1986 (Anon. 1986).

It was not, however, until June 1989 that Iceland, Norway and Greenland/Denmark signed an agreement with regard to the sharing of the capelin quota, reciprocal fishing rights and measures for the protection of juvenile capelin (Jónasson 1989a). The most important part of this agreement was the stipulation that a cautious approach be taken to the summer fishery of capelin. Thus, a precautionary catch quota should be set for the first half of the season, constituting only a part of the expected total seasonal catch. The final catch quota (TAC) would then be decided after the completion of stock assessment surveys in late autumn and/or winter. Furthermore, the quota would in both cases be divided in the ratio 78:11:11 between Iceland, Norway and Greenland, respectively, and vessels registered in these countries could fish for capelin irrespective of economic zones, except in those areas closed for the protection of the juvenile part of the stock. The only exception to this general rule was that in the winter season, Norwegian and Greenlandic vessels were not allowed to fish for capelin south of 64°30′N after 15 February, or in other words, on the actual spawning grounds off the south and west coasts of Iceland.

The above agreement was for three years and, therefore, due for renewal or to be re-negotiated in 1992. After a round of discussions, it was agreed in May 1992 that the old agreement should basically be extended for the next two years, *i.e.* until May 1994. In addition, Iceland and Norway came to the bilateral agreement that 65 percent of each nation's share of the precautionary catch quota, that would be set for the summer/autumn part of the 1992/93 and 1993/94 seasons, must be fished within each nation's economic zone (Jónasson 1992).

In order to facilitate an easy and unbiased access of the parties concerned to all data on capelin in the Iceland – Greenland – Jan Mayen area, the stock situation has been evaluated annually by the Atlanto-Scandian Herring and Capelin Working Group (ASH&C WG) of the International Council for the Exploration of the Sea (ICES) since the autumn of 1981. The working group subsequently submits its findings and recommendations to the Advisory Committee on Fisheries Management (ACFM), which in turn is responsible for the official ICES management advice.

17.3. Total allowable catch (TAC)

Due to the schooling nature and the frequently easy accessibility of capelin to a purse seine fishery, using modern fish finding techniques, high catch rates may be maintained even at low stock levels. The capelin have a high spawning mortality, and the fishery is almost entirely based upon the maturing part of the stock which is subject to large fluctuations in abundance due to the short life span and variable recruitment. This makes it a primary management objective to prevent the spawning stock from being fished down to a level of reduced recruitment, not to mention to recruitment failure. For the same reason, any attempts at stock assessment, based upon catch and effort statistics from a seine fishery, will fail, and other methods have to be found. This is in contrast to the Newfoundland capelin trap fishery where recent research indicates that stock abundance is indeed reflected in the catch rates (Carscadden *et al.* 1992).

In 1979, when the winter season ended in the second half of March, about 600,000 tonnes of capelin were left to spawn as calculated from acoustic estimates of stock size from January – February that year, when the catch and natural mortalities had been accounted for. In 1980 it was decided that while gaining further experience, it would be inadvisable to reduce the spawning stock to less than two thirds of the 1979 level or 400,000 tonnes. Since then the main management policy has been that 400,000 tonnes of capelin should be allowed to spawn each year and this, together with the protection of the immature part of the stock, has formed the basis of the fishing policy regarding the Icelandic capelin stock ever since.

The reference abundance of 400,000 tonnes of remaining spawning stock, was more or less an arbitrary choice, since a parent stock/recruitment relationship had not been established at the time, and indeed it has not been demonstrated yet for the Icelandic capelin. As pointed out in section 15.6.4, there is a general positive relationship between data on parent stock size in 1979–1992 and the abundance of 0-group capelin in the same year. However, this relationship breaks down when comparing parent stock abundance with the total number of 1 and/or 2 year old recruits.

The main reasons for the decision to preserve a large spawning stock, were the importance of capelin as a forage species, especially for the valuable cod and Greenland halibut stocks, and the possibility of overestimating capelin abundance by a method that had not previously been used for the purpose of assessing this capelin stock. And last but not least, the obviously low abundance of capelin in the winter of 1970 and 1978 had been associated with spawning in a limited part of the usual spawning grounds. In both cases spawning also lasted over a time span of a much shorter duration than normal. Furthermore, this had in 1978 been associated with the production of a very small year class, which was reflected in the drastic reduction in stock abundance in the 1980/81 season. In consequence, there was a concern that in the long run a small spawning stock might lessen the survival chances of larvae as compared to the more normal situation, when spawning takes place in a much more extensive area and lasts for a longer time.

As described in detail in Appendix I.1, the abundance of the fishable part of the Icelandic capelin stock has been assessed several times each year since the autumn of 1978. Since the 1979/80 season these in-season assessments have been the basis for all decisions on TACs for each fishing season (July – March) and also in some cases for descisions concerned with directing the fishery from one part of the stock to another. As examples of the latter, the fishery from the eastern spawning migration was stopped in early February 1980 in order to preserve that part of the spawning stock. Similarly, the autumn fishery was halted in early December 1990 and not reopened again until it had been established without a doubt, through further surveying in January 1991, that the stock abundance indeed exceeded the target spawning stock by a significant margin.

As stated above, TACs are set on the basis of estimates of fishable stock abundance obtained in autumn, fishable stock abundance being defined as that part of the stock having reached the 50 percent maturity length. As explained in section 14.4 this is on the average 13.5 cm for the Icelandic capelin (males and females combined) and has changed little over the years. Having obtained an estimate of the total number and average weight of maturing capelin by year classes, the calculation of a TAC for the period, extending from the time of the estimate until spawning is over by the end of March, is carried out in the following way.

The number of capelin that are necessary to obtain a spawning stock of 400,000 tonnes is variable from one season to another, mainly due to the variations from one season to another in the ratios of the two year classes. For each season the observed year class ratio in the spawning stock is, however, usually much the same in research vessel samples of the maturing part of the stock as in samples taken from the fishery. The year class ratio can, therefore, be safely determined from the survey data. There is some growth to be accounted for in the autumn-winter period, which seems to be weight specific where the smaller fish grow at a slightly higher rate than the larger ones. Using the slope and intercept from the regression of autumn weight on winter weight over the last decade, given in section 14.2.3, an expected weight increment can be calculated for each year class from the observed average weight of maturing 2- and 3-group capelin in the autumn estimate. After that the number of capelin, necessary to obtain a spawning stock of 400,000 tonnes at spawning time in the following spring, can be calculated from the measured percentage ratio of year classes and the average weight in each age group:

$$N_s = \frac{W_s}{w_3 \cdot n_3/n_{3+4} + w_4 \cdot n_4/n_{3+4}} \qquad (17.1)$$

where N_s denotes the number of fish in the remaining spawning stock, W_s the total weight of remaining spawning stock, $w_3 \cdot n_3/n_{3+4}$ and $w_4 \cdot n_4/n_{3+4}$ denote the mean weight multiplied by the fraction, belonging to age groups 3 and 4 respectively, obtained as described in the preceding paragraph.

To calculate TAC from the time of the relevant abundance estimate, the model developed by Beverton and Holt (1957) is used. First Z, the total mortality rate, is found:

$$N_s = N_1 \cdot e^{-Z} \qquad (17.2)$$

By rearranging we obtain:

$$Z = \ln \frac{N_s}{N_1}$$

where N_1 denotes the total estimate of maturing capelin by number, and N_s is the total number of capelin in the target spawning stock.

The estimated average natural mortality rate is given in section 14.10 as M = 0.035/month. Since the catch is usually fairly evenly distributed over the few months remaining of the fishing season, the fishing mortality is $F = Z - M$. Furthermore:

$$C_n = N_1 (1 - e^{-Z}) \frac{F}{Z} \qquad (17.3)$$

where C_n denotes the TAC in numbers from the time of estimated stock abundance and other parameters as explained above.

To convert TAC in numbers to weight, we take the observed average weights of each year class at the time of the assessment, and, assuming an even distribution of catches, add to these the expected weight increment for each age group to obtain the average weight of individual fish in the catch during the rest of the season. The TAC in weight is then obtained as follows:

$$C_w = C_n \cdot \frac{w_3 \cdot n_3}{n_3 + n_4} + \frac{w_4 \cdot n_4}{n_3 + n_4} \qquad (17.4)$$

where C_w denotes TAC in weight, C_n is catch in numbers, and the remaining terms as explained for equation 17.1.

As discussed in section 15.4.2, the most reliable estimates of the maturing and fishable stock abundance are usually obtained late in the fishing season *i.e.* in January and/or February. Such estimates have been obtained in most years since 1979. When these have differed significantly from previous ones, the late season estimates have, therefore, been considered more likely to reflect the true state of the stock, and in such cases TACs have been revised. The calculations are then carried out in the same way as described above, assuming, however, that there will be no further increase in the average weight of the age groups in the spawning stock.

17.4. The precautionary TAC

As described by Vilhjálmsson (1983) it was soon recognized that overfishing could well have taken place by the time the results from the autumn or winter surveys became available. The reason for this is of course the large fishing power of the multi-national fleet that inevitably will at times be operating during periods of low stock abundance but easy availability of capelin to the fishery. As early as 1979, the introduction af a low precautionary catch quota was therefore recommended, to be revised according to results from stock abundance surveys in autumn and winter during each season (Anon. 1979a).

This advice was not accepted by the authorities concerned. Instead, preliminary catch quotas were set on somewhat arbitrary grounds for the whole of the 1979/80, 1980/81 and 1981/82 seasons following bilateral negotiations between Iceland and Norway. These preliminary catch quotas were then divided between the two coun-

Table 17.1. Preliminary TAC for the summer/autumn fishery, recommended TAC for the whole season, landings, the remaining spawning stock in the 1978/79–1982/83 seasons (thous. tonnes) and the resulting year class abundance at age 2 (billions).

Season	*78/79*	*79/80*	*80/81*	*81/82*	*82/83*
Prelimin. TAC . . .	–	650	775	700	0
Recomm. TAC . . .	–	863	440	366	0
Landings	1,195	963	680	626	0
Spawning stock . . .	600	300	170	140	260
Recruits at age 2 . .	43.3	32.0	96.2	81.7	164.6

tries and allocated to individual vessels. Furthermore, it did not prove possible to reach an agreement with the EEC, which at the time was responsible for negotiations of fishing rights on behalf of Greenland. In consequence, vessels from the Faroes and Denmark could, on EEC licence, fish capelin in the economic zone of Greenland without restrictions.

The results of this unfortunate situation are given in Table 17.1. Recommended catch quotas were based on the results of acoustic surveys of stock abundance carried out for each season in October/November and/or January/February. By that time, however, the Norwegian vessels had always fished their agreed share, Faroese and Danish vessels had taken what they could, and the same applied to a varying part of the Icelandic capelin fleet. As a result, it proved impossible to have the fishery stopped in time to preserve the targeted spawning stock during the period of low recruitment in the early 1980s. Thus, the 1980 spawning stock was reduced to about 300,000 tonnes, and the 1981 and 1982 spawning stocks to extremely low levels, or 160,000 and 140,000 tonnes respectively (cf. Table 17.1). These figures are based on repeated estimates, the results of which were in accordance when account had been taken of catches in the relevant periods.

The 1981 autumn and winter fishery is an interesting example of how catch rates in a fishery of a pelagic, schooling species can remain high in spite of low stock abundance (cf. Appendix II.3, Table XIX). When the fishery was stopped in December 1981, weekly catches amounted to 30,000–40,000 tonnes and catch rates were in fact only limited by the production capacity of the Icelandic reduction plants and by occasional storms. The estimated fishable stock abundance at the time was less than 200,000 tonnes. Needless to say, the estimate was not considered very credible by many skippers of capelin boats, who did not realize that there was no adult capelin elsewhere in the usual autumn distribution area. However, in the period January – March of the following year eight boats were given permission to fish 2,000 tonnes each or 16,000 tonnes in all. The combined catch amounted to only 13,000 tonnes for a season when, together these same boats could easily have taken 80,000 tonnes or more under normal circumstances. However, it is only fair to state that the skippers of these vessels soon recognized the true stock situation and turned their attention to the fishing of other species. The dense spawning schools which aggregated in the shallow waters at the south coast of Iceland in late February 1982 were, therefore, not fished by these boats. The true situation was therefore never tested in full in the spring of 1982.

In spite of difficulties in assessing the abundance of juvenile capelin, it seemed evident from acoustic as well as 0-group surveys that the size of the 1980 year class, which was to spawn in 1983, would be very small. Consequently, the state of the stock was considered to be extremely serious, even without any fishery taking place. A fishing ban was, therefore, recommended for the 1982/1983 season, pending results from the autumn 1982 abundance survey. This recommendation was accepted by all parties concerned, *i.e.* Iceland, Norway, the Faroes and the EEC countries. Acoustic surveys in the autumn of 1982 and the winter of 1983 confirmed the low abundance of the 1983 spawning stock (cf. Appendix II.2, Tables XI and XII), and the 1982/83 season was never opened to the fishery.

After the sudden collapse of the Icelandic capelin stock in the early 1980s, a more cautious approach was taken with regard to its management. In the years to come, the management authorities concerned generally accepted the ICES advice and proceeded accordingly. Thus, although surveys of the juvenile stock component, carried out in summer and autumn 1982, had indicated a considerable improvement in the state of the stock, it was decided, in accordance with the advice given at the time, not to open the 1983 fishery until after an estimate of the fishable stock abundance had been obtained in the autumn of 1983. This estimate indicated a TAC of 375,000 tonnes after provisions had been made for natural mortality and a remaining spawning stock of 400 thousand tonnes. However, a later survey in January/February of the following year showed that the stock had been underestimated in October, mostly because of an unusually large weight increase in the intervening period (cf. Appendix II.2, Tables XII and XIII). The total allowable catch was subsequently increased to 575,000 tonnes.

As of the early 1980s, considerable emphasis was placed on assembling a data base for the abundance of the juvenile 1- and 2-group stock component through surveys in summer, autumn and winter. However, it was found that the resulting abundance estimates often conflicted and were therefore difficult to interpret. Because of this and the recent stock collapse, management advice for the summer and autumn season (July–November) tended to be over-cautious. This led the industry to press for an early conclusion of the autumn stock abundance surveys at a time of the year when part of the fishable stock was still feeding and dispersed and could not be assessed properly by acoustic methods. More effort than necessary was, therefore, for a while spent on repeated assessment surveys. On the other hand, the difficult problem of having to reduce previous allocations of catch quotas, which had to be faced in the early 1980s, was avoided for the time being.

After the mid-1980s, confidence in the August abundance estimates of 1-group capelin as an indicator of 2-group recruitment in the following year, began to increase. However, reliable estimation of the abundance of the immature part of the 2-group stock component still remained an unsolved problem. Tentative forecasts of the fishable stock abundance 9–12 months ahead of time were, therefore, made on the basis of the August 1-group estimates. Naturally, such forecasts of stock abundance were only used as a guideline to set precautionary TACs for the summer/autumn part of each season. TACs for the winter season, and consequently the season as a whole, have never been determined until after assessment surveys of the fishable stock in autumn (October/November) and/or winter (January/February). Although the method of forecasting stock abundance is different, this arrangement was similar to that used in managing the fishery of the Barents Sea capelin for a number of years (Hamre 1985).

Advance forecasts of fishable stock abundance, based on the above model, proved to be reasonably realistic for the 1984/85–1988/89 seasons. However, the forecast for the 1989/90 season, based on the same criteria, proved to be twice the concurrent assessment. This assessment was hotly contested by many skippers but obtained so late in the season that the fishery could not be stopped in time to preserve the targeted spawning stock.

For the following 1990/91 season, the prediction proved even more optimistic and this automatically led to the dismissal of the method of attempting to predict fishable stock abundance from August assessments of 1-group capelin abundance. Since all the available information

Table 17.2. Preliminary TAC for the summer/autumn fishery, recommended TAC for the whole season, landings and remaining spawning stock in 1983/84–1991/92 seasons (thous. tonnes) and the resulting year class abundance at age 2 (billions).

Season	*83/84*	*84/85*	*85/86*	*86/87*	*87/88*	*88/89*	*89/90*	*90/91*	*91/92*	*92/93*
Prelimin. TAC . . .	0	300	700	1,100	500	900	900	600	0	500
Recomm. TAC . . .	640	920	1,280	1,290	1,115	1,065	–	250	740	900
Landings	573	897	1,311	1,333	1,112	1,022	799	318	677	787
Spawning stock . . .	440	460	460	420	400	440	115	330	475	500
Recruits at age 2 . .	66.2	102.6	94.3	53.1	42.3	77.2	95.0*	–	–	–

* Preliminary

pointed to a small 1989 year class, the advice given by the Icelandic Marine Research Institute as well as ICES for the 1990/91 season was simply that the fishery should not be opened until after the autumn 1991 stock assessment survey. This advice was accepted by all nations concerned, and TACs for the 1991/92 season were set according to in-season acoustic assessments of fishable stock abundance. The history of the management of the capelin fishery in the 1983/84 – 1992/93 seasons is summarized in Table 17.2.

Due to the failure of predicting fishable stock abundance from August estimates of year class size at age 1, a new model for predicting the fishable stock abundance was developed. The new prediction model is based on autumn (October/November) assessments of the abundance of 1 and 2 group capelin. As before, the model is intended for use as a guideline by which to advise on precautionary catch quotas for the first half of the fishing season only. The following two sections describe the structure of both of these prediction methods and their historic performance is tested.

17.4.1. The old prediction method

Since the capelin recruit to the fishable stock as 2-group, and this age group normally constitutes by far the largest part of the fishable stock component, information on 1-group abundance may be used in an attempt to predict fishable stock abundance one year ahead.

Annual surveys of the distribution and abundance of 0-group fish, carried out in August in the area east and north of Iceland as well as between Northwest Iceland and Greenland, also yield information on the distribution and abundance of 1-group capelin. The numbers of capelin in this age group have been assessed by acoustic methods during these surveys since 1982 (year classes 1981–1991). The August surveys are described in section 15.5.3 and the resulting estimates of 1-group capelin abundance are given in Appendix II.2, Table XVI.

Since changes in measured 1-group abundance in August did at first seem to be reflected in fishable stock abundance in the following year, this information was soon made use of in the first attempts to advise on TACs for the first half of the capelin fishing season (August – December).

Having obtained these data from a few years, a simple model was developed, based on the relationship between measured numbers of 1-group capelin and back-calculations of year class abundance to that age. Because of the apparent total spawning mortality, the back-calculations of total year class abundance were based upon acoustic assessments of mature 2- and 3-group fish respectively, using a natural mortality of M = 0.035/month and catches in numbers (cf. sections 14.10 and 15.6.2).

The predicted number of 1-group capelin was then projected forward in time to the beginning of the next fishing season (1 August). Since the fishery is mostly based on maturing capelin, the predicted number of 2-group recruits was then multiplied by an average maturing ratio of 0.7. Since no information on the expected abundance of 3-group capelin in the fishable stock was available at the time, the contribution of this age group to the fishable stock was set at 25% of the total abundance in the fishable stock by number, this being near the "long term" mean.

Multiplication by the average mean weight of 2- and 3-group capelin in autumn (in the middle of the August – December part of the season) then gave estimated total fishable stock biomass in the beginning of the season. Assuming the above natural mortality rate and aiming for a remaining spawning stock of 400,000 tonnes in March of the following year, an expected catch could be calculated for the whole of the coming season. The TAC recommended for the first half of that season was generally limited to about one half of the expected seasonal catch. However, for the last two seasons when this model was used (1989/90 and 1990/91), the precautionary TAC was set at a higher level.

A forecast of the state of the fishable stock and TACs in the 1983/84–1992/93 seasons, based on the above model, is given in Table 17.3, together with TACs calculated from late season acoustic assessments of stock abundance and catches, but using the same criteria for the remaining spawning stock (400,000 tonnes), natural mortality (M = 0.035/month) and mean weight at age (17.0 and 24.3 g for 2- and 3-group capelin respectively) as used in section 17.3.

Clearly, the model just described would not have given very accurate results had it been used for the 1983/84 and 1984/85 seasons. Similarly, the very rich 1983 year class did not recruit to the adult stock in 1985/86 in the expected ratio. How-

Table 17.3. Predictions of fishable stock abundance and TAC based on acoustic assessments of the numbers of 1-group capelin in August in comparison to calculations of TAC for the 1983/84 – 1991/92 seasons based on in-season stock assessments.

The column headings Age 2 and Age 3 refer to numbers in age groups 2 and 3 at the beginning of each season. Fish.st. denotes calculated biomass of maturing capelin at the beginning of each season (1 August). TAC_{pred} denotes predicted and TAC_{adv} denotes advised TAC.

Mean weight of maturing 2- and 3-group capelin in October/November 1981–1991 was 17.0 and 24.5 g, respectively. Numbers are in billions; weights in thous. tonnes.

Season	*Year classes*	*Age 2*	*Age 3*	*Fish.st.*	TAC_{pred}	TAC_{adv}
1983/84	81–80	61	20	1,527	899	573
1984/85	82–81	69	23	1,736	1,084	897
1985/86	83–82	99	33	2,491	1,752	1,311
1986/87	84–83	40	13	990	431	1,333
1987/88	85–84	50	17	1,266	668	1,115
1988/89	86–85	57	19	1,434	817	1,036
1989/90	87–86	68	22	1,695	1,043	550
1990/91	88–87	58	19	1,451	832	265
1991/92	89–88	42	14	1,057	483	740
1992/93	90–89	45	15	1,132	550	1,250

ever, due to the extraordinary size of the 1983 year class this would not have mattered in the practical sense. Indeed, due to its high numbers and low maturity rate, this year class became the mainstay of the fishable stock in the following season (1986/87), outnumbering and outweighing the poor 1984 year class approximately in the ratio 6 to 4 and 7 to 3 respectively. That this would be so, became apparent already during acoustic surveys in the winter of 1986. As shown in Table 17.3, it is obvious that predictions of fishable stock abundance, based on this model, generally were far too often grossly in error.

17.4.2. A new model for predicting fishable stock abundance

As stated in section 17.4, stock prognoses based on August estimates of juvenile capelin abundance, gave very misleading forecasts for the 1989/91 and 1991/92 seasons. In consequence, a new model for predicting fishable stock abundance by number and biomass, was developed. As before, the prognosis procedure needed to predict the fishable stock in the beginning of the season in order to predict the effects of fishing. Furthermore, the prediction should include a measure of confidence to ensure that the precautionary TAC be set at such a level as to open the fishery before the October survey, yet keep it closed when it is likely that fishing will reduce the residual spawning stock below 400,000 tonnes.

The new model is based on the following assumptions:

1. For practical purposes, capelin belonging to this stock spawn only once and die thereafter.
2. The small contribution of 2- and 5-group spawners is insignificant.
3. Each year class spawns only partly as 3-group fish. The remainder spawns as 4-group.
4. Maturing rate differs from one year class to another and is inversely related to year class abundance.
5. It is possible to assess the number of fish in the fishable stock with a fair degree of accuracy by acoustic methods in autumn (October/November) and, as a rule, even more accurately in winter (January/February).
6. In the same way, it is possible to assess the abundance of immature 1- and 2-group fish in autumn. However, the abundance of these stock components is always underestimated, especially that of the immature 2-group capelin. Useful information on the numbers of 1-group capelin is sometimes also obtained in August and in the winter period.
7. The natural mortality rate (M) in the adult

stock, appears to be on the average 0.035/month (cf. section 14.10). The juvenile mortality rate (i.e. from 1- to the 2-group stage) is assumed to be the same as that of the older age groups (cf. section 15.6.2).

As described in the previous chapters the above assumptions accord reasonably with the present knowledge of the biology of the stock.

The abundance of year classes 1980–1990 as 1-group was assessed in the autumn surveys with one exception. This was the 1986 year class which was largely inaccessible since much of it was under ice in October 1987. The abundance of this year class was, however, successfully estimated at the 1-group stage in August 1987 and this estimate could, therefore, be projected to mid-October by adjusting for natural mortalities. On the other hand, it is clear that the 1989 year class has recruited to the fishable stock in much larger numbers than the autumn 1990 survey results indicated. All data from that survey have now been scrutinized anew, but in no way can it be ascertained whether the underestimate is due to an unusual behaviour pattern of the 1-group immatures in the survey area, unusually low rate of natural mortality or simply because the survey did not cover the entire distribution area of the 1989 year class. Due to the very low echo abundance in the 1990 autumn survey, this underestimate can not be explained *in toto* by an incorrect distribution of trawl samples either. The fact remains that the 1990 autumn acoustic estimate of 1-group capelin has failed (as did the August 1990 assessment also for that matter), and consequently we are left with 10 *valid* autumn estimates of 1-group capelin abundance in the 1980–1990 year class series (Appendix II.2, Table XIX).

The maturing part of the 2-group in summer (N_{2mat}, see Table 17.4) is a part of the survivors of the 1-group in the previous fall, which was measured in October (N_1, see Table 17.4). Regressing the back-calculated abundance of maturing 2-group capelin on 1 August (cf. section 15.6.2) against the 10 valid 1-group acoustic estimates for the 1980–1990 year classes gives an an $R^2 = 0.84$ ($P < 0.01$), the slope (b_1) and intercept (a_1) being 0.94 and 1.98 respectively. According to this model, the 95% confidence interval for the abundance of maturing 2-group capelin is ±10–16% for the range from 40 to 70 billion fish.

This comparison only deals with maturing capelin. Although the fishery will to some degree inevitably take immature 2-group capelin, it is directed at the adult stock component. For the purpose of predicting fishable stock abundance, it therefore seems reasonable to use the adult 2-group capelin measurement, *i.e.* the correlation between the autumn 1-group abundance estimates and the estimates of that part of the year class which matured and spawned at age 3.

Table 17.4. The data used in the comparisons between abundance of age groups (numbers in billions) when predicting fishable stock abundance for calculations of preliminary TAC.

Year class	*Age 1 Acoustics* (N_1)	*Age 2 Back-calc. Mature* (N_{2mat})	*Age 2 Acoustics Immature* (N_{2imm})	*Age 2 Back-calc. Total* (N_{2tot})	*Age 3 Back-calc. Mature* (N_3)
1980	23.7	17.1	1.7	32.1	9.8
1981	68.0	53.7	8.2	96.2	27.9
1982	44.1	40.7	4.6	81.6	27.0
1983	73.8	64.6	12.6	164.6	65.8
1984	33.8	35.6	1.4	65.0	20.1
1985	58.6	65.4	5.4	102.6	24.5
1986	70.2	70.3	6.7	94.3	15.8
1987	43.9	42.8	1.8	53.1	6.8
1988	29.2	31.9	1.3	42.0	6.7
1989	39.2*	67.7	5.2	77.4	6.4
1990	60.0	70.7	2.3*	73.1**	
1991	104.6				

* Invalid due to ice conditions.
** Calculated from total abundance recorded in autumn 1992, catches and natural mortality.

Furthermore, the maturing part of the 3-group in summer (N_3, see Table 17.4) corresponds to the surviving part of the year class which did not mature and spawn in the year before. Unfortunately, the surveys of the immature 2-group in the year before (N_{2imm}, see Table 17.4) are gross underestimates and will, therefore, not be used. Similarly, the January survey most frequently estimates only that part of this age group which will spawn (at age 3) and thus is no indication of what will appear in the following summer.

It is found, however, that maturity at age 2 is closely but inversely related to year class size (N_{2tot}, see Table 17.4)). Hence, the total abundance estimate of the 2-group in fall (matures + immatures) is an indication of what will appear as the 3-group in the following summer. A regression relating the back-calculated abundance of the year classes from 1980–1989 as 2 and 3 year olds in August (N_{2tot} and N_3, cf. section 15.6.2 and Table 17.4), results in an $R^2 = 0.80$ ($P < 0.01$), the slope (b_2) and intercept (a_2) in this case being 0.43 and −13.3 respectively. However, the confidence interval of the 3-group abundance is much wider than that for the 2-group, or ±25–40% for 3-group recruitment in the range of 15–30 billion fish.

As stated above, the capelin fishery in the summer and autumn season is mainly aimed at that part of the stock which is in the process of maturing and consists of individuals with high growth rate, feeding in the oceanic area between Iceland, Greenland and Jan Mayen. Indeed, areas known to contain a high proportion of juveniles have usually been closed to the fishery.

The rate of growth of maturing capelin is by far the highest in spring and summer but varies with feeding conditions and areas. Furthermore, capelin continue to increase their weight, almost until spawning commences in March. Although good catches have often been made in August and September, the highest catch rates are normally not obtained until in October and onwards. In order to forecast mean weights for the summer and autumn season July/August – November/December, it seems, therefore, most reasonable to use mean average weights by age in the fishable stock (maturing capelin) in autumn. Such information is obtained in acoustic surveys in October/November and is given for age group 2 (year classes 1980–1990) and age group 3 (year classes 1979–1989) in Table 17.5.

We can now predict fishable stock in number by age (N_2 and N_3) and biomass (W_{tot}) at the beginning of the next season. For age group 2:

$$N_2 = N_1 \cdot b_1 + a_1 \qquad (17.5)$$

where N_1 denotes the acoustic assessment of 1-group capelin in the fall of the previous year and b_1 and a_1 the slope and intercept respectively, from the regression above. For age group 3:

$$N_3 = N_{2tot} \cdot b_2 + a_2 \qquad (17.6)$$

where N_{2tot} denotes the total acoustic estimate of 2-group capelin in the fall of the previous year and b_2 and a_2 the slope and intercept respectively.

Hence the total biomass of the fishable stock W_{tot} is,

$$W_{tot} = N_2 \cdot w_2 + N_3 \cdot w_3 \qquad (17.7)$$

where w_2 and w_3 are average weights of 2- and 3-group capelin in autumn (at present 17.0 g and 24.3 g respectively, as given in Table 17.5) and N_2 and N_3 as already defined.

In order to check the performance of this new model, fishable stock abundance and TACs were calculated for the 1982/83 – 1992/93 seasons. For this purpose, we use the same criteria of remaining spawning stock, natural mortality rate and autumn assessments of the numbers of 1- and 2-group capelin. A comparison of stock abundance and TACs, calculated in this way, to actual advice on TACs set according to acoustic assess-

Table 17.5. Mean weight (g) in autumn of the 1979–1990 year classes.

	Age groups		
Year class	*2 immature*	*2 mature*	*3 mature*
1979			24.1
1980	10.2	16.5	22.6
1981	11.2	16.8	25.8
1982	12.6	15.8	23.8
1983	12.6	15.5	24.1
1984	13.1	18.1	25.8
1985	12.7	17.9	23.5
1986	14.2	15.5	25.5
1987	9.8	17.8	25.5
1988	10.1	18.1	25.3
1989	10.6	16.3	22.6
1990	12.1	16.5	
Average	11.7	17.0	24.3

Table 17.6. Predictions of fishable stock abundance and TAC for the 1982/83–1993/94 seasons. The last column gives contemporary advice on TAC for comparison.

Column headings Age 2 and Age 3 refer to numbers in age groups 2 and 3 at the beginning of the fishing season. Fish.st. denotes calculated biomass of maturing capelin before the fishery on 1 August. TAC_{calc} denotes predicted TAC and TAC_{adv} is advised TAC.

Mean weight of maturing 2- and 3-group capelin in October/November 1982–1992 is 17.0 and 24.3 g respectively. Numbers are in billions; weights in thous. tonnes.

Season	*Year classes*	*Age 2*	*Age 3*	*Fish.st.*	TAC_{calc}	TAC_{adv}
1982/83	80–79	24.2	5.5	545	13	0
1983/84	81–80	65.6	0.3	1,122	526	573
1984/85	82–81	43.3	27.5	1,404	769	897
1985/86	83–82	71.1	21.4	1,729	1,049	1,311
1986/87	84–83	33.6	56.6	1,946	1,236	1,333
1987/88	85–84	56.8	14.8	1,325	700	1,115
1988/89	86–85	67.7	30.2	1,885	1,184	1,036
1989/90	87–86	43.1	26.7	1,381	749	550
1990/91	88–87	29.3	9.2	722	160	265
1991/92	89–88	38.7	4.6	770	216	740
1992/93	90–89	58.1	19.4	1,459	816	900*
1993/94	90–91	99.9	17.7	2,138	1,390	1,250

* In January 1993 80,000 t were added to the 820,000 t recommended after the October 1992 survey due to an unexpectedly large increase in mean weights.

ments of fishable stock abundance at the time, is given in Table 17.6.

As shown in Table 17.6 the new model does indeed predict changes in stock abundance along similar lines as those experienced in reality with the exception of the 1991/92 season. It was explained earlier in this section, as well as in chapter 15, that the quite dramatic recovery of the stock from its previous low, was not indicated by stock assessment survey results. The 1989 year class proved much stronger than measured by acoustic surveys, both that of the autumn and that of the summer of 1990. There is no other available information pointing in this direction, and, consequently, no possibility to pinpoint the reason(s) why these surveys failed to record this year class in proportions comparable to other year classes. However, throughout the period of comparison, the new model would otherwise have provided much better forecasts of fishable stock abundance than the older method, and, consequently, also of final TAC decisions. A regression of TACs, predicted by the new model, on TACs recommended on the basis of stock assessments, results in an $R^2 = 0.75$ ($P<0.01$) with an intercept of 5.3 and a slope of 0.84.

The 95% confidence interval for TACs in the range of 700,000–1,200,000 tonnes, predicted by this model, is ±18–20%. However, the confidence interval quickly widens at lower ranges of TACs and has become 32% at 500,000 tonnes. It is, therefore, clearly indicated that precautionary TACs, set on the basis of this model, should generally not exceed ¾ of the TAC predicted for the whole season. Furthermore, special care should be taken when dealing with stock abundance where predictions indicate TACs below 500,000 tonnes.

17.5. Closed areas during the summer/autumn season

As explained earlier, a capelin fishery should for obvious reasons not take juveniles or kill them through repeated release and/or escape from the fishing gear.

In the period July – October, the capelin fishery in the Iceland – Greenland – Jan Mayen area has traditionally been conducted on that part of the stock which has migrated north to feed in the central and northern Iceland Sea. These migrations consist almost exclusively of adult fish and this type of summer/autumn fishery has not taken juveniles. In 1988 the adult stock did not migrate to feed in this area but stayed in the region of the Iceland-Greenland Channel, south of Scoresby Sound, until returning to the Icelandic area in November.

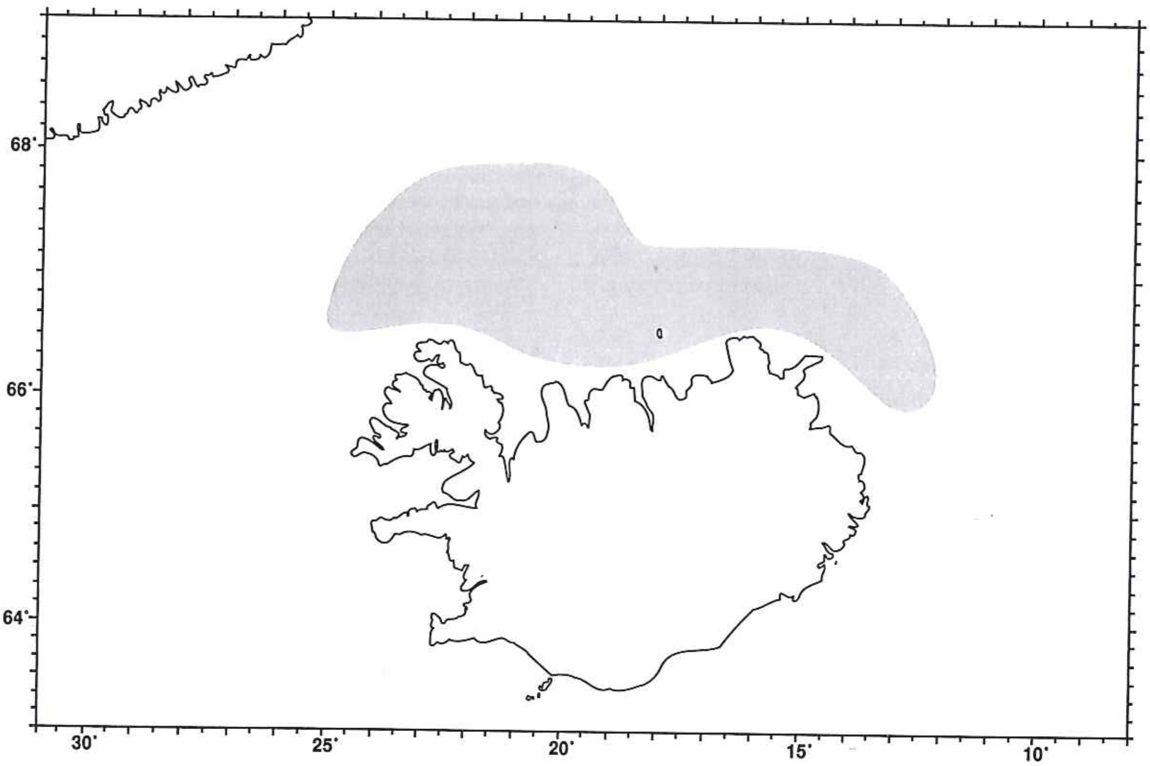

Figure 17.1. The main distribution area of 1-group capelin in August 1982–1992. See also Appendix III.2, Figures XLVIII–LVIII.

In the years 1989–1991 practically no capelin seem to have migrated to feed in the central and northern Iceland Sea. Instead, the adult stock apparently stayed in or near the shelf area north of Iceland, feeding there together with the immatures. The same was in part the case in 1992. In these years both the summer and autumn fishery was dependent upon mixed concentrations of adult and juvenile capelin. Although catches have mostly consisted of adult capelin by weight, there have been occasions when considerable parts of the catch by number have been juvenile fish. Furthermore, such fishery inevitably results in repeated escapes of 1-group fish, which are generally not retained by the mesh used in capelin seines. While there are no measurements of mortalities caused by an escape from a capelin seine, it is likely that fishing for prolonged periods on such mixed concentrations can cause mass mortality of 1-group capelin which goes unnoticed.

Through acoustic surveying, it is known that the main distribution area of juvenile 1-group capelin is usually in the shelf area north and northeast of Iceland. By comparing distribution maps from the August/September surveys in 1982–1992, the most important parts of the distribution area of this stock component have been localized and are shown in Figure 17.1 (cf. also Appendix I.2, Figs. XLVIII–LVIII). It seems advisable that for each season these areas should remain closed to a commercial fishery, at least until surveying in August and/or October/November has identified the current situation. This is further supported by the fact that immature juveniles are seldom encountered in the oceanic fishery between Greenland and Jan Mayen in summer and early autumn, while catches taken in Icelandic shelf waters sometimes contain a proportion of juveniles or are obviously taken from mixed concentrations of mature and juvenile fish, as was the case in the fall of 1980 as well as in 1989, 1990 and 1992.

18. FUTURE RESEARCH

In the past, rapidly developing pelagic fisheries were usually not preceded by detailed scientific studies of the target species. On the contrary, the main initial research effort often was a sampling programme for monitoring the catch composition followed by studies of behaviour and migrations in order to enhance the efficiency of the fishing fleet. The results were, at times, reflected in an almost astronomical increase in catch rates as described by Jakobsson (1971) for the Icelandic fishery of the Atlanto-Scandian herring. At the same time, knowledge of absolute stock abundance was incomplete, recruitment not sufficiently well known or understood and warnings of impending disasters, when given, were not heeded. For pelagic stocks this situation has indeed led to overfishing and at times even stock collapses (see *e.g.* Dragesund 1980; Jakobsson 1980).

The first systematic research on the Icelandic capelin essentially followed the course just outlined. The fishing for Icelandic capelin did not begin until in the mid-1960s, and the fishery had not developed in full until by the late 1970s. During this period a large data base of catch statistics and biological variations in samples from the catch was amassed. By using this information and the acoustic techniques of fish finding, developed in the 1950s and 1960s, it was possible to study and map the distribution and migrations of the adult part of the stock at various times of the year and thus facilitate the quick development of the capelin fishery. Indeed, the description of the biology of the Icelandic capelin stock, presented in this monograph, bears clear witness to the fact that the data collection was in the beginning determined by the needs of the developing fishery and later by information required for management purposes.

Fortunately, sophisticated acoustic techniques, developed in the 1970s, enabled an assessment of the abundance of pelagic fish on a real time basis. It is probably fair to state that the development and use of this technique, together with the disasters of previous decades of uninhibited fishery for other pelagic fish in Icelandic waters and other areas, were instrumental in containing the exploitation and management of the Icelandic capelin stock at an acceptable biological level. Thus, research on the Icelandic capelin has been successful, insofar as catastrophic man-made disasters have been avoided. Many of the questions, pertaining to capelin biology, have also been resolved. As stated above, past research on this capelin stock has, however, mainly revolved around the management of the resource and therefore is limited in its scope. For this reason, it is not surprising that the results of research in the past, presented in this monograph, unvail even more questions than they answer. There is, in other words, much to be learned about the ways of the Icelandic capelin and its interactions with other organisms as well as the physical environment. In addition to routine surveying of juvenile and adult capelin for management purposes, future research on the Icelandic capelin should, in the opinion of this author, be concentrated on the following main areas, some of which are necessarily interrelated:

1. *Spawning and spawning mortality.* Although the spawning behaviour of the Icelandic capelin has been observed directly in an aquarium tank and indirectly using acoustics, no direct observations have been made by divers or remote controlled underwater photography. Furthermore, the evidence presented in section 14.11, indicates that about one half of the 3-group females may recover from the spawning, provided that no males survive to spawn again. Naturally, if some males should survive, the survival rate of the females will be even higher. The theory should be tested since a spawning survival of that magnitude could considerably alter concepts of capelin biology and management strategies concerning this

stock. This could probably be done by following the spawning process at a convenient location as well as the subsequent migrations of spent fish, using underwater cameras and acoustics, and simultaneously collecting samples from the concentrations under observation.

