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MANAGEMENT STRATEGIES FOR COMMERCIAL MARINE SPECIES IN NORTHERN ECOSYSTEMS

Proceedings of the 10th Norwegian-Russian Symposium, Bergen, 27-29 August 2003

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Sigbjørn Mehl

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INSTITUTE OF MARINE RESEARCH, BERGEN, NORWAY
March, 2004

CONTENTS

PREFACE

This is the proceedings from the 10th Norwegian-Russian Symposium on Fisheries Research arranged by the Institute of Marine Research (IMR), Bergen and the Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Murmansk. This series of symposia started in 1983 as a part of the Norwegian-Russian (Soviet) cooperation on scientific investigations of marine resources and their environment.

Traditionally, Norwegian and Russian scientists have attended these symposia, while at the three most recent symposia fishery managers and representatives of the fishing industry in the two countries have also participated. This latest symposium also welcomed participants and contributions from other countries in the northern hemisphere.

The written contributions represent a wide range in terms of their scope. Some are comprehensive, others are extended abstracts of the presentations given, while in yet others, no written text was submitted and only the PowerPoint presentation is included on the enclosed CD. The proceedings and the PP presentations are also available on the IMR website, www.imr.no. As with earlier symposia, the contributions have not been subject to peer reviews. The editors are responsible for a few modest editorial changes for which it has not been possible to obtain the authors' approval. The editors are also indebted to Hugh M. Allen for correcting and improving the English text.

Bergen, February 2004

Åsmund Bjordal Harald Gjøsæter Sigbjørn Mehl

BACKGROUND and SCOPE

The 10th Norwegian-Russian Symposium on "Management Strategies for Commercial Marine Species in Northern Ecosystems" was arranged in Bergen, Norway, 27-29 August 2003 – jointly by the Institute of Marine Research (IMR), Bergen, Norway and the Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Murmansk, Russia – under the auspices of the Joint Norwegian-Russian Fisheries Commission.

The first Norwegian-Russian Symposium was held in 1983 and until 1999, these symposia were attended mainly by scientists from IMR and PINRO. In 1999 the scope was broadened by attendance of participants from fisheries management and the fishing industry – under the title: "Management strategies for the fish stocks in the Barents Sea". Since then the symposia have been attended by scientists, managers and representatives from the industry. Until 2003, the symposia had focused on themes related to the Barents Sea. However, for the 10th symposium, the scope was broadened to include other northern ecosystems as well: "*The symposium will focus on management strategies for the most important commercial stocks in the Barents Sea ecosystem. However, presentations of management strategies for exploited stocks in other northern marine ecosystems will be emphasised*." Thus the symposium included presentations on stock history and fisheries management of different species in the Barents Sea as well as Faroese-, Icelandic-, Greenland-, Canadian- and Alaskan waters.

We hope that the symposium and proceedings will make a valuable contribution to the development of sustainable Barents Sea fisheries and coastal communities.

Finally, we would like to thank the authors for their contributions to the symposium and the proceedings.

Bergen and Murmansk, February 2004.

Åsmund Bjordal and Aleksander Boltnev

Co-conveners

SESSION 1: Pelagic fish

H. Gjøsæter[1] and N.G. Ushakov[2]: Capelin in the Barents Sea

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Abstract

The report discusses the past and present management of the Barents Sea capelin stock. It also provides a short recapitulation of stock characteristics and the history of the stock and fishery.

Stock characteristics

This synopsis of capelin biology and history of the stock and its exploitation is partly taken from Gjøsæter (1998), where a more thorough discussion of capelin biology and exploitation, and references to the original literature, may be found. A thorough description of capelin with numerous references covering the period up to 1984 may be found in the Proceedings of the Second Soviet-Norwegian Symposium (Gjøsæter, 1985). Another important sources of information devoted to capelin of the northern hemisphere (with about one third of the papers dealing with Barents Sea capelin) is found in the proceedings of an ICES symposium, held in Reykjavik, 2001 (Hollingworth, 2002). A great deal of information on capelin (in Russian) can be also found in PINRO Press publications (Luka *et al.*, 1991; Prokhorov, 1965).

This capelin stock is confined to the Barents Sea, and on the basis of current knowledge there are no signs of exchange of individuals between this and other capelin stocks. Its distribution varies with season, and migrations are extensive, (Figure 1). Capelin have demersal eggs, and their spawning areas are limited to sandy bottom at depths of about 15-60m. The main spawning takes place along the coast of Norway and Russia from about 15°E to 35°E, but sporadic spawning further east has been observed (Luka *at al.*, 1991). The whole area between these longitudes is not utilized every year, and spawning may be concentrated in western, central or eastern areas.

The eggs hatch after about one month, and the fry are carried by the prevailing currents north and east into the central and eastern parts of the Barents Sea. The larvae normally metamorphose during spring in their second year of life, and they gradually adopt the seasonal migration pattern characteristic of adult capelin. During the feeding season, from late spring to late autumn, distribution gradually shifts northward, reflecting the peak of zooplankton production. Production of phytoplankton and zooplankton starts in the southern parts of the sea, in particular on the coastal banks, and as the water masses stabilize it moves further north. The ice, covering the waters north of the polar front in the winter, melts during the summer, and a plankton bloom tends to follow the receding ice edge. The capelin migrate northwards and into the previously ice covered areas, utilizing the rich zooplankton production there during late summer and autumn. When temperatures fall in late autumn and the ice forms again in the areas dominated by Arctic water in the north, the capelin move southwards, to winter in the ice-free areas south of the polar front. From these wintering areas, the maturing part of the stock migrates to the coast to spawn in spring. Large-scale changes in the water temperature generate a significant displacement of the distribution area of capelin, which thus change their pattern of migration (Ozhigin and Luka, 1985). The capelin becomes sexually mature at a length about 14 cm. Depending on growth rates, this change occurs at an age of three, four or five.

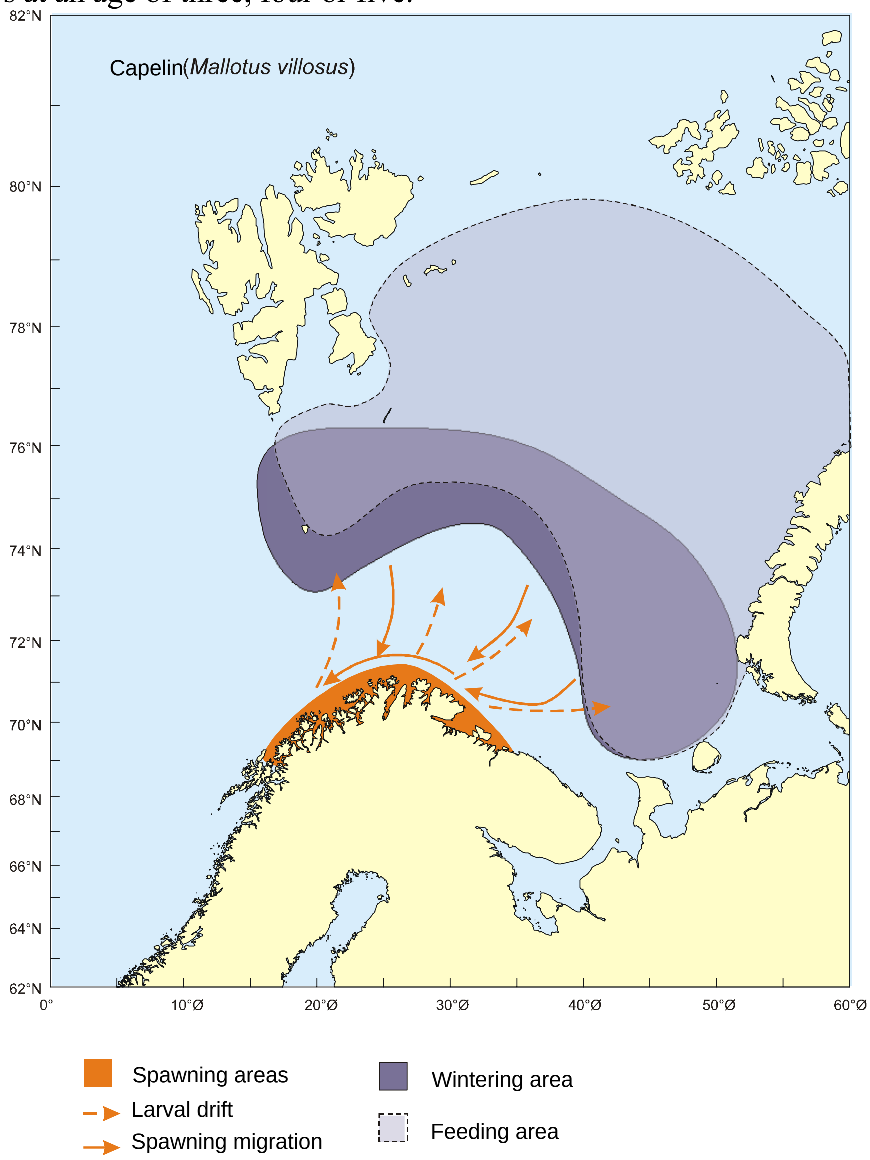

Figure 1. Distribution and migrations of the Barents Sea capelin stock

Capelin are mostly semelparous, i.e. they spawn only once and then die. Some individuals may survive the spawning, but since capelin are heavily preyed upon by cod, their main predator, during the spawning season, very few spent capelin survive to spawn for a second time. In the period 1984-2001, it has been estimated that cod consume from 0.2 to 3.0 million tonnes of capelin annually, depending on the sizes of the cod and capelin stocks (Figure 2). Apart from the three collapse periods (see below), the amount of capelin consumed annually by cod has been more than one million tonnes. Other fish predators include haddock, Greenland shark, Greenland halibut and Esmarks eelpout, thorny skate, long rough dab, deep sea redfish and various rockfishes. Other important predators are seals (mainly harp seals) and whales (mainly minke and humpback whales). Seabirds consume some capelin; their main avian predators are the common guillemot and puffin. There is lack of quantitative information about the annual consumption of capelin by these predators, but based on the estimates that have been published there are reasons to believe that the amount of capelin taken annually by predators other than cod may amount to less than one million tonnes. A special kind of predation is that which takes place when young herring feed on capelin larvae in summer and autumn (Huse, 1994; Huse and Toresen, 2000). This is thought to be one of the major mechanisms behind the recruitment failures that have been observed in the capelin stock (Hamre, 1985; 1988; 1991; 1994; Gjøsæter and Bogstad, 1998; Ushakov and Shamrai, 1995). These recruitment failures were the direct reason for the stock collapses referred to above (Gjøsæter, 1995; 1998).