2. *Stock/recruitment relationships.* It has been found that there is a marginally significant relationship between spawning stock biomass and the abundance of the resulting 0-group capelin. However, no such relationship has been detected, neither between parent stock size nor the numbers of 0-group capelin on one hand and the abundance of corresponding age groups on the other, when measured later in their life. However, there is a significant relationship between the numbers of 1-group capelin, measured in the autumn, and the numbers of capelin belonging to the same year class measured one year later as 2-group. The variables, physical or biological, which determine the survival rates of capelin, are not well known. Clearly, it is beyond human capability to influence survival rates to any degree. Nevertheless, it is important for us to understand the functioning of a resource which we exploit, especially since in this case we do so in competition with other exploited species of a much greater commercial value. In order to clarify the mechanism of capelin survival, it is necessary to gather much more detailed data than available at present. These should encompass hydrographic conditions as well as the development, species composition and abundance of phytoplankton and zooplankton for comparison with abundance estimates of the various age groups of capelin. Such studies would probably require repeated environmental observations in the shelf areas west, north and east of Iceland, lasting for several weeks in late winter, spring and summer. However, on the basis of available information on capelin biology and on the marine environment at Iceland, it should be possible to select strategic locations or sections for collecting sufficiently detailed information without unsurmountable expenditure with regard to research vessel time and manpower.
3. *Natural mortality.* As described in section 14.10 the survival or natural mortality rate of adult Icelandic capelin has been calculated. From a comparison of successive acoustic estimates and catch statistics it appears that on the average about 35% of the 3- and 4-group capelin will perish from natural hazards in the last year of their life. However, from the same data sources it is also indicated that the mortality rate may fluctuate considerably, or at least between 15 and 50 percent. Variations in natural mortality rates of capelin are to be expected due to the ever changing environmental conditions, the variable intensity of predation or both. A considerable improvement of mortality estimates would be expected from the tagging of adult capelin in spring or early summer, autumn and winter. The returns of tagged capelin could then be compared to acoustic estimates of the same stock components and catch data as well as the results of such environmental studies as described in the paragraph above. Tagging could in all probability also shed some light on the mortality rate of immature 1- and 2-group fish while obviously unsuitable for use in case of the very small larval and 0-group capelin.
4. *Diet and predator/prey interactions.* It is known that the Icelandic capelin feed mainly on copepod crustaceans, euphausiids and amphipods and are themselves one of the mainstays of the diet of many other species, such as cod and Greenland halibut and probably humpback whales to name but a few. However, the diet and feeding habits of the capelin are not known in detail and neither are their interactions with predators higher up in the food chain. For a better understanding of the status of the capelin in a multi-species context it is, therefore, necessary to enter upon detailed concurrent studies of the food and feeding of capelin and its predators as well as the availability of the prey items in relation to concurrent abundance and distribution of the predator species. Such studies were in fact begun in 1993, specifically aimed at investigating zooplankton-capelin-cod relationships, and should include the shelf areas around Iceland, the Iceland-Greenland region as well as the oceanic area between Iceland, Greenland and Jan Mayen.
5. *Variables affecting changes in distribution and migrations.* As described in chapters 7 and 13 we have observed large variations in the distribution and migrations of the stock, not only

with respect to the spawning in winter but also during the feeding period in spring and summer. It is, however, likely that an improved knowledge of environmental conditions, zooplankton abundance and the diet and feeding habits of the capelin, especially in the Iceland Sea, would greatly increase our possibility to throw light on this interesting and important subject. The changes in distribution and migration of capelin have almost certainly been brought about not only by variations in stock abundance of capelin, but first and foremost by variations in the environment, both physical and biological, which are inadequately known.

6. *Stock assessment and management.* For any heavily exploited stock it is of paramount importance to possess the means needed to assess its true abundance. In the case of the capelin, this is at present obtained by acoustic assessment, the underlying principle being that the strength of the returning echo signal is proportional to the abundance of the reflector. While this is certainly true, there are several ways in which errors may be introduced. Some of these arise from variations in the behaviour pattern of the fish, causing decreases or increases from the average due to abnornal tilt angles, near-bottom distribution and migrations of the fish. As explained in chapter 15, these variables can usually be identified and assessments repeated when conditions have improved. A serious error of another nature may, however, arise when different size categories occur in a mixture. Under such conditions, the sampling gear presently in use clearly favours the older and larger individuals, and thus the adult, fully grown part of the stock, will be overestimated at the cost of the immature and much smaller capelin. The design of a less selective fishing gear, or means for evaluating the degree of underestimation under such conditions, would greatly improve the reliability of the abundance estimates of the younger stock components in all circumstances and at times increase the accuracy of the assessment of the fishable stock size.

7. *Stock relationships.* It is common knowledge that capelin are also distributed, sometimes in fairly large quantities, in the East-Greenland shelf area from the Storfjord deep, which cuts across the East Greenland plateau west of the western side of the Iceland-Greenland Ridge, to Cape Farewell, the southernmost promontory of Greenland. In the past two decades or so, a considerable drift of capelin larvae to these areas has been observed in some years. At the present, the connection between the Icelandic capelin stock as here defined and the capelin in the shelf region off southern East-Greenland is otherwise unclear. This, however, would be a most interesting research project and should be aimed at as soon as feasible. Furthermore, the recent studies of possible genetic variations between capelin stocks have shown promise in differentiating between them. Such studies could also provide clues which might throw further light on capelin evolution and the ways by which the species colonized its present area of distribution. Because of difficult surveying conditions due to ice and weather in the shelf area off East-Greenland for parts of the year and for other practical reasons, it will be difficult in the immediate future to shed much light on the biology of these capelin and their possible relationship with capelin at Iceland or West-Greenland.

19. SUMMARY

1. The capelin *(Mallotus villosus)* is a small pelagic, schooling fish, native to the northern hemisphere and may in places occur in great numbers. In recent decades the species became the target of large fisheries. Due to the naturally occurring fluctuations in abundance and their schooling nature, capelin are sensitive to overfishing. Because of this as well as the importance of capelin in the food web of the areas which they occupy, the abundance and migrations of exploited stocks are now monitored as a matter of routine and their biology studied. One such stock is the Icelandic capelin which inhabit the area around Iceland and between Iceland, East-Greenland and Jan Mayen. The present work deals primarily with this stock, its biology and exploitation in general as well as in relation to the characteristics of the marine environment. The study is mainly based on research carried out since 1965. An outline is given of the distribution and biology of capelin in general. Records of and research on capelin in the Icelandic area prior to 1966 are described and discussed.

2. Capelin are salmonid fish which generally do not grow to more than 20 cm in length and 20–40 g in weight. In most cases they mature and spawn at 3–5 years of age. On reaching maturity there arises a considerable sex-linked dimorphism in growth and appearance, the males becoming larger than females of the same age and looking very different from them. The capelin are bottom spawners. The stocks in the Northeast Atlantic spawn at depth while most other stocks spawn on the beach or in very shallow waters. Spawning mortality is high. Capelin are plankton feeders and in turn they provide an important item in the diet of many species of fish, marine mammals and sea birds. They are widely distributed in the northern oceans, the northern boundary usually being the southern limit of the polar water. It is generally thought that the species originated in the Pacific. There are several stocks or stock complexes of capelin that do not seem to be panmictic. These are the Barents Sea capelin, the Icelandic stock (capelin in the Iceland – East Greenland – Jan Mayen area), the West Greenland capelin and the Newfoundland and Labrador capelin complex. On the Pacific side, capelin are not described in the literature as belonging to specific and well defined stocks.

3. Because of their common occurrence and large numbers, records of capelin at Iceland during past centuries are surprisingly few and far between. The species is first mentioned in 1638 by bishop Gísli Oddsson in his work on the wonders of Iceland and shortly thereafter by his contemporary Jón Guðmundsson in his Natural History of Iceland. About a century later an Icelandic naturalist, Jón Ólafsson, wrote a treatise on Icelandic fishes where he includes capelin under two section headings, *i.e.* hairy herring and hairy trout. From Ólafsson's work it is inferred that Icelanders may have considered it dangerous to eat capelin and hence the annalists of earlier centuries probably did not consider its appearance on local beaches worth mentioning. At any rate, it appears that it was first in the late 18th century that Icelanders begin to make some use of capelin.

4. It was not until in the 1890s that studies of the Icelandic capelin were undertaken beyond the descriptive stage. This was done through the work of the Danish scientist Paul Jespersen who investigated the spawning and larvae of capelin, and the first Icelandic fisheries biologist Bjarni Sæmundsson who concerned himself with the older age groups. During the period 1890–1920 these two scientists pieced together the life history of the Icelandic capelin stock in surprising detail considering the facilities at their disposal. However, it was left to Árni Friðriksson to discover that the age of capelin could easily be read from the structure of the otolith. Mrs. J. V. Magnússon carried out further studies on the growth and distribution of larval and 0-group capelin at Iceland in the early 1960s.

5. After initial experiments with gear and methods for processing, a capelin fishery for meal and oil was started in 1965. Concurrent with this, a sampling programme was set up for systematically studying the commercial and research vessel catch and shortly afterwards a search system was set up for investigating capelin distribution, behaviour and migrations. A special survey for monitoring the relative distribution and abundance of 0-group capelin has continued since 1970, and from 1978 the abundance of adult fishable capelin has been assessed by acoustic methods. Surveys of juvenile 1- and 2-group capelin have been carried out since 1980. In addition, the marine environment at Iceland has been monitored regularly since the 1950s.

6. A survey is given of the bathymetrical features of the sea area around Iceland and adjacent waters. The main feature of the area is a system of transversal submarine ridges, extending on one hand northwest from Scotland through the Faroes and Iceland to Greenland, and on the other hand, parts of the mid-Atlantic ridge, *viz.* the Reykjanes ridge to the southwest of Iceland and the Kolbeinsey ridge, leading to the northeast towards Jan Mayen. A third ridge extends due south from Jan Mayen to the submarine terrace northeast of Iceland.

A general description is given of the main ocean currents of the Iceland Sea and the waters to the southeast, south and west of Iceland. It has been shown that these are influenced by bathymetrical features as well as by meteorological conditions. The main components of the current system are the North Atlantic Drift, transporting warm Atlantic water to the south coast of Iceland, its continuation, the Irminger Current bringing this water to the west coast as well as to the north and east Icelandic shelf area, the East-Greenland Current the main branch of which transports polar water south along the east coast of Greenland and the East-Icelandic Current which branches off from the easternmost part of the East-Greenland Current, runs south and then east towards the area east and northeast of Iceland and is much less polar in character. A coastal current runs in a clockwise fashion around Iceland and is mainly driven by gravity forces due to the freshwater runoff.

Definitions are given of the main primary and secondary water masses of the area. The main features of temperature and salinity distribution in the Icelandic sea area are described. Changes of these variables have generally been related to large-scale changes in the atmospheric circulation in the arctic regions in the past. The area north of Iceland is characterized by markedly stronger stratification and smaller nutrient concentrations than found in the Atlantic water in the south and west. Fresh water runoff is important for the development of stratification in coastal areas.

Comparison with other sea areas indicates that primary production is relatively high in Icelandic waters, However, it has been found that production is highest where Atlantic water predominates but markedly lower in the highly stratified arctic waters north and east of Iceland. The reasons for the large variations in primary production of the Icelandic sea area are discussed.

The main features of zooplankton distribution and species composition in Icelandic waters in the last 25–30 years are outlined. There was a large drop in the volume of zooplankton and changes in species composition in the north Icelandic area during the ice years 1965–1969 followed by a partial recovery. Much smaller variations were observed in the Atlantic waters to the south and west of Iceland and in the oceanic area north of the Icelandic submarine terrace. In accordance with the development of primary production it has been found that zooplankton production generally begins in the shelf area north of Iceland in mid-May and peaks in June.

7. The winter migrations of the mature part of the capelin stock to the spawning areas off the south and west coasts of Iceland are described. It is found that as a rule these capelin follow the outer edge of the continental shelf north and east of Iceland in a clockwise direction along a temperature gradient of some 0–2.5°C. When arriving in the area about 50–80 naut. miles off the southern east coast the spawning migrations encounter sharp temperature gradients where waters of the North Atlantic drift meet the East Icelandic Current. From there the migrations either follow the boundary zone between the cold and warm water masses up to the southeast coast or enter the warm Atlantic water while still in deep waters southeast of Iceland and approach the south coast farther to the west. At this point the rate of maturation increases and the capelin will spawn off the south or southwest coast about 3 weeks after entering the warm Atlantic water in the southeastern area. Over the years, this route of

migration has changed little while the timing of the migrations and hence the distance travelled in the period January – March has been subjected to large variations. Migration speeds have also been highly variable. The reasons for such changes are discussed. Occasionally, part of the spawning stock remains off the Vestfirðir peninsula and enters the west and southwest coast spawning grounds directly from the northwest. While migrations from the west may constitute up to one half of the spawning biomass, such occurrences are rare. Small amounts of capelin migrate to spawn in fjords on the north coast of Iceland. These migrations arrive from the north.

8. In the past decades, the main spawning grounds of the Icelandic capelin have been in the warm Atlantic waters off South and Southwest Iceland where the sea temperature ranges from 5°C to 7°C. Lesser spawning takes place in fjords on the north coast. The stock does not seem to have any important spawning grounds outside Icelandic waters. Egg deposition has been recorded at depths ranging from 8 to 90 m with maximum density between 30 and 50 m. The nature of the substrate ranges from muddy sand to sandy gravel. Like the Barents Sea stock, the Icelandic capelin do not spawn on the beach as is the rule among capelin populations of the Northwest Atlantic and in the Pacific.

9. The behaviour of the Icelandic capelin during spawning has been studied in aquarium tanks and found to be similar to that observed *in situ* by divers off Northern Norway and among the beach spawners of Newfoundland. Thus, the sexes tend to segregate shortly prior to the actual spawning process which takes place in pairs or threes. The female enters the group of waiting males which hold the females to their sides by means of the spawning ridges and upturned pelvic and pectoral fins. The male may repeat the process of copulation while the female appears to become spent in one run and leave the spawning grounds. For this reason, the male/female ratio increases towards the end of the spawning season.

10. At the temperatures prevailing on the spawning grounds at Iceland capelin larvae hatch in 20–25 days. With the bulk of the spawning usually taking place in March, the hatching of capelin larvae usually begins in late March and peaks in April. Due to late migrations, arriving after the main spawning is over and spawning in the colder waters off the north coast, newly hatched capelin larvae may be found as late as June or even in July. On ascending to the surface waters the capelin larvae start drifting with the surface currents to the areas west and north of Iceland, gradually spreading into more offshore waters as they do so.

11. Variations in the distribution and abundance of 0-group capelin have been monitored annually in August since 1970. At that time of year this age group has mainly been found over the shelf west, north and east of Iceland. It has been found that part of the capelin larvae sometimes drift west across the Iceland-Greenland Ridge to the East-Greenland shelf. An examination of the distribution of the abundance indices by areas shows that variations in abundance are largest in the northern part of the Irminger Sea and east of Iceland, but smallest in the areas north and west of Iceland. Autumn surveys show that the 0-group may also drift to the southern and central Iceland Sea in some years.

12. Studies of the diet and feeding habits of the Icelandic capelin indicate that among the smaller size groups calanoid copepods, especially juvenile stages of *Calanus finmarchicus,* constitute the most important food category. These studies further indicate that as the capelin grow older and larger this group of food items is replaced by adult calanus, euphausiids and amphipods. There are two diurnal periods of main feeding activity coinciding with sunrise and sunset. Feeding intensity is highest in summer and generally decreases in autumn. However, intensive feeding may take place in the winter period and it is suggested that such occasions are linked to periods when feeding conditions have been inadequate in the preceding summer.

13. The feeding and early winter migrations of juvenile and adult capelin are described and discussed. By comparison to the August distribution of the previous year, it is concluded that the winter distribution of 1-group capelin is mostly the result of the 0-group drift pattern of the previous year and not due to active migration. In most years of the 1982–1992 period, the 1-group juveniles have mainly been distributed in the shelf area off the central and the northwest coast of Iceland where the distribution may reach farther north beyond the shelf. It is thought that occasional records of 1-group juveniles in the central Iceland Sea in summer is the result of lar-

val drift to these waters in the previous year. Immature 2-group capelin also tend to be distributed at lower latitude in summer although they are usually found somewhat farther to the west and north than the 1-group. In the last decade or so, immature capelin have mainly been distributed off the central and northwest coast in midwinter, while in the 1970s this stock component was often found off Northeast Iceland. The adult stock generally executes much more extensive feeding migrations. Thus, these capelin are frequently found in the central and northern Iceland Sea in summer, returning south to the outer part of the Icelandic shelf in autumn. It is seen, however, that these migrations are subject to large variations which appear to be linked to changes in the hydrographic conditions of the Iceland Sea and their effect on the planktonic communities of that area.

14. The average growth of the Icelandic capelin in length and weight by sex and maturity has been compiled, using the mean of all available data on length and weight in July/August, October/November and January/February in the 1979/80–1992/93 period. In the absence of satisfactory data from spring and early summer, it was assumed that the onset of growth coincided with the development of zooplankton in the area. It is found that the rate of growth is sex-related, being faster among the males after the maturity process begins. Among the juveniles, growth rates appear to be similar for both sexes. Mature males continue growing both in length and weight in the winter period.

Using the basic equation $w = \alpha l^{\beta}$, weight-length relationships were analyzed for each sex and the immature part of the Icelandic capelin stock from bi-monthly averages for the summer, autumn and winter seasons. The adequacy of the model was tested with respect to season and sex. It was found that all interaction terms are needed to describe physical condition in this way since α and β are variables depending upon sex and season. There are fundamental differences in the physical condition of capelin as a function of time, between the immature part of the population on one hand and that of the mature capelin on the other. The observation of a good condition of male capelin throughout the spawning season is contrary to the view that due to their greater expenditure of energy in the coupling process most of the males die of exhaustion after spawning.

It is found that maturity is closely related to increase in length. In October/November the length at which 50% of individuals are mature is 13.54 cm on the average. Furthermore, it is found that the 50% maturity length for females is 12.89 cm but 14.44 cm for males. Thus, females mature at a 1.55 cm smaller size than the males. This difference is larger than observed between maturing 2- and 3-group males and females, which implies that females of this capelin stock not only mature at a smaller size than males but also at a younger age.

The proportion of each year class which matures to spawn at age 3 is given. An analysis shows that the maturing ratio is inversely related to year class abundance which is most easily explained by competition for food. There is a considerable variation in the maturing ratio/year class abundance relationship, presumably due to variations in feeding and other external conditions.

The distribution of age groups in the spawning stock has varied through the years. In general, the contribution of 3 year olds has in most cases been by far the largest. This is followed by 4 year olds, which on rare occasions have contributed up to one half or more by number. The contribution of 2- and 3-group fish has always been relatively insignificant. As expected, females form a majority among age groups 2 and 3 while males are dominant in age groups 4 and 5.

The average lengths of 3-group females and males in the spawning stock are 15.0 and 16.4 cm respectively, and the corresponding figures for the 4-group are 16.0 and 17.3 cm. The weights af these stock components are 16.5, 23.4, 21.9 and 28.5 g in the same order. The lengths and weights have varied considerably over time with observed inter-annual variations of 1 cm and 4–6 g and long term variations approaching twice these figures. As expected, growth within an age group is seen to be more similar than when different age groups are compared. However, variations in growth of the different year classes coincide with variations in hydrographic conditions in the north Icelandic area as measured in the spring of the relevant feeding seasons.

By averaging the weekly values of the fat content of capelin catches, changes in percent fat of the maturing, fishable part of the stock have been compiled. There is a rapid accumulation of body fat in the summer/autumn season culminating in October after which time there is a slow decline for the rest of the year. Towards the end of January there is an acceleration in the rate of decline of fat content, and this energy reserve has become practically depleted at the time of spawning in March. While no such information is available on the immature stock, circumstantial evidence indicates that the fat content of this stock component is much lower. The fat content of the Icelandic capelin is subject to large temporal and spatial variations. During the summer fishery the highest fat content is registered in the northernmost parts of the distribution area.

The rate of maturation has been studied by comparing changes in the weight of the female ovaries in relation to the total weight of the body. It is seen that in October the weight of the ovaries is approximately 2% of the weight of the body and has reached about 5% by the end of the year. By the end of January, when the spawning migration enters the warm Atlantic water off the southeast coast, the weight of the ovary is 10–12% of the total body weight, increasing to approximately 30% at the time of spawning. Although fairly readily distinguished from females in October – November, the male capelin do not acquire their striking external sexual characteristics until January, and they do not become fully developed until shortly before spawning.

A measure of natural mortality among the maturing part of the stock is obtained by comparing within-season successive acoustic estimates of stock abundance and catches during the intervening period, using a method developed by Beverton and Holt. It is found that while there may be considerable inter-annual variations, the average monthly natural mortality rate in the period October – January is approximately $M = 0.035$ or 13.1% for the 4 month period.

Studies carried out by other workers indicate that as among most other fish, the initial sex ratio of capelin is 1:1. Given that there are no great sex-linked differences in natural or spawning mortalities, an equal contribution of each sex would therefore be expected in studies of whole year classes. However, this was not found to be the case. On the contrary, there was a clear and significant preponderance of females. With the above assumption of similar natural mortality rates for both sexes and considering the fact that gear selectivity, if it existed in case of adult capelin, would favour the largest fish (males), the above difference is best explained by sex-related spawning survival. Assuming a total spawning mortality of the males this indicates that in general terms about one half of the 3-group females survives the spawning process.

Vertebral counts were carried out on a regular basis in the 1970s and the early 1980s. The grand average is 69.23 and 69.25 for females and males respectively, including the urostyle. This is slightly lower than indicated by earlier studies. It is found that the vertebral count of the Icelandic capelin is similar to that of the capelin of the Barents Sea. Capelin of the Northwest Atlantic and the eastern North Pacific have a much lower number of vertebrae (66.30–66.80) while Greenlandic capelin are in an intermediate position (68.21).

15. The distribution and abundance of 0-group capelin of the Icelandic stock has been recorded annually since 1970. The main purpose of these studies was to obtain estimates of year class abundance as early as possible. It is found that there is a significant correlation between the abundance of 0-group capelin and the underlying parent stock size, while neither of these correlate with year class abundance measured later in life. It is concluded that, other things being equal, year class size must be primarily determined by environmental conditions during the first winter and feeding conditions in the following spring.

In the 1970s it was attempted to estimate stock size by tagging. This experiment yielded valuable information on capelin migrations over the Icelandic shelf area and into the Iceland Sea. Although the tag returns were also indicative of stock abundance, the results were not available in time for management purposes.

Since 1978, the abundance of the fishable stock has been assessed annually in autumn and during most years also in winter by acoustic methods. The requirements for a successful execution of acoustic stock assessments are discussed and descriptions given of the strategy employed as well as the equipment used, data acquisition and handling. A summary description of all surveys is also given. The reliability is tested of the acoustic estimates of fishable stock abundance thus obtained. A measure of precision is found by comparing consecutive surveys of the same stock component, carried out within very short time intervals. As a test of reliability, autumn estimates are compared to winter estimates when available, taking account of catches and natural mortalities in the intervening periods. There are 11 such pairs of comparable autumn/winter estimates. Statistical testing of these indicates a coefficient of variation of 13% for the full data set but 3% when the outliers of 1986/87, 1990/91 and 1991/92 are omitted. In all of the anomalous cases it is noted in the survey reports that the autumn estimate was suspect due to abnormal behaviour of the capelin. It seems, therefore, that when measurements are successful and all of the stock has been surveyed, the coefficient of variation is not likely to exceed 5%. In some years, however, there are problems with the autumn estimates which may have a potential for any amount of underestimation. However, experience has shown that such situations can usually be identified.

The abundance of juvenile 1- and 2-group capelin has been assessed since 1980 during the autumn surveys of adult stock abundance. Although the actual abundance of these stock components has always been grossly underestimated on these occasions, the underestimation appears to be systematic as is inferred from comparisons of these estimates to total year class abundance, calculated from acoustic estimates of adult capelin, catches and natural mortalities. Since 1982, the abundance of juvenile 1- and 2- group capelin has also been assessed in August. It appears that in some years the August surveys have not completely covered the juvenile stock and the resulting estimates do not correlate well with other estimates of year class strength.

On the basis of the biological characteristics of the Icelandic capelin stock and records of monthly catches, an estimate of changes in year class abundance by number and biomass have been estimated. This has been done for the year classes 1976–1990 by back-calculating acoustic stock estimates to a point in time before the year classes first became subjected to a fishery. Similarly, the biomass remaining to spawn at the end of each season in the period 1979–1993 may be calculated. Large variations in year class abundance have been observed in this period. From a comparison between spawning stock biomass and assessments of year class abundance at the 0-group stage and later in life, it appears that in these years variations in year class abundance in the Icelandic capelin stock have not been induced by the fishery, but most likely they have mainly been effected by naturally occurring phenomena.

16. The development of the fishery of the Icelandic capelin is described in detail. In short, the fishery began in coastal waters south and west of Iceland late in the spawning season in the mid-1960s. In 1972 there began an oceanic fishery east of Iceland which continued to the end of the spawning season in March – April. In this period the catch increased from 50 to almost 500 thous. tonnes. In 1976 a summer and autumn fishery for capelin was initiated in the deep water area off North and Northwest Iceland, and in the summer of 1978 Norway began fishing from this stock in the area between Jan Mayen and Greenland. This was soon followed by vessels from the Faroes and Denmark. With the advent of the summer-autumn fishery the catch increased to more than one million tonnes in the period 1976–1979. Since then the Icelandic capelin stock has been fished by a multi-national fleet in the period from July to March in the following year whenever stock abundance allowed. Annual catches have varied from zero to about 1.3 million tonnes.

17. The management of the capelin fishery is described. Initially, regulatory measures were precautionary in nature, consisting of a closed season in spring and summer, and regulations were imposed concerning minimum mesh size and minimum allowable landing size. All of these were primarily aimed at protecting the juvenile part of the stock from the fishery. Due to their extensive feeding migrations, the Icelandic capelin come under the jurisdiction of three countries, *i.e.* Iceland, Greenland and Norway. In 1980 an agreement was reached between Iceland and Norway on the setting and division of catch quotas, and in 1989 Greenland decided to become part of an agreement for the same purpose.

Because of the schooling nature, easy accessibility and modern techniques of fish finding and catching, capelin catch rates may remain high even under conditions of low stock abundance. Due to the very short life span and high spawning mortality, the fishery is primarily based upon recruits which are subject to large fluctuations. The primary management objective is, therefore, to preserve a sufficiently large spawning stock. For the same reasons management must largely rely on real-time assessments. Since 1980 a remaining spawning stock of 400,000 tonnes has been the management target. After obtaining an acoustic assessment of fishable stock abundance, age composition and weight at age, the total allowable catch for the season can be calculated if the natural mortality is known.

In the early 1980s, preliminary catch quotas were set at a relatively high level. Since the quota was allocated to vessels, all of which did not begin the fishery at the same time, this soon led to difficulties in cases when stock abundance proved to be much smaller than anticipated. This in turn led to the development of a model for forecasting stock abundance, primarily from assessments of juvenile capelin abundance, obtained during the August 0-group surveys, and setting the preliminary catch quota at about one half of the predicted total stock abundance. However, this model soon proved inaccurate and failed in forecasting the near stock collapse in the late 1980s. A new method was then devised and is presently used for fishable stock predictions. This improved model uses autumn assessments of the abundance of the younger component in next season's fishable stock while the maturing ratio is used to predict the contribution by the older age group. The retrospective performance of both models is tested using actual data. It is found that the new model, if applied to hindcasting, would have given predictions of stock abundance that are far superior to those given by the older method.

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APPENDIX I
Descriptions of surveys of stock distribution and abundance

Appendix I.1. Stock assessment surveys during autumn and winter in the 1978/79–1992/93 seasons

The following is a summary of all of the autumn and winter surveys of the maturing capelin stock as well as of 1- and 2-group juveniles. More detailed descriptions are given by Vilhjálmsson (1979–1989, 1991) and Sveinbjörnsson (1990–1993) as well as in unpublished survey reports listed in Appendix I.3.

Acoustic estimates of adult (maturing) capelin abundance in number and biomass, obtained in autumn 1978–1992 and winter 1979–1993, are given in Appendix II.2, Tables XII and XIII and the abundance of the 1- and 2-group juveniles by number in Appendix II.2, Tables XIV and XV, respectively.

The 1978/79 season. The first acoustic estimates of the abundance of the Icelandic capelin stock were obtained in the period 20–29 October 1978. Through scouting by research and fishing vessels in late September as well as in the first half of October, it had been established that practically all of the maturing fish were in the process of assembling in a very limited area in the southern Iceland–Greenland Channel. For this reason it proved possible to obtain three independent abundance estimates in this short period. Weather and ice conditions remained good except for a storm of short duration which prevented the completion of the second survey (Fig. I) and, consequently, lowered that abundance estimate. The two valid estimates of adult capelin abundance (Fig. I) amounted to 1,487,000 and 1,615,000 tonnes, respectively, yielding an average of about 1,550,000 tonnes (Appendix II.2, Table XII).

In the latter half of January 1979, a pilot survey located the spawning migration at the shelf edge east of Iceland and determined its extension. Because of good weather conditions the migration could be assessed three times in the first week of February (Fig. II). The average of these three surveys gave, however, a biomass of only 575,000 tonnes of adult capelin (Appendix II.2, Table XIII). In view of the results of the October survey in the year before, it was, therefore, clear that a large part of the adult stock must still have been missing.

The survey was continued in the area north of Iceland where there was much ice in February 1979. However, the shelf area off the Vestfirðir peninsula was ice-free and the rest of the mature stock was in fact located there and its abundance assessed on 8–9 February (Fig. IIIA). At that time there was some surface schooling in the western area, and mixed recordings of age groups caused difficulties in determining the proportion of mature fish. With the above reservations the total abundance of mature capelin was estimated to be about 535,000 tonnes (Appendix II.2, Table XIII).

The western area was surveyed again in the third week of February (Fig. IIIB). In the intervening 10 days the position of the adult stock had shifted to the southwest, while the immature part remained in the same area as before. After waiting out a few days of stormy weather, conditions improved greatly. The adult capelin were mostly distributed in a continuous scattering layer, and a reliable estimate of their abundance in the western area was obtained on 17–18 February. This survey gave an abundance estimate of about 605,000 tonnes of adult capelin (Appendix II.2, Table XIII).

In early March the size of the eastern migration was assessed once more at the southeast coast (Fig. IV). There were severe acoustic sampling difficulties due to surface schooling, shallow distribution and migration speed which had to be adjusted for. When this had been done and account had been taken of the large catches

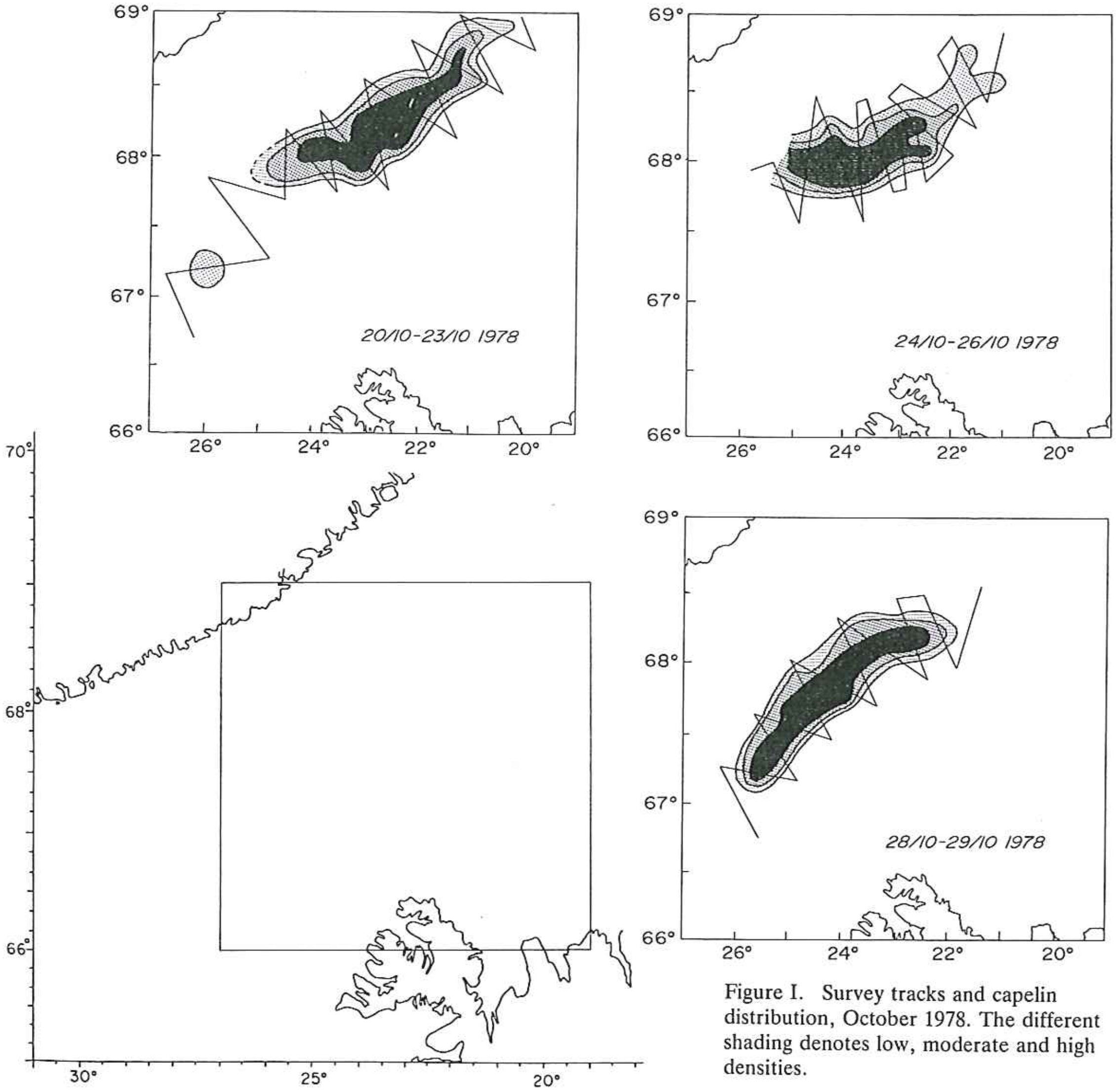


Figure I. Survey tracks and capelin distribution, October 1978. The different shading denotes low, moderate and high densities.

which had been removed from the stock in February, the resulting abundance estimate of 340,000 tonnes exceeded that obtained about 4 weeks earlier (575 000 tonnes) off the east coast by about 20% (Appendix II.2, Table XIII). However, due to the difficult surveying conditions, this stock estimate was judged to be too subjective for management purposes.

The 1979/80 season. An attempt to obtain an early estimate of fishable stock abundance was made by a joint Icelandic/Norwegian survey of capelin in the Iceland Sea in August 1979 (Fig. V). It later became clear that this survey had greatly underestimated the stock abundance. Thus, the August 1979 estimate of fishable stock biomass had to be scaled upwards by a factor of 3 in order to fit more reliable estimates of the same stock biomass, obtained later in the season (Vilhjálmsson 1980; Vilhjálmsson *et al.* 1982; cf. also Appendix II.2, Table XII). There appeared to be two main reasons for this discrepancy. As in the September 1978 experiment, near-surface distribution of dense, small schools was common, and in addition drift ice was widespread, in particular in the area between Northwest Iceland and Greenland as well as off Scoresby Sound.

From 25 September to 5 October 1979 Iceland

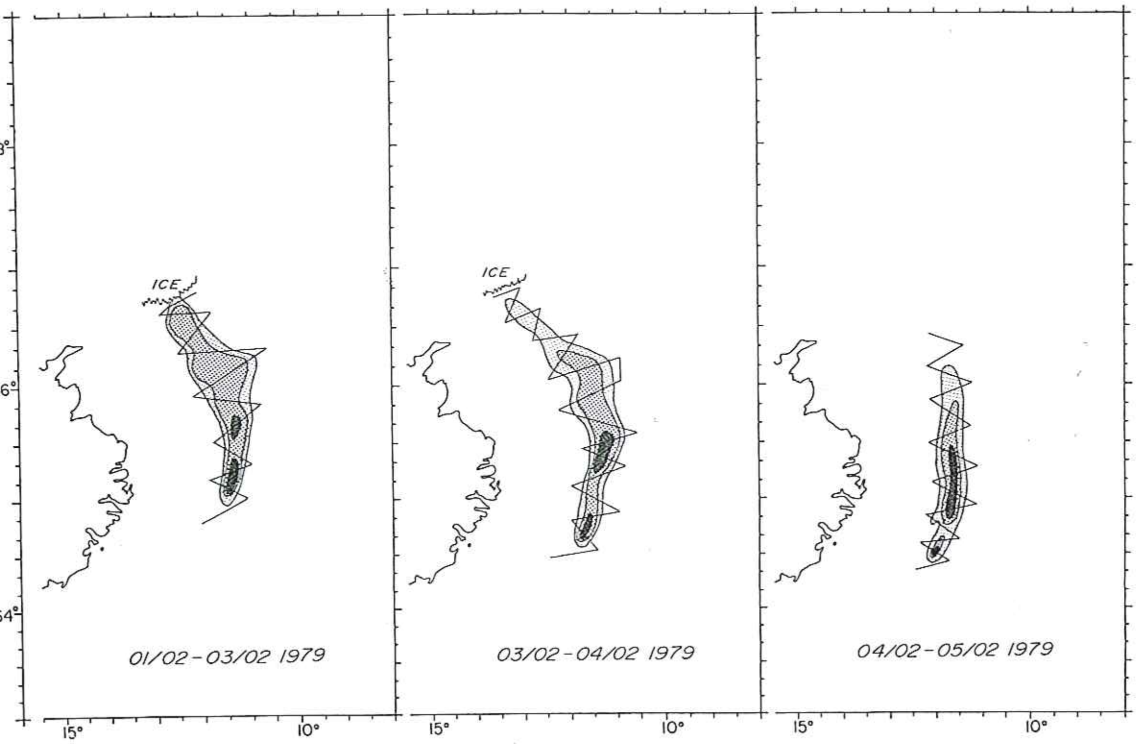


Figure II. Survey tracks and capelin distribution, East Iceland, February 1979. The different shading denotes low, moderate and high densities.

and Norway carried out a joint survey of the capelin in the Iceland Sea and the area between Northwest Iceland and Greenland east of 28°W (Fig. VI). In the northernmost part of the area surveying was somewhat inadequate due to stormy weather. For the remaining part, there was no interference by wind or drift ice and surface schooling did not seem pronounced. At the time of this survey most of the fishable stock was located at or just east of the Polar Front, from due east of Scoresby Sound to northwest of cape Horn on the Vestfirðir peninsula, with immatures being mainly recorded farther west. The resulting abundance estimate of about 800,000 tonnes of maturing capelin (Appendix II.2, Table XII) was, however, strongly contested by local fishermen and authorities which had judged the stock to be much larger. The main reason for this was the relatively low abundance, recorded by the research vessels, in and near the main fishing area, some 120 naut. miles north of the central north coast of Iceland.

The maturing stock was surveyed again in the latter half of October 1979 (Fig. VII). When adjusted for the catch in the intervening period, the new estimate was about 30% higher than the previous stock estimate (Appendix II.2, Table XII). A later assessment in January 1980 gave similar results when the large November catch had been accounted for. In retrospect, the most plausible explanation for the discrepancy between the first and the subsequent estimates seems to lie in the survey tracks being generally too sparsely spaced during the joint September/October survey, especially in some areas of very dense but discontinuous concentrations. At the time, however, the prevailing behaviour pattern of the capelin, while assembling on the wintering grounds (occasional schooling in the near-surface layer), was blamed for the low September/October abundance estimate.

A stock assessment survey was planned for the area east of Iceland in January 1980. However, in spite of extensive scouting no capelin had been located off East or North Iceland by the middle of the month, and at the time there was much drift ice off the Vestfirðir peninsula. This situation did not improve until around 20 January when it became clear that all of the mature stock was distributed at the shelf edge to the west and northwest of Vestfirðir. In the days that followed the adult stock migrated northeast and eastwards and its abundance could be assessed in the area north of Vestfirðir and the western north coast from 25 to 29 January (Fig. VIII). There was good weather throughout this period, the distribution of the stock relatively even, and, through previous scouting by fishing as well as research vessels, its position was known in detail. The resulting abundance estimate of 755,000 tonnes of adult capelin was, therefore, considered reliable (Appendix II.2, Table XIII).