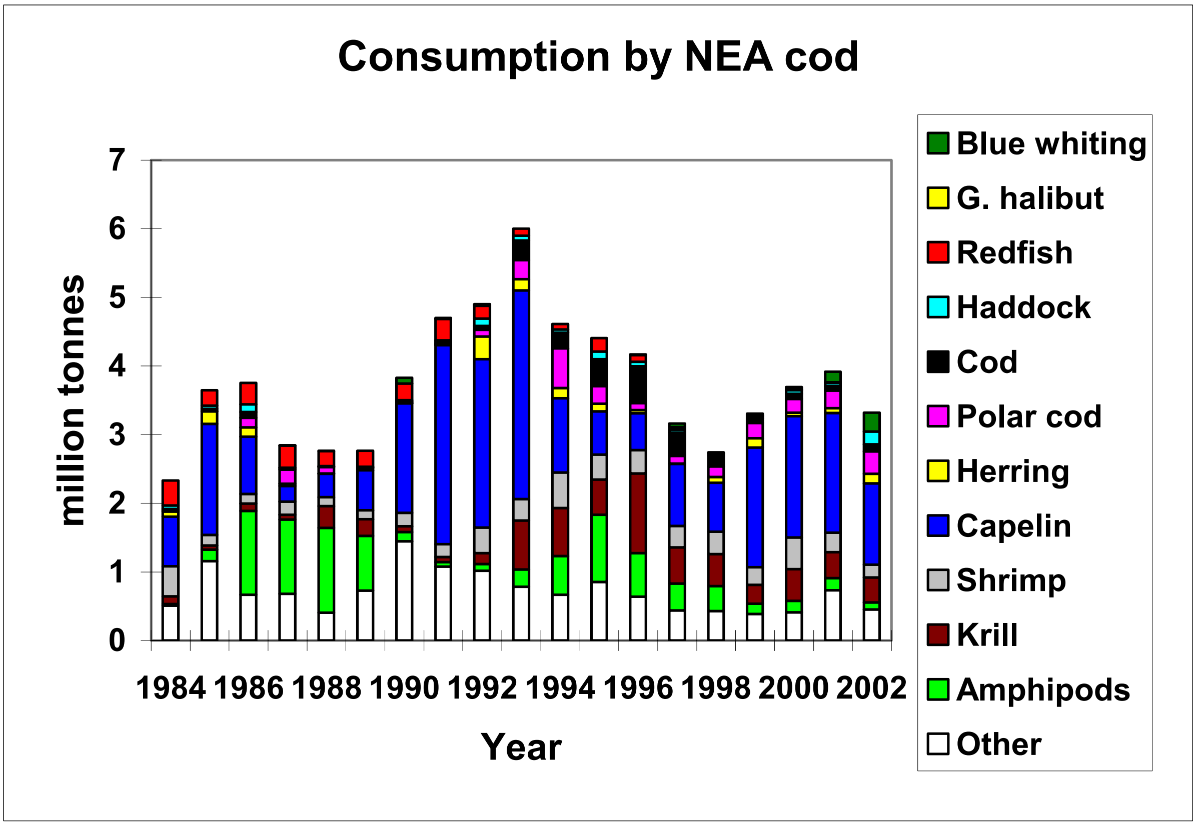

Figure 2. Annual consumption by cod based on the joint Norwegian-Russian cod stomach database (Mehl and Yaragina 1992, annually updated in the reports from the ICES Arctic Fisheries Working Group and the Northern Pelagic and Blue Whiting Fisheries Working Group).

The capelin is a specialized plankton feeder and is the most important planktivorous fish in the Barents Sea. Other fish at the same trophic level is herring and partly Polar cod, in addition to several species during their 0-group stages. Since herring, when present in the Barents Sea, are confined to the southern parts of the area, there is not much distributional overlap between these two species. The polar cod is not a specialized plankton feeder, and hence primarily consumes larger zooplankton forms. Due to their semipelagic way of life, adult polar cod mostly feed at near-bottom depths, while capelin may feed throughout the water column. Polar cod are distributed in Arctic and mixed water masses, while capelin feed in both Atlantic and Arctic waters. There is thus potential feeding competition between capelin and polar cod (Panasenko, 1990), and to a lesser extent between capelin and herring. Various 0-group fishes may overlap with capelin and act as competitors for food during the late summer and autumn. The practical implications of such competition from one year to the next are largely unknown.

The size of the capelin stock has been seen to vary widely in the thirty-year period during which the stock has been monitored (Figure 3). Based on indirect knowledge about stock dynamics in the Barents Sea, there are reasons to believe that fluctuations in capelin stocks are inherent in the ecological processes in the area, and should be looked upon more as natural perturbations than man-induced instability in the ecosystem. However, there is firm evidence that the exploitation of capelin and of its predator stocks may have affected the magnitude and length of periods when the capelin stock has been at low levels.

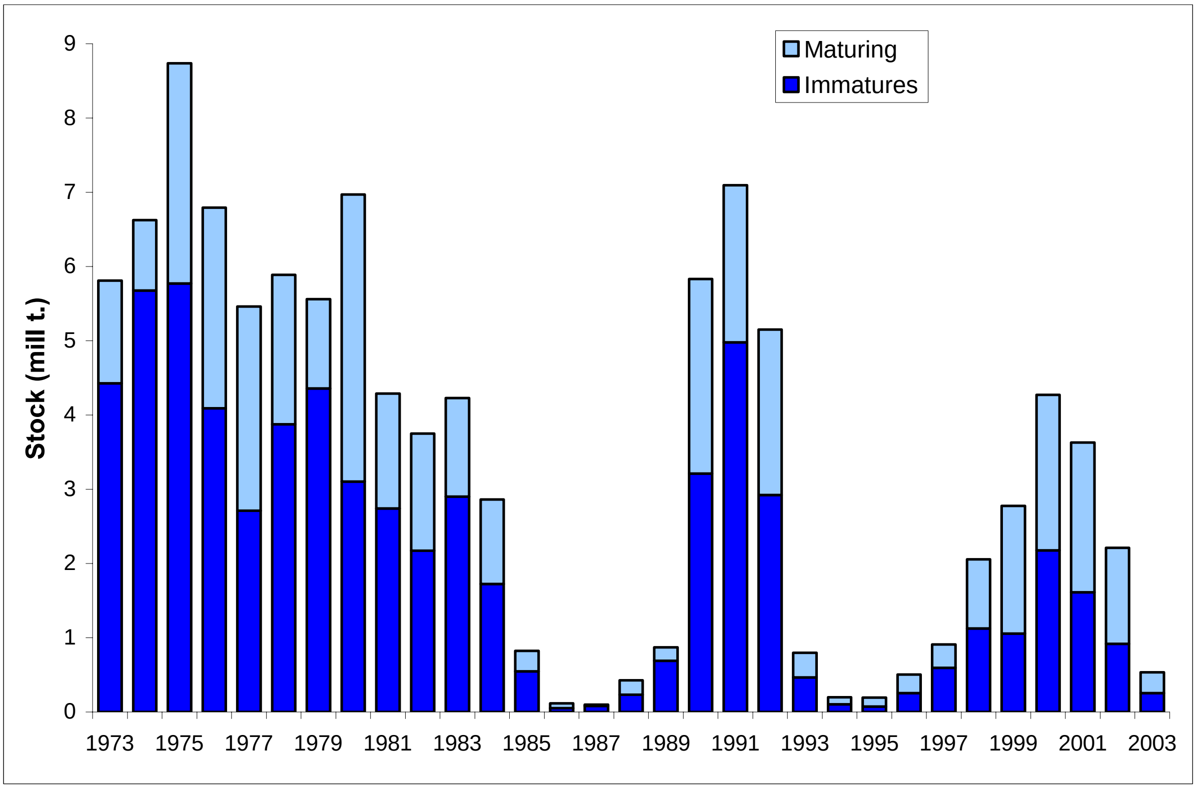

Figure 3. Stock history of the Barents Sea capelin. Acoustic estimates during the annual joint Norwegian-Russian acoustic survey in autumn.

The monitored history of capelin stock size is characterized by three stock collapses (according to the definition introduced by Gjøsæter et al. (2002), this is when the stock size is below one million tonnes when measured in autumn), in the periods 1985-1989, in 1993-1997, and from 2003. Except during these periods the stock size has mostly been at a level of 3-6 million tonnes, and peaked in 1975 and 1991, when the stock was measured acoustically to be above seven million tonnes.

History of the capelin fishery

The Norwegian capelin fishery has a long history. The capelin were originally fished with beach seines on the coast of Finnmark during the spawning season, and mainly used as bait, fertiliser or animal food. From 1916 on, capelin were used for meal and oil production in Finnmark, but it was not until the 1930s that a fishery for industrial purposes became important. Since the late 1950s, following the decline in abundance of the stock of Norwegian spring spawning herring, the purse seine fleet increasingly focused its efforts on the capelin, and by 1957 purse-seiners had totally replaced the beach-seines. From 1961 onwards, pelagic trawls were also employed in the fishery, which at that time took place in the spawning season only. Beginning in 1968, a summer fishery rapidly developed in the open sea.