The 1980/81 season. In view of previous experience, the joint Icelandic/Norwegian autumn stock assessment survey took place in the period 11–22 October 1980 (Fig. IX). At the time the stock was divided in two parts, one being registered in the Iceland–Greenland Channel south of Scoresby Sound and the other over the Iceland–Greenland Ridge, some 150 naut. miles farther south. Weather conditions remained good during the survey. There was drift ice over the Greenland shelf south from Scoresby Sound. However, this was not thought to have affected the adult capelin stock estimate of 505,000 tonnes (Appen-

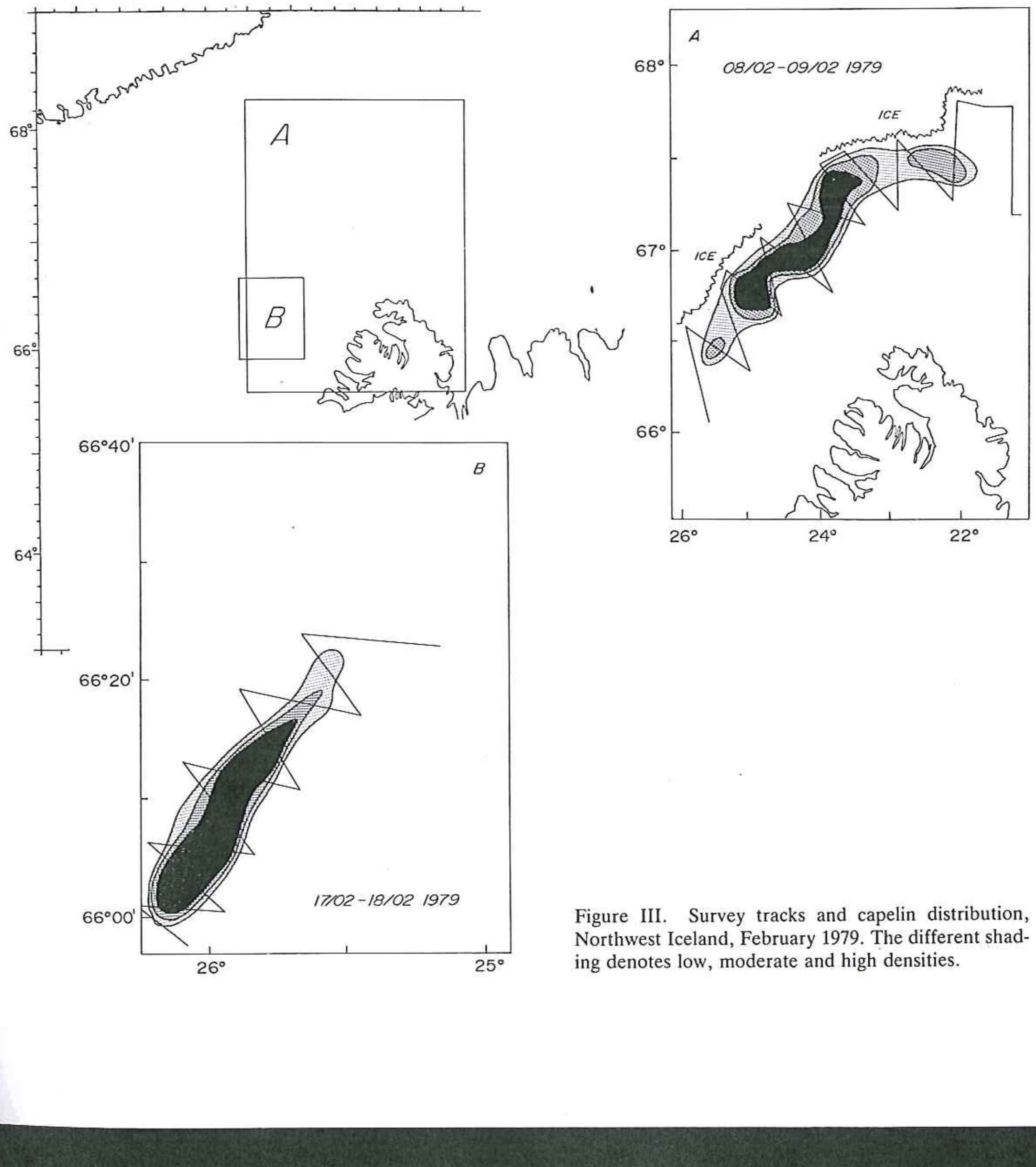
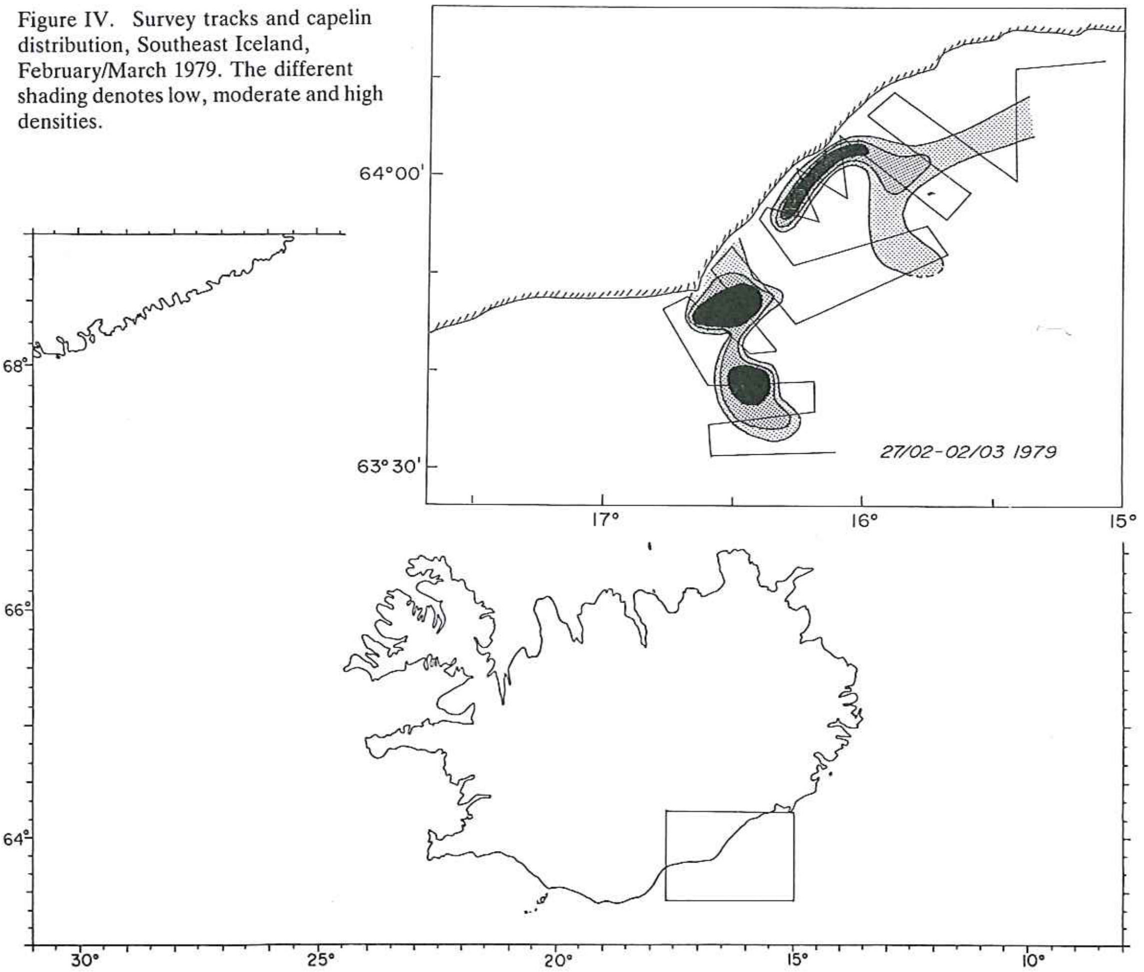


Figure III. Survey tracks and capelin distribution, Northwest Iceland, February 1979. The different shading denotes low, moderate and high densities.

Figure IV. Survey tracks and capelin distribution, Southeast Iceland, February/March 1979. The different shading denotes low, moderate and high densities.



dix II.2, Table XII), which was much lower than had been expected.

The credibility of the reduction in capelin biomass, measured by the new and "alien" acoustic method during the previous two seasons, had been doubted by the skippers of many of the Icelandic capelin boats. Because of this and the high financial stakes, the Icelandic Association of Fishing Vessel Owners engaged an FAO acoustics expert to judge the validity of the results, already obtained. After a thorough study of the methods applied, both in calibration and actual surveying, it was concluded that the acoustic measurements were valid and that the observed changes in stock abundance were real, at least in relative terms (Jóhannesson 1980).

The first part of the 1981 spawning migration was located northeast of the Langanes promontory on 10 January. At the time there was much ice in the area north of Iceland, the weather remained stormy for the next ten days and stock assessment could not be made.

During 20–22 January conditions improved greatly and the abundance of the spawning migration was assessed independently by two vessels at the shelf edge off Northeast Iceland (Fig. X). The resulting estimates differed considerably, being 430,000 and 270,000 tonnes respectively (Appendix II.2, Table XIII). However, after a comparison of echo recordings, obtained by the two vessels, it became clear that course lines had been far too sparsely spaced in view of the very uneven distribution of the capelin.

The 1981 spawning migration was, therefore, assessed for the third time during 27–29 January (Fig. X). This survey was carried out jointly by the two vessels and course lines much more densely spaced than in the previous assessments. The resulting estimate was 322,000 tonnes (Appendix II.2, Table XIII), which is similar to the average of the two assessments obtained before, and corresponds well with the autumn 1980 estimate when adjusted for the catch.

The 1981/82 season. In the period 14–23 October 1981 Iceland and Norway carried out a joint survey of capelin abundance in the Iceland – Greenland – Jan Mayen area west of 12°W (Fig. XI). As in the year before the maturing stock was distributed over two areas. The northern area was located between 69°00′N and 70°30′N while the southern part of the stock was found north of Iceland between 67°30′N and 68°30′N. At the time of this survey there was much drift ice between Northwest Iceland and Greenland, where the bulk of the stock had been located in the year before. Because of this and the generally scattered distribution, especially of the capelin

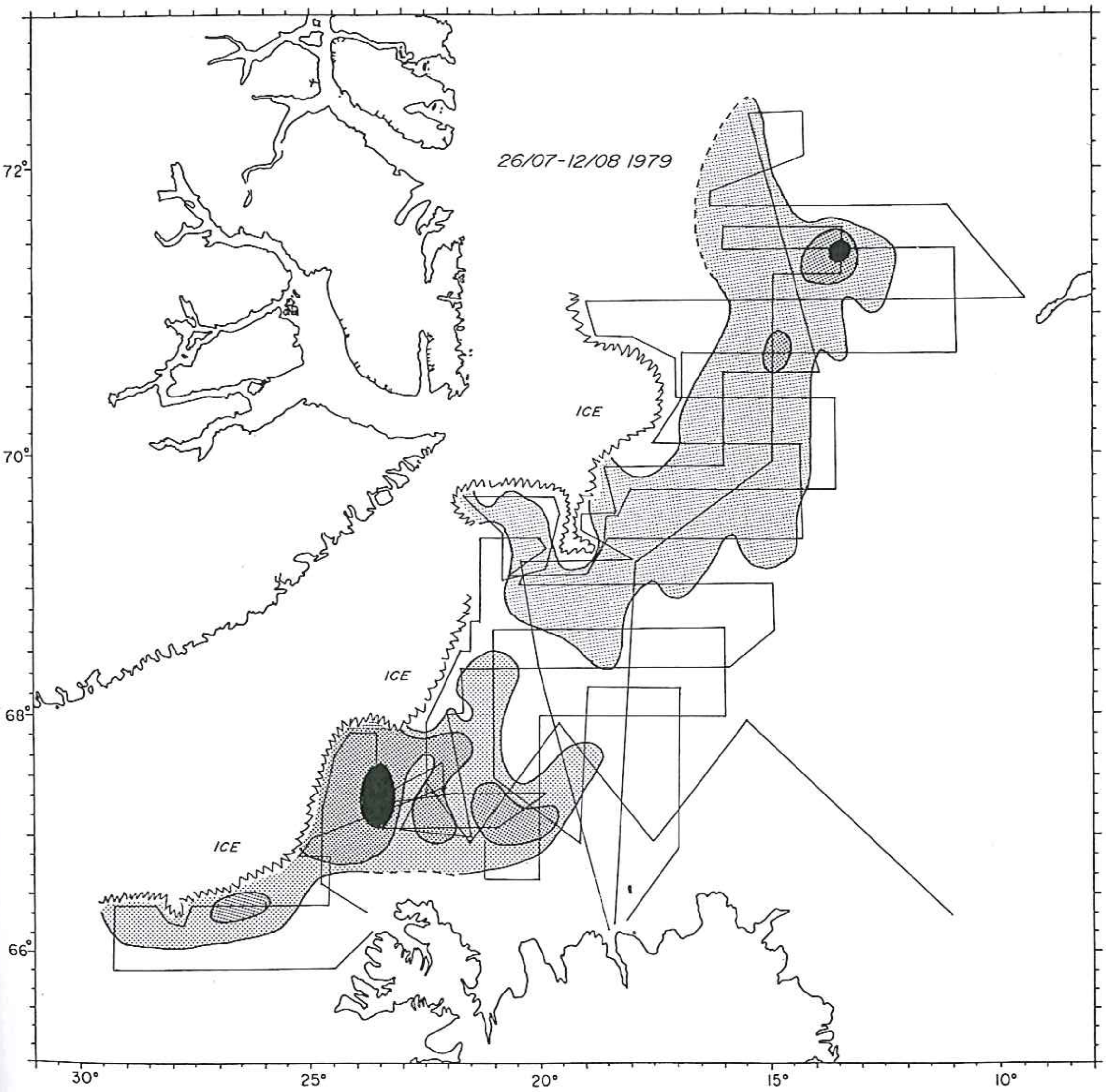


Figure V. Survey tracks and capelin distribution, July/August 1979. The different shading denotes low, moderate and high densities.

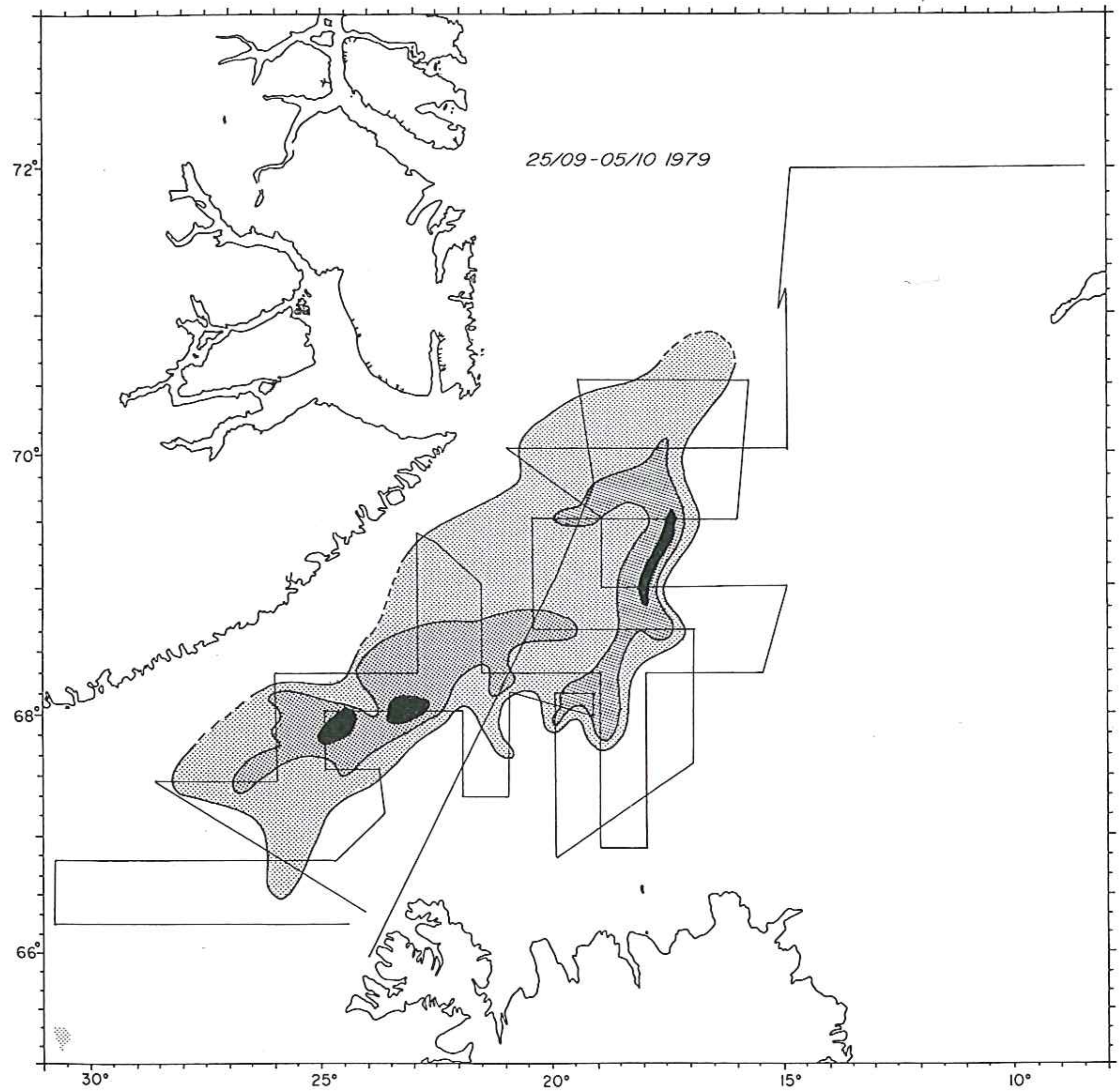


Figure VI. Survey tracks and capelin distribution, September/October 1979. The different shading denotes low, moderate and high densities.

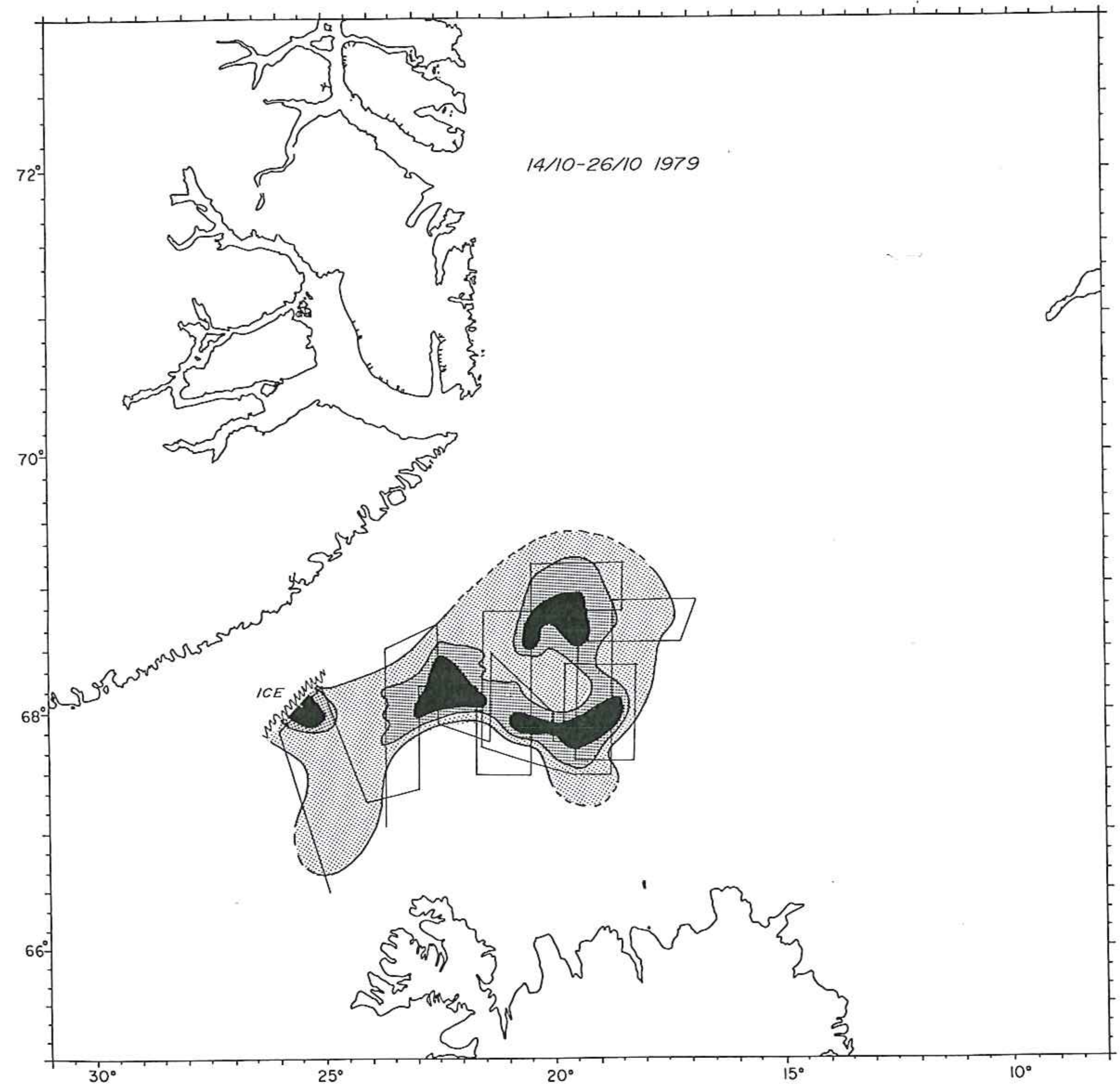


Figure VII. Survey tracks and capelin distribution, October 1979. The different shading denotes low, moderate and high densities.

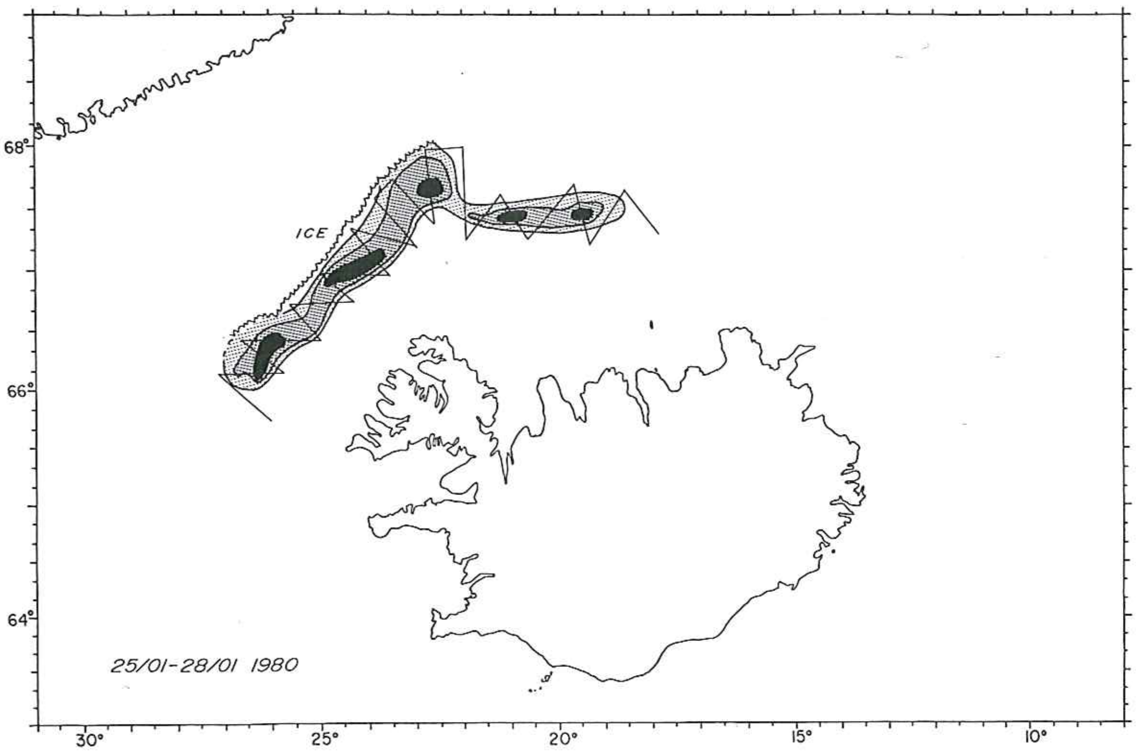


Figure VIII. Survey tracks and capelin distribution, January 1980. The different shading denotes low, moderate and high densities.

constituting the north migrating part of the stock, it was concluded that the recorded biomass of just under 140,000 tonnes (Appendix II.2, Table XII) probably represented an under-estimate.

During 3–25 November 1981 another survey of the stock was, therefore, carried out (Fig. XII). By that time the capelin had assembled near the shelf edge off the central and eastern north coast of Iceland. Surveying conditions were excellent, there was calm weather throughout this period and much less drift ice between Iceland and Greenland than in the month before. By this time the distribution area had become much reduced, and the even distribution pattern was very suitable for acoustic stock assessment. For these reasons the resulting abundance estimate of 325,000 tonnes (Appendix II.2, Table XII) was deemed reliable. Taking into account the catch and estimated natural mortality, that had taken place since the October survey, this estimate exceeded the October one by a factor of about 3. A third survey was then carried out in the last days of November (Fig. XIII). The resulting abundance estimate, about 245,000 tonnes (Appendix II.2, Table XII), was practically the same as that obtained earlier in the month when the large catches in the intervening period had been accounted for. In view of the low stock abundance and the high November catch rates, all capelin fishing was banned in early December 1981.

In view of the precarious state of the stock, much effort was placed on finding and assessing the 1982 spawning migration. This work extended over the period from 7 January to 21 February. Weather conditions were exceptionally difficult in the second and third weeks of January, and a valid estimate was, therefore, not obtained until in the beginning of the fourth week of the month (Fig. XIV). As expected, this abundance estimate was very low but amounted to about 150,000 tonnes. Around mid-February the abundance of another and much smaller spawning migration was assessed off East Iceland. In view of good external conditions, even distribution of capelin and the detailed knowledge of their location through scouting, the

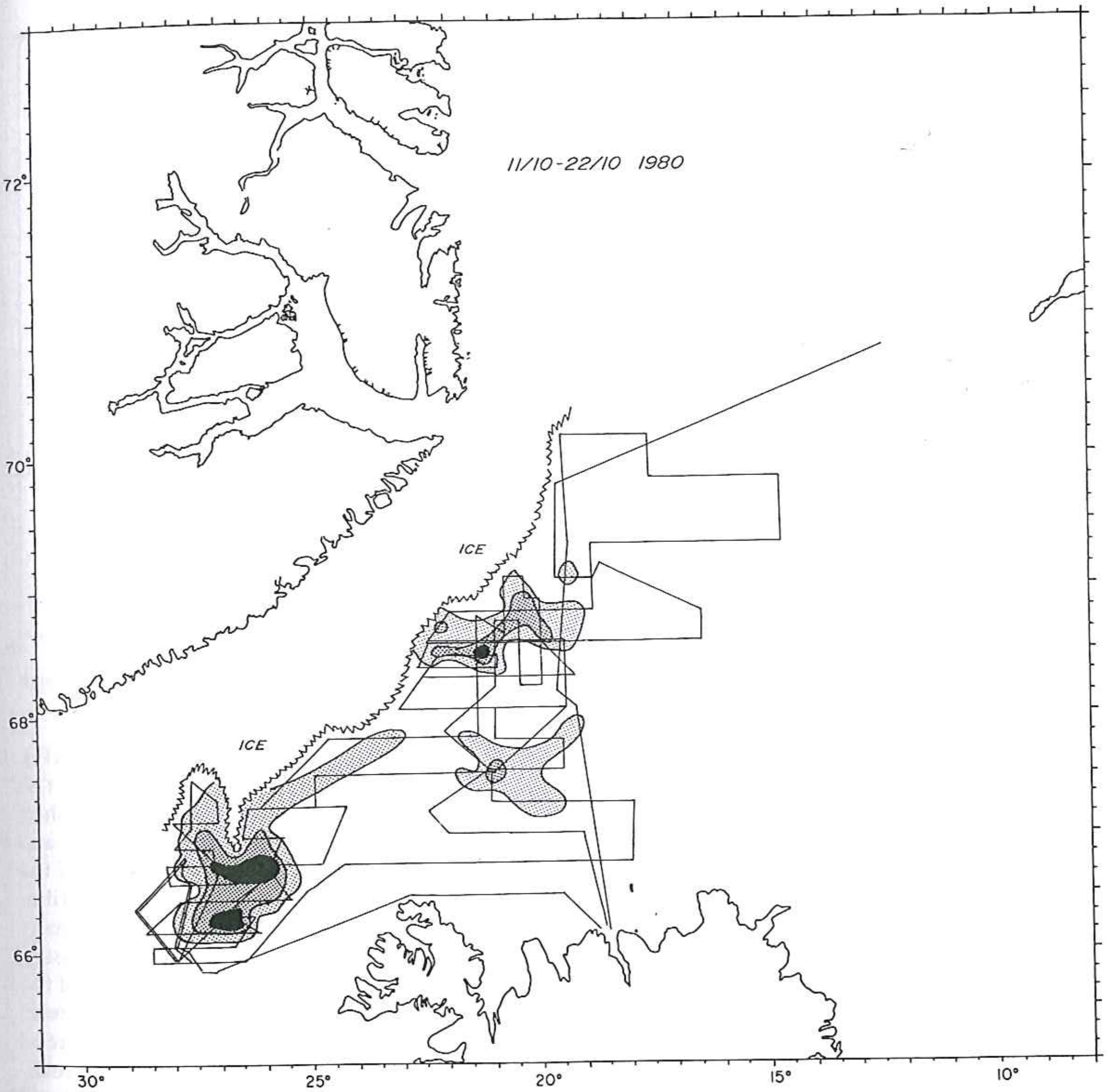


Figure IX. Survey tracks and capelin distribution, October 1980. The different shading denotes low, moderate and high densities.

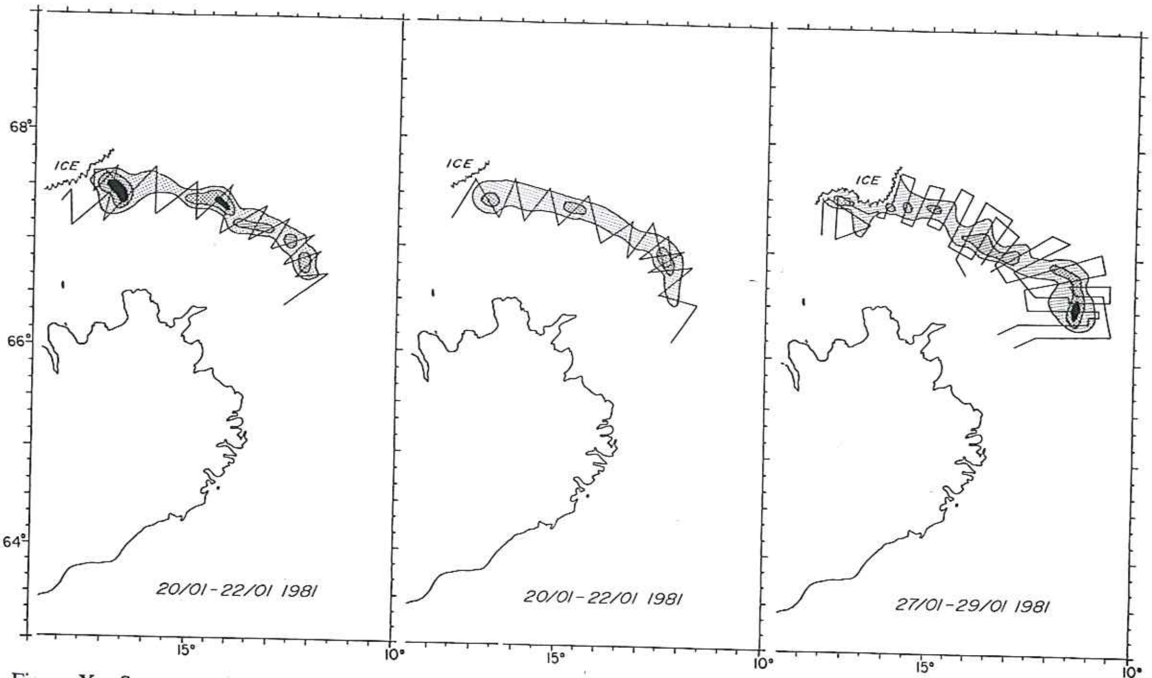


Figure X. Survey tracks and capelin distribution, January 1981. The different shading denotes low, moderate and high densities.

winter 1982 spawning stock estimate was considered valid. The total stock biomass was estimated to be about 165,000 tonnes (Appendix II.2, Table XIII) which agreed with the November estimate in the previous year, when account had been taken of catches from the time of that estimate until fishing ceased in December.

All of these abundance estimates were strongly contested by many skippers of capelin boats. In spite of the fishing ban, eight capelin boats were permitted to fish 2,000 tonnes each in the winter of 1982. At the time of year when catches of 10–15,000 tonnes by individual vessels were not uncommon, only 13,000 tonnes were fished collectively by these boats. Although this was naturally no measure of the accuracy of the winter 1982 acoustic estimate, the very low catch rates were at the time seen as reflecting an unusually low stock abundance.

The 1982/83 season. Because of the rapidly diminishing stock abundance and unreliable information on recruitment, no capelin fishing was allowed in the summer of 1982. The joint Icelandic/Norwegian autumn stock assessment survey was carried out in the period 2–20 October (Fig. XV) and gave an estimate of adult stock abundance of 285,000 tonnes (Appendix II.2, Table XII). Weather conditions were excellent during this survey and although the East-Greenland shelf was mostly under ice, there were only few and scattered capelin recordings in the vicinity of the ice border. In the northern part of the distribution area, capelin recordings were extremely scattered, and in the survey report it is suggested that this might have caused some lowering of the capelin abundance recorded there. However, due to the very low capelin abundance recorded in this area, it seemed unlikely that an underestimation there could have largely affected the total abundance estimate.

Due to the low capelin abundance recorded in the previous autumn survey, the fishery was not opened in the winter of 1983. In the second week of January a pilot survey of capelin distribution was carried out east and northeast of Iceland. The main migration was located off the central east coast and only scattered recordings farther north. Due to storms the spawning migration could, however, not be assessed until 25–29 January (Fig. XVI). The total abundance estimate amounted to about 300,000 tonnes (Appendix II.2, Table XIII) and thus was on a similar level as the autumn estimate in the year before.

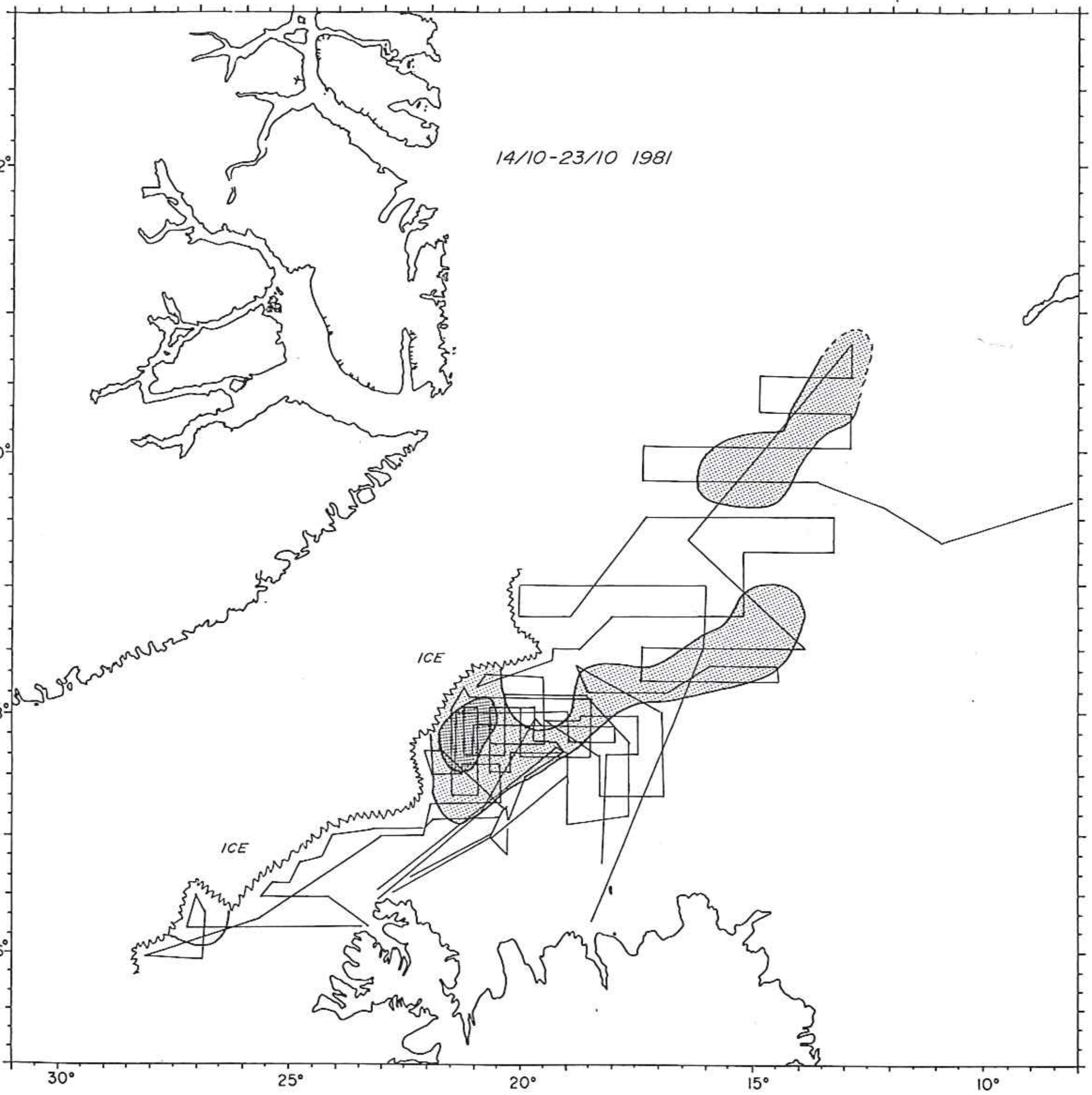


Figure XI. Survey tracks and capelin distribution, October 1981. The different shading denotes low, moderate and high densities.

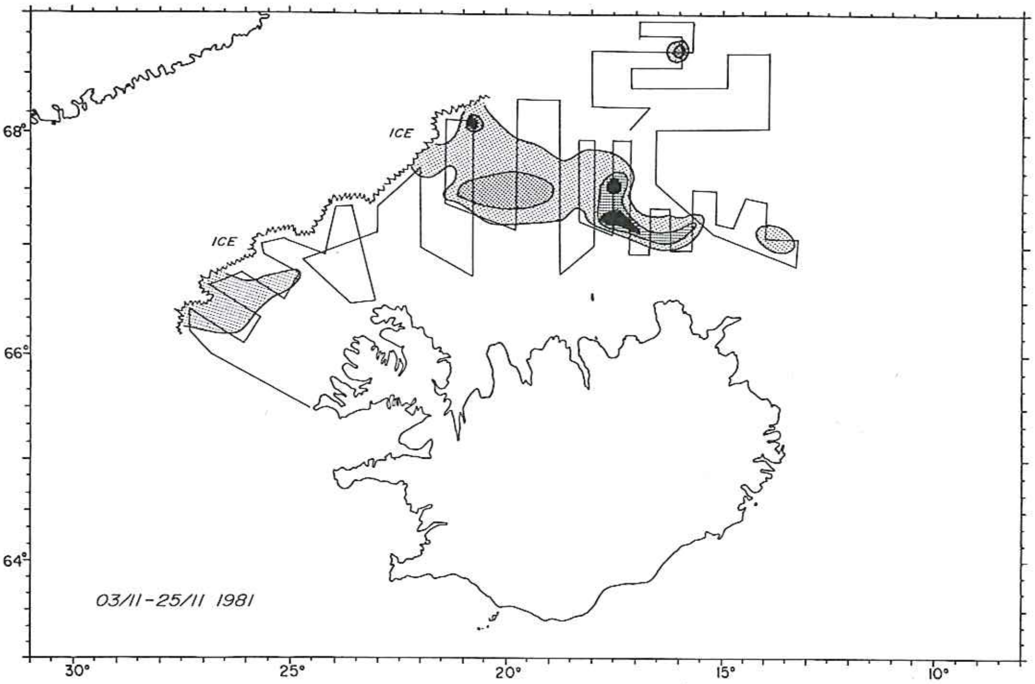


Figure XII. Survey tracks and capelin distribution, 3–25 November 1981. The different shading denotes low, moderate and high densities.

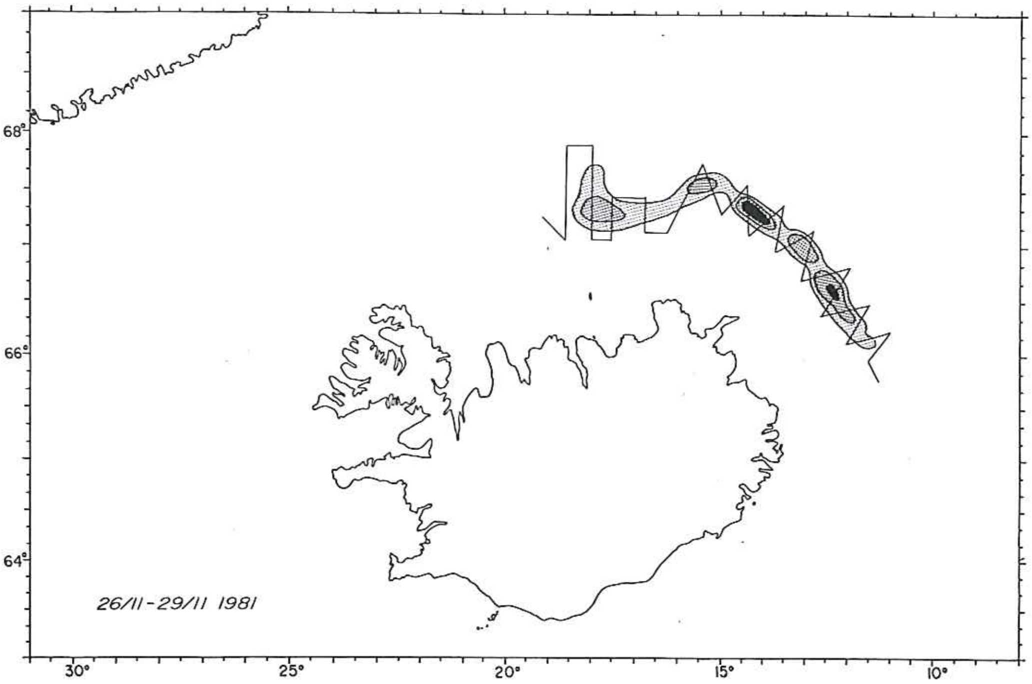


Figure XIII. Survey tracks and capelin distribution, 26–29 November 1981. The different shading denotes low, moderate and high densities.

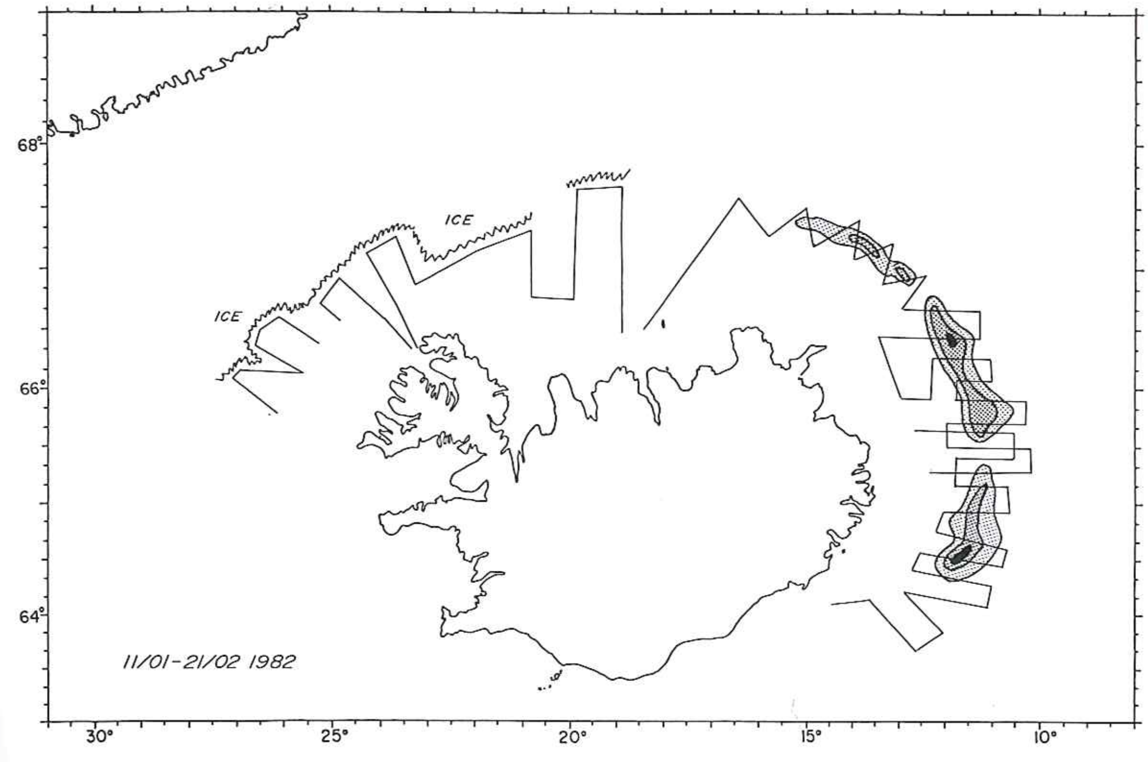


Figure XIV. Survey tracks and capelin distribution, January/February 1982. The different shading denotes low, moderate and high densities.

A second estimate was obtained, after the spawning migration had arrived at the southeast coast, and gave similar results. Scouting in the area off North and Northwest Iceland in February did not reveal any further spawning migrations.

The 1983/84 season. The joint autumn survey was carried out with three vessels during 3–22 October (Fig. XVII). There was practically no drift ice and the capelin often registered as scattering layers rather than schools. Weather conditions were good except for the area of the Iceland–Greenland Ridge where storms had to be waited out. The capelin recordings in this part of the distribution area consisted largely of immatures. Therefore, the estimate of the abundance of the maturing part of the stock was judged to be valid. Due to the good recruitment by the 1981 year class and the relatively high maturing ratio of these capelin, the total abundance of the adult stock was much higher than in the preceding two years and estimated at about 1,100,000 tonnes (Appendix II.2, Table XII).

In the winter of 1984 a two vessel acoustic survey began off Southeast Iceland on 14 January. In the next two weeks this survey covered the area east, northeast and north of Iceland to the Vestfirðir peninsula without registering but 200–300 thousand tonnes of mature capelin (Fig. XVIII). In view of the October survey results, this was an obvious underestimate and it was clear that the January survey had somehow missed most of the spawning stock. Subsequently, one vessel was deployed to search the coastal area off Southeast Iceland while the other carried out another survey east of Iceland.

In the beginning of February a large capelin fishery began in shallow waters off the southeast coast. One of the research vessels monitored this migration while the other assessed the part of the stock still remaining east of Iceland as stated before. Then, during 8–9 February both vessels assessed the first migration off the south coast in the area from east of cape Ingólfshöfði to cape Dyrhólaey on the central south coast (Fig. XIX; for place names see Fig 7.1). Weather conditions

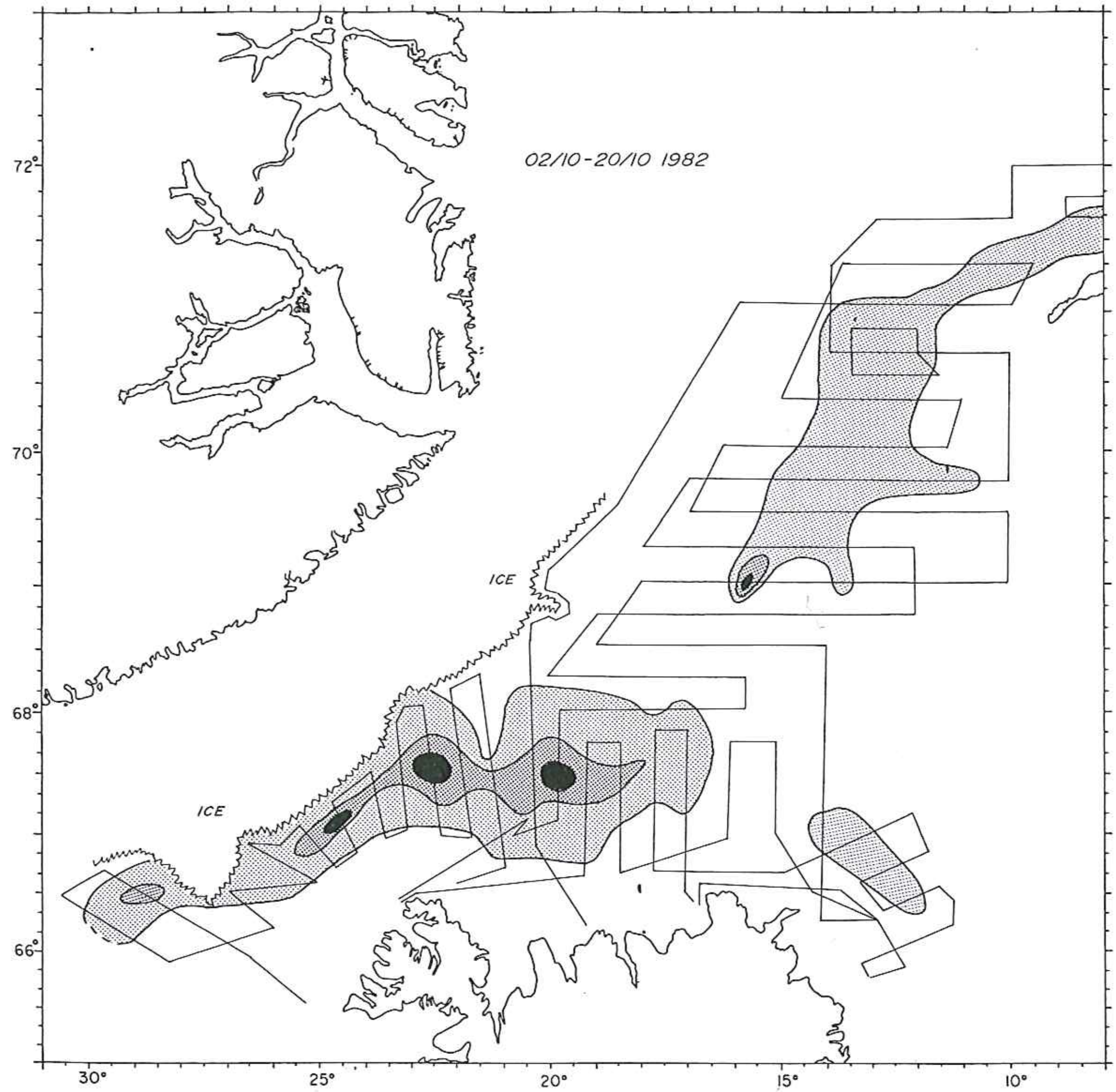


Figure XV. Survey tracks and capelin distribution, October 1982. The different shading denotes low, moderate and high densities.

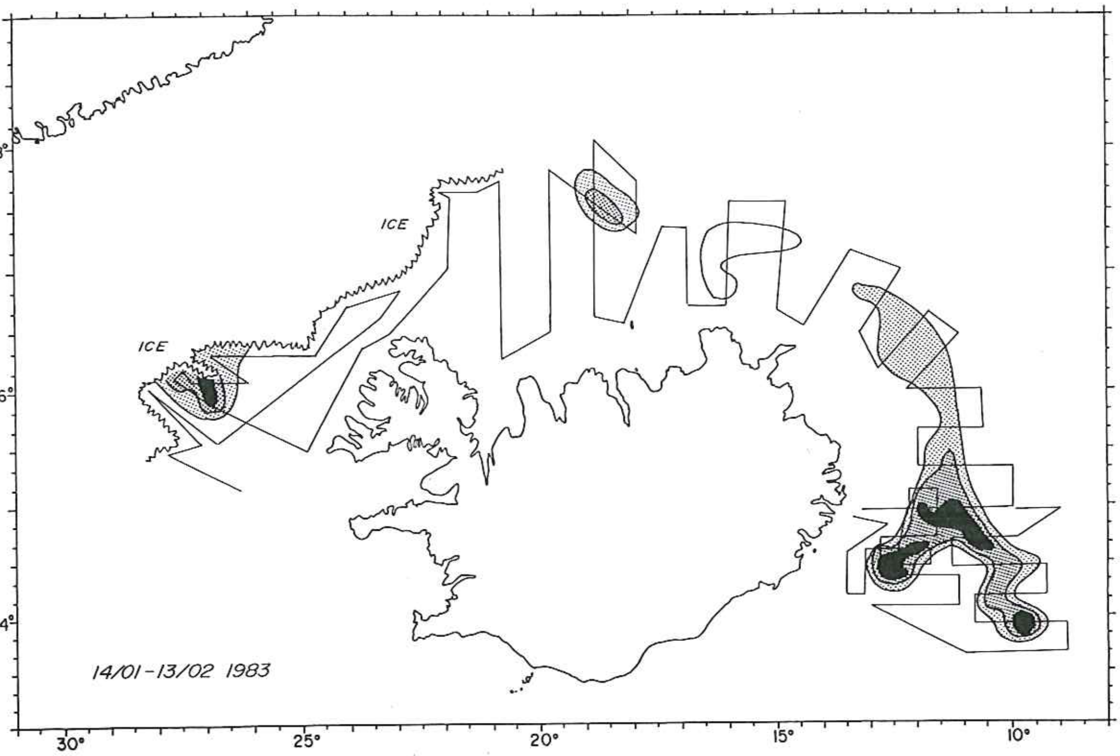


Figure XVI. Survey tracks and capelin distribution, January 1983. The different shading denotes low, moderate and high densities.

for acoustic assessment in the shallow southern area were good at the time, the distribution of capelin more or less continuous and surface schooling not pronounced. A certain drawback was experienced in a small part of the area where the survey could not reach the near-shore distribution limit of the capelin due to shallow water depth.

Nevertheless, the winter abundance estimate of 880,000 tonnes was considered successful (Appendix II.2, Table XIII). The estimated biomass was considerably larger than recorded in October of the year before, when adjusted for the catch and natural mortality. However, the difference is mostly explained by an unexpected weight increase, since the stock abundance by number was about the same. On the other hand, it is not clear where exactly the January survey missed the main part of the spawning migration. In retrospect, it is almost certain that this did happen off the southern east coast where these capelin must have entered the warm Atlantic water already by the time when the January survey started and were, therefore, not present in the area covered by that survey.

The 1984/85 season. As usual, the autumn 1984 survey was planned for October but had to be delayed due to unforeseen reasons and took place in the period 1–21 November, 3–4 weeks later than usual. Because of engagements in the Barents Sea, Norwegian research vessels could not participate in this survey and have in fact not participated in the autumn surveys since then. Surveying began west of the Vestfirðir peninsula and continued northeastward through the region between Iceland and Greenland where the survey area was limited in the northwest by drift ice. Off North Iceland the survey reached to 69°30′N and was terminated off Northeast Iceland at 66°N, 12°W on 11 November. For reasons described below the stock was surveyed twice.

Between 1 and 11 November capelin were recorded in three main areas, *i.e.* off the Vestfirðir peninsula, off the central north coast and just off the shelf edge at Northeast Iceland (Fig. XX).

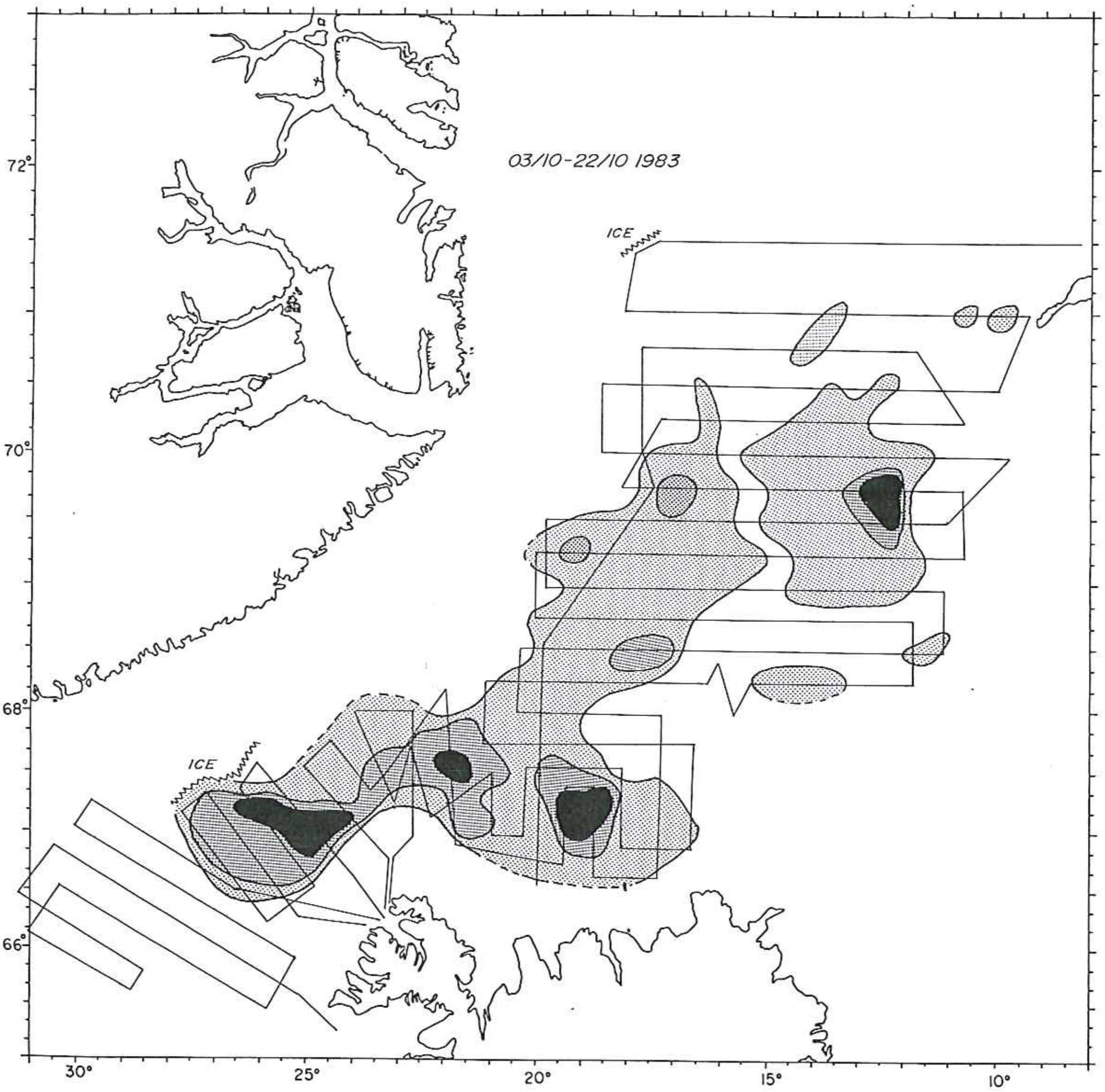


Figure XVII. Survey tracks and capelin distribution, October 1983. The different shading denotes low, moderate and high densities.

Juvenile capelin, recorded in all areas, dominated in the central region while the bulk of the biomass off Northeast Iceland, as well as off the Vestfirðir peninsula, consisted of adults.

On 9–10 November dense concentrations of capelin were reported by fishing vessels over the Iceland–Greenland Ridge, where the survey had begun a week earlier without recording such densities. In addition, a fishery started east of Iceland, about 30 naut. miles south of the southeastern limit of the previous survey area, a few days after work was finished there. Since information from the fishing fleet indicated that earlier surveying might not have covered all of the stock, it was decided to run a second survey using previous information to optimize the coverage. The latter survey took place in the time period 15–21 November.

During the short time between the two surveys a considerable shift in biomass had taken place. This was due to an eastward migration of age groups 2 and 3 by about 50–70 naut. miles in the

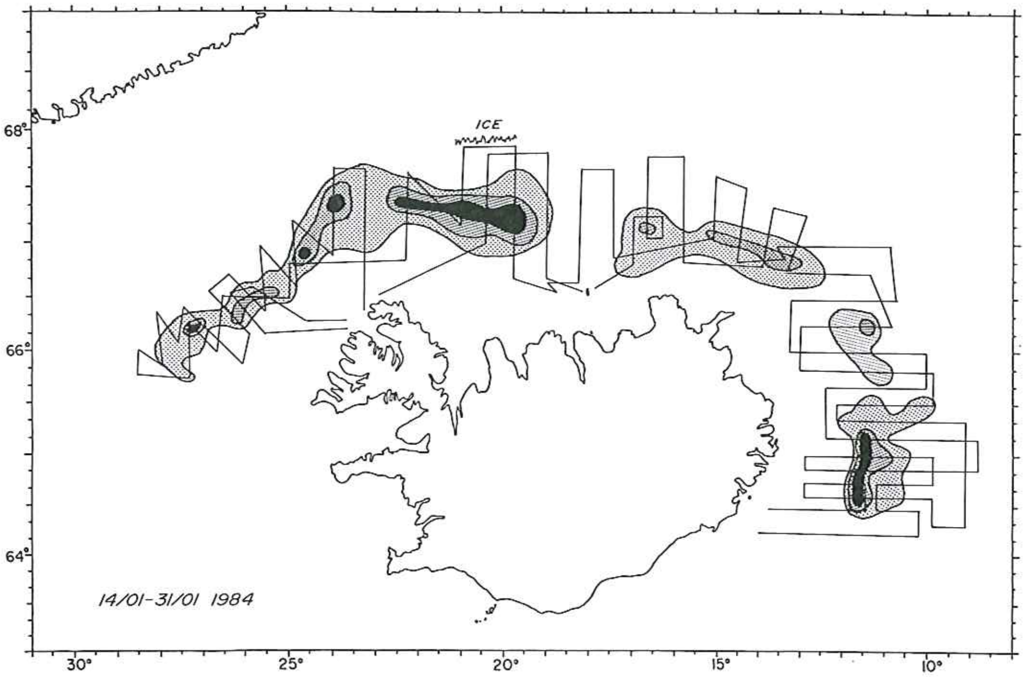


Figure XVIII. Survey tracks and capelin distribution, January 1984. The different shading denotes low, moderate and high densities.

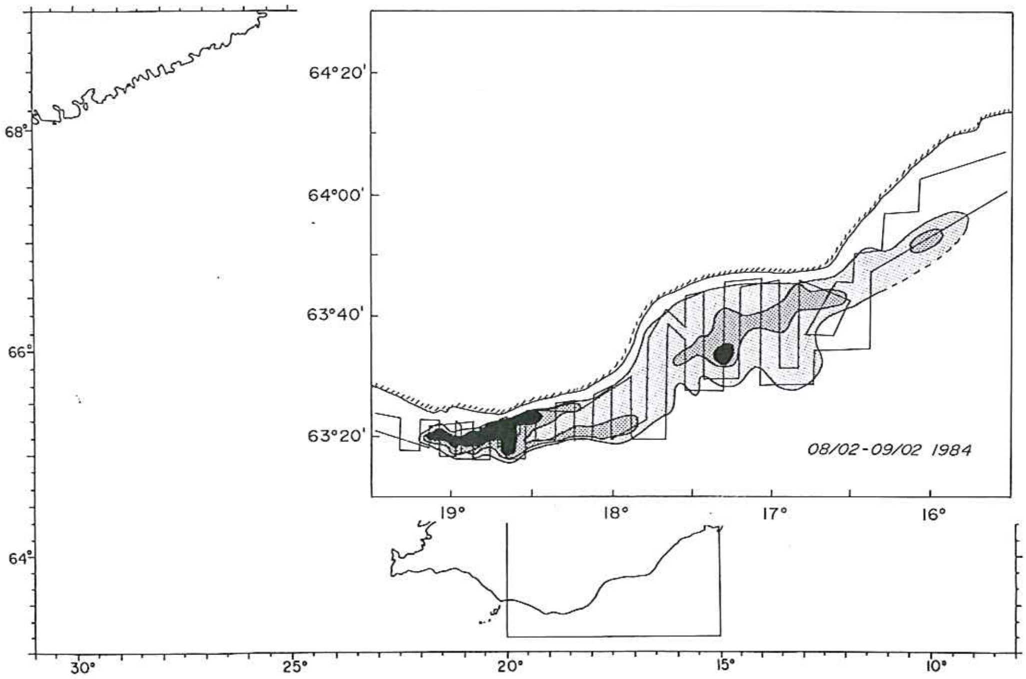


Figure XIX. Survey tracks and capelin distribution, Southeast Iceland, February 1984. The different shading denotes low, moderate and high densities.

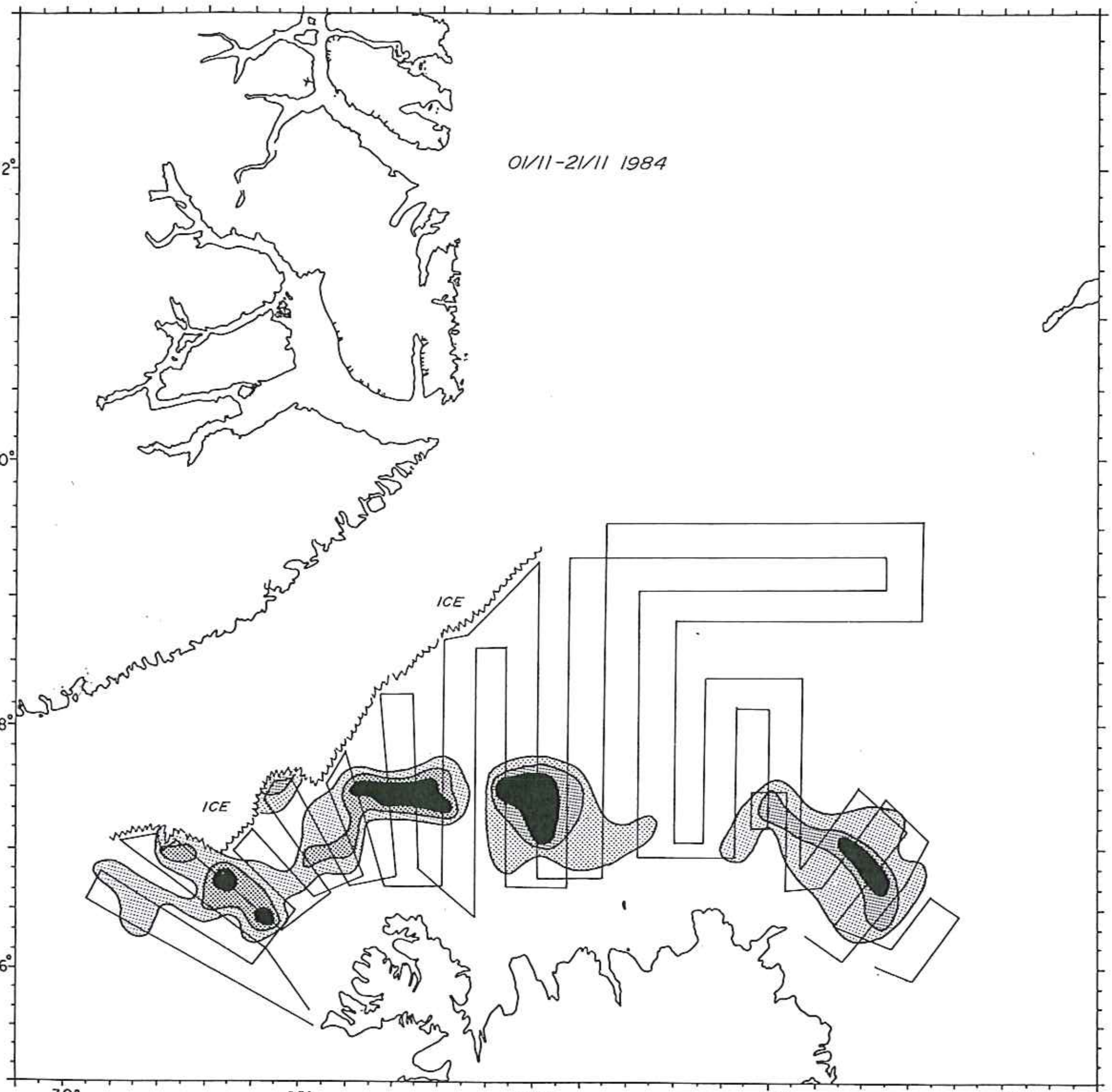


Figure XX. Survey tracks and capelin distribution, November 1984. The different shading denotes low, moderate and high densities.

area off North and Northwest Iceland. On the other hand, a southeastward shift in the adult biomass by about 100 naut. miles had taken place in the area off Northeast and East Iceland. In the latter half of November 1984 most of the adults were thus recorded off the western north coast and the central east coast of Iceland while the 1-group capelin were recorded in much the same position as before. The presence of large concentrations of maturing capelin off the central east coast of Iceland as early as November is unusual and had in fact never been recorded before. Furthermore, due to the high concentration of capelin in a small area east of Iceland and the on-going fishery which limited access to it, this part of the adult stock was difficult to survey and could have been underestimated in the latter November survey.

The total abundance estimate of mature capelin was about the same in both November surveys, amounting to 888,000 tonnes in the first, and 815,000 tonnes in the latter. The difference

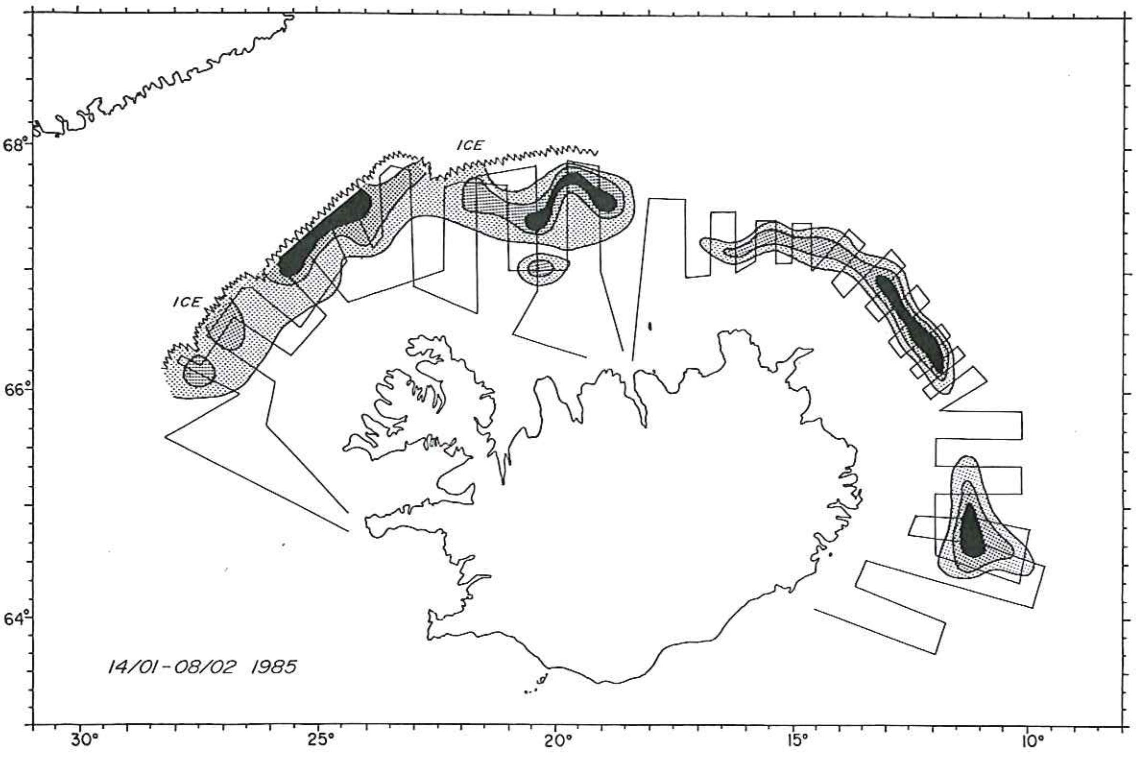
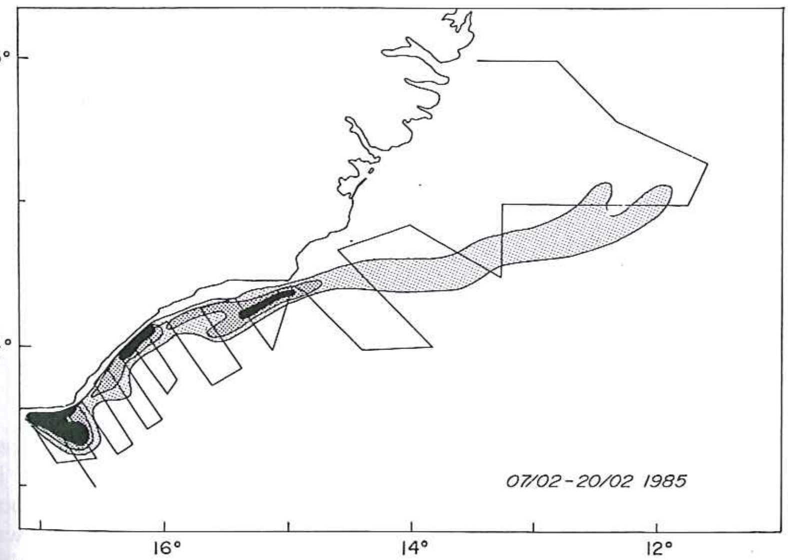


Figure XXI. Survey tracks and capelin distribution, January 1985. The different shading denotes low, moderate and high densities.



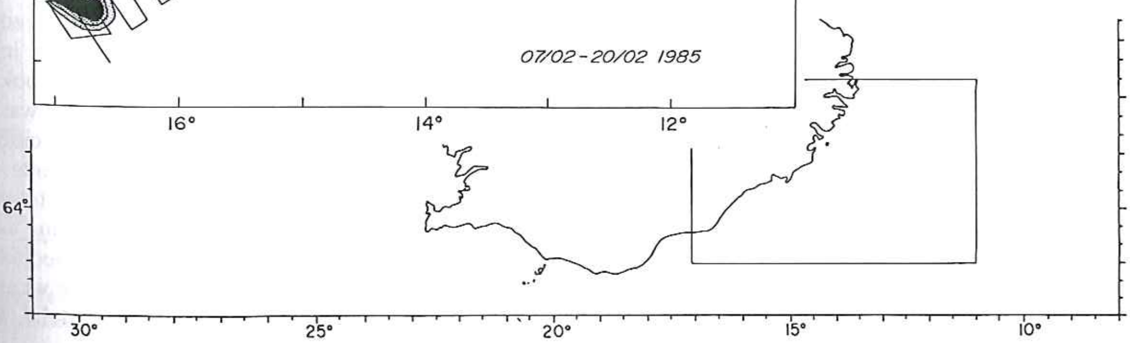


Figure XXII. Survey tracks and capelin distribution, Southeast Iceland, February 1985. The different shading denotes low, moderate and high densities.

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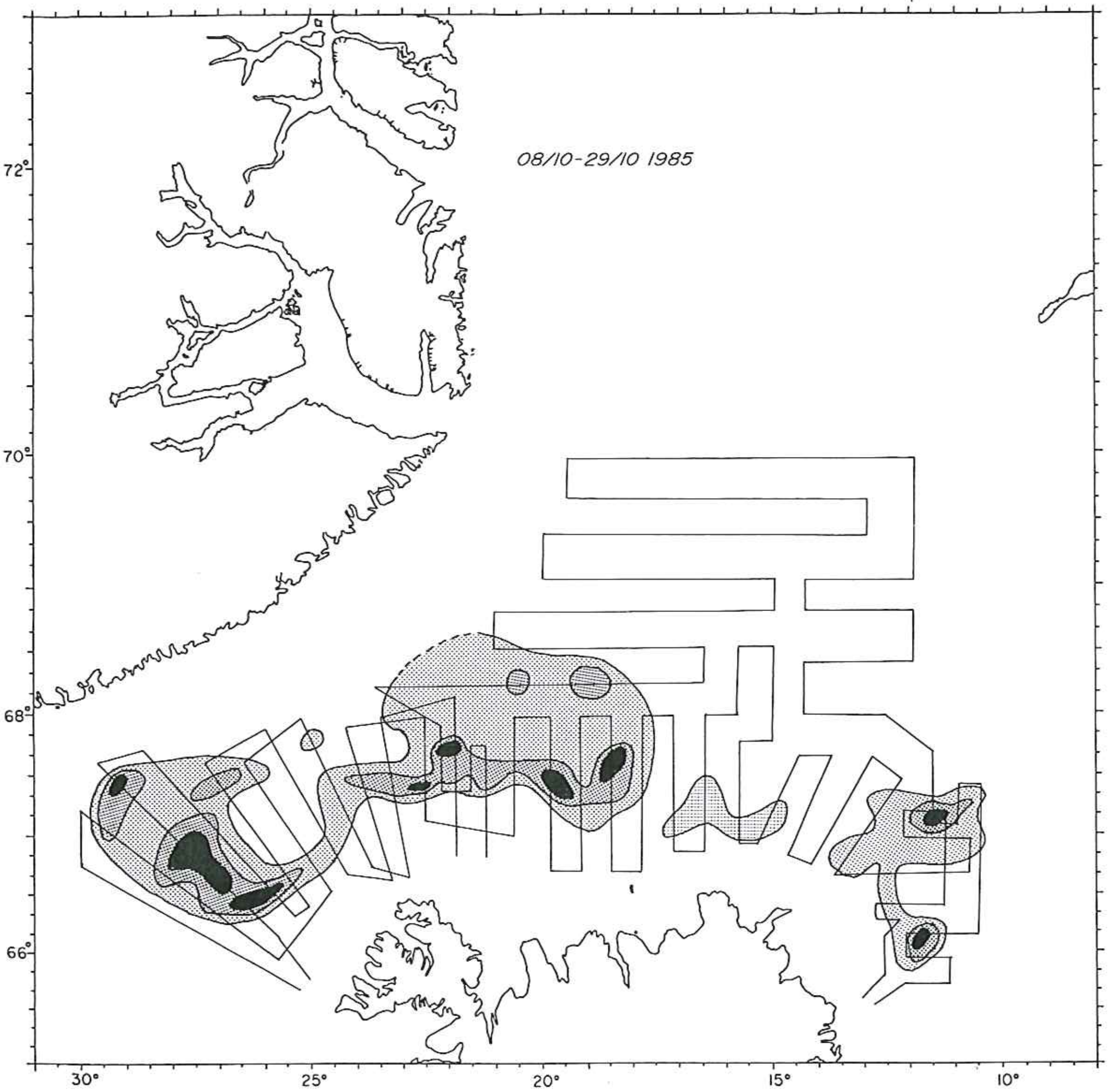

Figure XXIII. Survey tracks and capelin distribution, October 1985. The different shading denotes low, moderate and high densities.

corresponds to the catch taken during the intervening period. There was no mentionable disruption of work due to weather on either occasion, and ice conditions did not cause problems except in a limited region west of the Vestfirðir peninsula. Due to the reduced mixing between adult and juvenile capelin in the latter half of November, there were less problems in allocating echo-registrations to age groups, and the second survey was, therefore, considered the more accurate (Appendix II.2, Table XII). For this reason, it seems most likely that both the surveys covered all the fishable stock and that the rapid shift in the location of the capelin biomass, which took place in the second week of November, was caused by migrations, occurring in that specific period, and did not affect either stock estimate.

In January 1985 it was difficult to obtain a total abundance estimate of the spawning stock due to frequent weather changes. However, as expected in view of the November distribution, there were two main spawning migrations separated by a considerable distance. Because of this, the few and short periods of adequate weather conditions could be utilized to the utmost. Thus, the first migration was assessed off the east coast on 14–18 January and the latter on 27–29 January (Fig. XXI). The total abundance was about 680,000 tonnes of mature capelin (Appendix II.2, Table XIII) which corresponds well with that indicated by the November estimate, counting the catch and natural mortality in the intervening period.

An attempt was made to survey the 1985 spawning migrations on 17–20 February after both of them had migrated into the shallow waters off the southeast coast. This experiment was unsuccessful, not only due to the very heavy schooling and uneven distribution in the westernmost part of the area, but mainly because of the near-shore location of the capelin, which in places rendered it impossible to reach the distribution limit on the shore side of the spawning migration (Fig. XXII and Appendix II.2, Table XIII).

The 1985/86 season. The autumn survey was carried out by two Icelandic vessels in the period 8–29 October (Fig. XXIII). There was no drift ice, but unstable weather conditions were reported in parts of the area of the Iceland–Greenland Ridge. Elsewhere, surveying conditions were excellent. Because there was not much capelin in the Iceland–Greenland Ridge area, the effect of a possible underestimation in that region was considered minimal with regard to the stock estimate as a whole. The total abundance estimate of the adult stock was nearly 1,030,000 tonnes (Appendix II.2, Table XII). Only moderate numbers of immature capelin were recorded during this survey. In view of the relatively complete coverage of the October survey, the very low abundance of immatures belonging to the large 1983 year class came in fact as a complete surprise.

No assessment of the spawning migration was carried out in the winter of 1986. However, the area east and north of Iceland was surveyed in the period 1–21 February (Fig. XXIV). Rich

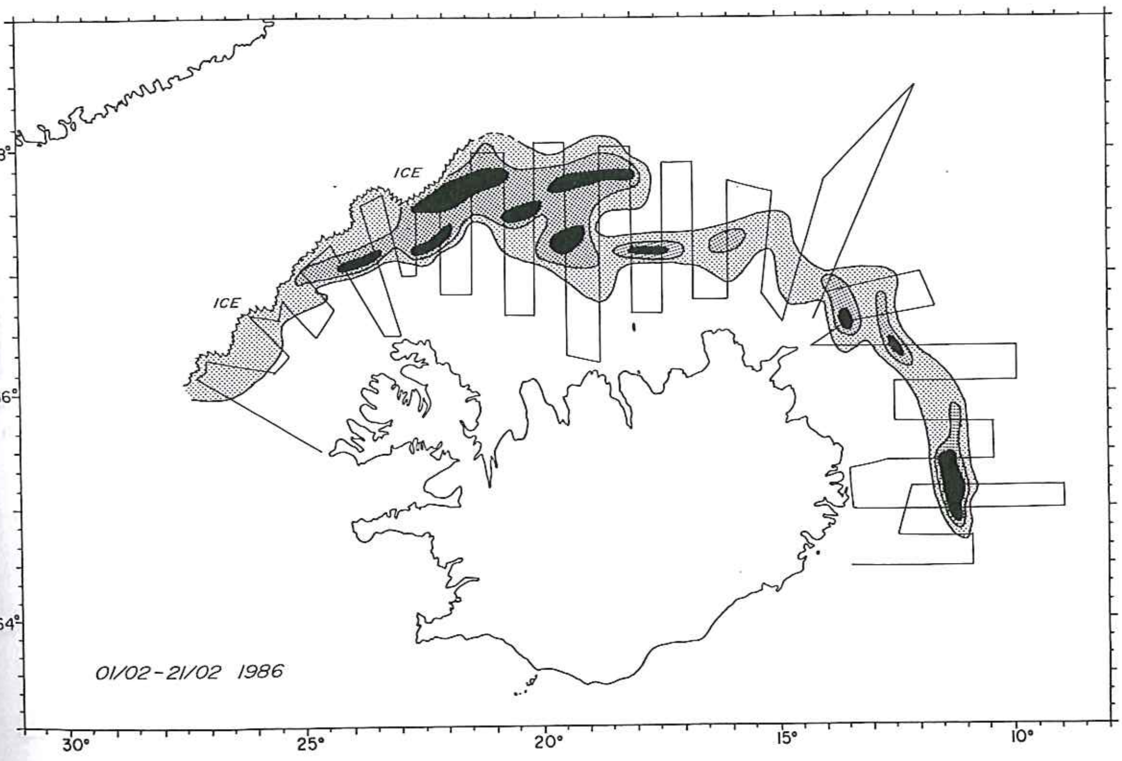

Figure XXIV. Survey tracks and capelin distribution, February 1986. The different shading denotes low, moderate and high densities.

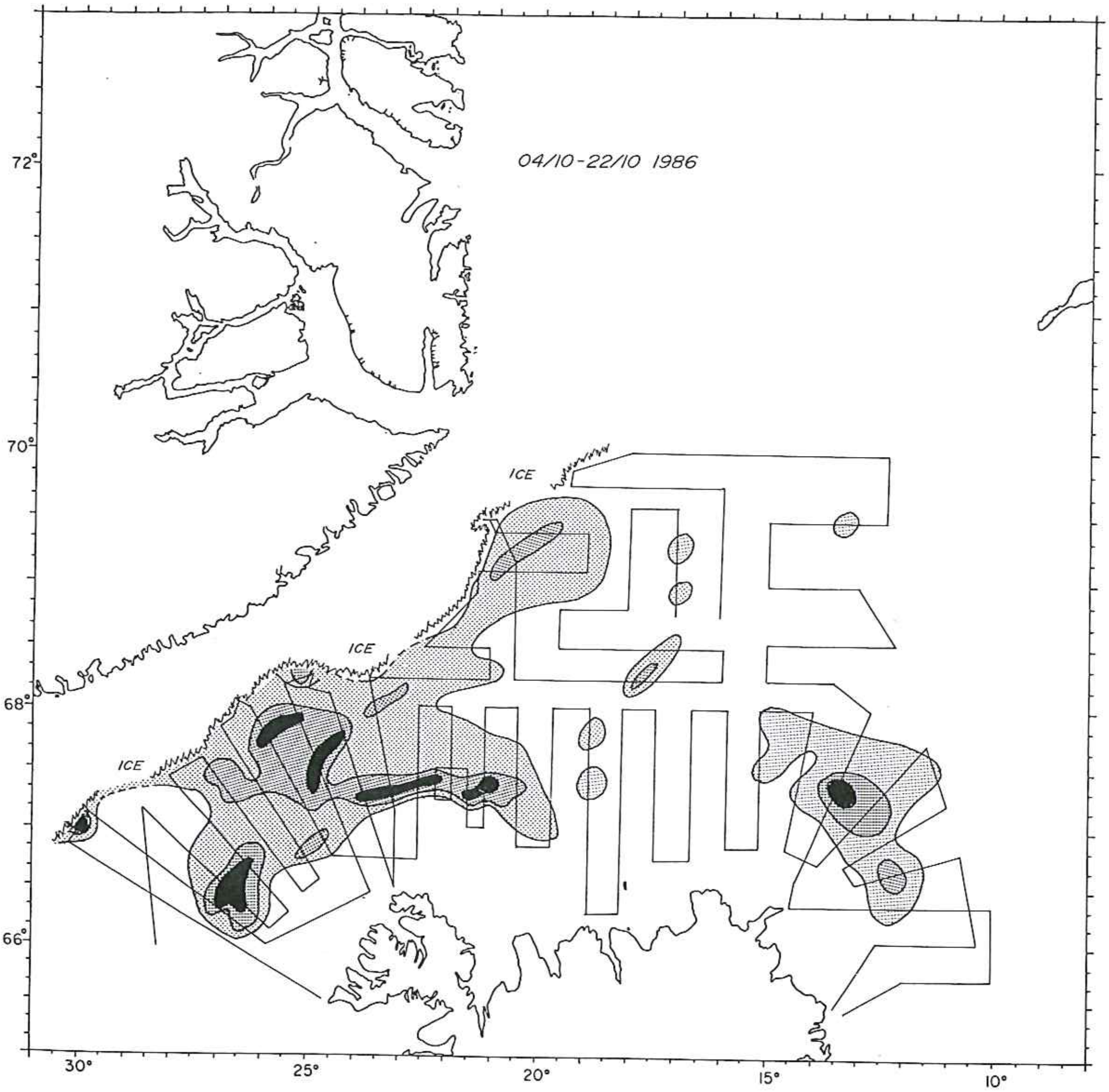

Figure XXV. Survey tracks and capelin distribution, October 1986. The different shading denotes low, moderate and high densities.

concentrations of immature 2- and especially 3-group capelin (year class 1983) were registered during this survey, particularly off East and Northeast Iceland and north of the western north coast and the Vestfirðir peninsula (Appendix II.2, Table XV). In view of the relative scarcity of the immature 2-group stock component (year class 1983) in the autumn survey in the year before, it seems most likely that at the time of that survey these capelin were distributed over the East-Greenland shelf quite close to the coast, as was the case in 1979.

The 1986/87 season. As usual, the autumn survey was carried out with two vessels in the period 4–22 October (Fig. XXV). In general, weather conditions were good and the drift ice over parts of the East Greenland shelf was thought to have prevented access to only a part of the immature stock. However, it is noted in the survey report that near-surface schooling in the area of the Iceland–Greenland Ridge might have lowered the abundance estimate of the adult stock as compared to previous October estimates. The adult stock was estimated to be about 1,100,000 tonnes (Appendix II.2, Table XII).