The Russian (former Soviet) capelin fishery also has long traditions, and was carried out using beach seines and nets along the Kola coast during the spawning season. Starting in the early 1960s, purse seines and pelagic trawls replaced the beach seines and the fishery expanded into the open areas of the Barents Sea in the 1970s.

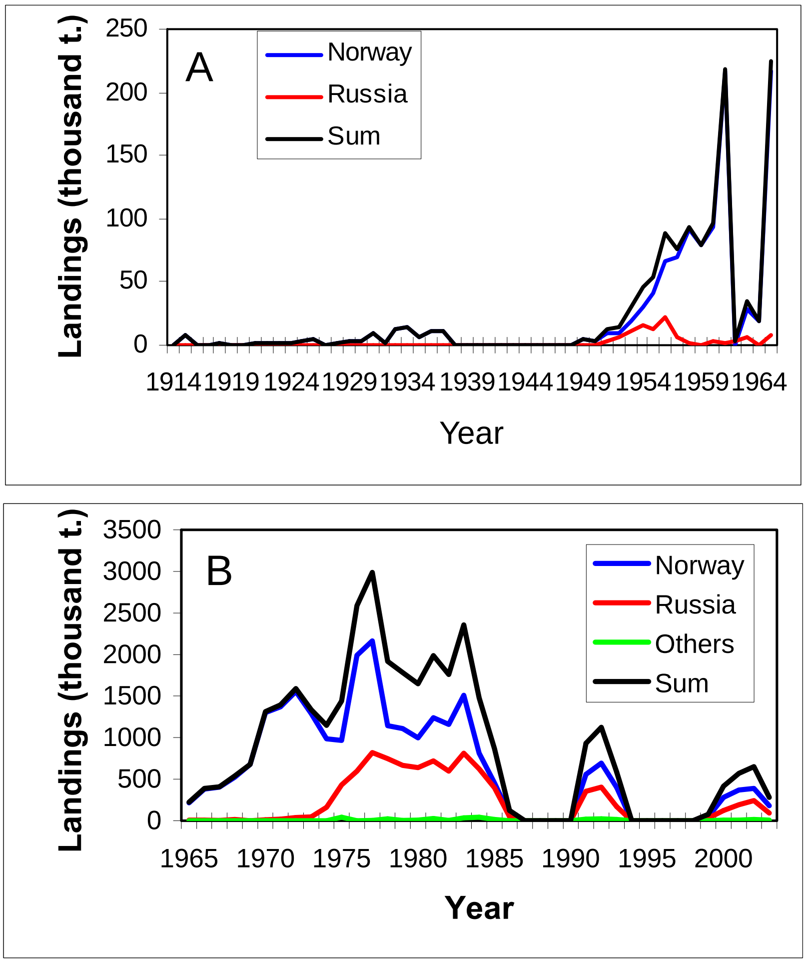

Figure 4. Catch history of the Barents Sea capelin. Panel A: 1914-1965. Panel B: 1965-2003. (Gjøsæter, 1998; updated based on reports of the ICES Northern Pelagic and Blue Whiting Fisheries Working Group)

In the 1970s, the capelin fishery became of prime importance to Norwegian and Russian fleets, with nearly three million tonnes being landed in 1977. Since then, the three stock collapses have resulted in the capelin fisheries becoming more variable. Furthermore, the fishery was closed from 1987-1990 and again from 1994 to 1998. Figures 4A and B present catch statistics for 1914 to 1965 and 1965 to 2003. Landings increased sharply in the 1950s, but declined almost to zero in 1962-1964. From 1965 onwards, the increase in catch continued until the early 1970s. From 1972 to 1983 Norwegian landings fluctuated around 1.5 million tonnes, while Russian landings increased and brought total annual landings up to 2-3 million tonnes. From 1984, catches decreased, partly because of quota restrictions, but primarily because the stock collapsed. The fishery was closed from autumn 1986 until autumn 1990, and the catches taken from the recovered stock in 1991-1993 were relatively small compared to the period 1970-1985. The fishery was closed again in spring 1994, when a new stock collapse was evident, but was opened on a recovered stock in 1999. In recent years, the fishery has been restricted to a winter fishery only, and about 500 000 tonnes have been taken annually. From 2004, the fishery was again closed.

History of the management system

This synopsis is partly taken from Gjøsæter *et al.*, 2002, where a more detailed presentation of the management of the Barents Sea capelin and references to the original literature can be found. Management goals in the period prior to the first stock collapse were rather *ad hoc*. Only in two years, 1974 and 1978, was a national catch quota introduced in the Norwegian fishery. These catch quotas were introduced on the basis of the results of the acoustic stock measurements, because a reduction in the mature component of the stock was observed, and it was felt that a fishery on this component might endanger recruitment. No attempts were made to evaluate the consequences of an alternative management policy due to lack of basic knowledge of the stock-recruitment relationship, natural mortality, and consistency of the acoustic stock measurements (Hamre, 1985).

In 1978, the Soviet/Norwegian Fishery Commission requested scientists from both countries to evaluate the state of the stock and submit proposals for necessary joint management actions. Two meetings of scientists were held in 1978, resulting in the following agreement:

A total allowable catch (TAC) assessment of capelin should be based on acoustic stock measurements carried out jointly in the autumn, the assessment period should cover the winter and subsequent autumn fishery and the assessment should aim at maintaining a minimum spawning stock of 500 000 tonnes. The strategy was based on a rough evaluation of the curve of spawning stock biomass vs. recruitment: for spawning stocks below this limit the risk of poor recruitment apparently grew.

During this period, Sigurd Tjelmeland developed the model “Capelin” (Tjelmeland, 1985), as an aid to performing the assessment outlined above.

The model was also augmented with a recruitment module, which enabled long-term prognoses to be made to study maximum sustainable yield, etc. Using this model Hamre and Tjelmeland (1982) analysed the yield functions for various fishing patterns and allocations of the total catch on the autumn and winter fisheries. They introduced the new concept “M-output biomass”, which denoted the production of capelin available for predators. One of their conclusions was that the maximum sustainable yield of capelin would be reached with a spawning stock biomass of about 400 000 tonnes. Another observation was that fishing during the autumn would maximize the yield but lower the M-output biomass considerably. In a multispecies context, winter fishing would therefore be preferable to autumn fishing. Based on those analyses, the recommended minimum spawning stock level was kept at 500 000 tonnes, but it was recommended that most catches should be taken during the winter season.

During the period 1986 to 1990, a fishing ban was recommended because, even in the absence of any fishing, the spawning stock size was estimated to be below the 500 000 tonnes limit.

After the stock collapse during 1985-1989, it was realised that the assessment model used previously was inadequate. First of all, the method for estimating the natural mortality of the mature capelin during the winter months was too simplistic (Tjelmeland and Bogstad, 1994). In 1984, a joint Norwegian/Russian cod (*Gadus morhua* L.) stomach sampling programme was launched (Mehl and Yaragina, 1992), and it was found that capelin made up a considerable part of the diet of cod during the winter. Furthermore, cod is the most important predator on capelin. A project that had the aim of constructing a multispecies model (MULTSPEC) including the principal fish and sea mammal stocks in the Barents Sea was launched (Tjelmeland and Bogstad, 1998). This model, however, was rather complex and data-intensive, and was never used in its full version as a stock assessment tool for quota regulation purposes. An attempt was made to utilize the data in the stomach content database to estimate the amount of capelin consumed by cod (Bogstad and Gjøsæter, 1994), and to use this as an estimate of the natural mortality of maturing capelin during winter. This was a first attempt to include the influence of other species in the assessment of capelin. Based on a combination of the capelin model and some *ad hoc* methods related to the calculation of presumed capelin consumption by cod, TAC recommendations were made from 1991 to 1993. However, it was soon realized that the large stock size in this period was based on one single year class, the 1989 year class. From 1992 onwards, a new period of recruitment failures was apparent, the stock dwindled and once again a fishing ban was recommended and introduced (Gjøsæter, 1998).

The development of assessment methods capable of taking the influence of other fish stocks into account continued during and after the second capelin stock collapse. This process included continuing work on the inclusion of the influence of the cod stock on capelin mortality during the winter (Bogstad and Gjøsæter, 2001). However, since the recruitment failure of the capelin, resulting in the two stock collapses, was partly attributable to the stock of young herring appearing infrequently in the Barents Sea, focus was now also put on including the effect of herring (Gjøsæter and Bogstad, 1998). During this period, the single-species model capelin was abandoned in favour of a model in the MULTSPEC family of models: the Bifrost (former CapSex) model (Gjøsæter *et al.*, 2002). This model is also a multispecies model but, unlike the MULTSPEC model, it has no geographical resolution. For TAC-calculations, it is combined with the spreadsheet model CapTool implemented in the @RISK add-on to MS Excel. The parameters of the model are estimated using Bifrost, and this model is used to construct replicate parameter files for the future stochastic development of the stocks. These replicate files are fed into CapTool, which, for given catch quotas, gives probability functions for capelin stock development. This pair of models has been used to calculate TACs since 1998 until the present, but has continuously been updated and augmented during this period. These models introduce a probabilistic assessment . Although it is based on multispecies considerations, this is still a single species assessment, since neither the effect of fishing on the herring stock (affecting the capelin recruitment) nor the effect on the growth of cod of fishing on the capelin stock is quantified.