The winter survey was carried out with one research vessel in the period 13 January – 5 February (Fig. XXVI). Due to stormy weather, the first week could only be used for locating the migration, but after 20 January conditions improved greatly and work could proceed uninterrupted from then on. The total acoustic estimate of mature capelin abundance amounted to about one million tonnes (Appendix II.2, Table XIII). Most of the spawning stock was distributed off East Iceland, but a later migration was also located between 17°W and 18°W off the central north coast as well as west from there, where the adult capelin were mixed with immatures. Otherwise, much of the immature stock was obviously under ice farther north off the Vestfirðir peninsula. Thus, the densest concentrations of immature capelin were recorded by the echo-sounder at the ice border, the sonar showing large schools actually underneath the ice floes. The winter

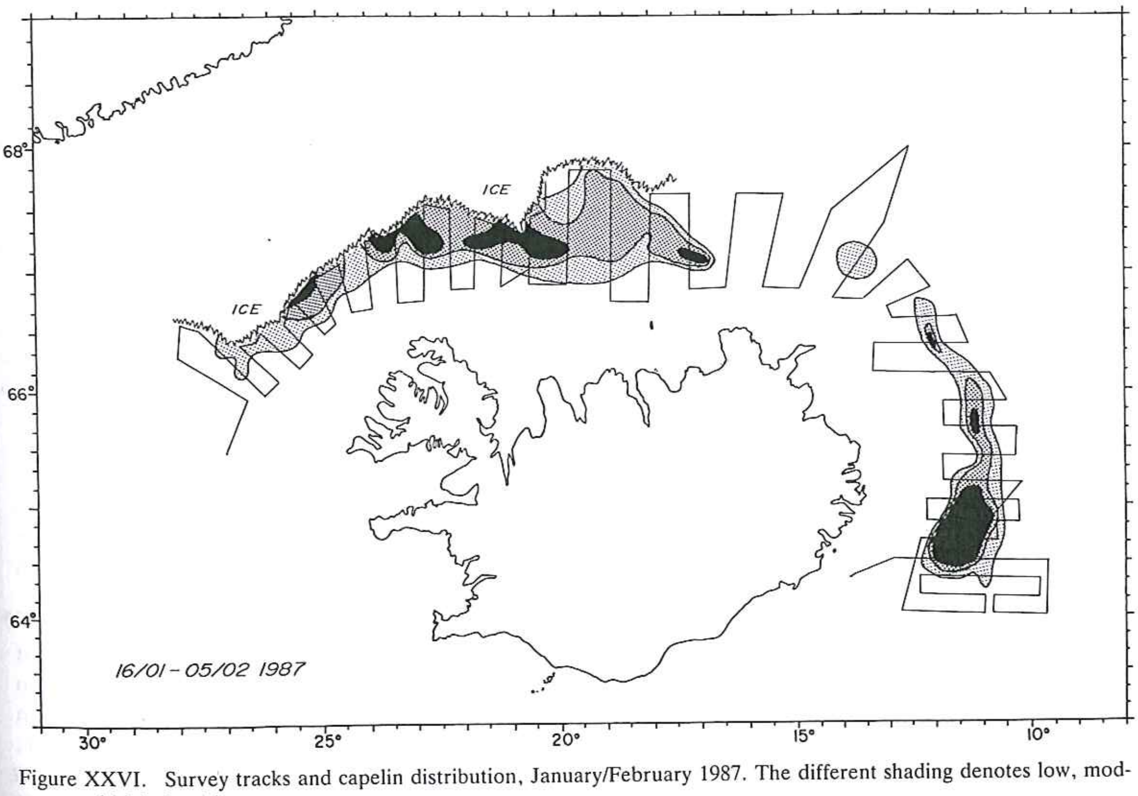

Figure XXVI. Survey tracks and capelin distribution, January/February 1987. The different shading denotes low, moderate and high densities.

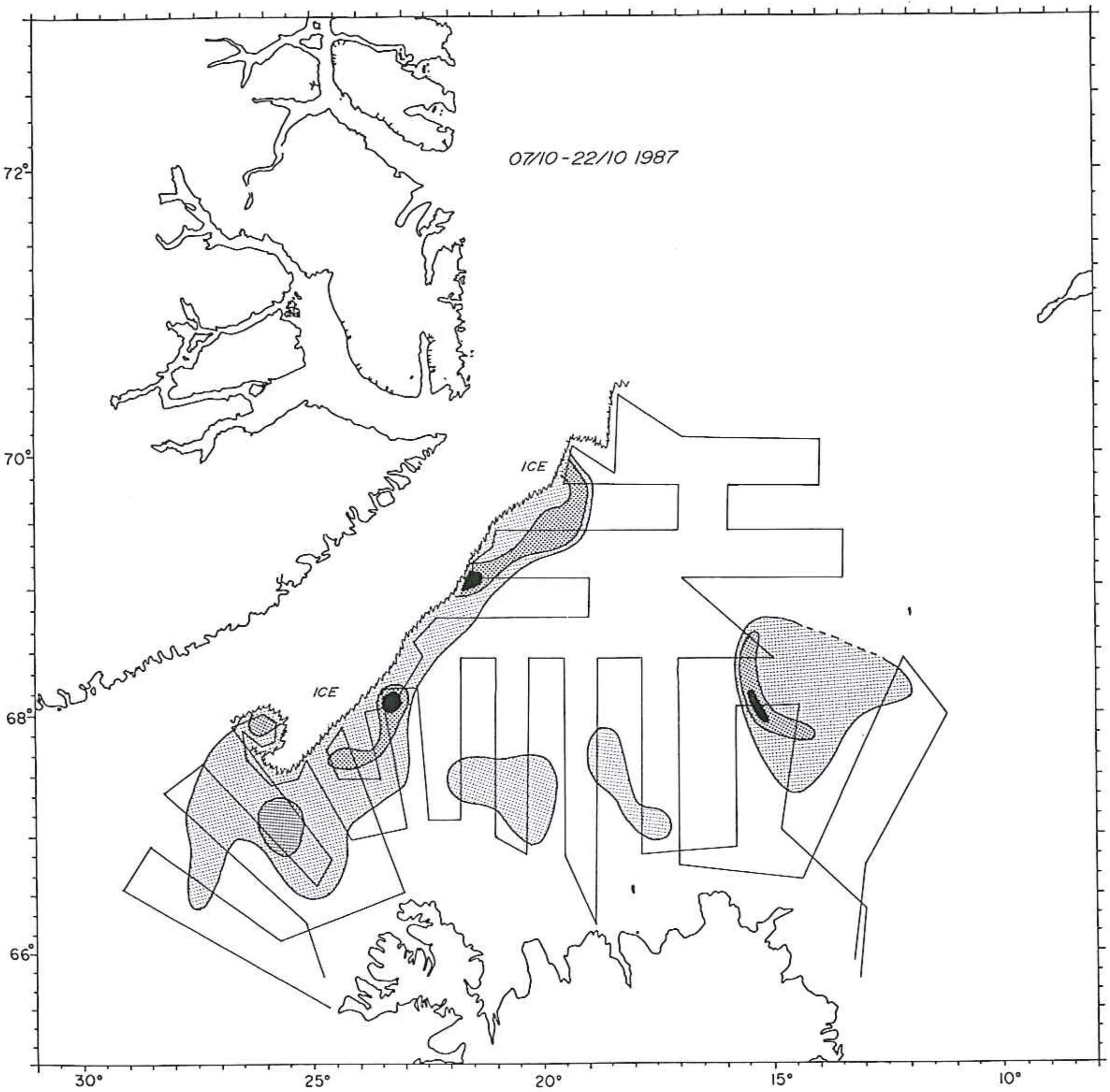

Figure XXVII. Survey tracks and capelin distribution, October 1987. The different shading denotes low, moderate and high densities.

1987 estimate of the spawning stock abundance was considerably higher than the one in autumn 1986, but as pointed out in the above paragraph, this possibility had been anticipated.

The 1987/88 season. In October 1987 adult capelin were almost exclusively recorded in the southernmost part of the Iceland–Greenland Channel and from there northeastwards along the Greenland shelf edge and the outer part of the shelf to the east of Scoresby Sound (Fig. XXVII). In spite of relatively high temperatures in the survey area, drift ice covered most of the shelf area south and southwestward from Scoresby Sound for a distance of about 200 naut. miles.

The October 1987 abundance estimate of maturing capelin was much lower than had been forecast from estimates of 1-group abundance in the year before (Vilhjálmsson 1988). However, high abundance was recorded in some areas near the ice edge, especially in the northwestern part of the survey area. It thus appeared that due to the ice conditions, parts of the area, possibly containing capelin in high concentrations, had not been surveyed. Therefore, the October 1987 survey results, indicating just over 400,000 tonnes of adult capelin (Appendix II.2, Table XII), were judged invalid, and a descision was made to carry out another survey as soon as it could be assumed from catch rates and the position of the fishing fleet that the adult stock had returned to the usual wintering grounds off North and Northwest Iceland.

The second 1987 autumn survey was carried out during 20 November – 3 December under nearly ideal conditions with respect to the maturing, fishable stock (Fig. XXVIII). Thus, there was no interference by drift ice or weather, and most frequently the capelin were recorded as continuous scattering layers. The biomass was distributed in three main areas: 1) to the northwest and north of the Vestfirðir peninsula, 2) off the western part of the north coast and 3) about 80 naut. miles farther east, off the eastern north coast. The total adult stock abundance was estimated to be just under 1,300,000 tonnes (Appendix II.2, Table XII). When the catch since October had been taken into account, this later abundance estimate was more than 3 times higher than that obtained in the previous survey.

Due to the apparent reliability of the November 1987 abundance estimate, no attempt was made to assess the spawning stock in the winter of 1988. On the other hand, an attempt was made to assess the immature part of the stock in late January – early February 1988. No such capelin were, however, recorded off East and Northeast Iceland, and the distribution area off the western north coast and the Vestfirðir peninsula was impassable because of ice.

The 1988/89 season. As described in sections 13.3–13.5, the adult stock did not migrate to feed in the central and northern Iceland Sea in 1988. This was first established during a Norwegian survey in July and August that year. Thus, the Norwegians located the adult stock off the Vestfirðir peninsula in the second week of August 1988, in the region of the Iceland–Greenland

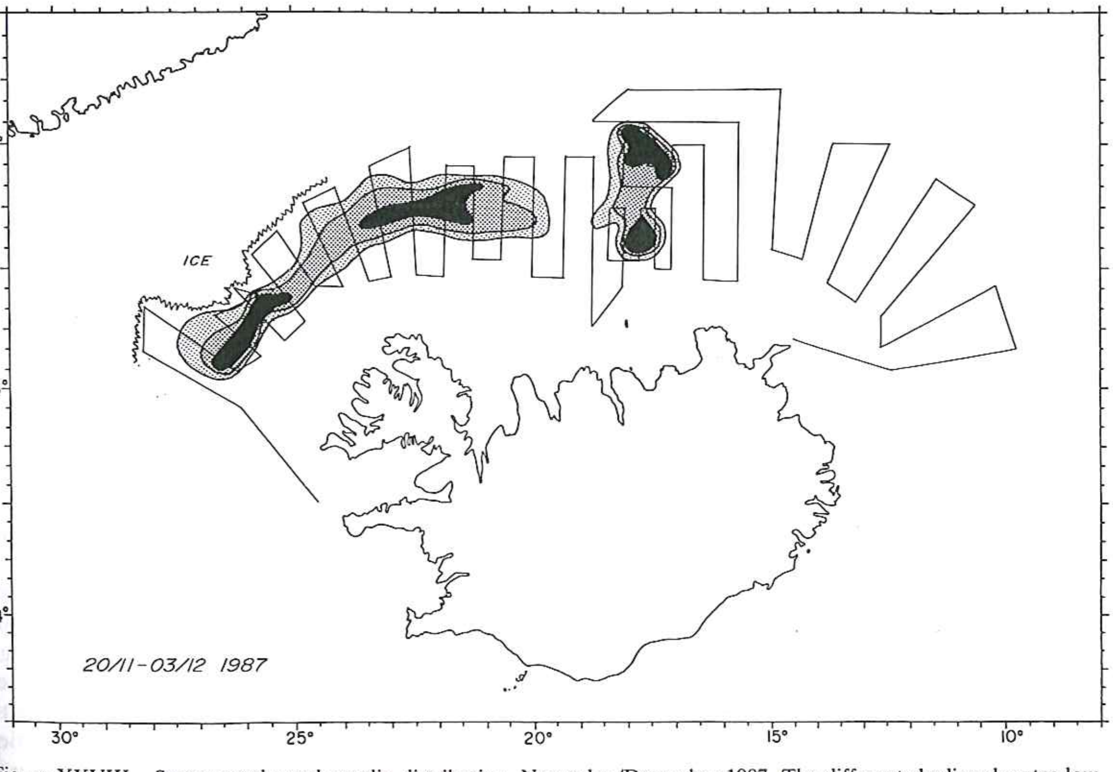

Figure XXVIII. Survey tracks and capelin distribution, November/December 1987. The different shading denotes low, moderate and high densities.

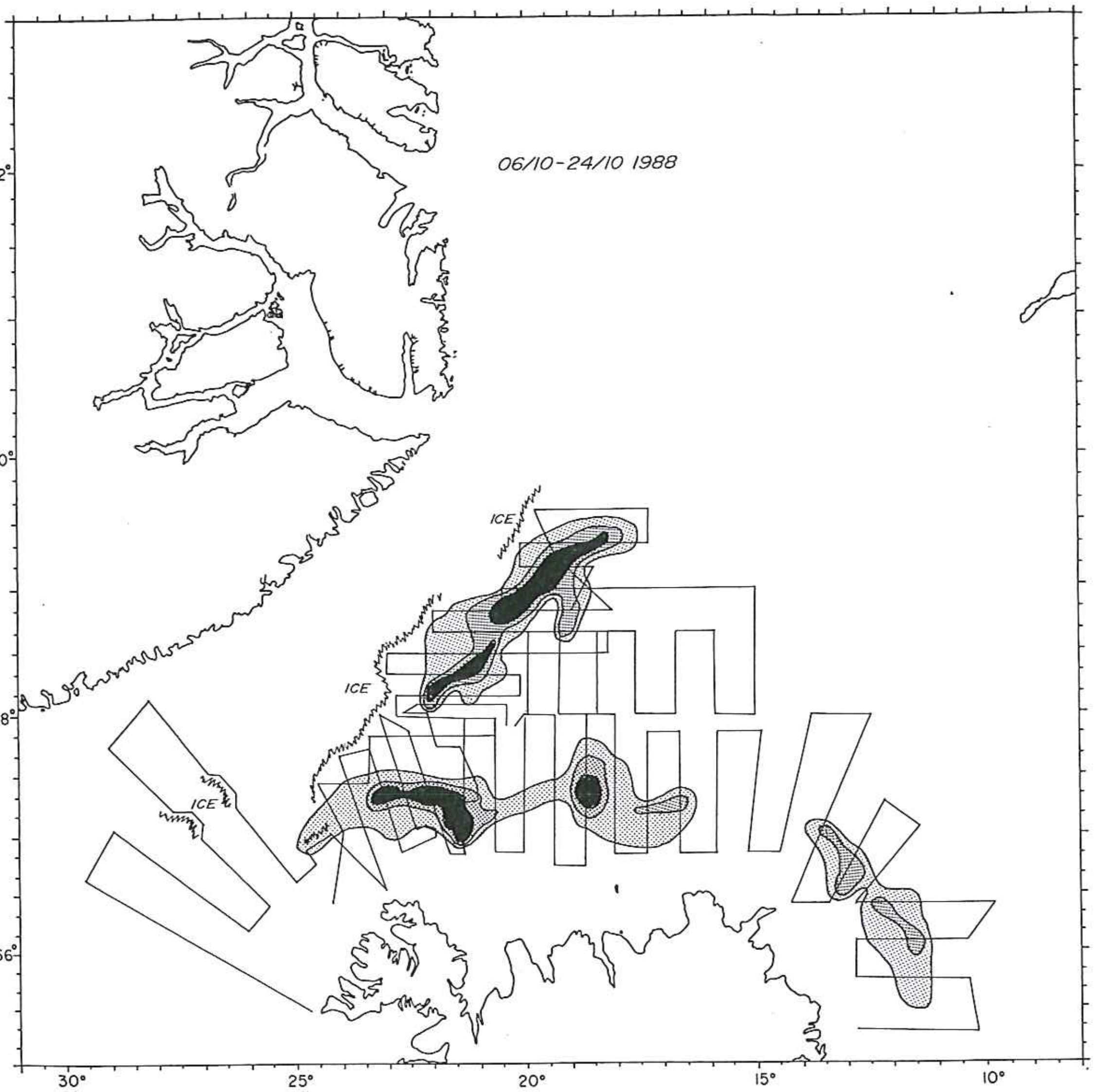

Figure XXIX. Survey tracks and capelin distribution, October 1988. The different shading denotes low, moderate and high densities.

Ridge and the southernmost part of the Iceland–Greenland Channel, and estimated the abundance of maturing capelin to be about one million tonnes. Until 1992, this was the only example of a credible biomass assessment being obtained for this part of the capelin stock in summer. A Greenlandic survey registered considerable numbers of capelin in the same area in early September and also indicated that much of the stock had migrated farther to the northeast. Later in September this was verified by an Icelandic survey of the Iceland and Greenland Seas which registered capelin concentrations east and southeast of Scoresby Sound.

The Icelandic October survey began on the southern Iceland–Greenland Ridge as usual, but capelin were not located until at the shelf edge north of the Vestfirðir peninsula. North of Iceland, from the Vestfirðir to the eastern north coast, there were considerable capelin densities consisting of mixed age and maturity groups, but east of Langanes the survey recorded only

1-group capelin. By far the largest part of the adult stock was, however, located in the deep waters of the Iceland–Greenland Channel and in the southwestern Iceland Sea from about 68°N, 22°30′W to 69°30′N, 18°W (Fig. XXIX). Weather conditions were good during the survey and very little capelin were recorded in the vicinity of the ice border which constituted the northwestern limit of the survey area. It should be noted that neither Greenlandic nor Icelandic surveys of the Iceland Sea in September had detected any capelin north of 70°N. Results from the October 1987 survey were considered reliable, when the adult capelin abundance was estimated to be 1,230,000 tonnes (Appendix II.2, Table XII).

The winter survey was carried out with one research vessel in the period 5–30 January. The spawning stock was almost exclusively recorded off the east coast where it was not mixed with immatures (Fig. XXX). On the other hand, immature capelin were mainly registered in unmixed concentrations off the Vestfirðir peninsula where ice prevented the completion of the estimate of their abundance (Fig XXX). Throughout the survey of the maturing capelin the weather remained good, and consequently the estimate of 930,000 tonnes was considered reliable (Appendix II.2, Table XIII). When account had been taken of the catch and natural mortality, this agreed closely with the October estimate from the year before.

The 1989/90 season. The autumn stock assessment survey was delayed until late October because of adverse ice conditions, particularly in the western part of the usual distribution area. Furthermore, the fleet had only been able to find and fish small quantities of capelin in the summer and autumn period. This was presumably in part due to an extensive ice cover, but could certainly also have been the result of reduced stock abundance and/or changed migration and behaviour pattern. In short, the autumn survey only located small concentrations of adult capelin in October and November and only off the central north coast of Iceland (Fig. XXXI). The abundance estimate of some 67,000 tonnes (Appendix II.2, Table XII) is the lowest ever on record, and it

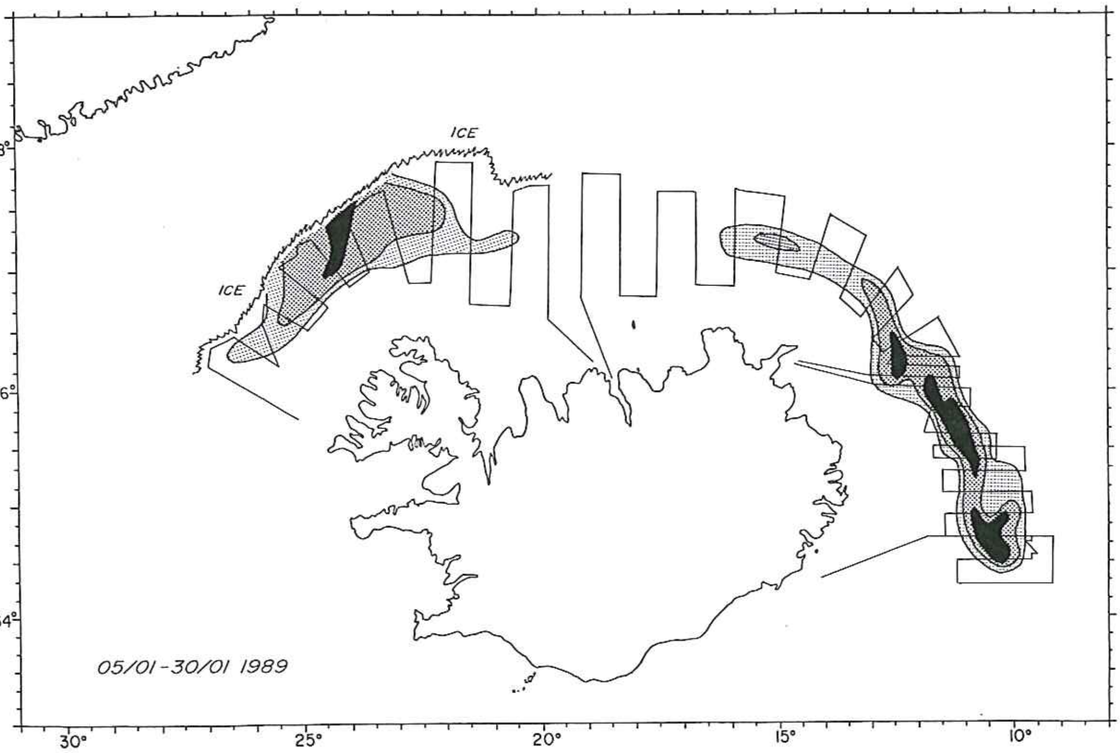

Figure XXX. Survey tracks and capelin distribution, January 1989. The different shading denotes low, moderate and high densities.

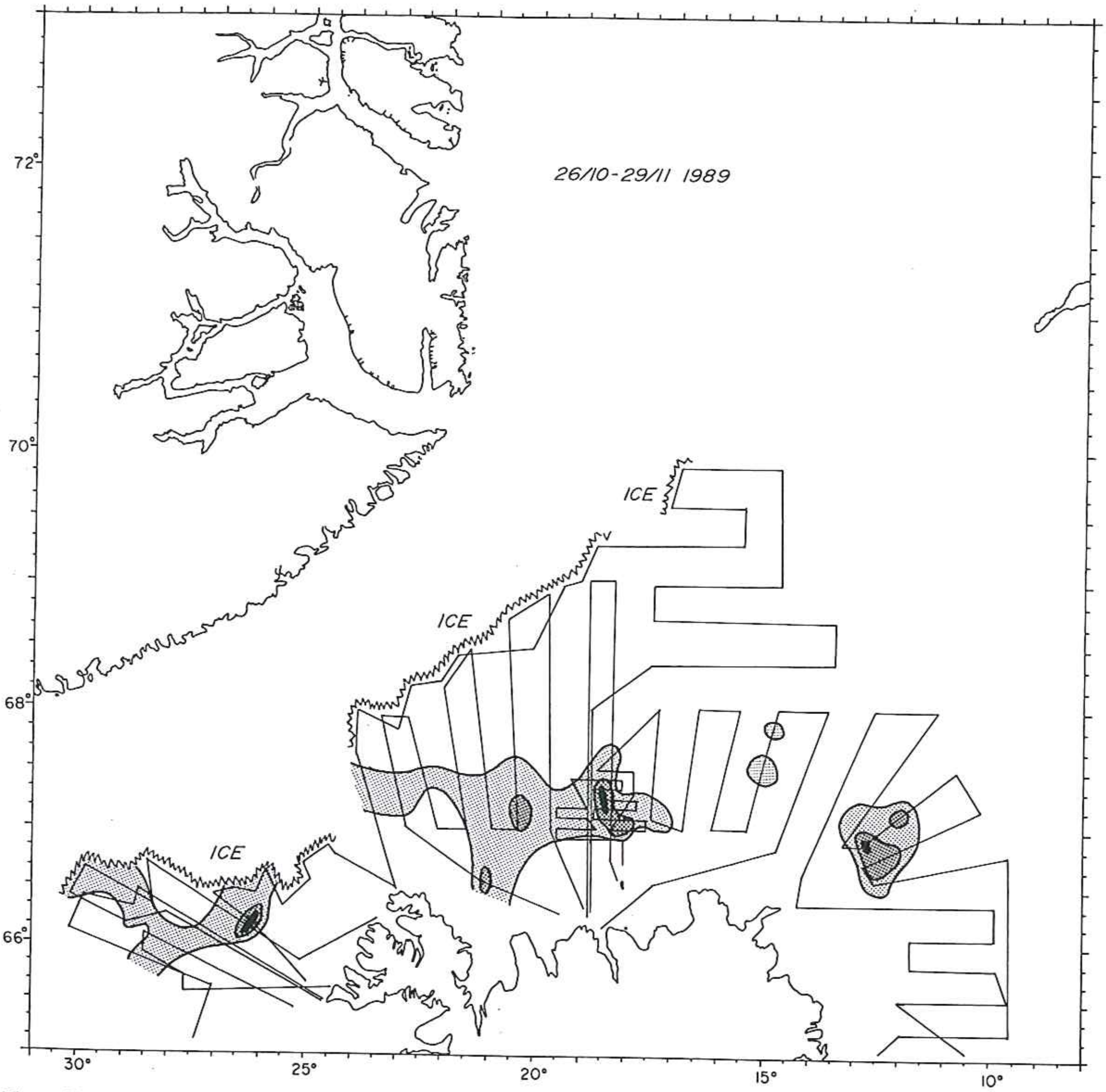

Figure XXXI. Survey tracks and capelin distribution, October/November 1989. The different shading denotes low, moderate and high densities.

was believed that the main reason for this was the continuing cover by drift ice of the western areas. In December large concentrations of capelin were reported by the fishing fleet off the central north coast, but a new survey of the ice free area there recorded only 95,000 tonnes which was similar to the previous result (Fig. XXXII and Appendix II.2, Table XII).

In spite of the bleak outlook after the summer/autumn 1989 season, a heavy fishery began east of the Langanes promontory in early January 1990. However, the first part of the spawning migration was located off the central and southern east coast on 6 January where its abundance was assessed during 6–8 January (Fig. XXXIII). At this point, assessment work was interrupted by a storm and could not be resumed until 13 January. The remainder of the spawning migration was then assessed during 13–16 January off the central and northern east coast (Fig. XXXIII). No further spawning migrations were found north of Langanes. Although work proceeded only in good weather, conditions during this survey left much to be desired. This was due to the short distance between the first and the second part of the migration, the speed of which necessitated an uninterrupted survey to ensure adequate acoustic sampling. The resulting estimate of about 740,000 tonnes (Appendix II.2, Table XIII) fell far short of the forecast as well as of the catch quota already established.

Due to the uncertainties in the January estimate, two additional attempts were made to assess the size of the spawning migration in shallow waters at the southeast coast in the first week of February. The first of these is shown in Figure XXXIV. However, because of schooling in the near surface layers these experiments were not altogether successful. Adjustments had to be made for catches taken during the intervening period and for negative bias due to near-surface schooling. The latter was done by assuming densities in the uppermost few metres of the water column to be similar to those recorded in the layer just below. The result of the first of these estimates was then about 13% lower than that obtained in January off the east coast.

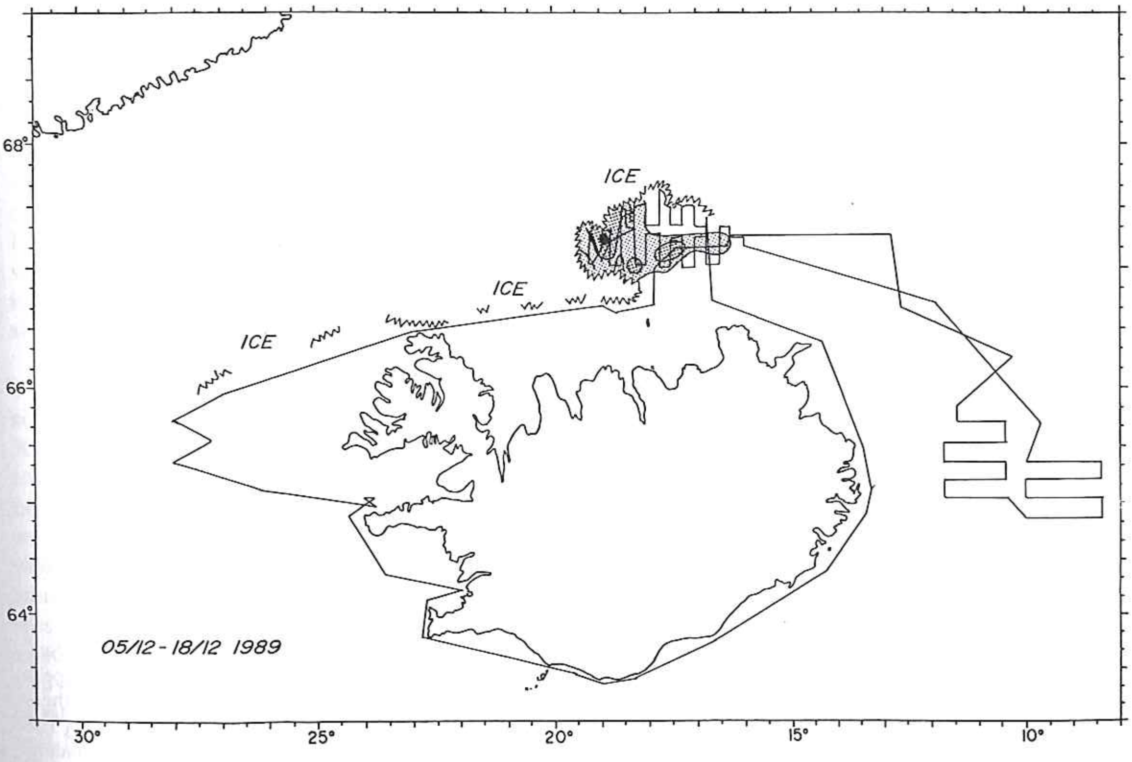

Figure XXXII. Survey tracks and capelin distribution, December 1989. The different shading denotes low, moderate and high densities.

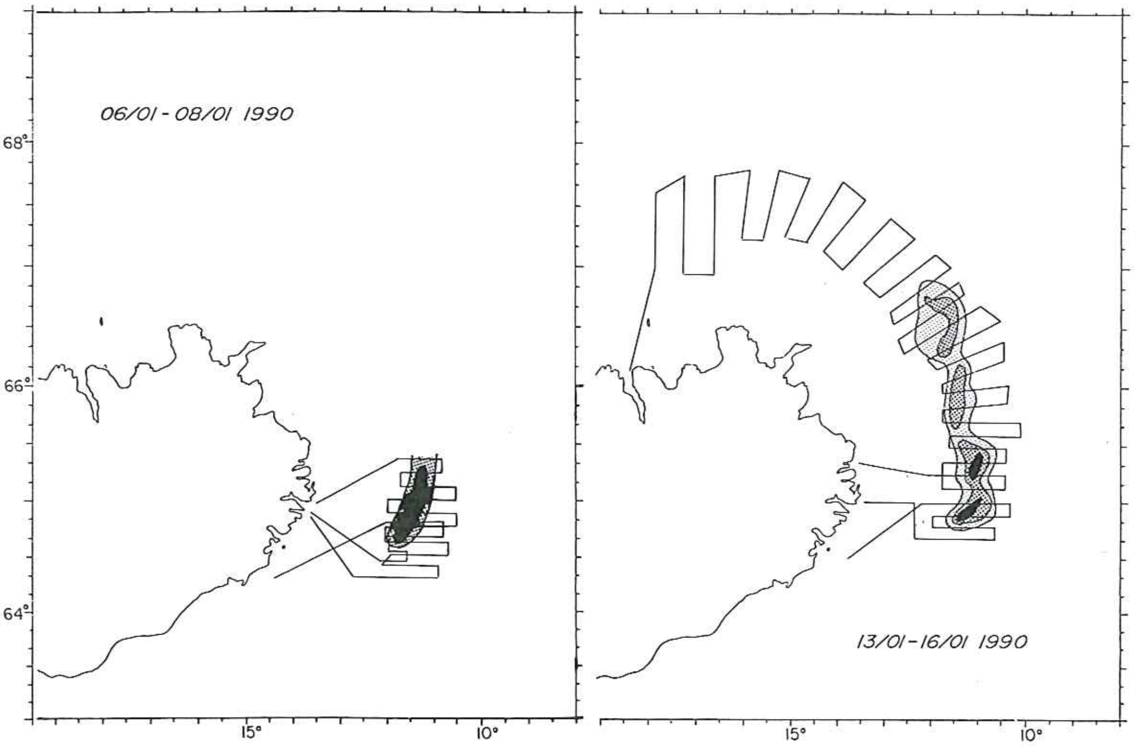

Figure XXXIII. Survey tracks and capelin distribution, East Iceland, January 1990. The different shading denotes low, moderate and high densities.

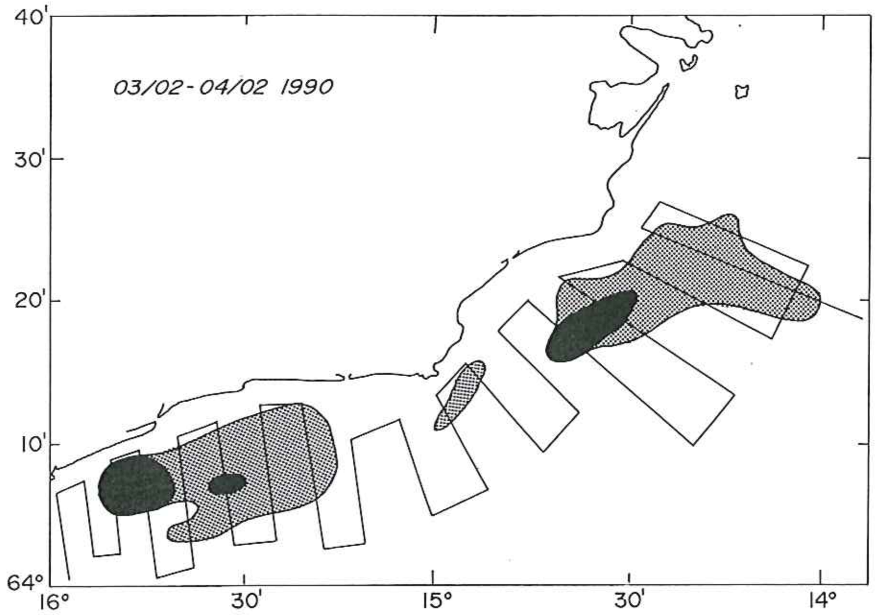

Figure XXXIV. Survey tracks and capelin distribution, Southeast Iceland, February 1990. The different shading denotes moderate and high densities.

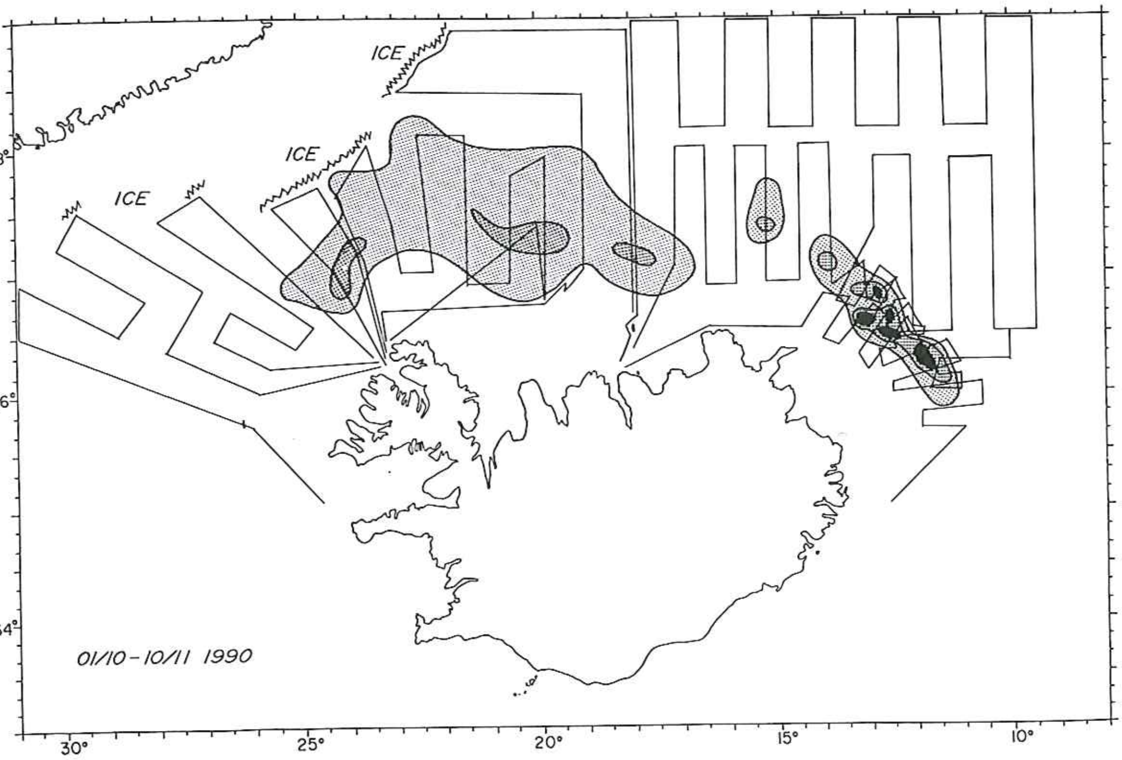

Figure XXXV. Survey tracks and capelin distribution, October/November 1990. The different shading denotes low, moderate and high densities.

The 1990/91 season. Again, no feeding migrations of capelin were registered in the central and northern Iceland Sea during the summer of 1990. In view of the difficulties experienced in the previous autumn it was decided to run a pilot survey in October and then conduct the actual stock assessment at a later date.

The pilot survey was carried out in the period 1 October – 10 November and covered an area south of 69°N from about 31°W to 9°W (Fig. XXXV). The distribution of drift ice was limited to the East Greenland shelf to the north and northwest of the Vestfirðir peninsula, and weather conditions were satisfactory except when working in the area north of Vestfirðir. Capelin were recorded in two main areas, *i.e.* north of Vestfirðir and off the western north coast on one hand and off Northeast Iceland on the other. Only immatures were recorded off the north coast, while the capelin in the areas off Vestfirðir and Northeast Iceland consisted of a mixture of adult fish and immatures. Observed capelin abundance was low, and it was difficult to divide the capelin into age groups due to variable size ratios from sample to sample.

The main assessment survey took place during 8–27 November (Fig. XXXVI) and was designed on the basis of earlier findings. There had been considerable changes in distribution in the intervening weeks. Thus, most of the immatures, previously recorded off the north coast, had migrated westward and were consequently recorded mixed with the maturing fish north of Vestfirðir. A similar situation was recorded in the eastern area where the maturing fish had, however, migrated east and south and mixed with the juveniles already there. In addition, a small area of mature capelin was now located off the central east coast. External conditions were good during the November survey. Mainly for that reason, the resulting abundance estimate was somewhat higher than that obtained from the previous survey, but the problem of allocating echo-recordings to age groups remained the same. Due to the low stock abundance, of which only about 370,000 tonnes were estimated to be maturing to

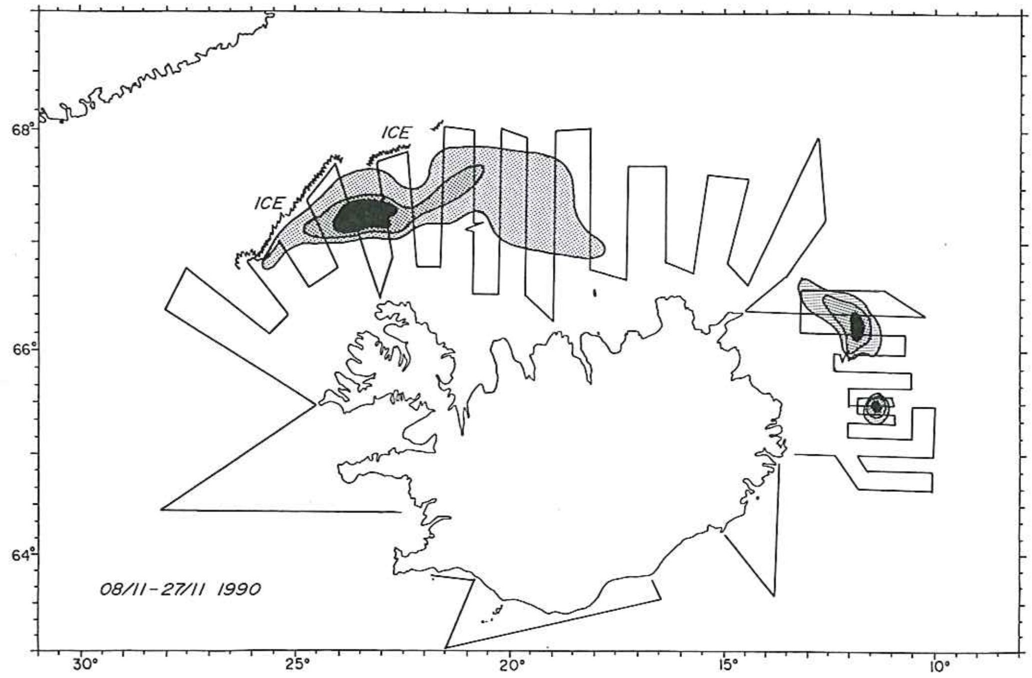

Figure XXXVI. Survey tracks and capelin distribution, November 1990. The different shading denotes low, moderate and high densities.

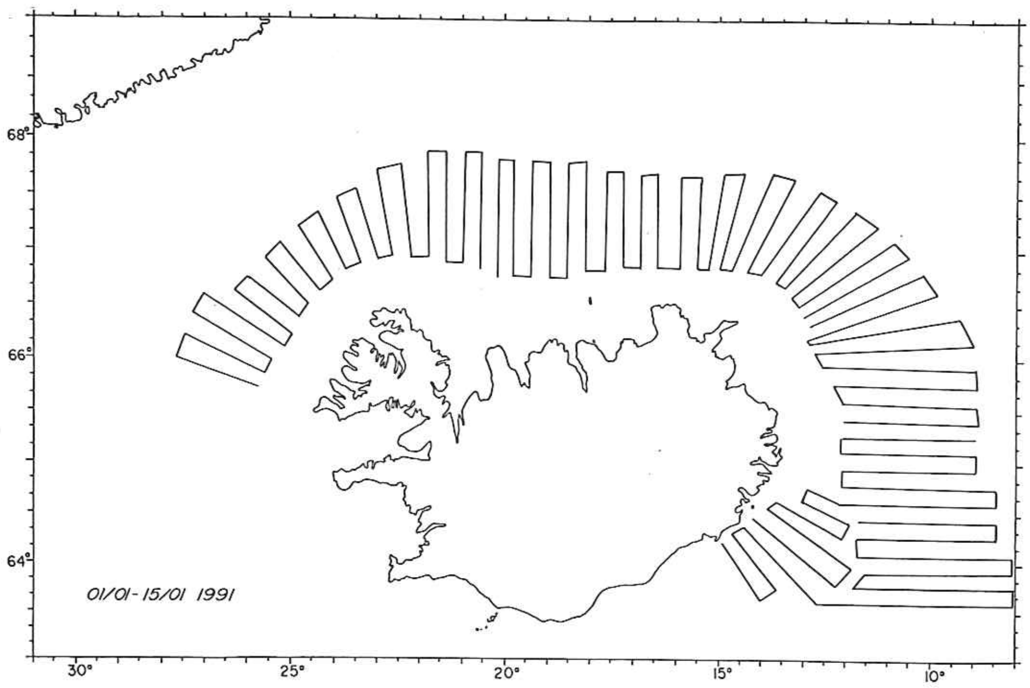

Figure XXXVII. Cruise tracks of pilot survey vessels, January 1991.