Current managements strategy

Once the assessment of capelin had been made probabilistic, ACFM started to propose for the Norwegian-Russian Fishery Commission a management strategy with the following elements: A B_{lim} of 200 000 tonnes, only fishing on the prespawning fish in spring, and an escape strategy with a risk of 5% that the spawning stock size would be less than B_{lim}. In most years this strategy is somewhat more cautious than the previous strategy used when the assessment gave a deterministic prognosis for the spawning stock size; to let 500 000 t spawn. This is because in most years, the uncertainty in the assessment is so large that when the fifth percentile is at 200 000 t, the median of the probability distribution, comparable to the old deterministic estimate, is greater than 500 000 t. ACFM considers this strategy to be in accordance with the precautionary approach. During its meeting in November 2002 the Joint Norwegian-Russian Fishery Commission adopted this strategy and stated in the protocol: *"The Parties agreed on a exploitation strategy for capelin where the TAC is not set higher than that, with 95% probability, at least 200 000 tonnes of capelin are allowed to spawn. The Parties decided to open the fishery in the winter months from 1 January to 30 April in 2003"*. ACFM will therefore continue to present its advice on a TAC for Barents Sea capelin on this management strategy.

Throughout the whole period of capelin management by the Joint Norwegian-Russian Fishery Commission (agreed in 1978), the TAC has been allocated to Norway and Russia in the proportion 60/40. In 1978, a rule defining a closed season from 1 May to 14 August was introduced, and the catch of juvenile capelin below 11 cm was limited to 15 % by weight. In 1981, the proportion of the allowable catch of fish below 11 cm was reduced to 10 %, and in 1984, the opening date of the autumn fishery was postponed to 1 September. In 1981, a minimum mesh size of 16 mm in capelin nets (both trawls and purse seines) was introduced. In recent years, the mesh size regulations and the minimum landing size regulations have remained the same, but the fishing season has been restricted to January until April. Only areas south of 74°N have been open to the fishery, in order to avoid catching juveniles. During the fishing season, the parties may close the fishery in particular areas south of this latitude, if problems with by-catches of herring or other species are detected in certain areas.

Enhancements to the current management strategy

The assessment group that meets after the capelin survey every autumn has expressed concern that, since it is known that the presence of young herring in the Barents Sea may seriously hamper capelin recruitment, this should be taken into consideration when setting the TAC, so that in "herring years" the amount of spawners should be kept higher, in order to counteract the negative influence of the herring. The assessment group has suggested that a variable B_{lim} could be used for this purpose, since the interesting quantity here is not the spawning stock as such, but the recruitment that will result from its spawning. The assessment group has also suggested that a target reference point should be sought, since the recruitment may gain from a higher spawning stock than that resulting from the present target escape strategy. ACFM has agreed to these ideas but has maintained that, so far, the basis for suggesting a variable B_{lim} or a B_{target} is too uncertain.

In addition, further work needs to be done with the aim of moving from a spawning stock biomass to a quantity that takes into account the quality and amount of eggs spawned. On the basis of population fecundity analysis, and taking into account the fact that the spawning stock size should be large enough to create sufficient recruitment even in years with poor survival conditions for the larvae, a proposal has been put forward that nearly one million tonnes of spawning stock biomass should be saved (Ushakov and Tereshchenko, 1992; Tereshchenko, 2002). This estimate is somewhat higher than that corresponding to a B_{lim} of 200 000 tonnes. The spawning stock biomass corresponding to a preferred level of population fecundity will vary from year to year due to changes in the age and size structure of the stock. To date, ICES has not considered this proposal.

Even with these enhancements. the management strategy will still be a single species strategy, and as such, would be inadequate in the long run. The ultimate goal should be to manage the stock complex found in the Barents Sea together, so that the amount taken from the stocks of say, capelin, cod, shrimp, seals and whales would be based on their effects on each other and also on their respective economic values. There is a long way to go until we are there, but on the other hand: the Barents Sea ecosystem is one of the best known in the world as far as multispecies effects are concerned, and as such, would be the right place to start experimenting with a more integrated management system.

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H. Vilhjálmsson and J. Sigurjónsson: Capelin of the Iceland-East Greenland-Jan Mayen area: biology, exploitation and management

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Introduction

Capelin, *Mallotus villosus* (Müller), are pelagic, migratory fish occurring in large quantities in the Iceland-East Greenland-Jan Mayen area. The ecological importance of capelin and the large capelin fishery that has taken place in this area since the early 1970s has generated intensive research and monitoring of the state of capelin stocks since the mid-1960s. The biology and exploitation of the stock have been studied by Vilhjálmsson (1994) and later by Vilhjálmsson (2002), Vilhjálmsson and Carscadden (2002) and Gudmundsdottir and Vilhjalmsson (2002), respectively.

The present paper briefly summarises our current knowledge of the biology, exploitation and management of the capelin stock in these waters (hereafter referred to as the Icelandic capelin (stock)).

Oceanographic features

The hydrography of the waters surrounding Iceland and of those between Iceland, East Greenland, and the island of Jan Mayen (the Iceland Sea and Denmark Strait; Fig. 1) have been described by many authors (e.g. Stefánsson 1962; Stefánsson and Ólafsson 1991; Malmberg 1972, 1984). Atlantic water (Irminger Current branching from the Gulf Stream) of relatively high temperature and salinity predominates off the south and west coasts. Off Northwest Iceland, the Irminger Current splits into two branches; the larger branch flowing west towards Greenland, while the smaller branch, the North Icelandic Irminger Current, flows eastwards onto the shelf north and east of Iceland. A coastal current, essentially driven by gravity forces resulting from land run-off, runs clockwise round Iceland.

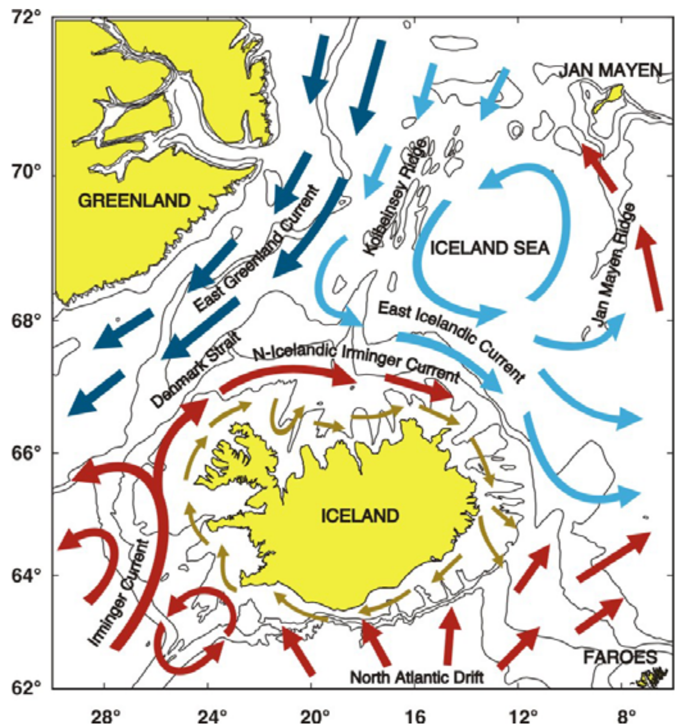

Figure 1. Main ocean surface currents in the Iceland-East Greenland-Jan Mayen area. Red: Atlantic water; Dark blue: Arctic or polar water; Light blue: Mixed cold waters

The cold East Greenland Current transports polar water from the Greenland Sea (north of 72°N) southwards along the East Greenland shelf and branches off and forms the East Icelandic Current. The cold East Icelandic Current is of a less polar character. The East Icelandic Current runs east and then southeast along the outer slope of the shelf off North and Northeast Iceland and dissipates into the western Norwegian Sea, north of the Faroe Islands. South and southeast of Jan Mayen, a current flows to the north and northwest, bringing relatively warm, saline water into the Iceland Sea, where a cyclonic eddy is formed in the basin between the Jan Mayen and Kolbeinsey Ridges. For these reasons, conditions in the waters of the Iceland Sea are considerably milder than they would be if the only contributors were the East Greenland and East Icelandic Currents.

Variations in the relative strength of these ocean currents, and hence in the distribution of the main water masses in the area, have resulted in large temporal variations in the hydrograpic conditions and productivity of north Icelandic waters, and probably also in the Iceland Sea farther north. On the other hand, the hydrography of the Atlantic water south and west of Iceland is more stable (see e.g. Thórdardóttir 1984; Stefánsson and Ólafsson 1991; Astthorsson and Gislason 1998).

Stock characteristics and life history

The oceanographic conditions and currents around Iceland provide the basis for the principal stock characteristics of the Icelandic capelin, including the distinctive migratory pattern. The Icelandic capelin spawn in March/early April in the warm Atlantic waters off South and West Iceland, mostly within a depth range of 10-150 m. After spawning, the larvae hatch in about three weeks, whereafter they drift with the surface currents in a clockwise direction to the shelf area north and east of Iceland, and to a varying extent across the northern Irminger Sea and the southern Denmark Strait to the East Greenland plateau (Figs 1 and 2).

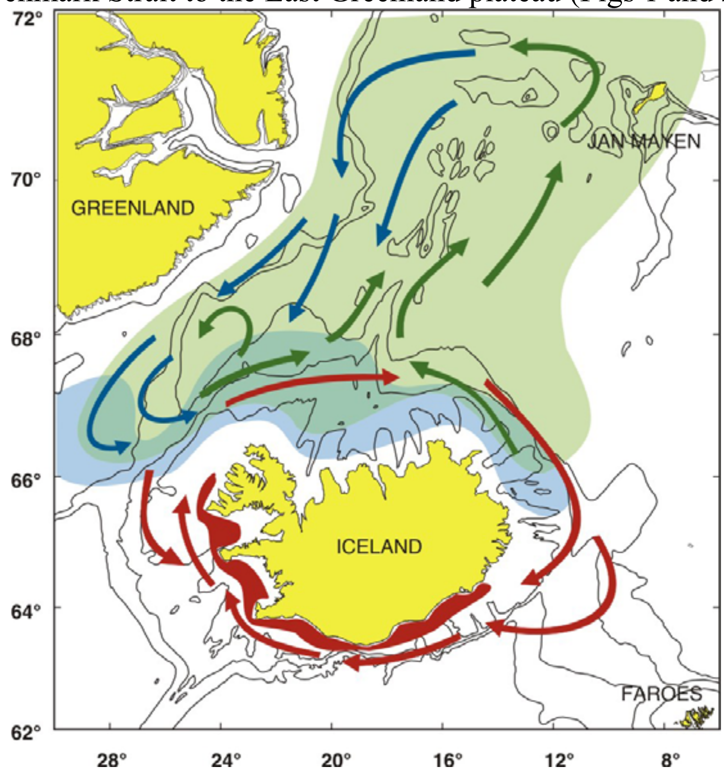

Figure 2. Distribution and migration of Icelandic capelin. Blue shade: Distribution of juveniles; Green arrows: Feeding migrations; Blue arrows: Return migrations; Red arrows: Spawning migration

Most juveniles grow up over or near the continental shelf northwest to northeast of Iceland and on the East Greenland plateau northwest of Iceland. The larger part of each year-class matures and spawns at three years of age, the remainder at four. There are only few spawners aged two, and five-year-old spawners are very rare. Thus, there are only two age groups in the spawning stock. Due to extreme high spawning mortality, the spawning stock is practically completely renewed every year.

Growth is fastest during the first two years, but slows thereafter. Nevertheless, the weight increases by about a factor of four and two among age groups two and three respectively in the spring and summer, before spawning takes place at ages four and five in the following year, while the total fat content also increases from about 2-4% to 15-20% during the same period.

Maturing capelin aged two and three (spawning at ages three and four during the following year) usually undertake extensive northward feeding migrations into the Iceland Sea in spring and summer as shown in Figure 2. The return migration takes place in September-November. By late November/early December, these capelin have usually assembled near the shelf edge off Northwest, North, and Northeast Iceland, from where the spawning migration starts in December/January. In most years, the spawners follow a clockwise direction along the warm/cold water boundary near the shelf break north and east of Iceland, entering the warm Atlantic waters off the eastern south coast. The first spawning migration then continues west along the coast to the main spawning grounds off Southwest Iceland. Late arrivals usually spawn off the central and eastern south coast. On occasion, however, large spawning migrations may arrive on the spawning grounds off West- and Southwest Iceland directly from the northwest. The most recent example was in winter 2002, when approximately 75% of the spawning stock arrived in this manner.

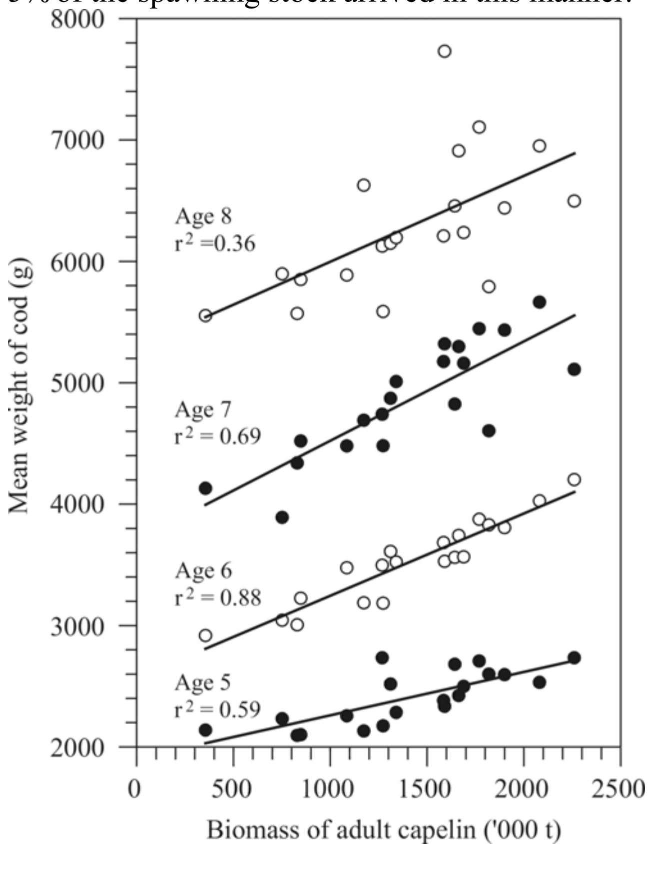

Figure 3. The relationship between adult capelin biomass and mean weight of cod.

Although the above general migration and distribution pattern of the Icelandic capelin is true for most years since 1970, there are large annual variations, both in the extent of the northward feeding migration and in the spawning migration. Such variations have been attributed to environmental variability, although the behaviour/environmental relationship is poorly documented due to lack of field observations in high northern latitudes.

As in other areas where they occur, capelin play a key role in the marine ecosystem of Icelandic waters as well as in the sea area between Iceland, East-Greenland and Jan Mayen. They not only fall prey to several marine mammal species and seabirds, but they are also the main single item in the diet of Icelandic cod, *Gadus morhua,* (Fig. 3) and highly important as food for several other commercial fish species in Icelandic and Greenland waters, e.g. Greenland halibut (*Reinhardtius hyppoglossoides*), saithe (*Pollachius virens*), haddock (*Melanogrammus aeglefinus*) and others. The estimated annual removal of Icelandic capelin by their main predators in the range of 2-3 million metric tonnes is shown in Figure 4.

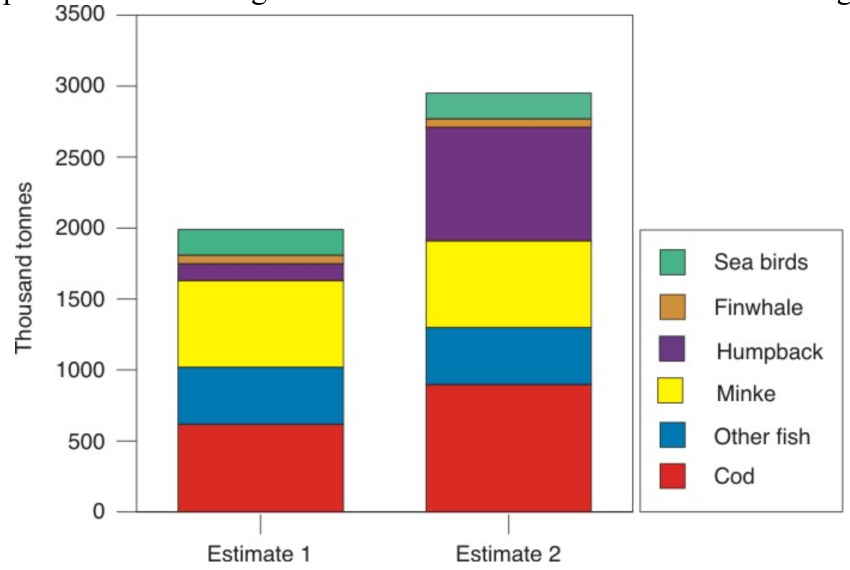

Figure 4. Estimated total annual consumption of capelin by various predators and groups of predators

Development and targets of the fishery

In the mid-1960s, the Icelandic capelin stock became the target of a purse-seine fishery that quickly developed into a large-scale operation. During its first eight years, this fishery was conducted in February and March on schools of pre-spawning fish, on or close to the spawning grounds nearshore south and west of Iceland, and the catch gradually increased from about 10 000 t in 1964 to 275 000 t in 1972. Then, in January 1973, a successful capelin fishery was initiated in deep water near the shelf break east of Iceland. This brought the total winter catch to some 450 000 t, i.e. close to the processing capacity of the land-based reduction plants at that time.

In July 1976, a summer capelin fishery began in the southern Iceland Sea. This fishery soon became multinational, with participation by Icelandic, Norwegian, Faroese, and Danish vessels. The seasonal (July–March) catch increased rapidly and reached almost 1 200 000 t in the 1978/1979 season. Since then, the seasonal catch has varied between about 700 000 and 1 600 000 t, depending on the success of the summer/autumn fishery. Exceptions are periods of low stock size, when the winter catch has been restricted or the fishery closed altogether.

The total catch of Icelandic capelin distributed over fishing season (summer/autumn and following winter until spawning) is shown in Figure 5. The fishery in the summer and autumn, and in the shallow coastal waters in winter, is carried out with purse seines. In the last few years there has been an increase in the use of pelagic trawls in deep waters east of Iceland, particularly in January.

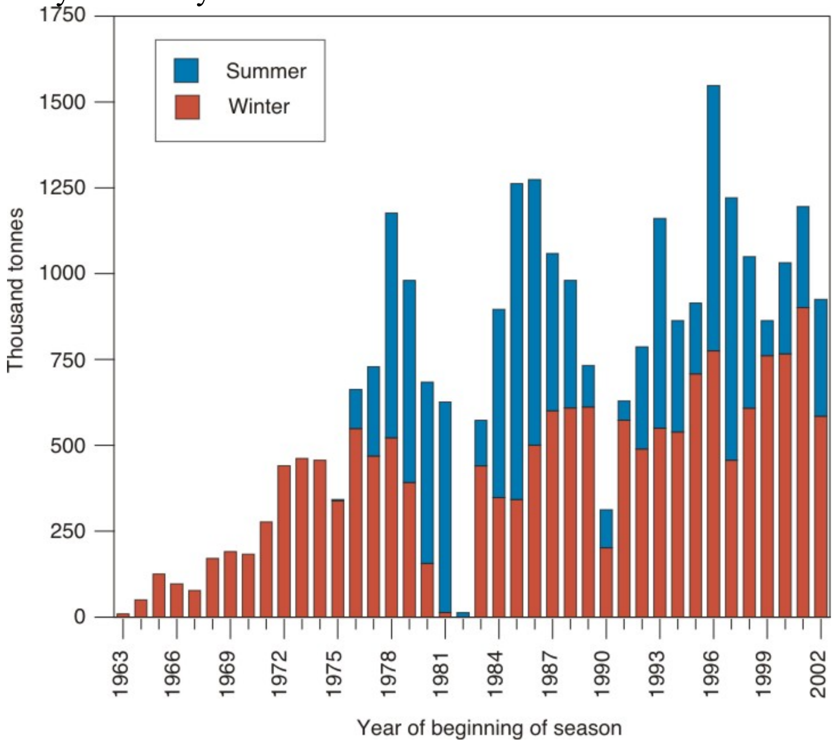

Figure 5. Total international catches of Icelandic capelin in the summer/autumn and winter seasons 1963/64-2002/03.