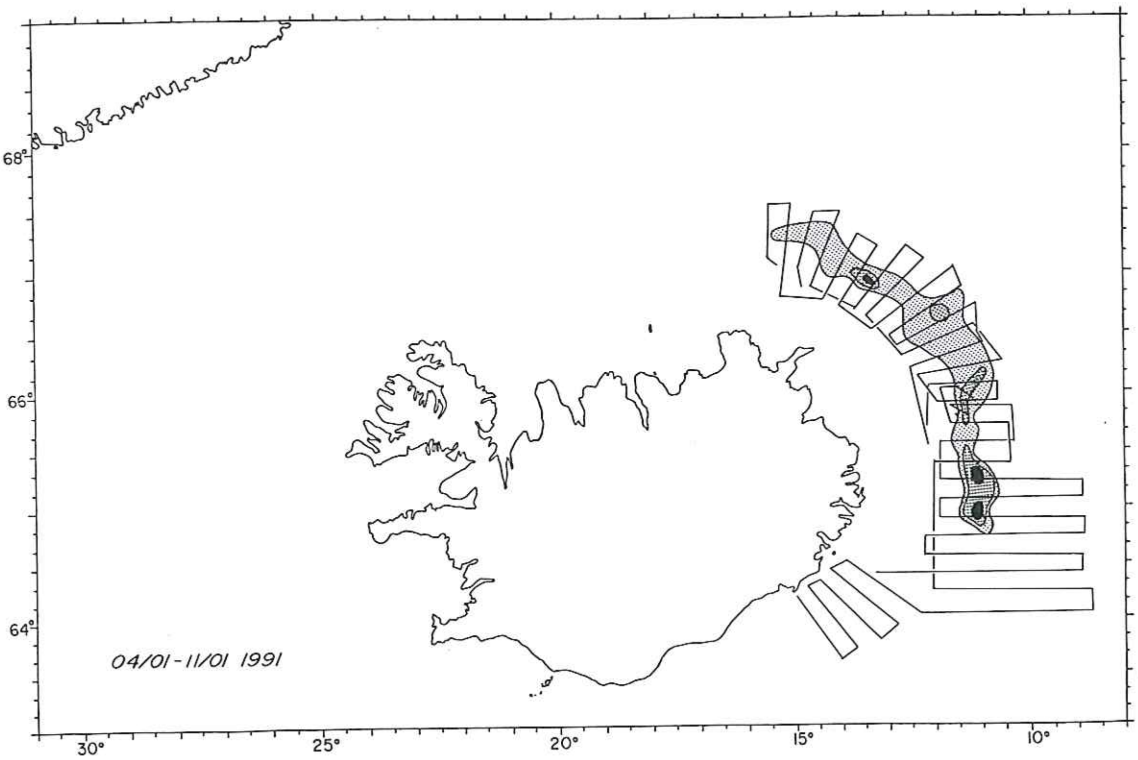

Figure XXXVIII. Survey tracks and capelin distribution, 4–6 January, 1991. The different shading denotes low, moderate and high densities.

spawn in 1991 (Appendix II.2, Table XII), the ongoing fishery was stopped pending further stock assessments in early 1991.

In the beginning of December large schools of mature capelin were reported off the central north coast. An investigation by a research vessel around the middle of the month showed that this was due to an eastward migration of capelin from the Vestfirðir area.

The October and November abundance estimates of 1990 were strongly contested by many skippers of capelin boats who maintained that stock abundance must be much higher than indicated by the survey results. For that reason and in order to ensure quick results and adequate coverage, six fishing vessels were chartered for scouting all possible capelin grounds off Northwest, North and East Iceland in January 1991 (Fig. XXXVII).

The January stock assessment survey began as usual off Southeast Iceland, and using the information from the scouting vessels, it was possible to complete the first assessment of the spawning migration east and northeast of Iceland by 6 January (Fig. XXXVIII). The migration was divided in two separate parts, and the total abundance estimate, obtained under good surveying conditions as regards weather and the behaviour of the capelin, amounted to 315,000 tonnes, 35% of which derived from the northern area. Due to the distance between the two parts of the migration, it proved possible to carry out another survey of the more southern area during a 24 hour period on 7 and 8 January (Fig. XXXIX). The level of abundance, obtained by the second survey, was about 5% lower than that obtained by the first one, but it is stated in the survey report that the capelin were obviously migrating in a southerly direction against the survey at a considerable speed. Nevertheless, the January results seemed to confirm the main findings from November in the year before, *i.e.* that abundance was indeed low and in order to meet the management target of 400,000 tonnes of spawning biomass, it was clear that according to these surveys the stock could not sustain a fishery.

The southern component soon entered the warm Atlantic waters off the southern east coast

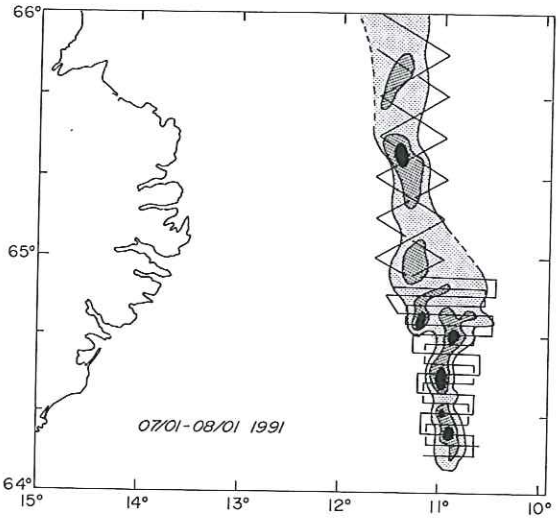

Figure XXXIX. Survey tracks and capelin distribution, 7–8 January, 1991. The different shading denotes low, moderate and high densities.

and scattered. The northern part of the migration was re-assessed off the central east coast during 20–23 January but with the same result as obtained earlier in the month. This migration, on the other hand, continued to follow the cold/warm water boundary up to the southeast coast. In spite of intensive search, other migrations were not located by the scouting vessels in January.

Due to the longer route taken by the first spawning migration, both components arrived in the coastal area off the southeast coast at about the same time. For that reason the spawning stock could be surveyed there in its entirety in less than 24 hours during 8–9 February (Fig. XL). Surveying conditions were good with regard to weather and the distribution pattern of the capelin was relatively even. There was little schooling in the near-surface layer and no difficulties in reaching waters without capelin schools in the shallowest part of the survey area. The resulting estimate amounted to 475,000 tonnes, but in addition a small spawning migration was located a few days later off the southern east coast, bringing the total to about 525,000 tonnes (Appendix II.2, Table XIII). Although practically no catches were taken, this is a very large deviation from the January estimate of about 320,000 tonnes and the November estimate which corresponded to about about 345,000 tonnes by early February when natural mortalities had been accounted for. At the time, it was strongly suspected that an unusually fast migration speed, in an opposite direction to that in which the January surveys proceeded, could be responsible.

The size of the main migration was assessed once again off the western south coast during 17–18 February (Fig. XLI). Conditions were not altogether favourable due to very dense schooling in part of the area and worsening weather during the last 2–3 hours of the survey. However, the abundance estimate amounted to about 400,000 tonnes which was in good agreement with the estimate of 425,000 tonnes, obtained 10 days earlier off the eastern south coast, when account had been taken of the catch.

During 23–24 February a final attempt was made to assess the size of the spawning migration when it had arrived in the bay of Faxaflói. This, however, proved impossible due to the formation of a number of separate schools with a density of up to 3 times that previously recorded off the south coast and 20 times the usual density experienced in the deep water area off East Iceland. Under such circumstances, the calculation of mean densities per unit area is futile and, therefore, each school has to be assessed separately.

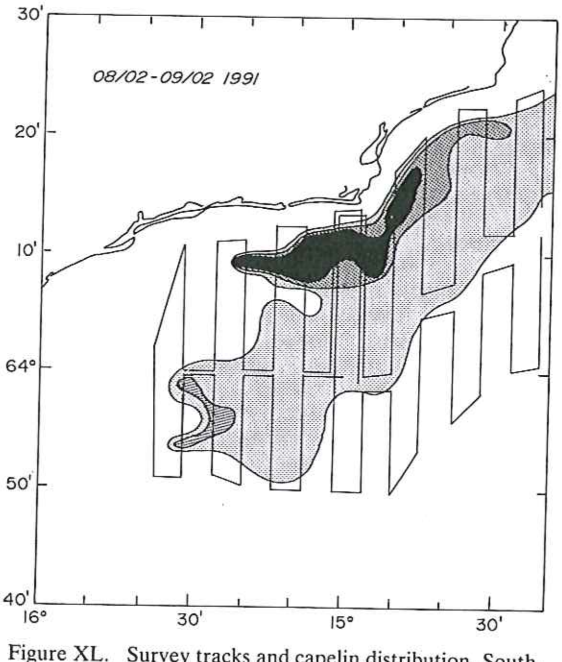

Figure XL. Survey tracks and capelin distribution, Southeast Iceland, 8–9 February 1991. The different shading denotes low, moderate and high densities.

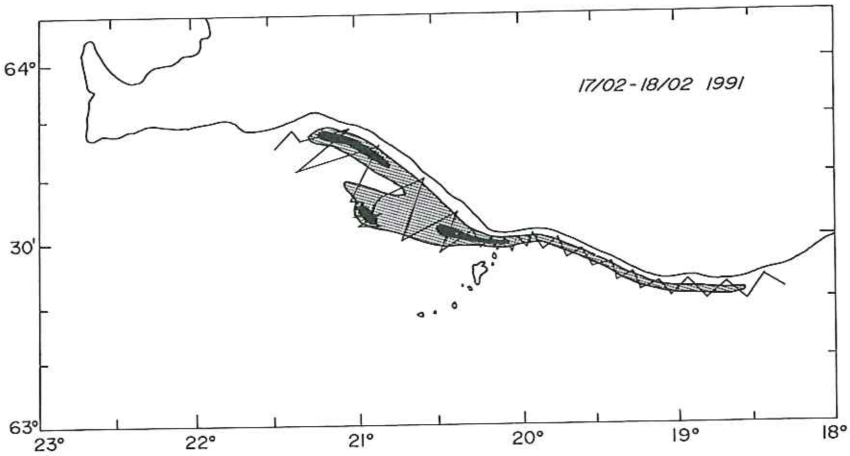

Figure XLI. Survey tracks and capelin distribution, western south coast, 17–18 February 1991. The different shading denotes moderate and high densities.

Because the capelin were migrating rapidly north across the bay, this was clearly an impossible task.

During the next two weeks the possibility of a late spawning migration directly from the Vestfirðir area was investigated, but with negative results. On the other hand, it became clear that part of the main migration did not spawn in the Faxaflói–Breiðafjörður region but continued northward to spawn on the banks off the Vestfirðir peninsula. Furthermore, the age and size of capelin, reported by fishing vessels at the southwest coast in late March and April, indicated that those fish almost certainly belonged to the migration that was located off the southern east coast around 10 February.

The last section in the history of this eventful season deals with reports by trawler skippers, working off the Vestfirðir peninsula, of large quantities of capelin migrating in over the shelf edge to spawn on the western and northern banks of the peninsula in April. Unfortunately, the news was received too late for a survey to be mounted. While this phenomenon was not new and had been observed before, migrations of capelin from the west to spawn on the outer part of the Vestfirðir shelf, have usually been on a relatively small scale and not amounted to more than a few thousand tonnes (Vilhjálmsson 1980a, 1989 and 1991).

The 1991/92 season. Due to expectations of relatively low stock abundance and unaccepable uncertainties in predictions of stock abundance from August assessments of immature capelin for the preceding two fishing seasons, it was decided not to open a capelin fishery until the abundance of the maturing fishable stock had been assessed. In view of the experience from the preceding winter season, it was further decided to commission 4 capelin boats to work with the research vessels during the autumn survey to help locating the stock (Fig. XLII).

The 1991 autumn survey was carried out during 5–27 October (Fig. XLIII). The survey was begun with 4 scouting vessels as planned, but unfortunately only one research vessel was available to work with them during the first ten days. As a result, the scouting vessels soon outran the research ship and their information reporting became ever more out of step, as the assessment work progressed. In spite of this, however, the cooperation was very useful, and the information provided by the scouting vessels saved considerable time which could be profitably used in obtaining better coverage of the actual distribution of capelin than otherwise possible.

In October 1991 the distribution and abundance of capelin was as follows: Layers of scattered mature and immature capelin in about equal proportions were registered on the Greenland shelf between about 31°W and 33°W, from 66°15′N to 67°15′N. Adult 3-group capelin dominated in deep water areas to the west and north of the Vestfirðir peninsula, but schools were generally small and scattered, and the capelin were not abundant. On the other hand, an area, particularly rich in capelin, was located off the north coast of Iceland just south of 67°30′N, between about 20°00′W and 22°30′W. In this area the capelin were registered as extensive and dense scattering layers at various depths, consisting of a

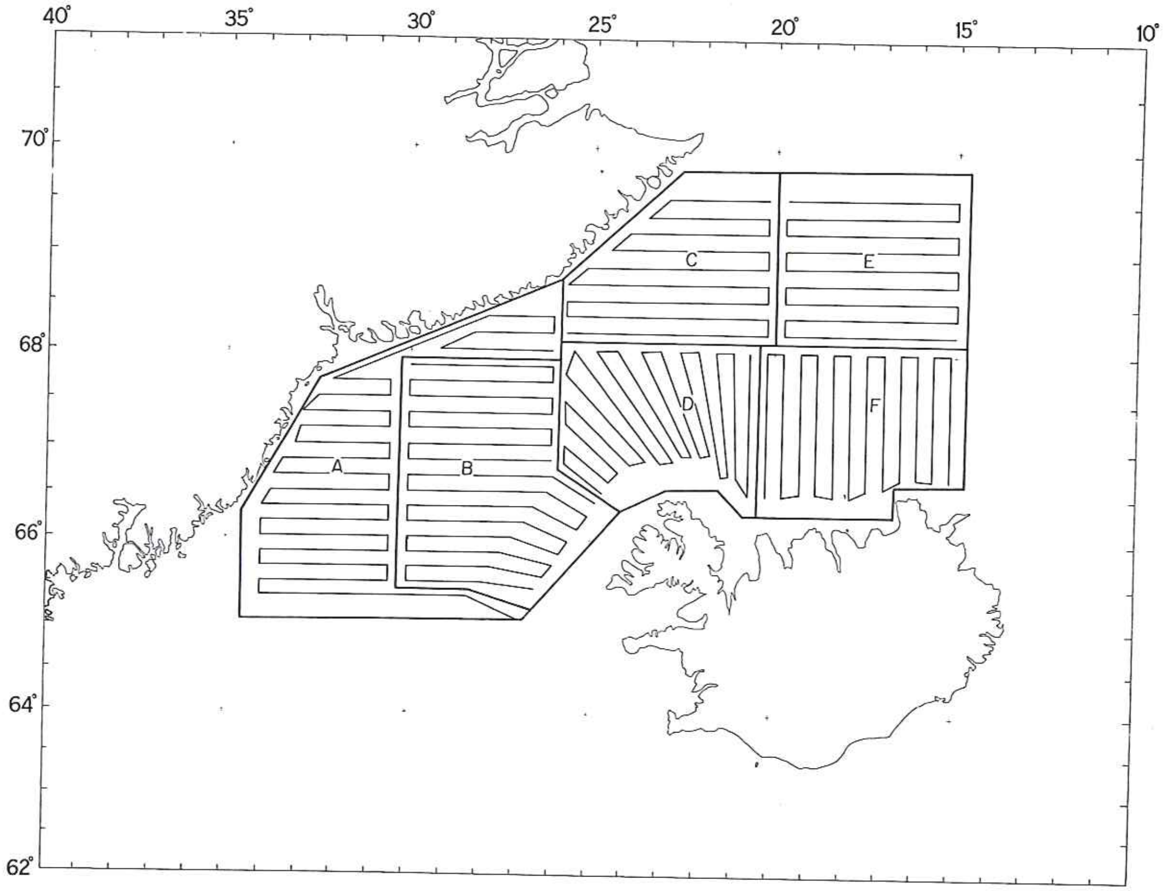

Figure XLII. Cruise tracks of pilot survey vessels, October 1991.

varying mixture of mature and immature fish. In addition, some very scattered capelin were recorded near the shelf edge off Northeast Iceland. These last mentioned recordings, however, consisted almost exclusively of immature 1-group fish.

The October survey indicated that about 650,000 tonnes of capelin were maturing to spawn in 1992 (Appendix II.2, Table XII). There was no interference by drift ice during the survey, but weather conditions were far from ideal while working in the western part of the survey area. For this reason, and due to the scattered and uneven distribution in parts of the area, it was felt that this survey probably underestimated the adult part of the stock.

A second survey was therefore carried out in November (Fig. XLIV). At the time there was much drift ice in the Iceland-Greenland Channel, which precluded an effective survey, but only small concentrations of maturing capelin were located near the ice border in parts of this area. As in October, an area rich in capelin was located off the central and western north coast of Iceland, mainly from 67°15′N to 67°45′N, between about 23°00′W and 18°30′W, but extending south to about 67°00′N in the eastern part of the area. As before, the capelin in this area were registered as extensive and dense scattering layers at various depths, usually consisting of a varying mixture of mature and immature fish. Furthermore, adult capelin in moderate densities were located off the eastern north coast at around 16°W, with immature fish to the west and north from there. Finally, a small area containing immature 1-group capelin was located outside the shelf edge off the Langanes promontory.

In late November 1991 the capelin distribution in the North Icelandic area was, therefore, quite similar to what it was in the month before, and the age and maturity groups had not yet segregated. Apart from the ice cover in the Iceland-Greenland Channel area, external surveying conditions were excellent in November 1991. The capelin were distributed in scattering layers of varying densities but very suitable for acoustic abundance estimation. The main drawback was the mixture of age and maturity groups which was difficult to separate correctly.

The November 1991 abundance estimate of mature capelin came to about 845,000 tonnes. It was, however, also noted that the capelin, which were recorded in the area of the Iceland-Greenland Ridge and over the Greenland shelf in the month before, and amounted to about 90,000 tonnes, might not be included. This was confirmed in December, when fishing vessels observed schools of adult capelin migrating into the waters at the shelf edge off Vestfirðir from the west. The total November 1991 estimate of mature capelin, therefore, amounted to 935,000 tonnes (Appendix II.2, Table XII).

The winter 1992 survey was carried out during 3–20 January in the usual way, beginning off Southeast Iceland and continuing north and westward from there (Fig. XLV). Capelin were recorded almost continuously at and outside the shelf edge from the southern border of the East Icelandic Current off Southeast Iceland to the north of the Vestfirðir peninsula. Almost all capelin recorded near the shelf edge east of Iceland, south of the Langanes promontory (66°30′N), were maturing fish belonging to the 1992 spawning stock. In this area schooling was not pronounced, and capelin recordings were almost always in the form of scattering layers of varying densities. About 85% of the 1992 spawning stock were located there.

An additional but much smaller spawning migration was located in a narrow region near the shelf edge from northeast of the Langanes promontory westwards to about 17°W. In this area the mature capelin were considerably smaller than east of Iceland and mixed with immature 2- and 3-group fish. Off the central and western north coast, as well as off the Vestfirðir peninsula, the survey recorded large numbers of immature 2-group capelin (year class 1990). The

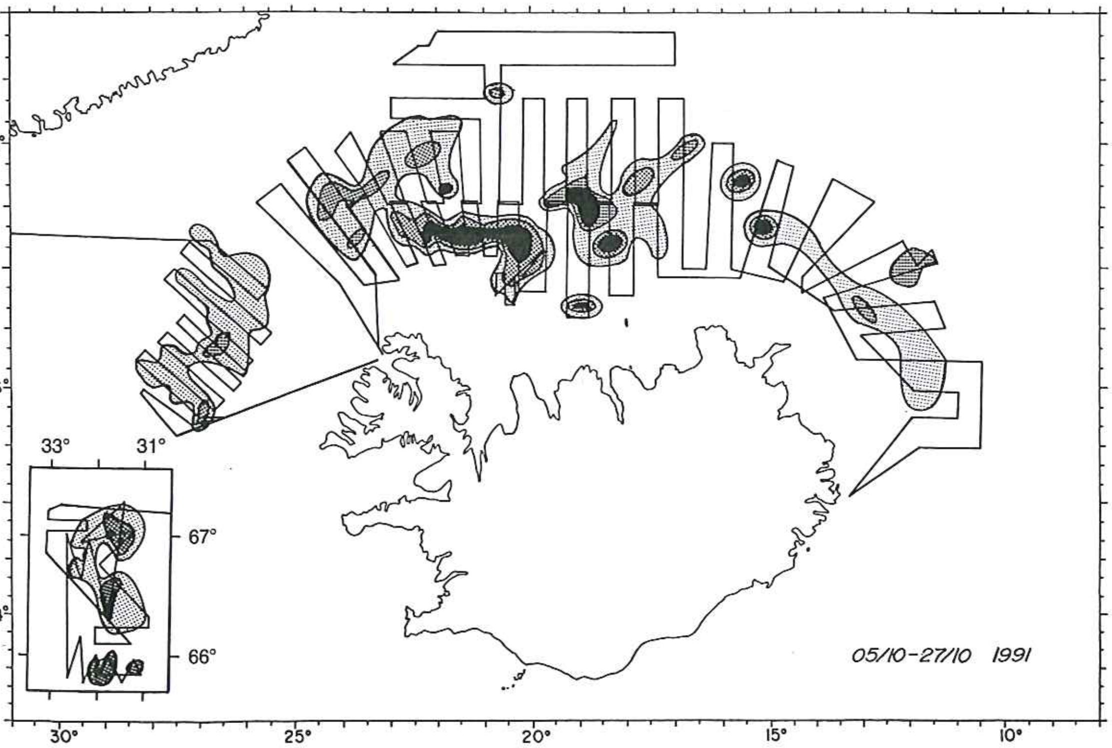

Figure XLIII. Survey tracks and capelin distribution, October 1991. The different shading denotes low, moderate and high densities.

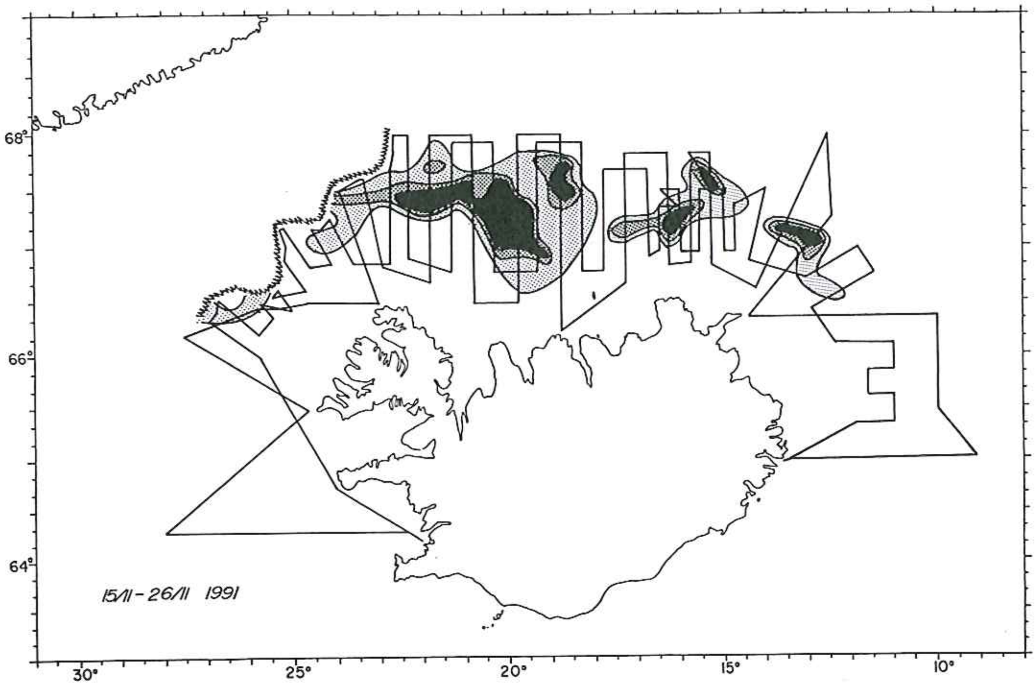

Figure XLIV. Survey tracks and capelin distribution, November 1991. The different shading denotes low, moderate and high densities.

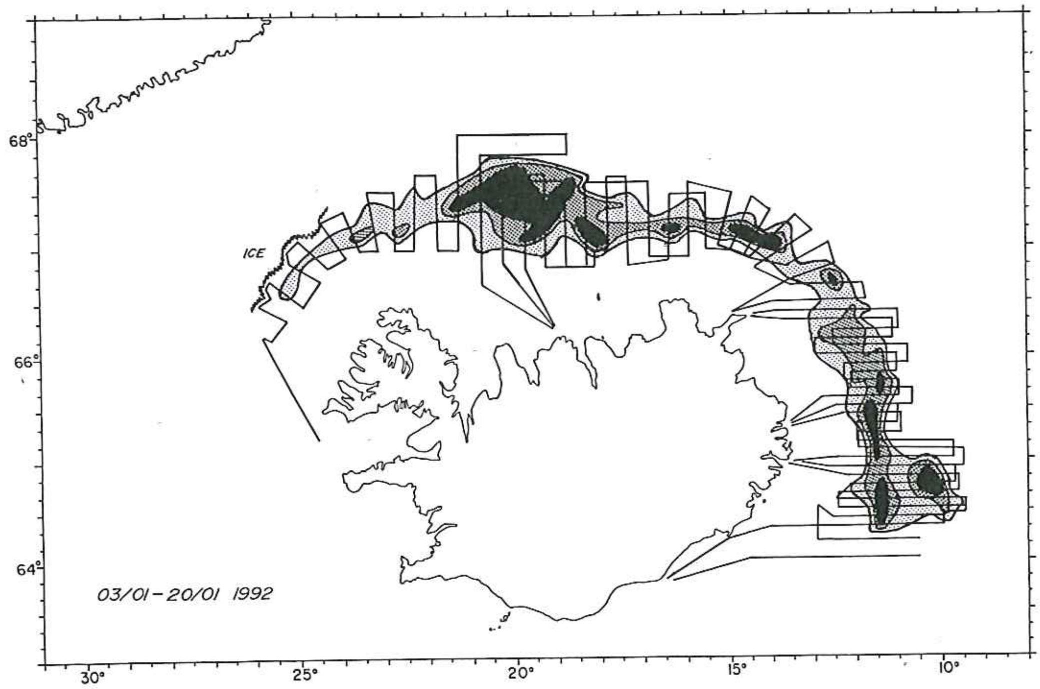

Figure XLV. Survey tracks and capelin distribution, January 1992. The different shading denotes low, moderate and high densities.

main concentrations were located from 18°W to 21°W, between about 67°00′N and 67°45′N. West of that region capelin concentrations diminished quickly, and none were reorded south of 66°30′N off the Vestfirðir peninsula. Only small numbers of spawners were recorded among the immatures off the central and western north coast. No capelin were recorded in the vicinity of the ice border off the Vestfirðir peninsula.

In January 1992 surveying was halted on three occasions to wait out short storm periods, when working in the area east of Iceland. Otherwise, weather conditions were exceptionally good, and no adjustments had to be made in order to compensate for losses due to aeration or sea swell. As usual at this time of the year, the survey progressed in the opposite direction to that of the migration of the spawners. In order to ensure that new arrivals would not go undetected, the last two survey tracks were repeated when work was resumed after the above halts. Only minor changes were detected in the low echo abundance previously recorded in the area east of Iceland. The values recorded on these occasions were, therefore, omitted. The capelin were almost always recorded as scattering layers of varying densities at depths of 70–150 m during the hours of darkness, but somewhat deeper in the daytime. The distribution and behaviour of the fish were, therefore, about as favourable as could be for acoustic estimation of total echo abundance. Although maturing capelin were registered together with juveniles off Northeast Iceland, this will not have biased the estimate to a significant degree since only a minor proportion of both stock components were located there. The total abundance of mature capelin, recorded in January 1992, amounted to 1,070,000 tonnes (Appendix II.2, Table XIII).

No further attempt was made to assess the main spawning migration in the winter of 1992. On the other hand, trawlers fishing for cod off the Látrabjarg promontory on the southern Vestfirðir peninsula, reported large concentrations of mature capelin migrating south in this area in late February. A subsequent investigation of this migration by a research vessel was carried out in early March. While the presence of south migrating capelin was verified, it was found that their abundance was low and could not have amounted to more than 30–50 thousand tonnes.

The 1992/93 season. The fishing season started around mid-July with Norwegian vessels making good catches in deep waters north of Melrakkaslétta at approximately 68°30′N, 16°00′W. The Norwegians were soon joined by Icelandic and Faroese capelin boats which followed the northward migration of this part of the stock to about 70°N. Around mid-August these capelin headed back south again and joined the main part of the maturing fishable stock, which a survey of 0-group fish and capelin abundance located in the shelf area off the western north coast of Iceland in the latter half of the month. After August, no capelin were located by the fishing fleet north of 68°N. The Icelandic August survey of the area off northern Iceland and between Iceland and Greenland, south of 68°30′, estimated adult capelin abundance to be about 1 million tonnes.

The autumn survey was carried out during 13–29 October (Fig. XLVI). Weather conditions were unusually good, there was little interference by aeration due to wind or sea swell in any part of the survey area, and necessary adjustments for losses of echo signals for these reasons were minimal. Ice prevented surveying in a considerable part of the channel area between Northwest Iceland and Greenland. Since only very scattered capelin recordings were obtained in the vicinity of the ice border, except in a small area north of cape Horn, it seemed unlikely that much capelin can have gone undetected because of the ice cover. However, since the ice covered a part of the common distribution range of adult capelin in October, the possibility of some of the fishable stock having gone undetected, could not be categorically excluded.

In October 1992 an area rich in capelin was located off the western north coast of Iceland from about 67°10′N to 67°30′, between 19°W and 22°W. In this area the capelin were registered as extensive and dense scattering layers at various depths, consisting of a varying mixture of mature and immature fish. Off the central and eastern north coast, capelin recordings similarly consisted of a mixture of 1-group and older fish, but were more scattered and contained in a narrower region along the shelf edge. Large concentrations of capelin were also recorded to the northeast of Iceland. However, the general distribution pattern was somewhat different from that farther

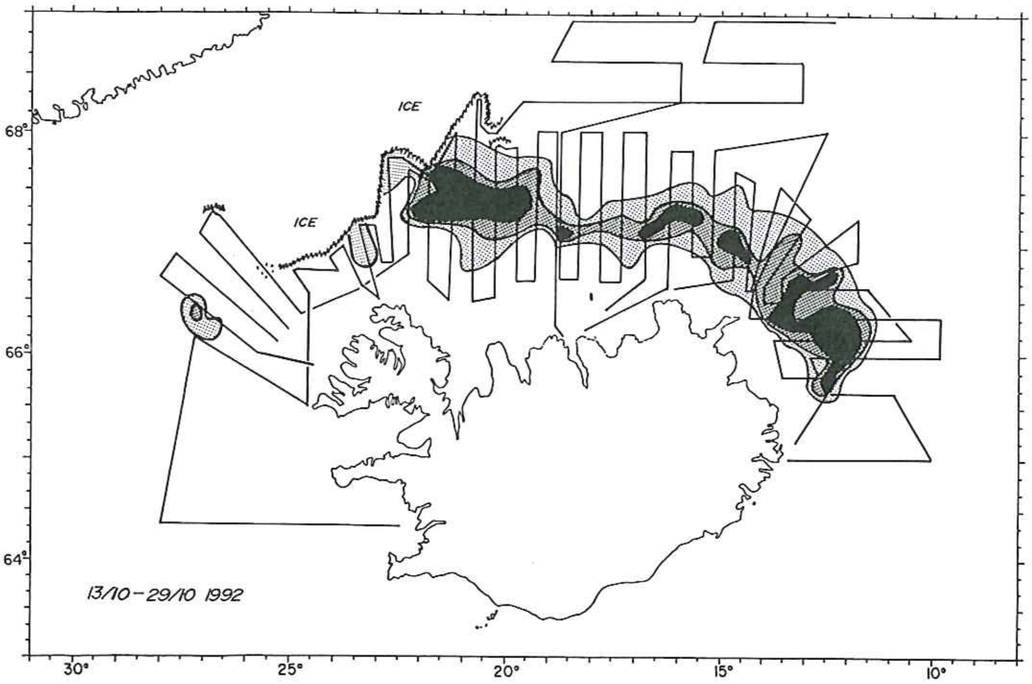

Figure XLVI. Survey tracks and capelin distribution, October 1992. The different shading denotes low, moderate and high densities.

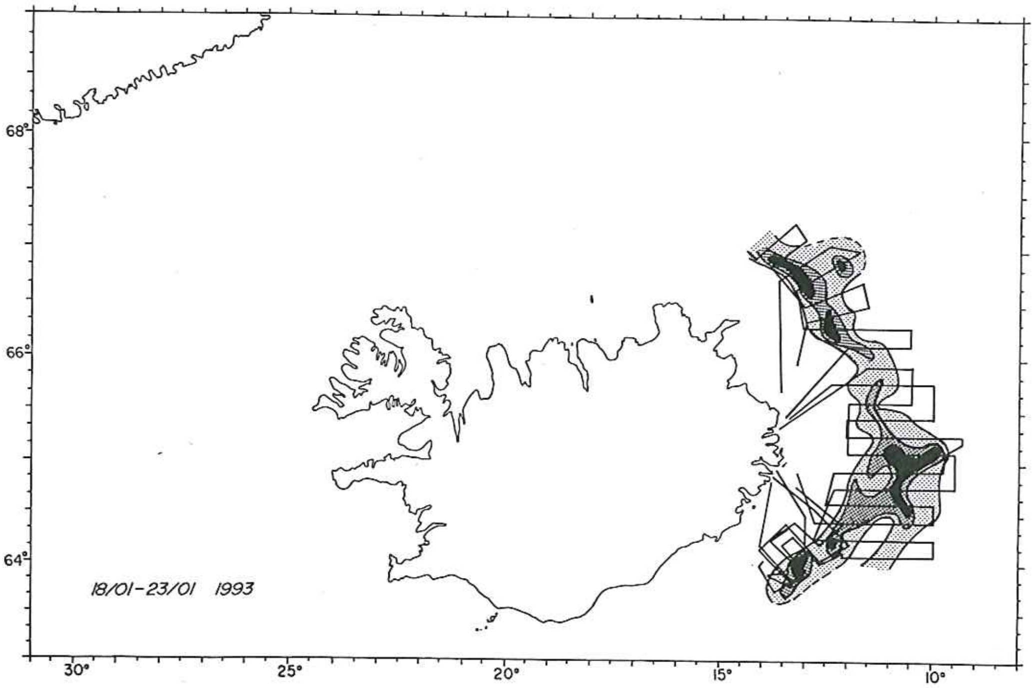

Figure XLVII. Survey tracks and capelin distribution, January 1993. The different shading denotes low, moderate and high densities.

west. In this area the 1-group juveniles were mainly recorded in the shallow waters of the Icelandic shelf, while the 2- and 3-group capelin were located at the edge of the shelf and in deeper waters. No capelin were recorded in those parts of the Iceland Sea and the Iceland-Greenland Channel which could be investigated.

In comparison to both the October and November surveys in 1991 the distribution of juvenile 1-group and adult 2- and 3-group capelin was now considerably wider. The reasons for this are the higher total abundance of both of these stock components, and also the fact that this year about 40% of the adult stock had migrated to the area off Northeast Iceland, where only juveniles were recorded in 1991. On the other hand, the situation was similar to that of both 1991 and 1990 in that most of the adult stock was heavily mixed with juveniles. The total abundance estimate amounted to almost 1.4 million tonnes, of which analyses of maturity indicated that capelin maturing to spawn in 1993 amounted to 995,000 tonnes (Appendix II.2, Table XII).

The winter 1993 survey was carried out during 5–23 January (Fig. XLVII). On arriving in the area off SE-Iceland capelin were registered in the border area between the warm and cold water masses between about 64°20′N and 64°40′N. However, weather conditions were extremely unfavourable to begin with. Thus, in the first two weeks surveying had to be halted on numerous occasions to wait out stormy periods. In fact, work could not be continued without unacceptable interuptions until 18 January. From then until 23 January the area east of Iceland, from 64°N to northeast of the Langanes promontory, was surveyed under reasonable conditions. At this point, however, the survey had to be broken off once again due to a storm and was not resumed.

Practically all of the capelin recorded east of Iceland, south of the Langanes promontory (66°N), were maturing fish belonging to the 1993 spawning stock. About 80% of the 1993 spawning stock recordings were obtained in this area. Additional recordings of mature capelin were located farther north in a narrow region, near the shelf edge off Northeast Iceland. In this area the mature capelin were considerably smaller than east of Iceland, and in places mixed with immature 2-group fish (year class 1991). The overall age distribution was similar to that recorded in October of the previous year, but the January 1993 survey indicated that the mean weight at age was 1.5 g higher than that predicted from the October 1992 estimate.

The southernmost part of the spawning migration had by 6 January reached the warm water front off Southeast-Iceland at about 64°20′N. As often happens, some of these fish migrated south along the Icelandic shelf edge around 11°30′W. These were recorded in relatively shallow waters, some 40–50 naut. miles off the southeast coast in the third week of January. Other spawning migrations were found in deeper waters, between approximately 09°30′W and 11°W, where they appeared to enter the warmer Atlantic water before heading west. Practically no schooling was observed in the area east of Iceland, and capelin recordings were almost always in the form of scattering layers, usually of very low densities.

Although the presence of capelin in the warm, deep water region off Southeast Iceland could not be verified, it seemed certain in view of catches taken from south migrating schools off the central east coast in December about 6–7 weeks earlier, that some of the spawning stock had migrated to an area south of that which could be properly covered by the present survey. Furthermore, previous surveying has shown that it is difficult to follow and assess capelin after they have entered this zone of transition, before the migrations arrive in the shallow waters at the southeast coast. Therefore, the January 1993 assessment of 605,000 tonnes of 2- to 4-group capelin, of which 550,000 tonnes were maturing to spawn in 1993 (Appendix II.2, Table XIII), was clearly a gross underestimate of the 1993 spawning stock.

Further surveying of the main spawning migrations in the coastal area off Souteast Iceland was not attempted. However, in the first half of March the area off Breiðafjörður and west of the Vestfirðir peninsula was surveyed in order to ascertain whether additional spawning migrations could be expected from the west. No such migrations were detected, but the survey recorded large amounts of spawning and spent capelin in wide areas in the more coastal parts of this region.

Appendix I.2. Surveys of the distribution and abundance of juvenile capelin in summer.

The following charts (Figs. XLVIII–LVIII) show survey tracks and the distribution of juvenile 1- (and 2-) group capelin, recorded during Icelandic surveys of 0-group fish distribution and abundance in August (September) 1982–1992.

A short description of the August survey procedures and discussion of the results is contained in section 15.5. The number and biomass of the 1-group juveniles are given in Appendix II.2, Table XVI.

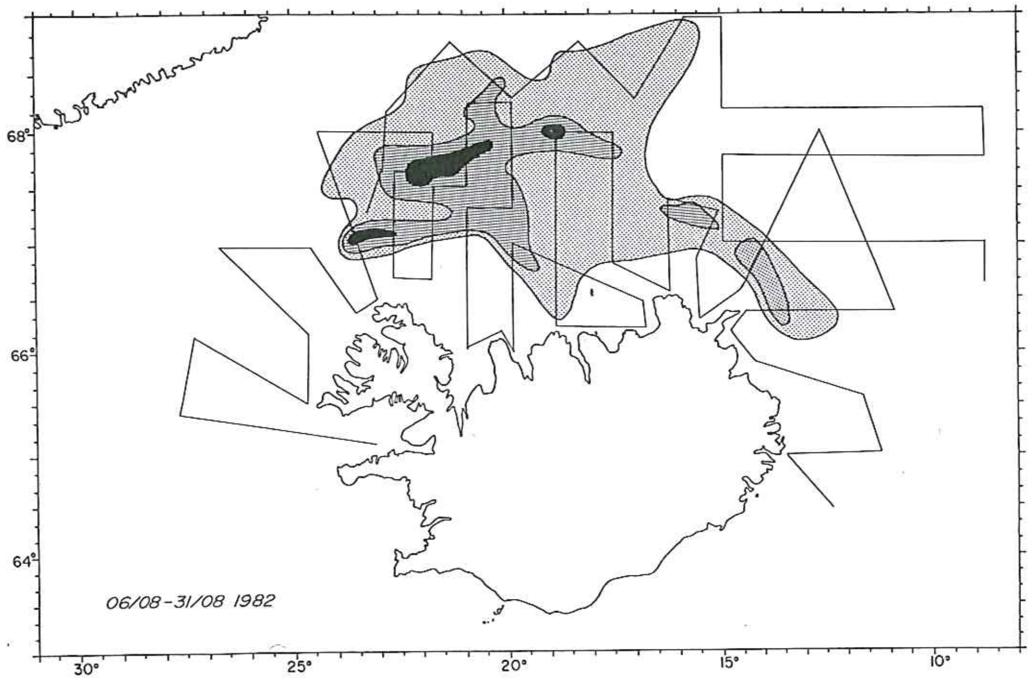

Figure XLVIII. Survey tracks and juvenile 1- and 2-group capelin distribution in the north Icelandic area, August 1982. The different shading denotes low, moderate and high densities.