The fishery on this stock is almost entirely based on the maturing part of the stock. Owing to the short lifespan and high spawning mortality, the adult fishable stock is renewed annually. Because recruitment is highly variable and the larger proportion of each year class matures and spawns at the age of three, the abundance of the fishable stock, and thus of the spawning stock, is subject to large fluctuations. Furthermore, high catch rates may be maintained even at low stock levels owing to the schooling nature of capelin and its often easy accessibility to a modern purse-seine fishery. The primary management objective is therefore to prevent the stock from being fished down to a level of reduced recruitment, not to mention recruitment failure.

Stock monitoring and stock size

The Icelandic capelin has been assessed annually since 1978 by acoustic methods (supported by trawl sampling), by research vessels of the Marine Research Institute (MRI), Reykjavik. The first assessment surveys were aimed specifically at the adult, fishable part of the stock, where efforts were made to determine the appropriate harvest level that would safeguard minimum spawning stock biomass. Today, the capelin stock assessment surveys conducted by the MRI have two main aims:

1. To obtain an estimate of juvenile abundance at ages one and two that can be used to predict fishable stock abundance in the next season.
2. To assess the actual size of the fishable stock (ages two and three in July–December, changing to ages three and four in January–March) as soon as possible before or during the current fishing season.

The adult fishable stock migrates over large distances during the summer of the year before spawning (Fig. 2). Owing to these migrations, the resulting large and variable extent of the distribution area, and frequent feeding near the sea surface (above echo-sounder range), it is technically difficult and usually impossible to assess stock abundance by acoustic methods during the feeding season (May-September). However, under suitable environmental conditions, reliable estimates of adult stock abundance can be obtained offshore northwest, north, and northeast of Iceland in late autumn/early winter, east and/or northwest of Iceland in January/February, and in the shallow coastal waters of the eastern south coast in February.

Since adult and juvenile capelin cohabit over the shelf and near the shelf edge northwest, north, and east of Iceland in November and December (Fig. 2), juvenile abundance (next season's fishable stock) can be estimated concurrently with adult stock measurements in late autumn (Vilhjálmsson, 1994; Gudmundsdottir and Vilhjálmsson, 2002). Ideally, therefore, one acoustic assessment survey in late autumn should produce estimates of both juveniles and the adult fishable stock, thus meeting the two objectives noted above. However, this has often not been the case and the conditions for acoustic measurements on the grounds, the behaviour of the capelin or inconsistent assessment results have necessitated repeated surveys.

Since 1998, in fact, the autumn surveys have failed to register part of the adult fishable stock and in November 2002 the juvenile capelin estimate was far too low. These last cases have coincided with unusually warm conditions north of Iceland and in the Denmark Strait in autumn as compared to most years before 1998. In view of the high abundance of adult capelin as measured by acoustic methods in January/February 1999-2003, it seems clear that in November 1998-2002 the capelin must have been outside their usual autumn area of distribution. The problem of identifying such conditions and reacting to them correctly, remains largely unresolved. The history of assessments of the fishable stock during the 1978/79-2001/02 season is shown in Figure 6.

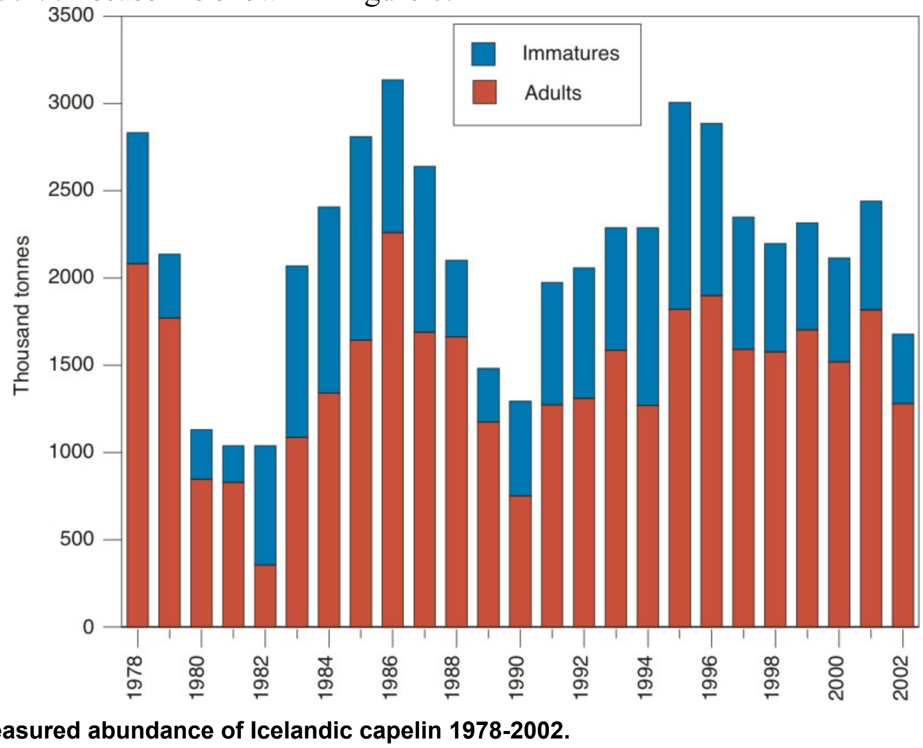

Figure 6. Measured abundance of Icelandic capelin 1978-2002.

Management of the fishery

The Icelandic capelin is considered to be a separate stock. It spawns in relatively shallow waters south and west of Iceland, but migrates to feed in the Iceland Sea and the Denmark Strait, i.e. within the EEZs of Iceland, Greenland and Norway (Jan Mayen), respectively. Therefore, the stock is shared and managed by the three countries according to an agreement, where the shares of each party from the total agreed quota are Iceland 81%, Greenland 11% and Norway 8%, respectively.

A detailed description of the management of the fishery of Icelandic capelin was given by Vilhjálmsson (1983, 1994) and Vilhjálmsson and Carscadden (2002). The first regulatory measures were purely precautionary and were aimed at preventing the juvenile part of the stock from coming into contact with the fishery. Thus, a closed season in spring and early summer, lasting from two to four months, was introduced in the early 1970s for protecting immature 1- and 2-group capelin in deep water east and northwest of Iceland. This was followed in 1975 by regulations of minimum landing and mesh sizes. Moreover, large areas south of 68°N, which are often rich in juveniles, have been closed to all capelin fishing during the summer in many years.

A target of 400 000 t of remaining spawning stock was adopted in 1979. Because a parent stock/recruitment relationship had not then been established (and indeed still has not been demonstrated) for Icelandic capelin, the choice of this value was based in part on the apparently successful Norwegian/Russian catch rule for Barents Sea capelin, which required a remaining spawning stock of 500 000 t. Also of relevance was the importance of capelin as a forage species and the possibility of overestimating capelin abundance using the recently invented acoustic assessment method.

It was soon recognized that overfishing might have taken place by the time the results from autumn or winter surveys became available. The reason for this, of course, is the large fishing power of a multinational fleet that may be operating during periods of low stock abundance but easy availability of capelin. As early as 1979, the introduction of a low precautionary catch quota was recommended by scientists, but not adopted, resulting in too heavy fishing pressure during the following seasons (Vilhjálmsson 1994). Subsequently, the 1980 spawning stock fell to about 300 000 t, and the 1981 and 1982 spawning stocks were reduced to extremely low levels. After this sudden stock collapse, a more cautious management approach was adopted by the authorities and on that basis, advice has been formally provided annually through the International Council for the Exploration of the Sea (ICES). The management history of the Icelandic capelin is shown in Figure 7.

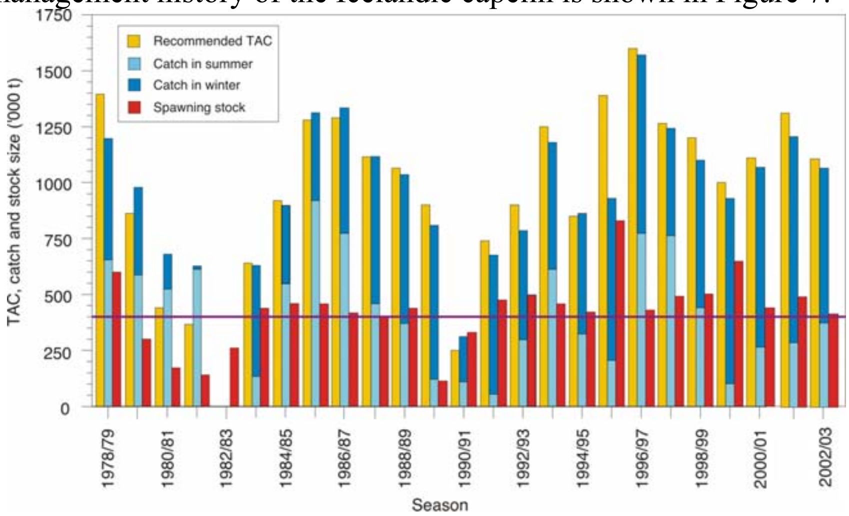

Figure 7. The management history of Icelandic capelin.

Basically, the approach involves setting in May each year a precautionary TAC (Total Allowable Catches or catch quota) for the summer/autumn part of each season, based on 2/3 of the predicted fishable stock size in the following season after acoustic surveys of subadults in the preceding season. TACs for the winter season, and thus for the fishing season as a whole, were determined on the basis of acoustic assessment surveys of the adult stock in autumn (October/November) and/or winter (January/February) of the current fishing season (Vilhjálmsson 1994).

The prediction procedure has to take into account that 400 000 t will be left for spawning. As described earlier, the fishable stock consists for all practical purposes of only two year-classes, i.e. age-classes two and three in the autumn, spawning at ages three and four at the end of the fishing season in the following year. Therefore the predicted numbers of two- and three-year-olds and their mean weight are needed at the beginning of the season, as well as continued growth, i.e. their mean weight at spawning time. The prediction should also ensure that a precautionary TAC will be set at such a level, so that there is a minimum risk of overfishing before a within-season stock estimate has been obtained. Figure 8 shows retrospective comparison of predicted (precautionary) TAC's set in May each year and final the TAC set after the conclusion of acoustic assessments, usually carried out in the January/February.

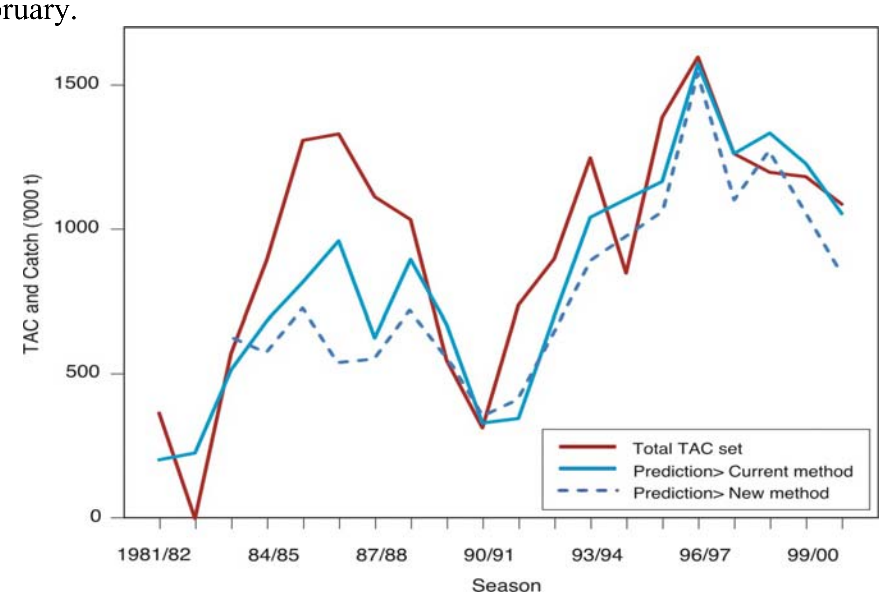

Figure 8. Retrospective view of performance of two alternative models for predicting fishable stock abundance of Icelandic capelin used as basis for generating precautionary TAC prior to the start of the season, compared to the final TAC set at the conclusion of acoustic assessment of the stock size, usually carried out the following January/February.

Advance forecasts of fishable stock abundance, based on the above model and age 1 capelin measured in August, proved to be quite conservative for the 1983/1984–1988/1989 seasons. However, the forecast for the 1989/1990 season, based on the same criteria, proved to be twice as large as the concurrent stock assessment. For the following 1990/1991 season, the prediction was even more optimistic in relative terms, and this led to the dismissal of the method of attempting to predict fishable stock abundance from August assessments of the abundance of one-year-old capelin.

When analysing the historic acoustic dataset and stock abundance estimates, it was found that the number of age 1 capelin recorded in the October/November surveys gave a much better fit than had been previously provided by the August estimates of juveniles (age 1). The autumn estimates of age group 1 were therefore substituted for those from August but otherwise using the same model as before.

Discussion and conclusions

The above makes it clear that the management of the Icelandic capelin stock has resulted in a sustainable harvest of this resource. Models can be used to set a start quota at two-thirds of the predicted TAC for the next fishing season without jeopardising the stock. However, the final TAC can only be determined after a within-season acoustic survey, which requires close and dynamic monitoring and management of the stock.

The rather recently adopted method of pelagic trawling for capelin raises the pressure on the stock, given that larger quantities can be taken under conditions that prevented catches in the past when only purse seine netting was employed. This requires special attention and caution in terms of close monitoring and the adoption of management measures when needed. An even more important question also arises, i.e. whether the pelagic trawl causes mortality of fish that are lost through the meshes. Research on this aspect is urgently needed.

Although the general ecological status of the Icelandic capelin is relatively well-known, in-depth studies of various aspects of capelin biology and capelin consumption by other species are needed for better determination of safe future harvest levels.

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W.R. Bowering and D.B. Atkinson: Capelin stocks in Canadian and NAFO waters

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Abstract

Historically, capelin (*Mallotus villosus*) has been the most important forage species for high-end predators of the Northwest Atlantic Ocean. Such predators include many commercially important groundfish species, especially cod, Greenland halibut and American plaice. Others include a variety of marine mammals and sea birds. Although four stocks of capelin have been identified in the Canadian Northwest Atlantic, two major stocks have been widely studied and heavily fished. Historically, the largest stock is found from southern Labrador to the northern Grand Bank (NAFO Divisions 2J, 3KL). This stock comprises the center of capelin distribution in the Northwest Atlantic. It spends most of its life cycle in the offshore but spawns primarily on or just off the beaches of inshore locations. The other major capelin stock is found on the southern Grand Bank (NAFO Division 3NO) where it spends its entire life cycle spawning on the southeastern Grand Bank in about 60 m of water in an area known as the Southeast Shoal. Both stocks spawn at about the same time (June-July). The two stocks mix somewhat during their time offshore and are known to move outside Canada's 200-mile limit, although most spawning occurs in the Canadian zone.

There have been several changes in the biology of capelin that first became evident in the early 1990s and have persisted until the present. These include: 1) later spawning on the beaches; 2) increased off-beach spawning; 3) large-scale changes in the distribution within the normal range of distribution as well as to areas in which capelin would have not normally occurred, such as Flemish Cap and the Scotian Shelf; 4) smaller fish size accompanied by poorer condition and 5) occurrence deeper in the water column with reduced diurnal activity. These changes in biological characteristics were initially thought to have occurred as a result of the very cold temperatures experienced during the early 1990s. However, the changes in biology have persisted despite temperatures returning to more normal levels.

The most recent scientific assessment of capelin stocks was conducted in 2000, and although stocks are no longer formally assessed, abundance appears to have declined in recent years. Density estimates offshore have been low during the 1990s and have declined further in the last few years. Results of opinion surveys started in 1994 note that capelin trap fishermen have consistently expressed the opinion that abundance has been lower since the mid-1990s until the present. Increased demersal off-beach spawning appears to result in poor survival and this may be contributing to population decline. The effects of changes in other biological characteristics on population health have not been quantified but they are viewed as negative and are not considered to be signs of a healthy population.

Historical catches, all inshore near spawning beaches, are estimated to have been 20 000-25 000 t annually and were used for human consumption, food for dog teams, bait and fertilizer for crops. In the early 1970s a non-Canadian offshore fishery started, mainly in NAFO Divisions 2J, 3KLNO and peaked at around 360 000 t in 1976 but declined rapidly during the late 1970s. Offshore non-Canadian catches continued at a low level until they were eliminated in 1992. The Canadian inshore fishery developed during the late 1970s to catch ripe females for the Japanese market but catches were generally lower than those of the offshore fishery. Inshore catches have been lower during the 1990s than in the 1980s, with

gear types mainly consisting of trap nets and purse seines, with less fishing effort using cast nets and beach seines.

Capelin resources have been managed by annual quotas which are based on scientific advice from ICNAF (now replaced by NAFO) or domestic evaluations since 1979. Current strategy states that because of the capelin's importance in the food chain, no more than 10% of the projected mature biomass should be removed by a fishery (considered a conservative approach). Estimates of projected mature biomass have not been available since the early 1990s. The general approach since then, as biomass estimates have not been available, has been to roll over previous years' quotas with some annual adjustments being made on the basis of expected market demand. Historically, there is no scientific evidence to suggest that the fishery has had an impact on the stocks.

SESSION 2: Demersal fish

Cod

A. Aglen[1], K. Drevetnyak[2] and K. Sokolov[2]: Cod in the Barents Sea (Northeast Arctic cod) - a review of the biology and history of the fishery and its management

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Abstract

This paper briefly reviews our knowledge of the spatial distribution, ecology, stocks dynamics and fishery for Northeast Arctic cod. The history of stock assessments and scientific advice, and of fisheries regulations and management strategies, are described and discussed.

Key words: Northeast Arctic cod, stock, fishery, scientific advice, management strategy.

Stock characteristics

Stock distribution

Northeast Arctic cod (*Gadus morhua L.*) has the most northerly area of distribution of all North Atlantic cod populations, including the Barents Sea and adjacent waters of the Norwegian and Greenland Seas. According to ICES divisioning it comprises ICES area I and subareas IIa and IIb.

The northern border of cod distribution is usually is the polar front zone (a zone where warm Atlantic waters mix with cold waters of the Arctic and the Barents Sea origin) with steep gradients in its physical and chemical parameters. From the east, the distribution of cod is limited by the edge of summer ice. The western border is the shelf edge of the Norwegian Sea.

The Barents Sea is influenced by warm Atlantic water flowing in from the southwest and cold Arctic water coming from the north (Midttun, 1969; Blindheim and Loeng, 1981). There are major spatial, seasonal and interannual fluctuations in the temperature of the water masses (Bochkov, Tereshchenko, 1992; Tereshchenko, 1996).