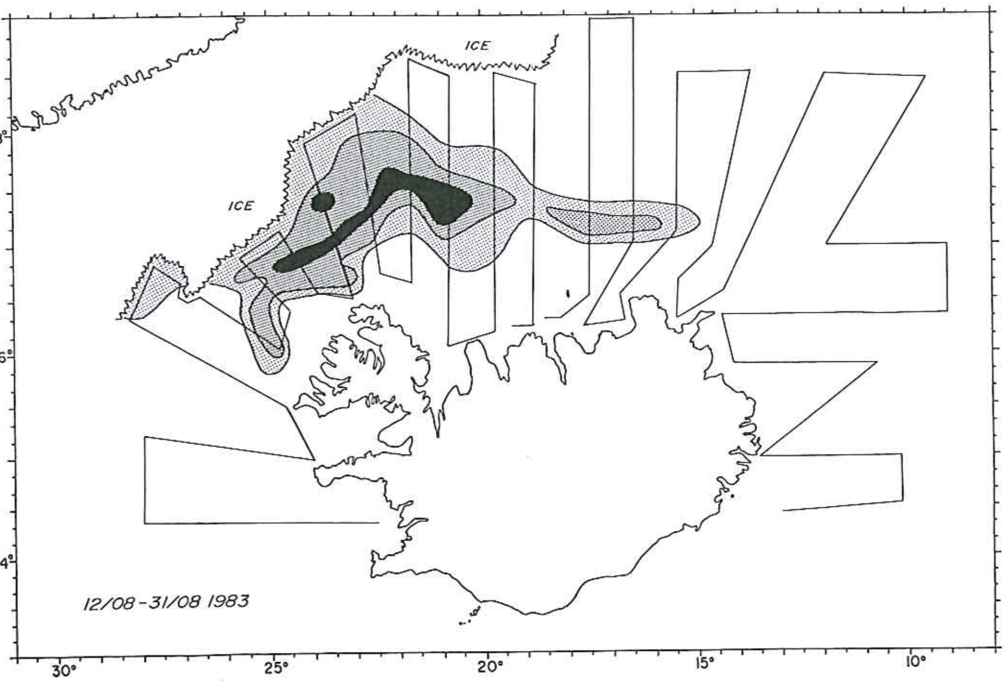

Figure XLIX. Survey tracks and juvenile 1- and 2-group capelin distribution in the north Icelandic area, August 1983. The different shading denotes low, moderate and high densities.

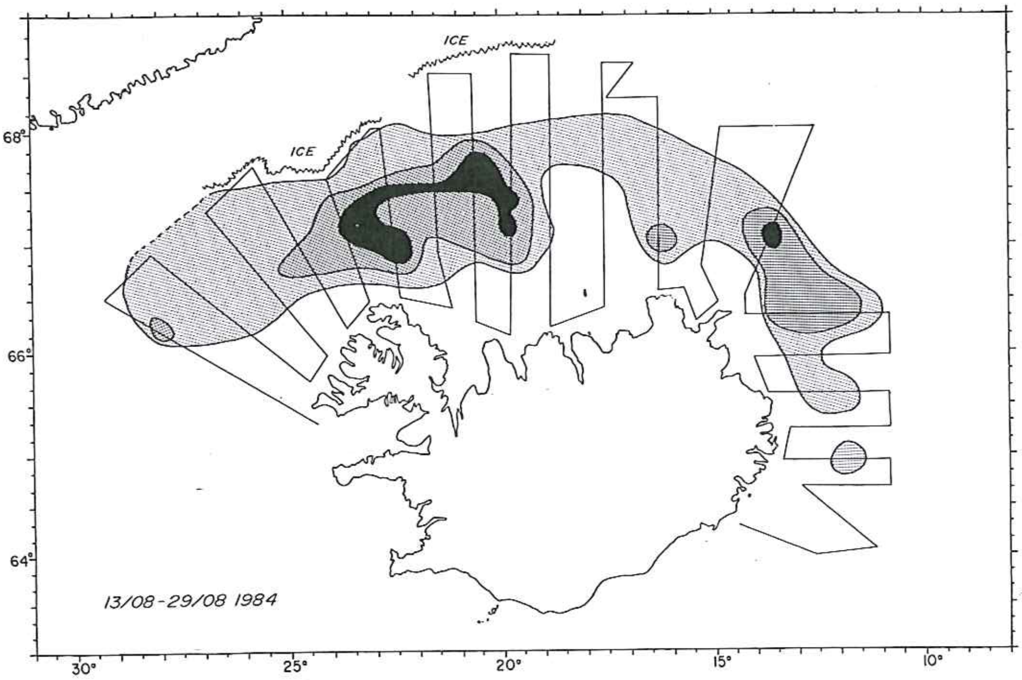

Figure L. Survey tracks and juvenile 1- and 2-group capelin distribution in the north Icelandic area, August 1984. The different shading denotes low, moderate and high densities.

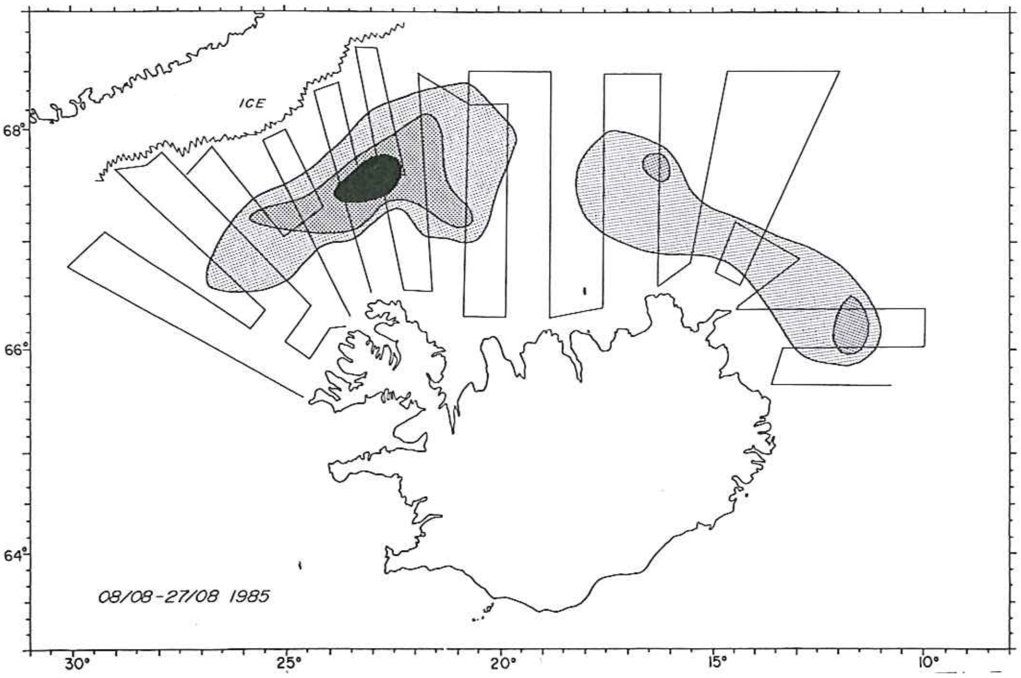

Figure LI. Survey tracks and juvenile 1- and 2-group capelin distribution in the north Icelandic area, August 1985. The different shading denotes low, moderate and high densities.

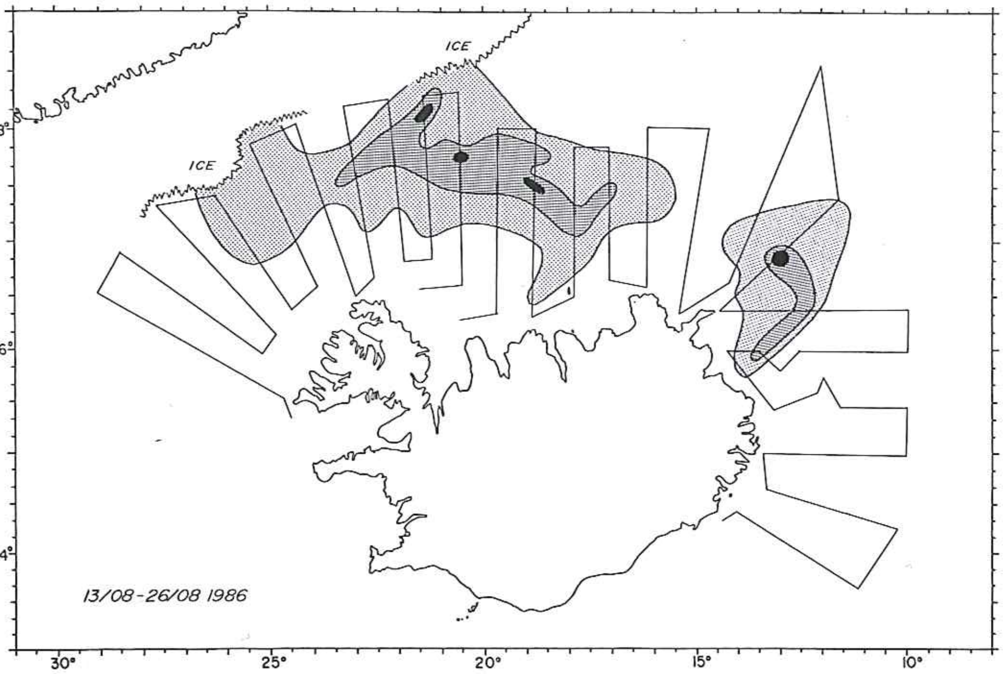

Figure LII. Survey tracks and juvenile 1- and 2-group capelin distribution in the north Icelandic area, August 1986. The different shading denotes low, moderate and high densities.

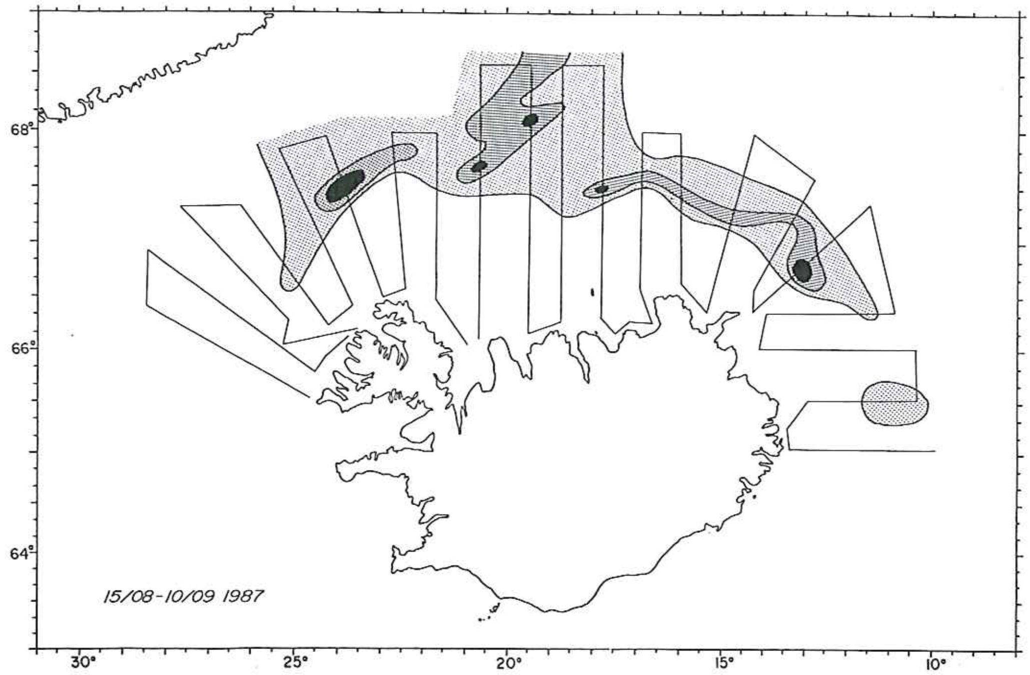

Figure LIII. Survey tracks and juvenile 1- and 2-group capelin distribution in the north Icelandic area, August/September 1987. The different shading denotes low, moderate and high densities.

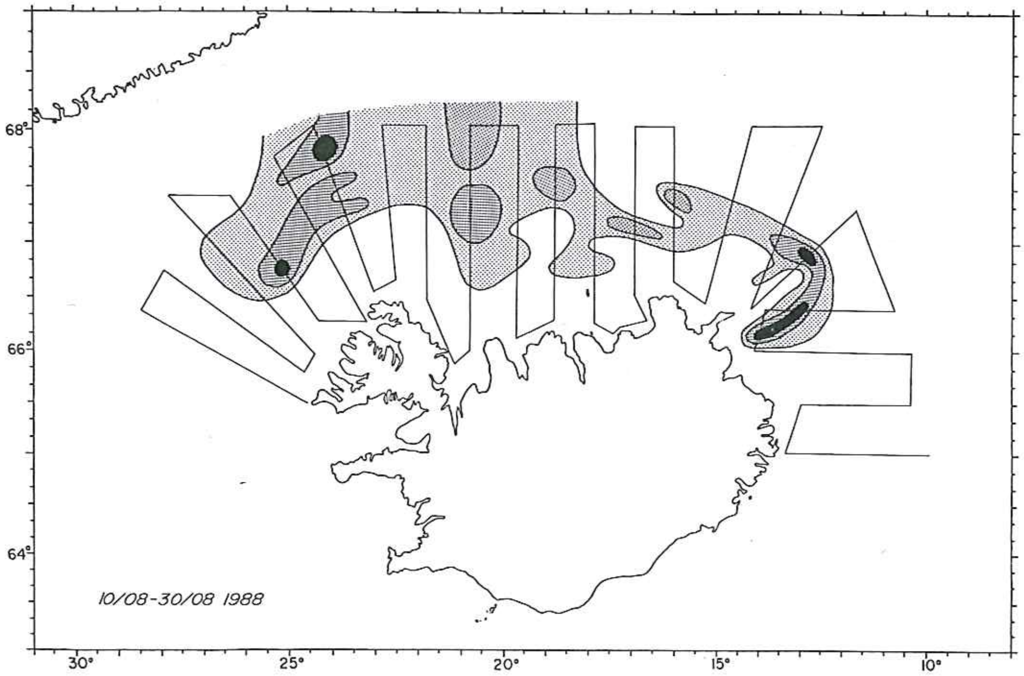

Figure LIV. Survey tracks and juvenile 1- and 2-group capelin distribution in the north Icelandic area, August 1988. The different shading denotes low, moderate and high densities.

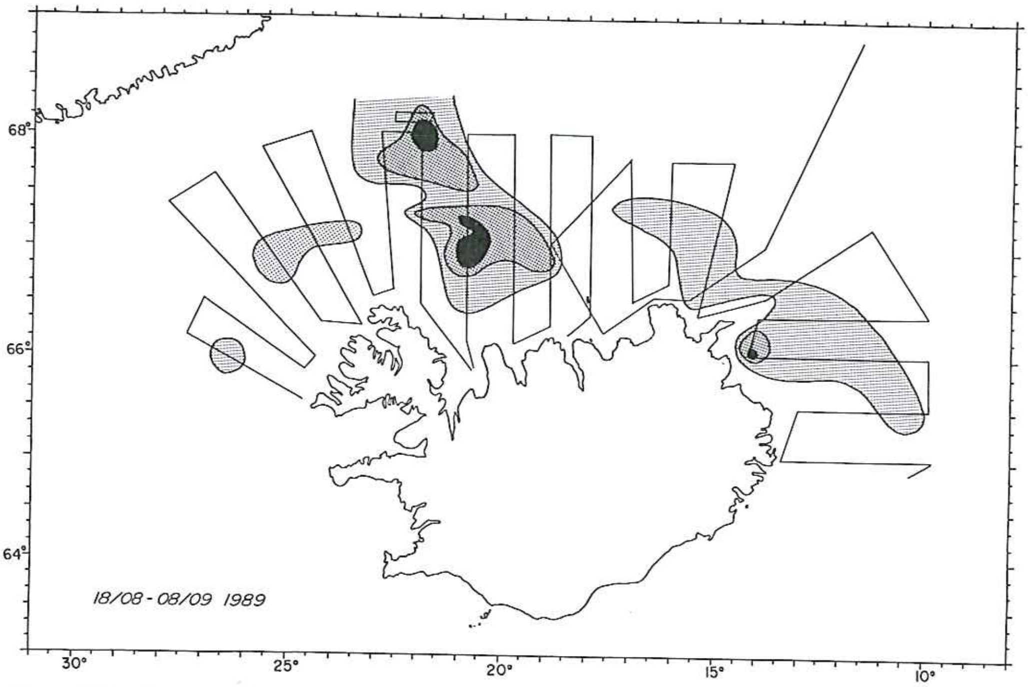

Figure LV. Survey tracks and juvenile 1- and 2-group capelin distribution in the north Icelandic area, August/September 1989. The different shading denotes low, moderate and high densities.

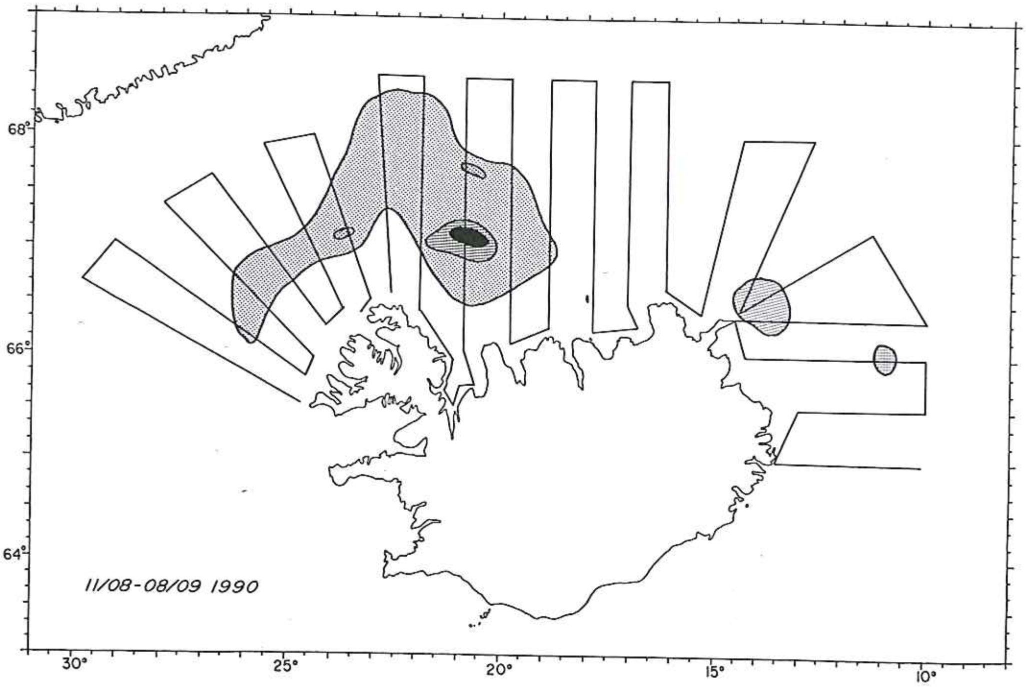

Figure LVI. Survey tracks and juvenile 1- and 2-group capelin distribution in the north Icelandic area, August/September 1990. The different shading denotes low, moderate and high densities.

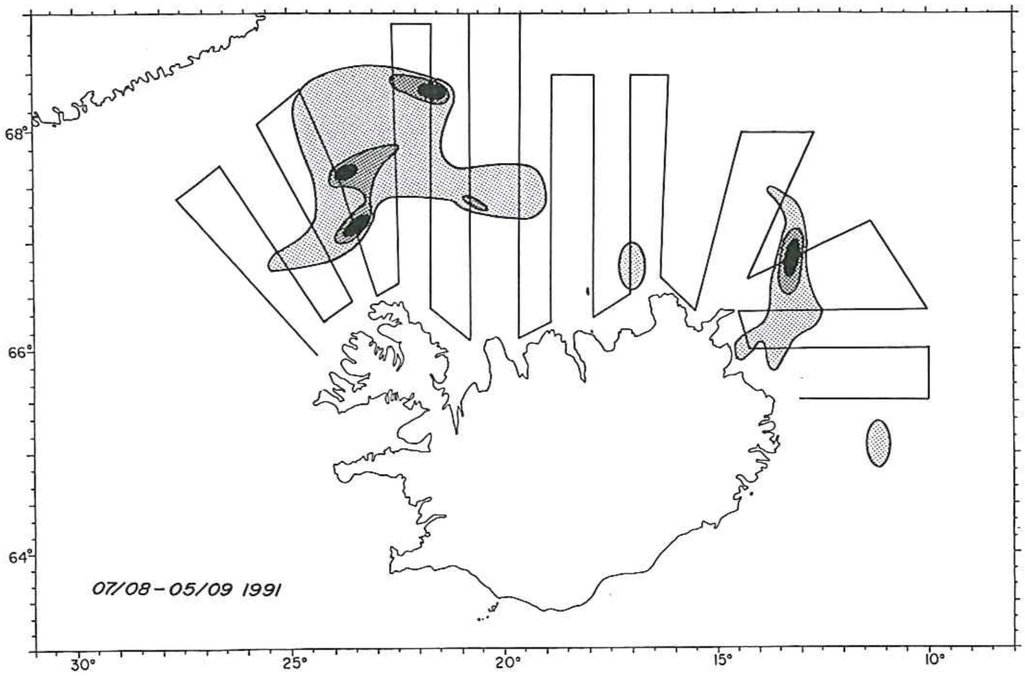

Figure LVII. Survey tracks and juvenile 1- and 2-group capelin distribution in the north Icelandic area, August/early September 1991. The different shading denotes low, moderate and high densities.

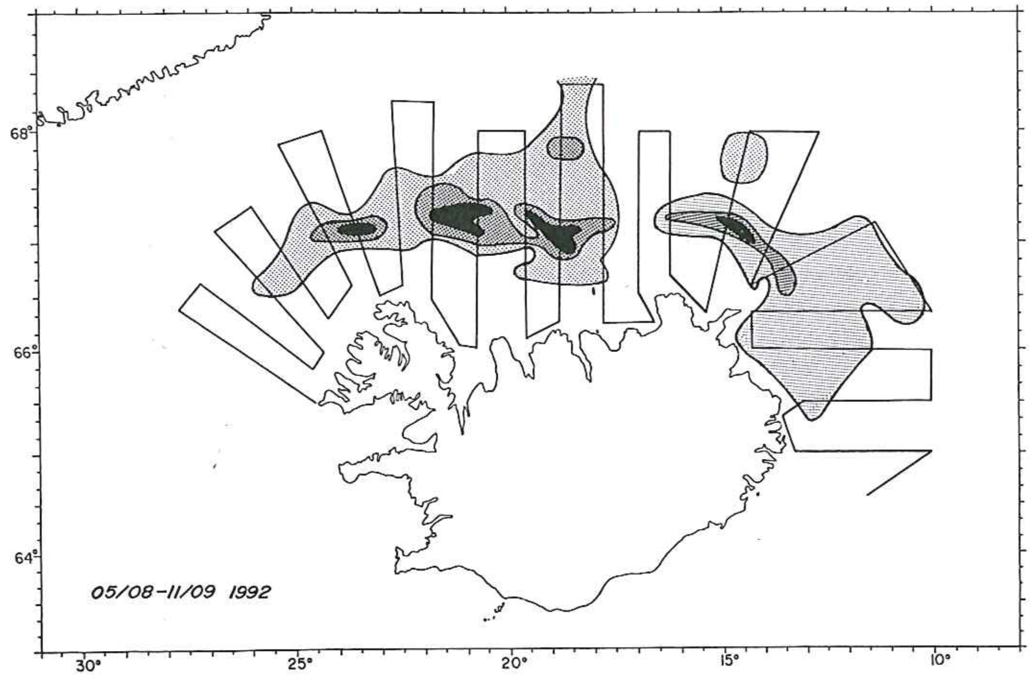

Figure LVIII. Survey tracks and juvenile 1- and 2-group capelin distribution in the north Icelandic area, August/September 1992. The different shading denotes low, moderate and high densities.

Appendix I.3. List of unpublished reports on surveys of the Icelandic capelin stock. The reports are in English unless otherwise stated. They are available at the Marine Research Institute, Reykjavík and the Institute of Marine Research, Bergen.

I.3.1. Stock assessment surveys, carried out in autumn and winter in the 1978/79–1992/93 seasons.

1. Report on the Icelandic/Norwegian capelin survey of the Iceland – Jan Mayen area in September/October 1979.
2. Report on the survey of the size and distribution of the 1980 spawning stock of the Icelandic capelin, 14–26 October 1979.
3. Report on the Icelandic – Norwegian acoustic survey of the Icelandic capelin stock in October 1980.
4. Report on the acoustic survey of the Icelandic capelin stock in January/February 1981.
5. Report on the Icelandic – Norwegian acoustic survey of the Icelandic capelin stock in October 1981.
6. Report on the Icelandic – Norwegian acoustic survey of the Icelandic capelin stock in November 1981.
7. Acoustic assessment of the capelin spawning stock, 11–22 January 1982 (in Icelandic).
8. Acoustic assessment of capelin abundance, 27 January – 21 February 1982 (in Icelandic).
9. Report on the Icelandic – Norwegian acoustic survey of the Icelandic capelin stock in October 1982.
10. Acoustic assessment of capelin stock abundance, 14 January – 13 February 1983 (in Icelandic).
11. Report on the Icelandic – Norwegian acoustic survey of the Icelandic capelin stock, 3–22 October 1983.
12. Report on the acoustic survey of the Icelandic capelin stock in January/February 1984.
13. Report on the Icelandic – Norwegian acoustic survey of the Icelandic capelin stock, 1–22 October 1984.
14. Report on the acoustic survey of the Icelandic capelin stock in January/February 1985.
15. Report on the acoustic survey of the spawning migration of the Icelandic capelin stock, 17–20 February 1985.
16. Report on the acoustic survey of the Icelandic capelin stock, 8–29 October 1985.
17. Report on the acoustic survey of the Icelandic capelin stock, 1–19 February 1986.
18. Report on the acoustic survey of the Icelandic capelin stock, 4–22 October 1986.
19. Report on the acoustic survey of the capelin stock in the Iceland – Greenland – Jan Mayen area in January/February 1987.
20. Report on the acoustic survey of the capelin stock in the Iceland – Greenland – Jan Mayen area in October 1987.
21. Report on the acoustic survey of the capelin stock in the Iceland – Greenland – Jan Mayen area in November 1987.
22. Report on the acoustic survey of the capelin stock in the Iceland – Greenland – Jan Mayen area in October 1988.
23. Acoustic assessment of the spawning stock of capelin in December 1988 (in Icelandic).
24. Report on the acoustic survey of the capelin stock in the Iceland – Greenland – Jan Mayen area in January 1989.
25. Report on an acoustic survey of the capelin stock in the Iceland – Greenland – Jan Mayen area in October/November 1989.
26. Report on the acoustic survey of the capelin stock in the Iceland – Greenland – Jan Mayen area in December 1989.
27. Report on the acoustic survey of the capelin stock in the Iceland – Greenland – Jan Mayen area in January 1990.
28. Report on the acoustic survey of the capelin spawning stock at the E-, SE- and SW-coasts of Iceland in January/February 1990.
29. Report on the acoustic survey of the capelin stock in the Iceland – Greenland – Jan Mayen area in October/November 1990.
30. Report on the acoustic survey of the capelin stock in the Iceland – Greenland – Jan Mayen area in November 1990.
31. Capelin scouting and acoustic assessment 8–18 December 1990 (in Icelandic).
32. Stock assessment surveys of the spawning component of the Icelandic capelin stock in the period January/February 1991.
33. Assessment of a capelin spawning migration in Faxaflói in February 1991 (in Icelandic).
34. Report on an acoustic survey of the Icelandic capelin stock in October 1991.
35. Report on an acoustic survey of the Icelandic capelin stock in November 1991.

36. Report on an acoustic survey of the Icelandic capelin stock in January 1992.
37. The influence of migration speed on acoustic assessment, March 1992 (in Icelandic).
38. Assessment of capelin spawning migrations from the west in the winter of 1992 (in Icelandic).
39. Report on an acoustic survey of the Icelandic capelin stock in October 1992.
40. Report on an acoustic survey of the Icelandic capelin stock in January 1993.

I.3.2. Stock assessment and/or scouting surveys of the Icelandic capelin in summer 1979–1992.

1. Report on the Icelandic/Norwegian capelin survey of the Iceland – Jan Mayen area in August 1979.
2. Internal survey report. R/v *G. O. Sars,* 4–24 August 1980 (in Norwegian).
3. Report on capelin scouting at Jan Mayen with r/v *Michael Sars* in the period 16–27 July 1981 (in Norwegian).
4. Report on capelin investigations at Jan Mayen 8–13 August 1982. A survey report from r/v *Michael Sars* (in Norwegian).
5. Report on capelin investigations at Jan Mayen with r/v *G. O. Sars* in the period 7–14 August 1983 (in Norwegian).
6. Report on acoustic abundance surveys of the juvenile component of the Icelandic capelin stock, carried out in August 1982 and 1983.
7. Abundance estimates of 1–3 group capelin, 8–29 August 1984.
8. Report. Capelin investigations with the r/v *Eldjarn* in the Jan Mayen – Greenland – Iceland area, 5–15 August 1985.
9. Icelandic/Norwegian abundance estimates of 1–3 group capelin, 8–29 August 1985.
10. Internal survey report. R/v *Eldjarn,* 29 July–19 August 1986 (in Norwegian).
11. Preliminary report on the survey of the capelin stock in the Iceland – Greenland – Jan Mayen area carried out by Iceland and Norway in August 1986.
12. Survey report. R/v *G. O. Sars,* 28 July – 16 August 1987.
13. Report on the survey of 1-group capelin in the Iceland – Greenland – Jan Mayen area in August – September 1987.
14. Internal survey report. R/v *G. O. Sars,* 23 July – 21 August 1988 (in Norwegian).
15. Report on an acoustic survey of 1-group capelin in the Iceland – Greenland – Jan Mayen area in August 1988.
16. Internal survey report. R/v *G. O. Sars,* 25 July – 20 August 1989 (in Norwegian).
17. Report on an acoustic survey of 1-group capelin in the Iceland – Greenland – Jan Mayen area in August/September 1989.
18. Internal survey report. R/v *G. O. Sars,* 27 July – 20 August 1990 (in Norwegian).
19. Report on an Icelandic survey of 1-group capelin in the Iceland – Greenland – Jan Mayen area in August/September 1990.
20. Survey report. M/v *Inger Hildur,* 11 July – 19 August 1991 (in Norwegian).
21. Survey report. R/v *Michael Sars,* 22 July – 7 August 1991 (in Norwegian).
22. Report on an Icelandic survey of 1-group capelin in the Iceland – Greenland – Jan Mayen area in August/September 1991.
23. Survey report. M/v *Inger Hildur,* 14–18 July 1992 (in Norwegian).
24. Report on an Icelandic survey of 1-group capelin in the Iceland – Greenland – Jan Mayen area in August/September 1992.

APPENDIX II. TABLES

Appendix II.1. The statistical basis of various figures in chapter 14.

Table I. Average length and weight by maturity and age in July/August 1979–1992. Column headings: Numbers denote age groups, IM denotes immature capelin, F and M denote females and males respectively.

	Length (cm)											
Year	*0*	*1F*	*1M*	*1IM*	*2F*	*2M*	*2IM*	*3F*	*3M*	*3IM*	*4F*	*4M*
1979	4.2	12.1	11.9	11.1	14.2	14.7	13.4	15.2	16.3	–	–	–
1980	4.5	–	–	10.5	–	–	14.2	–	–	–	–	–
1981	5.5	–	–	9.9	14.5	15.8	14.3	14.0	15.3	14.5	–	–
1982	5.1	–	–	10.0	–	–	13.4	–	–	13.4	–	–
1983	4.3	–	–	10.4	–	–	13.7	–	–	13.5	–	–
1984	4.3	11.5	11.7	9.7	13.9	15.2	13.6	15.6	16.8	–	–	–
1985	3.8	11.6	12.0	10.2	14.1	15.1	13.2	16.2	17.1	–	16.9	17.1
1986	4.1	–	–	9.5	14.8	15.7	13.8	15.7	16.7	14.3	16.5	17.7
1987	5.3	–	–	9.1	14.1	14.9	14.2	15.5	16.0	–	–	–
1988	5.0	–	–	8.8	13.8	14.9	13.1	14.5	15.5	14.4	14.8	15.7
1989	5.3	–	–	10.1	13.3	13.2	14.0	15.8	16.7	–	–	–
1990	5.5	12.1	12.1	10.4	13.5	14.1	12.8	14.6	14.6	–	–	–
1991	4.6	12.5	12.6	10.7	14.3	14.4	12.8	14.7	14.9	12.6	–	–
1992	4.4	–	–	9.2	15.0	15.5	14.1	15.9	16.5	–	–	–
Count	14	5	5	14	11	11	14	11	11	6	3	3
Average . . .	4.7	12.0	12.1	10.0	14.1	14.9	13.6	15.2	16.0	13.8	16.1	16.8
Minimum . . .	3.8	11.5	11.7	8.8	13.3	13.2	12.8	14	14.6	12.6	14.8	15.7
Maximum . .	5.5	12.5	12.6	11.1	15	15.8	14.3	16.2	17.1	14.5	16.9	17.7
SD	0.56	0.41	0.34	0.65	0.51	0.76	0.51	0.70	0.84	0.75	1.12	1.03
	Weight (g)											
Year	*0*	*1F*	*1M*	*1IM*	*2F*	*2M*	*2IM*	*3F*	*3M*	*3IM*	*4F*	*4M*
1979	0.17	7.0	6.1	4.9	12.7	14.9	12.5	16.9	21.6	–	–	–
1980	0.19	–	–	5.4	–	–	14.4	–	–	–	–	–
1981	0.34	–	–	5.3	17.2	24.2	14.6	13.9	24.7	14.5	–	–
1982	0.27	–	–	3.4	–	–	11.9	–	–	11.4	–	–
1983	0.17	–	–	4.0	–	–	12.9	–	–	12.8	–	–
1984	0.17	6.9	8.3	3.6	13.4	18.4	11.9	20.7	27.9	–	–	–
1985	0.13	6.4	8.0	3.8	13.0	17.4	10.5	21.9	28.5	–	23.6	30.1
1986	0.16	–	–	3.3	15.5	19.7	11.7	19.1	25.1	12.5	22.9	31.0
1987	0.28	–	–	3.0	14.1	17.0	9.7	18.5	21.5	–	–	–
1988	0.25	–	–	2.6	13.6	18.0	11.1	16.8	21.2	14.4	18.3	22.9
1989	0.28	–	–	3.4	11.1	13.0	14.2	20.7	27.9	–	–	–
1990	0.34	4.8	6.1	4.0	12.0	14.0	10.0	15.7	21.2	–	–	–
1991	0.20	9.7	9.4	5.1	13.9	14.4	9.7	17.0	19.0	10.1	–	–
1992	0.18	–	–	3.0	16.3	18.8	15.5	20.0	24.7	–	–	–
Count	14	5	5	14	11	11	14	11	11	6	3	3
Average . . .	0.22	7.0	7.6	3.9	13.9	17.3	12.2	18.3	23.9	12.6	21.6	28.0
Minimum . . .	0.13	4.8	6.1	2.6	11.1	13.0	9.7	13.9	19.0	10.1	18.3	22.9
Maximum . .	0.34	9.7	9.4	5.4	17.2	24.2	15.5	21.9	28.5	14.5	23.6	31.0
SD	0.07	1.77	1.45	0.92	1.82	3.18	1.92	2.45	3.25	1.71	2.88	4.44

Table II. Average length and weight by maturity and age in September/October 1979–1992. Column headings: Numbers denote age groups, IM denotes immature capelin, F and M denote females and males respectively.

	Length (cm)											
Year	*0*	*1F*	*1M*	*1IM*	*2F*	*2M*	*2IM*	*3F*	*3M*	*3IM*	*4F*	*4M*
1979	5.0	12.2	12.4	11.5	14.5	15.4	13.8	15.2	16.7	14.6	14.7	17.8
1980	6.1	–	–	11.5	15.1	16.1	13.8	16.2	17.0	–	–	–
1981	7.1	11.2	11.6	10.8	15.2	16.3	14.3	15.7	17.1	14.5	–	–
1982	6.7	12.2	12.8	10.2	14.9	15.8	13.6	16.6	17.3	–	–	–
1983	5.9	12.6	12.9	10.5	14.6	15.4	13.7	16.3	16.8	15.2	–	–
1984	5.9	13.3	13.5	9.5	14.8	16.0	13.9	16.0	17.1	15.4	15.9	16.8
1985	5.4	12.4	13.5	10.4	14.9	15.8	13.8	15.9	17.0	15.4	16.4	17.4
1986	5.7	12.5	14.0	10.6	15.1	16.1	14.1	16.0	17.1	15.1	16.4	17.7
1987	6.9	–	–	9.8	14.8	15.9	14.1	16.0	17.2	15.2	16.9	17.8
1988	6.6	12.5	13.0	10.1	14.6	15.3	14.1	15.9	16.8	15.7	16.2	16.0
1989	6.9	12.0	13.3	10.0	13.8	15.0	13.3	15.5	16.8	14.8	16.5	18.0
1990	7.1	12.6	12.8	10.4	14.1	14.9	13.1	15.2	16.8	13.8	15.5	16.8
1991	6.2	12.9	13.4	10.8	14.6	15.6	13.6	15.6	16.7	14.5	–	–
1992	5.7	13.1	13.3	10.2	14.9	16.0	14.2	16.2	17.1	–	–	–
Count	14	12	12	14	14	14	14	14	14	11	8	8
Average . . .	6.2	12.5	13.0	10.5	14.7	15.7	13.8	15.9	17.0	14.9	16.1	17.3
Minimum . . .	5.0	11.2	11.6	9.5	13.8	14.9	13.1	15.2	16.7	13.8	14.7	16.0
Maximum . .	7.1	13.3	14.0	11.5	15.2	16.3	14.3	16.6	17.3	15.7	16.9	18.0
SD	0.67	0.55	0.62	0.57	0.39	0.43	0.34	0.40	0.19	0.55	0.69	0.69

	Weight (g)											
Year	*0*	*1F*	*1M*	*1IM*	*2F*	*2M*	*2IM*	*3F*	*3M*	*3IM*	*4F*	*4M*
1979	0.47	7.6	7.8	5.8	13.9	18.5	11.5	16.8	23.6	14.4	13.7	31.5
1980	0.49	–	–	6.8	17.7	22.9	11.5	22.7	28.2	–	–	–
1981	0.64	5.3	6.3	4.5	16.9	22.7	12.6	20.4	27.8	14.1	–	–
1982	0.57	7.4	8.6	3.8	16.5	21.2	10.2	21.5	28.0	–	–	–
1983	0.47	7.8	8.9	4.0	14.6	18.6	11.2	21.6	26.5	15.6	–	–
1984	0.47	10.9	11.8	3.3	16.0	22.2	12.6	21.2	28.4	17.6	20.9	26.5
1985	0.43	8.3	12.9	4.1	16.4	21.4	12.6	21.0	27.6	17.8	24.0	30.2
1986	0.46	8.5	12.0	4.8	17.1	22.1	13.1	21.1	25.8	17.2	22.5	31.8
1987	0.58	–	–	3.5	15.9	21.0	12.7	21.1	28.0	18.2	25.3	34.3
1988	0.55	8.4	9.0	3.8	14.7	18.2	14.2	20.2	25.4	21.5	22.3	24.3
1989	0.58	6.3	10.2	3.3	12.8	17.4	9.8	19.9	28.0	17.8	23.4	33.4
1990	0.64	8.8	9.1	4.0	13.4	17.6	10.1	17.9	26.1	13.7	19.2	26.9
1991	0.50	9.3	10.6	4.6	14.8	19.5	10.6	18.8	25.1	17.0	–	–
1992	0.46	9.3	10.7	3.8	15.7	21.1	12.1	20.7	27.7	–	–	–
Count	14	12	12	14	14	14	14	14	14	11	8	8
Average . . .	0.52	8.2	9.8	4.3	15.5	20.3	11.8	20.4	26.9	16.8	21.4	29.9
Minimum . . .	0.43	5.3	6.3	3.3	12.8	17.4	9.8	16.8	23.6	13.7	13.7	24.3
Maximum . .	0.64	10.9	12.9	6.8	17.7	22.9	14.2	22.7	28.4	21.5	25.3	34.3
SD	0.07	1.46	1.90	0.98	1.46	1.95	1.29	1.57	1.46	2.26	3.63	3.58

Table III. Average length and weight by maturity and age in January/February 1980–1993. Column headings: Numbers denote age groups, IM denotes immature capelin, F and M denote females and males respectively.

Year	Length (cm)											
	1IM	*2F*	*2M*	*2IM*	*3F*	*3M*	*3IM*	*4F*	*4M*	*4IM*	*5F*	*5M*
1980	6.2	13.4	14.1	11.6	14.7	15.9	14.2	15.4	16.9	–	16.1	17.4
1981	7.2	13.4	14.5	12.9	15.4	16.7	14.7	16.4	17.6	–	–	–
1982	6.8	12.8	14.1	11.8	15.1	16.6	14.6	16.1	17.6	–	–	–
1983	6.0	13.2	14.0	10.7	14.9	16.2	14.1	16.1	17.3	–	–	–
1984	6.0	14.0	15.2	10.9	14.9	16.5	13.9	15.9	17.3	14.3	15.5	16.6
1985	5.5	12.6	14.0	11.0	15.1	16.4	14.0	16.3	17.7	–	16.4	18.0
1986	5.8	–	–	11.1	15.3	16.9	13.8	16.3	17.6	15.7	15.7	18.0
1987	7.0	13.7	15.5	11.2	15.3	16.9	14.2	16.4	17.6	15.6	16.6	18.1
1988	6.7	–	–	–	15.2	16.5	14.6	16.5	17.7	–	17.3	17.4
1989	7.0	–	–	9.8	14.7	16.2	13.4	15.9	17.1	–	17.0	18.4
1990	7.2	13.6	14.9	10.4	14.7	16.1	13.3	15.8	17.1	15.6	16.5	17.1
1991	6.3	14.3	15.7	10.4	15.0	16.6	14.3	15.9	17.4	–	16.0	17.9
1992	5.9	14.2	15.6	11.8	15.0	16.4	14.0	16.0	17.2	–	16.2	17.8
1993	6.1	14.8	15.3	10.1	15.4	16.8	14.2	16.5	17.9	–	–	–
Count	14	11	11	13	14	14	14	14	14	4	10	10
Average ...	6.4	13.6	14.8	11.1	15.1	16.5	14.1	16.1	17.4	15.3	16.3	17.7
Minimum ...	5.5	12.6	14.0	9.8	14.7	15.9	13.3	15.4	16.9	14.3	15.5	16.6
Maximum ..	7.2	14.8	15.7	12.9	15.4	16.9	14.7	16.5	17.9	15.7	17.3	18.4
SD	0.56	0.66	0.69	0.83	0.25	0.30	0.41	0.31	0.29	0.67	0.55	0.54

Year	Weight (g)											
	1IM	*2F*	*2M*	*2IM*	*3F*	*3M*	*3IM*	*4F*	*4M*	*4IM*	*5F*	*5M*
1980	0.52	10.5	12.1	5.8	14.8	19.6	11.6	17.8	25.7	–	21.3	31.0
1981	0.67	10.3	14.4	8.3	17.8	24.0	13.4	22.5	29.8	–	–	–
1982	0.60	8.7	12.5	6.0	16.0	23.3	12.6	20.0	29.0	–	–	–
1983	0.50	10.6	12.5	4.2	16.0	22.5	11.9	21.7	29.4	–	–	–
1984	0.50	12.2	16.3	4.5	15.5	23.4	10.9	19.9	28.6	13.7	18.1	24.2
1985	0.46	11.9	12.3	4.7	16.7	22.9	11.2	22.8	32.1	–	25.4	34.2
1986	0.49	–	–	4.9	18.0	24.7	10.5	22.4	31.4	17.1	21.6	34.1
1987	0.61	11.2	18.1	5.0	18.2	26.4	12.0	22.5	31.0	16.8	23.0	34.2
1988	0.58	–	–	–	17.1	23.8	13.1	22.9	31.0	–	26.2	29.4
1989	0.61	–	–	3.2	15.1	22.4	10.2	19.7	27.4	–	23.7	36.2
1990	0.67	10.9	16.2	3.7	15.3	22.3	9.2	20.1	28.4	17.3	24.1	28.1
1991	0.53	13.7	19.9	3.8	15.9	24.6	11.8	20.2	29.0	–	27.0	31.6
1992	0.50	12.9	18.9	6.0	16.2	23.1	11.3	20.5	27.5	–	20.5	32.2
1993	0.51	14.5	15.0	3.8	17.1	23.7	12.4	22.4	30.3	–	–	–
Count	14	11	11	13	14	14	14	14	14	4	10	10
Average ...	0.55	11.6	15.3	4.9	16.4	23.3	11.6	21.1	29.3	16.2	23.1	31.5
Minimum ...	0.46	8.7	12.1	3.2	14.8	19.6	9.2	17.8	25.7	13.7	18.1	24.2
Maximum ..	0.67	14.5	19.9	8.3	18.2	26.4	13.4	22.9	32.1	17.3	27.0	36.2
SD	0.07	1.67	2.82	1.36	1.10	1.53	1.15	1.56	1.77	1.70	2.76	3.55

Table IV. The ratio of age groups in the spawning stock of 1970–1993.

Year	*Age 2*	*Age 3*	*Age 4*	*Age 5*
1970	0.00	0.24	0.75	0.01
1971	0.06	0.72	0.21	0.00
1972	0.03	0.87	0.09	0.01
1973	0.03	0.70	0.27	0.01
1974	0.02	0.77	0.20	0.01
1975	0.02	0.78	0.20	0.01
1976	0.00	0.53	0.47	0.00
1977	0.02	0.56	0.42	0.00
1978	0.03	0.49	0.47	0.00
1979	0.03	0.80	0.16	0.00
1980	0.04	0.83	0.13	0.00
1981	0.08	0.71	0.21	0.00
1982	0.04	0.88	0.08	0.00
1983	0.04	0.83	0.13	0.00
1984	0.03	0.86	0.11	0.00
1985	0.01	0.58	0.41	0.01
1986	0.07	0.58	0.34	0.01
1987	0.01	0.34	0.65	0.00
1988	0.00	0.76	0.24	0.00
1989	0.00	0.72	0.28	0.00
1990	0.02	0.70	0.27	0.00
1991	0.03	0.82	0.15	0.00
1992	0.07	0.85	0.08	0.00
1993	0.02	0.84	0.13	0.00
Count	24	24	24	24
Average	0.03	0.70	0.27	0.00
Minimum	0.00	0.24	0.08	0.00
Maximum	0.08	0.88	0.75	0.01
SD	0.023	0.170	0.179	0.005

Table V. The ratio of females (F) and males (M) within age groups in the spawning stock of 1970–1993.

Year	*Age 2F*	*Age 2M*	*Age 3F*	*Age 3M*	*Age 4F*	*Age 4M*	*Age 5F*	*Age 5M*
1970	1.00	0.00	0.73	0.27	0.45	0.55	0.33	0.67
1971	0.68	0.32	0.51	0.49	0.42	0.58	0.00	1.00
1972	0.83	0.17	0.57	0.43	0.27	0.73	0.36	0.64
1973	0.76	0.24	0.60	0.40	0.36	0.64	0.36	0.64
1974	0.77	0.23	0.57	0.43	0.40	0.60	0.33	0.67
1975	0.76	0.24	0.56	0.44	0.33	0.67	0.32	0.68
1976	1.00	0.00	0.65	0.35	0.44	0.56	0.20	0.80
1977	0.55	0.45	0.54	0.46	0.51	0.49	0.50	0.50
1978	0.84	0.16	0.59	0.41	0.39	0.61	0.62	0.38
1979	0.86	0.14	0.60	0.40	0.38	0.62	0.42	0.58
1980	0.84	0.16	0.58	0.42	0.33	0.67	0.00	1.00
1981	0.79	0.21	0.63	0.47	0.34	0.66	0.00	1.00
1982	0.73	0.27	0.57	0.43	0.38	0.62	0.00	1.00
1983	0.59	0.41	0.55	0.45	0.52	0.48	0.50	0.50
1984	0.76	0.24	0.66	0.34	0.43	0.57	0.46	0.54
1985	0.71	0.29	0.62	0.38	0.33	0.67	0.38	0.62
1986	0.68	0.32	0.62	0.38	0.45	0.55	0.60	0.40
1987	0.83	0.17	0.68	0.32	0.47	0.53	0.62	0.38
1988	1.00	0.00	0.54	0.46	0.34	0.66	0.14	0.86
1989	1.00	0.00	0.60	0.40	0.39	0.61	0.00	1.00
1990	0.60	0.40	0.61	0.39	0.41	0.59	0.00	1.00
1991	0.74	0.26	0.56	0.44	0.34	0.66	0.20	0.80
1992	0.72	0.28	0.57	0.43	0.45	0.55	0.00	1.00
1993	0.89	0.11	0.57	0.43	0.38	0.62	0.00	1.00
Count	24	24	24	24	24	24	24	24
Average	0.79	0.21	0.60	0.40	0.40	0.60	0.26	0.74
Minimum	0.55	0.00	0.51	0.27	0.27	0.48	0.00	0.38
Maximum ...	1.00	0.45	0.73	0.49	0.52	0.73	0.62	1.00
SD	0.128	0.128	0.050	0.051	0.061	0.061	0.225	0.225

Table VI. Average lengths in the spawning stock, measured in January/February 1970–1993.

Year	*Females*				*Males*			
	Age 2	*Age 3*	*Age 4*	*Age 5*	*Age 2*	*Age 3*	*Age 4*	*Age 5*
1970	–	14.4	15.3	16.0	–	15.6	16.6	16.8
1971	12.4	14.0	15.2	15.1	13.7	14.8	16.1	17.5
1972	13.8	14.5	15.1	15.6	14.6	15.7	16.2	16.3
1973	14.1	15.3	15.7	16.4	16.0	16.7	17.2	16.6
1974	13.3	16.0	16.5	16.5	14.7	17.5	18.4	17.0
1975	13.8	15.2	16.1	17.3	15.5	16.7	17.7	18.1
1976	12.8	15.0	15.6	15.8	–	16.6	17.0	17.8
1977	14.7	15.3	16.0	15.8	16.2	16.9	17.5	17.4
1978	13.8	15.0	15.8	16.1	15.2	16.2	17.1	17.2
1979	13.2	14.8	15.7	16.1	15.5	16.1	17.0	17.5
1980	13.4	14.7	15.4	16.1	14.1	15.9	16.9	17.4
1981	13.4	15.4	16.4	–	14.5	16.7	17.6	–
1982	12.8	15.1	16.1	–	14.1	16.6	17.6	–
1983	13.2	14.9	16.1	–	14.0	16.2	17.3	–
1984	14.0	14.9	15.9	15.5	15.2	16.5	17.3	16.6
1985	12.6	15.1	16.3	16.4	14.0	16.4	17.7	18.0
1986	–	15.3	16.3	15.7	–	16.9	17.6	18.0
1987	13.7	15.3	16.4	16.6	15.5	16.9	17.6	18.1
1988	–	15.2	16.5	17.3	–	16.5	17.7	17.4
1989	–	14.7	15.9	17.0	–	16.2	17.1	18.4
1990	13.6	15.0	15.8	16.5	14.9	16.1	17.1	17.1
1991	14.3	15.0	15.9	16.0	15.7	16.6	17.4	17.9
1992	14.2	15.0	16.0	16.2	15.6	16.4	17.2	17.8
1993	14.8	15.4	16.5	–	15.3	16.8	17.9	–
Count	20	24	24	20	19	24	24	20
Average	13.6	15.0	15.9	16.2	15.0	16.4	17.3	17.4
Minimum	12.4	14.0	15.1	15.1	13.7	14.8	16.1	16.3
Maximum ...	14.8	16.0	16.5	17.3	16.2	17.5	18.4	18.4
SD	0.66	0.40	0.41	0.57	0.75	0.54	0.51	0.58

Table VII. Average weights in the spawning stock, measured in January/February 1970–1993.

	Females				Males			
Year	*Age 2*	*Age 3*	*Age 4*	*Age 5*	*Age 2*	*Age 3*	*Age 4*	*Age 5*
1970	–	13.9	17.9	18.0	–	20.7	25.1	24.5
1971	8.8	14.0	18.6	–	14.1	17.4	23.7	30.5
1972	12.7	14.6	17.0	17.8	16.5	20.4	23.5	20.4
1973	14.2	18.7	21.2	19.8	19.8	26.9	30.3	24.8
1974	10.8	18.5	23.0	22.5	16.4	26.4	32.4	25.7
1975	14.0	18.1	22.5	24.2	19.9	26.5	32.2	35.8
1976	10.1	16.9	19.6	28.9	–	25.0	27.0	31.0
1977	15.5	17.9	18.9	20.3	22.4	25.8	26.6	30.1
1978	12.0	16.8	20.4	21.6	17.2	22.7	28.2	29.0
1979	11.0	16.8	20.6	21.3	15.5	23.3	27.8	31.6
1980	10.5	14.8	17.8	21.3	12.1	19.6	25.7	31.0
1981	10.3	17.8	22.5	–	14.4	24.0	29.8	–
1982	8.7	16.0	20.0	–	12.5	23.3	29.0	–
1983	10.6	16.0	21.7	–	12.5	22.5	29.4	–
1984	12.2	15.5	19.9	18.1	16.3	23.4	28.6	24.2
1985	11.9	16.7	22.8	25.4	12.3	22.9	32.1	34.2
1986	–	18.0	22.4	21.6	–	24.7	31.4	34.1
1987	11.2	18.2	22.5	23.0	18.1	26.4	31.0	34.2
1988	–	17.1	22.9	26.2	–	23.8	31.0	29.4
1989	–	15.1	19.7	23.7	–	22.4	27.4	36.2
1990	10.9	15.3	20.1	24.1	16.2	22.3	28.4	28.1
1991	13.7	15.9	20.2	27.0	19.9	24.6	29.0	31.6
1992	12.9	16.2	20.5	20.5	18.9	23.1	27.5	32.2
1993	14.5	17.1	22.4	–	15.0	23.7	30.3	–
Count	20	24	24	19	19	24	24	20
Average	11.8	16.5	20.6	22.4	16.3	23.4	28.6	29.9
Minimum	8.7	13.9	17.0	17.8	12.1	17.4	23.5	20.4
Maximum . . .	15.5	18.7	23.0	28.9	22.4	26.9	32.4	36.2
SD	1.88	1.42	1.78	3.10	2.98	2.31	2.54	4.25

Table VIII. Average weights in the spawning stock, measured in January/February 1970–1993 and deviations in temperature (Δ_t) and salinity (Δ_S) north of Iceland, measured in the spring of the preceding year.

Year	*Age 3*	*Age 4*	Δ_t *Year-1*	Δ_S *Year-1*
1970	16.1	22.1	−1.588	−0.355
1971	16.1	22.1	−0.992	−0.232
1972	17.1	22.1	−1.757	−0.133
1973	22.1	27.1	0.683	0.077
1974	22.1	29.1	1.124	0.134
1975	22.1	29.1	1.137	0.158
1976	20.1	24.1	−1.100	−0.129
1977	22.1	23.1	0.295	0.042
1978	19.1	25.1	−0.109	−0.123
1979	19.1	25.1	0.755	0.034
1980	17.1	23.1	−1.496	−0.235
1981	21.1	27.1	1.438	0.267
1982	19.1	26.1	−1.083	0.084
1983	19.1	25.1	−0.616	−0.101
1984	18.1	25.1	−1.280	−0.071
1985	21.1	29.1	−0.200	0.091
1986	22.1	28.1	1.075	0.234
1987	21.1	27.1	0.045	0.185
1988	20.1	28.1	1.041	0.107
1989	18.1	24.1	−0.725	−0.134
1990	18.1	25.1	−0.470	0.113
1991	20.1	26.1	−1.049	−0.038
1992	19.1	24.1	1.193	0.214
1993	21.1	28.1	1.290	0.228
Count	24	24	24	24
Average	19.5	25.5	−0.1	0.0
Minimum	15.7	21.6	−1.8	−0.4
Maximum	22.0	29.4	1.4	0.3
SD	1.89	2.35	1.06	0.17

Table IX. Weekly changes in the fat content (%) of capelin in the Icelandic catch in the 1972/73–1992/93 fishing seasons.

Week	Fishing seasons (week 1 = 1st week in July)																									
number	72/73	73/74	74/75	75/76	76/77	77/78	78/79	79/80	80/81	81/82	82/83	83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	91/92	92/93	Count	Mean	Min.	Max.	SD
01	–	–	–	–	11.6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	11.6	11.6	11.6	0.00
02	–	–	–	–	12.2	13.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	12.6	12.2	13.0	0.57
03	–	–	–	–	11.8	14.4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	15.8	3	14.0	11.8	15.8	2.03
04	–	–	–	–	12.7	15.2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	16.7	3	14.9	12.7	16.7	2.02
05	–	–	–	–	13.8	16.0	11.4	–	–	–	–	–	–	–	–	–	–	–	–	–	18.3	4	14.9	11.4	18.3	2.96
06	–	–	–	–	16.0	16.7	12.0	–	–	–	–	–	–	–	–	–	–	–	–	–	17.3	4	15.5	12.0	17.3	2.39
07	–	–	–	–	15.5	17.0	12.9	–	–	13.4	–	–	–	–	–	–	–	–	–	–	18.5	5	15.5	12.9	18.5	2.37
08	–	–	–	–	17.9	17.6	13.4	11.1	–	14.7	–	–	–	22.9	15.6	–	–	–	–	–	16.3	8	16.2	11.1	22.9	3.51
09	–	–	–	–	14.5	17.7	13.6	12.7	18.0	14.9	–	–	–	23.5	–	–	–	–	–	–	16.0	8	16.4	12.7	23.5	3.43
10	–	–	–	–	12.8	17.8	16.4	12.2	18.2	15.8	–	–	–	21.7	17.4	–	–	–	–	–	15.3	9	16.4	12.2	21.7	2.88
11	–	–	–	–	12.3	17.9	16.7	13.1	18.0	17.0	–	–	–	20.7	18.7	–	–	–	–	–	15.1	9	16.6	12.3	20.7	2.69
12	–	–	–	–	12.0	17.9	16.9	14.4	17.5	16.9	–	–	–	20.2	18.0	–	–	–	–	–	16.4	9	16.7	12.0	20.2	2.33
13	–	–	–	–	12.6	17.8	18.5	14.4	16.8	16.9	–	–	–	17.9		17.8	–	–	–	–	–	8	16.6	12.6	18.5	2.04
14	–	–	–	–	12.7	17.7	19.0	14.6	17.3	16.8	–	–	18.8	18.0		17.3	–	–	–	–	16.5	10	16.9	12.7	19.0	1.92
15	–	–	–	–	11.9	17.6	18.6	15.1	16.7	16.7	–	–	18.7	16.9	17.6	16.7	–	–	–	–	15.5	11	16.5	11.9	18.7	1.90
16	–	–	–	–	15.6	17.3	18.0	15.5	16.3	16.6	–	–	19.0	15.3		17.8	–	–	–	–	15.3	10	16.7	15.3	19:0	1.30
17	–	–	–	–	17.7	17.0	17.4	15.5	16.0	16.2	–	15.4	18.6	15.5	–	17.3	–	–	–	–	15.7	11	16.6	15.4	18.6	1.08
18	–	–	–	–	17.5	16.7	16.7	15.7	16.1	16.3	–	16.0	18.6	–	16.6	17.5	–	–	–	–	16.1	11	16.7	15.7	18.6	0.85
19	–	–	–	–	17.2	16.3	16.3	15.1	15.5	16.3	–	14.7	18.1	15.1	–	16.9	–	–	–	–	16.2	11	16.2	14.7	18.1	1.01
20	–	–	–	–	16.7	15.8	15.7	–	15.1	15.6	–	15.8	17.7	15.8	–	16.5	–	–	–	15.6	16.1	11	16.0	15.1	17.7	0.70
21	–	–	–	–	16.1	15.2	15.3	–	15.2	15.6	–	15.3	17.6	15.5	–	16.3	15.8	–	–	16.5	14.8	12	15.8	14.8	17.6	0.76
22	–	–	–	–	15.0	14.7	15.2	–	15.0	14.9	–	14.6	17.2	–	15.2	16.4	15.9	–	–	17.2	14.6	12	15.5	14.6	17.2	0.96
23	–	–	–	–	14.9	14.0	15.1	–	15.0	14.6	–	15.0	16.9	–	15.8	16.3	15.9	–	–	16.0	14.4	12	15.3	14.0	16.9	0.85
24	–	–	–	–	14.9	13.8	14.9	–	13.8	13.8	–	–	16.5	–	–	16.0	–	–	–	15.3	–	8	14.9	13.8	16.5	1.04
25	–	–	–	–	14.6	13.2	–	–	–	13.6	–	–	16.4	–	–	16.3	–	–	–	–	–	5	14.8	13.2	16.4	1.49
26	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
27	–	–	14.2	–	–	12.5	–	–	13.2	–	–	–	15.7	13.2	–	14.3	13.7	16.3	16.3	14.7	–	10	14.4	12.5	16.3	1.33
28	–	13.4	13.9	–	13.4	11.9	12.8	11.2	12.7	–	–	13.6	14.9	11.9	–	13.6	13.6	15.7	15.7	14.4	–	15	13.5	11.2	15.7	1.31
29	16.5	12.8	13.3	12.8	12.7	11.3	12.2	11.2	12.4	10.2	–	13.3	14.1	11.3	12.5	12.9	13.3	15.4	15.4	13.5	–	19	13.0	10.2	16.5	1.56
30	15.3	12.2	12.6	12.4	11.9	10.7	11.6	10.0	11.8	10.2	–	11.7	14.1	9.8	11.9	12.3	12.5	14.0	14.0	11.8	13.1	20	12.2	9.8	15.3	1.43
31	14.0	11.1	11.6	11.7	10.8	10.0	10.9	9.9	11.0	9.3	–	10.8	13.1	–	11.5	10.9	–	13.2	13.2	11.9	11.4	18	11.5	9.3	14.0	1.25
32	13.1	9.8	10.4	10.7	9.8	9.2	10.2	9.1	10.2	8.1	–	9.2	11.7	–	9.9	10.2	11.2	12.3	12.3	10.8	10.5	19	10.5	8.1	13.1	1.25
33	11.9	8.4	9.2	9.5	8.6	8.1	9.0	7.7	9.9	6.6	–	7.8	11.1	–	8.9	9.0	7.1	10.6	10.6	9.9	8.8	19	9.1	6.6	11.9	1.37
34	10.8	7.4	7.9	8.4	7.4	7.2	6.9	7.3	8.9	5.1	–	6.6	9.8	–	7.9	7.5	6.8	8.9	8.9	7.8	7.6	19	7.8	5.1	10.8	1.26
35	9.8	6.3	6.6	7.1	6.2	6.1	5.7	5.2	6.9	5.4	–	5.8	7.8	–	–	6.5	6.0	8.2	8.2	6.8	5.7	18	6.7	5.2	9.8	1.18
36	8.6	5.3	5.8	5.9	5.0	4.8	5.1	4.5	4.3	6.3	–	5.0	5.9	–	–	5.3	6.1	8.8	8.8	5.5	4.6	18	5.9	4.3	8.8	1.43
37	7.5	4.4	4.4	4.8	3.6	3.3	4.5	3.4	4.0	–	–	4.0	3.6	–	4.9	4.4	5.2	6.7	6.7	–	–	16	4.7	3.3	7.5	1.25
38	6.4	3.4	3.4	3.7	2.6	1.8	3.8	2.8	3.7	–	–	3.1	3.6	–	4.7	3.5	5.3	7.5	7.5	–	–	16	4.2	1.8	7.5	1.68
39	5.4	2.8	2.8	2.9	2.0	1.3	2.6	–	3.3	–	–	2.1	–	–	–	3.8	–	–	–	–	2.0	11	2.8	1.3	5.4	1.10
40	3.7	2.5	2.4	2.3	–	–	–	–	2.1	–	–	–	–	–	–	–	–	–	–	–	–	5	2.6	2.1	3.7	0.63
41	–	2.5	2.3	2.1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	2.3	2.1	2.5	0.20
42	–	–	–	2.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	2.0	2.0	2.0	0.00

Table X. Weekly changes in fat content (%) of capelin in the Norwegian catch in the summer/autumn fishery of the 1980/81–1992/93 seasons.

	Fishing seasons (week 1 = 1st week of July)														
Week No.	*80/81*	*81/82*	*84/85*	*85/86*	*86/87*	*87/88*	*88/89*	*89/90*	*90/91*	*92/93*	*Count*	*Average*	*Min.*	*Max.*	*SD*
01															
02															
03	–	–	–	19.6	17.7	17.1	16.6	13.8	–	14.6	6	16.6	13.8	19.6	2.11
04	–	–	–	20.6	19.1	17.3	16.7	13.4	16.2	17.0	7	17.2	13.4	20.6	2.27
05	–	–	22.7	20.8	19.3	18.3	15.0	15.6	16.1	15.0	8	17.9	15.0	22.7	2.90
06	20.6	–	20.3	21.8	22.8	18.6	–	16.1	17.0	–	7	19.6	16.1	22.8	2.47
07	21.8	17.1	19.0	22.2	20.7	17.1	–	–	–	20.6	7	19.8	17.1	22.2	2.10
08	–	16.0	19.8	17.8	19.6	18.3	–	14.8	–	20.3	7	18.1	14.8	20.3	2.06
09	–	–	–	21.0	17.0	15.9	–	–	–	–	3	18.0	15.9	21.0	2.68
10	–	–	–	–	–	17.0	–	–	–	–	1	17.0	17.0	17.0	0.00
11	–	–	–	–	20.1	–	–	–	–	–	–1	20.1	20.1	20.1	0.00

Appendix II.2. Results of stock abundance surveys.

Table XI. Abundance indices of 0-group capelin in the years 1970–1993 and their division by areas.

Year	*Northwestern Irminger Sea*	*Iceland West*	*North*	*East*	*Total*
1970	1	8	2	0	11
1971	+	7	12	+	19
1972	+	37	52	+	89
1973	14	39	46	17	116
1974	26	44	57	7	134
1975	3	37	46	3	89
1976	2	5	10	15	32
1977	2	19	19	3	43
1978	+	2	29	+	31
1979	4	19	25	1	49
1980	3	18	19	1	41
1981	10	13	6	0	29
1982	+	8	5	+	13
1983	+	3	18	1	22
1984	+	2	17	9	28
1985	1	8	19	3	31
1986	+	16	17	4	37
1987	1	6	6	1	14
1988	3	22	26	1	52
1989	0	16	7	0	23
1990	+	7	12	2	21
1991	8	2	43	1	54
1992	3	11	20	+	34
1993	2	21	13	15	51
Average	3.5	15.4	21.9	3.5	44.3
SD*	5.94	12.57	15.80	5.21	32.11

* In computations of SD, + values were substituted by 0.1.

Table XII. Acoustic abundance estimates of the maturing stock in number (billions) and biomass (thous. tonnes) by age groups in autumn 1978–1992. Vessels: BS = *Bjarni Sæmundsson;* ÁF = *Árni Friðriksson;* GOS = *G. O. Sars;* MS = *Michael Sars.*

Year	*Date*	*Vessels*	*No/Biom.*	*Age* 2	3	4	*Total*
1978	16/10–29/10	BS	Number	60.6	13.9	0.4	74.9
			Biomass	1,189.1	353.3	10.5	1,552.9
1979 *	27/07–12/08	BS GOS	Number	33.0	5.0	+	38.0
			Biomass	390.2	85.8	0.8	476.8
1979 *	25/09–05/10	BS MS	Number	42.0	8.0	0.1	50.1
			Biomass	638.8	166.5	3.6	808.9
1979	14/10–26/10	BS	Number	49.7	9.1	0.4	59.2
			Biomass	780.3	209.3	8.3	997.9
1980	11/10–22/10	BS GOS	Number	19.5	4.8	+	24.3
			Biomass	377.5	128.2	+	505.7
1981 *	14/10–23/10	BS GOS	Number	6.9	0.2	–	7.1
			Biomass	134.0	4.4	–	138.4
1981	03/11–12/11	BS	Number	16.6	0.3	–	16.9
			Biomass	316.9	7.5	–	324.4
1981	26/11–29/11	BS	Number	11.9	0.6	–	12.5
			Biomass	230.4	13.5	–	243.9
1982	02/10–20/10	BS GOS	Number	15.0	1.6	–	16.6
			Biomass	247.2	38.6	–	285.8
1983	03/10–22/10	BS ÁF GOS	Number	58.6	5.6	0.1	64.3
			Biomass	982.7	126.8	2.3	1,111.8
1984	01/11–21/11	BS ÁF	Number	31.9	10.3	0.3	42.5
			Biomass	542.1	265.8	7.0	814.9
1985	08/10–29/10	BS ÁF	Number	43.7	14.4	0.4	58.5
			Biomass	677.7	341.9	11.8	1,031.4
1986 **	04/10–22/10	BS ÁF	Number	19.9	29.8	0.3	50.0
			Biomass	359.9	719.3	8.6	1,087.8
1987 *	07/10–23/10	BS ÁF	Number	17.1	4.1	0.1	21.3
			Biomass	300.3	103.0	3.1	406.4
1987	18/11–04/12	BS	Number	52.0	13.5	–	65.5
			Biomass	929.1	348.1	–	1,277.2
1988	06/10–24/10	BS ÁF	Number	53.1	17.0	0.4	70.5
			Biomass	820.2	399.3	8.4	1,227.9
1989 *	26/10–29/11	BS ÁF	Number	2.9	0.6	–	5.3
			Biomass	37.4	16.0	–	67.0

Table XII. (continued)

Year	Date	Vessels	No/Biom.	Age 2	Age 3	Age 4	Total
1989	05/12–18/12	BS	Number	4.5	0.4	–	4.9
*			Biomass	80.1	10.4	–	94.8
1990	08/11–27/11	BS	Number	16.4	2.7	0.1	19.2
			Biomass	296.0	68.8	3.6	368.4
1991	05/10–27/10	BS ÁF	Number	37.7	1.9	–	39.6
*			Biomass	607.5	41.6	–	649.1
1991	15/11–26/11	BS ÁF	Number	50.4	4.5	–	54.9
			Biomass	821.8	113.8	–	935.6
1992	13/10–28/10	BS ÁF	Number	54.5	4.3	–	58.8
			Biomass	897.6	97.5	–	995.1

* Invalid results due to ice conditions and/or abnormal capelin distribution and behaviour.
** Assessment suspect due to near-surface schooling in part of distribution area.

Table XIII. Acoustic abundance estimates of the maturing stock in number (billions) and biomass (thous. tonnes) by age groups in winter 1979–1993. Vessels: BS = *Bjarni Sæmundsson;* ÁF = *Árni Friðriksson.*

Year	Date	Vessels	No/Biom.	Age 3	Age 4	Age 5	Total
1979	01/02–18/02	BS	Number	44.1	10.3	0.3	54.7
*			Biomass	890.2	254.8	9.0	1,154.0
1979	27/02–01/03	BS	Number	13.5	3.7	+	17.2
			Biomass	249.5	92.8	+	342.3
1980	25/01–28/01	BS ÁF	Number	41.7	3.8	+	45.5
			Biomass	633.7	92.1	+	755.8
1981	20/01–29/01	BS ÁF	Number	12.0	3.4	+	15.4
*			Biomass	268.0	92.7	+	360.7
1982	20/01–21/02	BS ÁF	Number	7.7	0.5	–	8.2
			Biomass	151.8	13.5	–	165.3
1983	14/01–13/02	BS ÁF	Number	13.6	1.9		15.5
			Biomass	251.7	47.9	–	299.6
1984	14/01–09/02	BS ÁF	Number	36.1	7.1	+	43.2
			Biomass	695.8	183.2	+	879.0
1985	14/01–29/01	BS ÁF	Number	21.1	11.5	0.1	32.7
			Biomass	402.8	312.7	3.5	719.0
1985	17/02–20/02	ÁF	Number	18.0	11.1	0.2	29.3
			Biomass	373.7	309.4	6.2	689.3
1986			No survey				
1987	16/01–04/02	BS ÁF	Number	17.4	27.6	0.2	45.2
			Biomass	333.5	689.2	5,8	1,028.5

Table XIII. (continued)

Year	*Date*	*Vessels*	*No/Biom.*	*Age* 3	4	5	*Total*
1988			No survey				
1989	05/01–20/01	BS	Number	35.1	11.5	–	46.6
			Biomass	652.9	274.5	–	927.4
1990 **	06/01–21/01	BS ÁF	Number	24.9	10.1	0.3	35.3
			Biomass	462.5	270.4	8.5	741.4
1991 **	04/01–25/01	BS ÁF	Number	13.3	2.3	–	15.6
			Biomass	258.3	57.3	–	315.6
1991	08/02–12/02	BS ÁF	Number	20.5	4.0	–	24.5
			Biomass	412.7	110.4	–	523.1
1992	03/01–20/01	BS ÁF	Number	53.3	4.4	–	59.7
			Biomass	956.0	113.7	–	1,069.7
1993 ***	04/01–23/01	BS ÁF	Number	24.4	2.5	–	26.9
			Biomass	479.4	73.6	–	553.0

* Average of repeated surveys.
** Estimate suspect due to weather and/or capelin behaviour.
*** Invalid due to storms and/or abnormal capelin distribution.

Table XIV. Acoustic abundance estimates of juvenile 1- and 2-group capelin in number (billions) and biomass (thous. tonnes) by age groups in autumn surveys 1980–1992. Vessels: BS = *Bjarni Sæmundsson;* ÁF = *Árni Friðriksson;* GOS = *G. O. Sars;* MS = *Michael Sars.*

Year	*Date*	*Vessels*	*No/Biom.*	*Age 1*	*Age 2*
1980	11/10–22/10	BS GOS	Number	23.5	+
			Biomass	170.6	+
1981	03/11–29/11	BS	Number	23.7	1,4
			Biomass	89.8	15,1
1982	02/10–20/10	BS GOS	Number	68.0	1.7
			Biomass	260.4	14.4
1983	03/10–22/10	BS ÁF	Number	44.1	8.2
		GOS	Biomass	224.5	77.9
1984	01/11–22/11	BS ÁF	Number	73.8	4.6
			Biomass	215.5	38.2
1985	08/10–29/10	BS ÁF	Number	33.8	12.6
			Biomass	129.0	107.1
1986	04/10–22/10	BS ÁF	Number	58.6	1,4
			Biomass	237.1	8,5
1987	18/11–04/12	BS	Number	*70.2	5,4
			Biomass	280.0	48.1
1988	06/10–24/10	BS ÁF	Number	43.9	6.7
			Biomass	133.5	52,3
1989	26/10–29/11	BS ÁF	Number	29.2	1.8
			Biomass	102.0	14.4
1990	08/11–27/11	BS	Number	39.2	1.3
			Biomass	148.9	10.9
1991	15/11–26/11	BS ÁF	Number	60.0	5,2
			Biomass	282.1	45.8
1992	13/10–28/10	BS ÁF	Number	104.6	2.3
			Biomass	382.6	19.8

* Invalid for 1-group due to ice. Estimated from August survey.

Table XV. Acoustic abundance estimates of juvenile 2- and 3-group capelin in number (billions) and biomass (thous. tonnes) by age groups in winter surveys 1983–1993. Vessels: BS = *Bjarni Sæmundsson;* ÁF = *Árni Friðriksson.*

Year	*Date*	*Vessels*	*No/Biom.*	*Age* 2	3
1983	14/01–13/02	BS ÁF	Number	15.5	1,0
*			Biomass	70.7	12.1
1984	14/01–09/02	BS ÁF	Number	51.8	16.2
			Biomass	232.9	161.7
1985	14/01–29/01	BS ÁF	Number	58.7	18.6
			Biomass	267.7	196.6
1986	18/01–22/02	BS	Numbers	72.4	52.5
			Biomass	332.0	524.6
1987	16/01–04/02	BS ÁF	Numbers	40.8	11.3
			Biomass	218.5	120.0
1988	Failed due to ice				
1989	05/01–30/01	BS	Numbers	51.5	3.7
			Biomass	162.7	34.5
1990	No survey				
1991	Failed due to ice and weather				
1992	03/01–20/01	BS ÁF	Numbers	77.8	5.5
			Biomass	412.3	51.6
1993	No survey				

* Invalid due to ice.

Table XVI. Acoustic abundance estimates of juvenile 1-group capelin in number (billions) and biomass (thous. tonnes) by age groups in August 1982–1992. Vessels: BS = *Bjarni Sæmundsson;* ÁF = *Árni Friðriksson.*

Year	*Date*	*Vessel*	*Number*	*Biomass*
1982	12/08–31/08	ÁF BS	119.0	535.5
1983	13/08–31/08	ÁF BS	154.6	649.9
1984	12/08–29/08	ÁF BS	285.4	1,013.4
1985	08/08–27/08	ÁF BS	30.9	117.4
1986	15/08–26/08	ÁF BS	71.1	230.9
1987	15/08–10/09	ÁF	101.5	306.1
1988	10/08–31/08	Á	146.9	378.1
1989	11/08–08/09	ÁF BS	110.6	371.7
1990	08/08–03/09	ÁF BS	36.2	145.4
1991	06/08–05/09	ÁF BS	49.6	251.6
1992	05/08–11/09	ÁF BS	86.6	291.2

Appendix III.3. Catch in numbers.

Table XVII. The total international catch of capelin in the Iceland-Greenland-Jan Mayen area by age groups in numbers (billions) and the total catch by numbers and weight (thous. tonnes) during the autum season (August – December) in 1978–1992.

Age	Year							
	1978	1979	1980	1981	1982	1983	1984	1985
1	–	0.6	4.9	0.6	–	0.6	0.5	0.8
2	21.4	29.4	17.2	27.9	–	7.2	19.8	25.6
3	12.2	6.1	5.4	2.0	–	0.8	7.8	15.4
4	–	–	–	+	–	–	0.1	0.2
Total number ..	33.6	36.1	27.5	30.5	–	8.6	28.2	42.0
Total weight ...	655.0	588.0	527.6	613.0	–	133.4	548.5	919.7

Age	Year						
	1986	1987	1988	1989	1990	1991	1992
1	a	+	0.3	1.7	0.8	0.3	1.7
2	10.0	27.7	13.6	6.0	5.9	2.7	14.0
3	23.3	6.7	5.4	1.5	1.0	0.4	2.1
4	0.5	+	+	+	+	+	+
Total number .	33.8	34.4	19.3	9.2	7.7	3.4	17.8
Total weight ..	772.9	458.6	371.4	121.0	111.2	56.0	298.1

Table XVIII. The total international catch of capelin in the Iceland-Greenland-Jan Mayen area by age groups in numbers (billions) and the total catch by numbers and weight (thous. tonnes) during the winter season (January – March) in 1979–1993.

Age	Year							
	1979	1980	1981	1982	1983	1984	1985	1986
2	1.0	1.3	1.7	–	–	2.1	0.4	0.1
3	20.8	17.6	7.1	0.8	–	18.1	9.1	9.8
4	4.8	3.5	1.9	0.1	–	3.4	5.4	6.9
5	0.1	–	–	–	–	–	–	0.2
Total number ..	26.7	22.4	10.7	0.9	–	23.6	14.5	17.0
Total weight ...	539.9	392.1	156.0	13.2	–	439.6	348.5	391.8

Age	Year						
	1987	1988	1989	1990	1991	1992	1993
2	a	+	0.1	1.4	0.7	2.7	0.2
3	6.9	23.4	22.9	24.8	9.5	29.4	20.1
4	15.5	7.2	7.8	9.6	1.9	2.8	2.5
5	–	0.3	+	0.1	+	+	+
Total number .	22.4	30.9	30.8	35.9	12.1	34.9	22.8
Total weight ..	560.5	657.2	665.1	686.8	258.4	621.0	489.1

Table XIX. The total international capelin catch in numbers (billions) by year classes and months 1978–1993.

Year	*Age*	*Year class*	*Jan*	*Feb*	*Mar*	*Apr*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
1978	1	1977	–	–	–	–	–	–	–	–	–	–
	2	1976	0.2	0.2	0.2	–	0.9	6.3	5.5	4.5	3.2	1.0
	3	1975	1.3	4.5	4.0	–	0.8	2.2	5.6	2.5	0.4	0.7
	4	1974	1.5	4.9	4.4	–	–	–	–	–	–	–
	5	1973	–	–	–	–	–	–	–	–	–	–
1979	1	1978	–	–	–	–	–	0.1	0.2	0.3	–	–
	2	1977	0.2	0.5	0.3	–	–	8.5	7.4	11.0	2.5	–
	3	1976	4.9	10.1	5.8	–	–	2.3	1.7	1.7	0.4	–
	4	1975	1.1	2.0	1.7	–	–	–	–	–	–	–
	5	+	0.1	+	–	–	–	–	–	–	–	–
1980	1	1979	–	–	–	–	–	0.4	0.1	2.2	2.1	0.1
	2	1978	1.0	0.1	0.2	–	–	4.6	2.2	5.5	3.1	1.8
	3	1977	7.4	6.3	3.9	–	–	0.9	0.8	2.0	1.1	0.6
	4	1976	1.2	1.5	0.8	–	–	–	–	–	–	–
	5	1975	–	–	–	–	–	–	–	–	–	–
1981	1	1980	–	–	–	–	–	0.1	0.2	0.3	–	–
	2	1979	0.9	0.2	0.6	–	–	6.9	2.9	7.7	8.3	2.1
	3	1978	1.4	2.5	3.2	–	–	0.8	0.3	0.2	0.5	0.2
	4	1977	0.5	0.6	0.8	–	–	–	+	–	–	–
	5	1976	–	–	–	–	–	–	–	–	–	–
1982	1	1981	–	–	–	–	–	–	–	–	–	–
	2	1980	–	–	–	–	–	–	–	–	–	–
	3	1979	0.8	–	–	–	–	–	–	–	–	–
	4	1978	0.1	–	–	–	–	–	–	–	–	–
	5	1977	–	–	–	–	–	–	–	–	–	–
1983	1	1982	–	–	–	–	–	–	–	–	0.3	0.3
	2	1981	–	–	–	–	–	–	–	–	3.4	3.8
	3	1980	–	–	–	–	–	–	–	–	0.4	0.4
	4	1979	–	–	–	–	–	–	–	–	–	–
	5	1978	–	–	–	–	–	–	–	–	–	–
1984	1	1983	–	–	–	–	–	–	–	0.1	0.4	+
	2	1982	+	1.9	0.2	–	–	1.9	–	3.4	5.1	1.3
	3	1981	0.1	10.1	7.9	–	–	2.5	–	1.2	4.3	2.3
	4	1980	+	1.9	1.5	–	–	0.1	–	–	0.1	+
	5	1979	–	–	–	–	–	–	–	–	–	–
1985	1	1984	–	–	–	–	+	0.2	+	0.1	0.3	0.2
	2	1983	–	0.1	0.3	–	2.7	2.4	3.7	5.7	6.3	4.8
	3	1982	1.6	4.5	3.0	–	3.2	2.6	2.2	2.3	2.9	2.2
	4	1981	2.1	2.6	0.7	–	0.1	+	+	0.1	+	+
	5	1980	+	+	+	–	–	–	–	–	–	–
1986	1	1985	–	–	–	–	–	+	+	+	+	+
	2	1984	–	+	0.1	–	1.1	1.5	2.6	1.6	1.9	1.3
	3	1983	5.0	3.5	1.3	–	4.7	2.9	4.4	3.4	4.8	3.1
	4	1982	3.7	2.8	0.4	–	0.4	0.1	+	+	+	+
	5	1981	0.1	0.1	+	–	–	–	–	–	–	–
1987	1	1986	–	–	–	–	–	+	+	+	+	–
	2	1985	+	–	–	–	2.5	3.4	+	0.6	8.0	13.2
	3	1984	2.5	2.4	2.0	–	1.0	1.0	+	0.2	1.8	2.7
	4	1983	5.0	6.1	4.4	–	+	+	+	+	+	–
	5	1982	–	–	–	–	–	–	–	–	–	–

Table XIX. (continued)

Year	*Age*	*Year class*	*Jan*	*Feb*	*Mar*	*Apr*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
1988	1	1987	–	–	–	–	–	0.1	+	0.1	0.1	–
	2	1986	+	+	+	–	–	1.3	0.6	1.9	6.1	3.7
	3	1985	7.9	8.4	7.1	–	–	0.7	0.3	0.6	1.9	2.5
	4	1984	2.9	2.4	1.9	–	–	–	–	+	+	–
	5	1983	0.1	0.1	0.1	–	–	–	–	–	–	–
1989	1	1988	–	–	–	–	–	–	–	–	1.5	0.2
	2	1987	–	+	0.1	–	1.9	1.8	–	+	1.4	0.9
	3	1986	7.0	5.9	8.1	1.9	0.6	0.2	–	+	0.5	0.2
	4	1985	3.1	2.9	1.6	0.2	+	+	–	–	+	+
	5	1984	–	+	–	–	–	–	–	–	–	–
1990	1	1989	–	–	–	–	–	0.1	–	0.1	0.6	+
	2	1988	0.2	0.4	0.8	–	–	1.3	–	1.3	3.0	0.3
	3	1987	8.9	11.8	4.1	–	–	0.5	–	0.5	0.5	+
	4	1986	3.6	5.2	0.8	–	–	+	–	+	+	+
	5	1985	0.1	+	+	–	–	–	–	–	–	–
1991	1	1990	–	–	–	–	–	–	–	–	–	0.3
	2	1989	0.1	0.2	0.4	–	–	–	–	–	–	2.7
	3	1988	0.6	5.9	3.0	–	–	–	–	–	–	0.4
	4	1987	0.1	1.2	0.6	–	–	–	–	–	–	+
	5	1986	+	+	+	–	–	–	–	–	–	–
1992	1	1991	–	–	–	–	–	–	0.9	0.6	0.2	+
	2	1990	+	1.7	1.0	–	2.2	3.3	2.1	3.1	3.0	0.3
	3	1989	4.2	15.8	9.4	–	0.8	0.4	0.1	0.2	0.6	+
	4	1988	0.4	1.5	0.9	–	+	+	–	–	–	–
	5	1987	–	+	+	–	–	–	–	–	–	–
1993	1	1992	–	–	–	–						
	2	1991	+	0.2	+	–						
	3	1990	1.7	11.2	3.5	–						
	4	1989	0.2	2.3	1.0	–						
	5	1988	–	+	+							