The main feeding areas for cod are the central and eastern parts of the Barents Sea and the waters near the Spitsbergen Archipelago. However the area whose waters are favourable for cod decreases in cold years and increases in warm years.

The main cod spawning areas are nearshore banks and open fjords along the Norwegian coast from 62º N to 71º N. The larvae drift northwards, north-eastwards and eastwards. The spatial distribution of cod larvae and fry in shallow waters around Bear Island, the Spitsbergen area and in the southern part of the Barents Sea varies, mainly due to fluctuations in the distribution of the various water masses.

The period of regular spawning/postspawning migrations of mature fish as well as feeding/wintering migrations of young immature fish is highly influenced by water temperature conditions in the Barents Sea. The hydrologic regime of the Northeast Arctic cod distribution area has an important impact on reproduction and abundance dynamics. Thus, stronger than average year classes tend to appear when temperature anomaly cycles change from cold to warm (Sætersdal and Loeng, 1987; Nilssen *et al.*, 1993), while poor year classes tend to appear in cold years (Tretyak *et al.*, 1995).

Stock separation and management units

From a management point of view the cod in the Barents Sea and adjacent waters are treated as two units: Northeast Arctic cod and coastal cod. From a biological point of view, cod in the Barents Sea, the Norwegian Sea and in the coastal areas living under variable environmental conditions form groups with some peculiarities in geographical distribution, pattern of migration, growth, maturation rates, genetic features, etc. (Rollefsen, 1933: Møller, 1968; Jørstad, 1984).

The degree of intermingling of different groups is uncertain. However, taking into account some biological characteristics of cod in the coastal zone and the specifics of the coastal fishery, the ICES Arctic Fisheries Working Group (AFWG) assess the Norwegian coastal cod stock separately from North-East Arctic cod.

It should be noted that some research has considered this division of the cod stock as theoretical, which has not yet been finally proved (Artemieva, 1988).

Stock size and history

The Northeast Arctic cod stock is one of the most important cod stocks in the North Atlantic. Figure 1 shows the dynamics of total biomass (age three and older, labelled "commercial" in the Figure) and spawning stock biomass estimated by the virtual population analyses (VPA) from 1946 to 2002. During these years the stock has displayed wide fluctuations, and a gradual decrease in the stock was observed from the 1950s to the 1980s.

In the 1980s two minima in the cod stock were registered. The total stock fell to a minimum in 1982-1983 and again in 1988-1989, when its size was about 0.8 million tonnes. The spawning stock had its first minimum in 1980-1981 and its second in 1986-1989, when its size was estimated as 140-160 000 tonnes. In the early 1990s the stock increased, mainly as a result of strong regulations that reduced the fishing pressure, and the average spawning stock in the 1990s was high in comparison the previous period. In 2002, according to Arctic Fishery Working Group (AFWG) estimates, the total stock was 1.6 million tonnes and the spawning stock was about 500 000 tonnes (Anon., 2003). Such large fluctuations in stocks are caused mainly by variations in recruitment abundance (cod year-classes at age three).

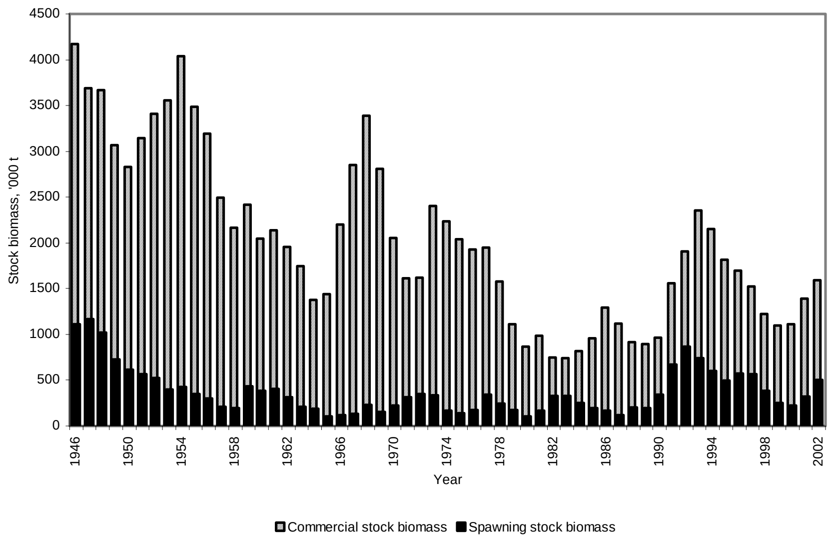

Figure 1. Commercial stock biomass and spawning stock biomass of Northeast Arctic cod in 1946-2002, in thousand tonnes.

Figure 2 shows the abundance dynamics of cod year-classes at age three. As we can see, the rich year-classes are more than ten times as abundant as the poor ones. The appearance of several successive poor cod year-classes is greatly unfavourable. The stock minima mentioned above were caused by five successive poor year-classes recruited to the stock in 1979-1983.

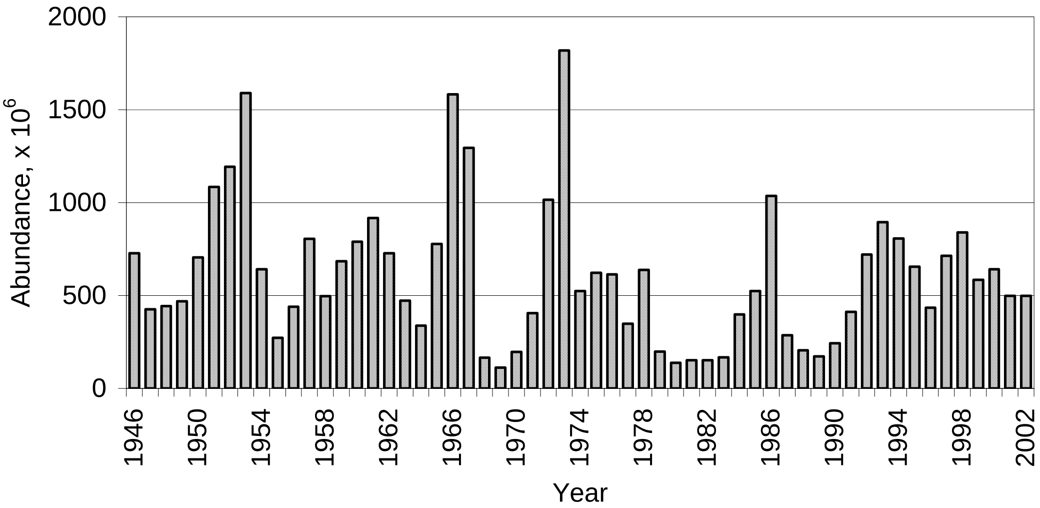

Figure 2. Year-class abundance of Northeast Arctic cod at age 3.

Position in the food web

The Northeast Arctic cod can be characterized as an active predator. Key objects in its diet are fish and crustaceans. The food habits of cod vary with its size. *Calanus* at various stages is the most important food item for cod larvae at all stages (Wiborg, 1948; Sysoeva, 1971; Tilseth and Ellertsen, 1984). When fish reach a length of 30-50 cm (at an age of three or four years) the importance of ephausiids, amphipods and shrimp in the diet increases. Fish prey (capelin, herring, polar cod, sand eel, young gadoids, etc.) make up to 70% of the total food consumption for cod between 30 and 80 cm (Zatsepin and Petrova, 1939; Mehl, 1986). Cod individuals more than 80 cm in length consume almost only fish. Annual cod consumption of different prey species in the Barents Sea and adjacent waters comes to between 1.4 and 6.0 million tonnes (Anon., 2003a). About one third of this amount is capelin.

In the years when consumption of capelin decreases the proportion of other prey species in the cod diet increases.

One of the important components of the cod's diet is its own juveniles. Cannibalism increases when there is a lack of other prey. For example, it was relatively high in 1986-1988 when stocks of capelin and young herring were small. Cannibalism increased especially in 1995-1996, when the biomass of young fish of their own species consumed by cod reached 400-500 000 tonnes (25×10^9 - 33×10^9 spec.) compared to 10-100 thousand tonnes ($0,4 \times 10^9$ – $1,0 \times 10^9$ spec.) in the 1980s (Korzhev, Tretyak, 1989; Bogstad *et al*., 1994; Anon., 2003).

The main predators for cod is harp seal (*Phoca groenlandica*) and minke whale (*Balaenoptera acutorostrata*). The total annual consumption of cod by these species was estimated to be 350-550 thousand tonnes (Nilssen *et al*., 2000; Folkow *et al*,. 2000).

History of the fishery

The Northeast Arctic cod is a traditional fishing object in the Barents Sea and adjacent waters. First references to cod fishery in the Barents Sea are found in historic documents of the 16th century (Dyrvik *et al*., 1979; Øiestad, 1994).

Statistics of the Norwegian cod fishery in spawning grounds near Lofoten islands have existed since 1866 and first Russian fishery statistical data near Murmansk are dated 1880 (Sætersdal and Hylen, 1964; Glebov, 1963). Annual catches of cod in this period were about 200-300 000 tonnes. The major part of these landings (75-85%) has been fished on the spawning grounds near the north-western coast of Norway.

The rapid development of the cod fishery started in first decades of the 20th century with the introduction of bottom trawls. Cod landings in this period depended generally on fishing effort and grew up to the 1950s.

The landings of Northeast Arctic cod in 1946-2002 varied considerably from the mean long-term level, which is around 700 thousand tonnes. In the 1950s the mean catch was about 850 000 tonnes and in the 1960s and70s it came to about 750 000 tonnes (Fig. 3). A fall in cod landings occurred in the 80s, when annual catches fell to 350 000 tonnes, which was preceded by high fishing mortality during a number of previous years.

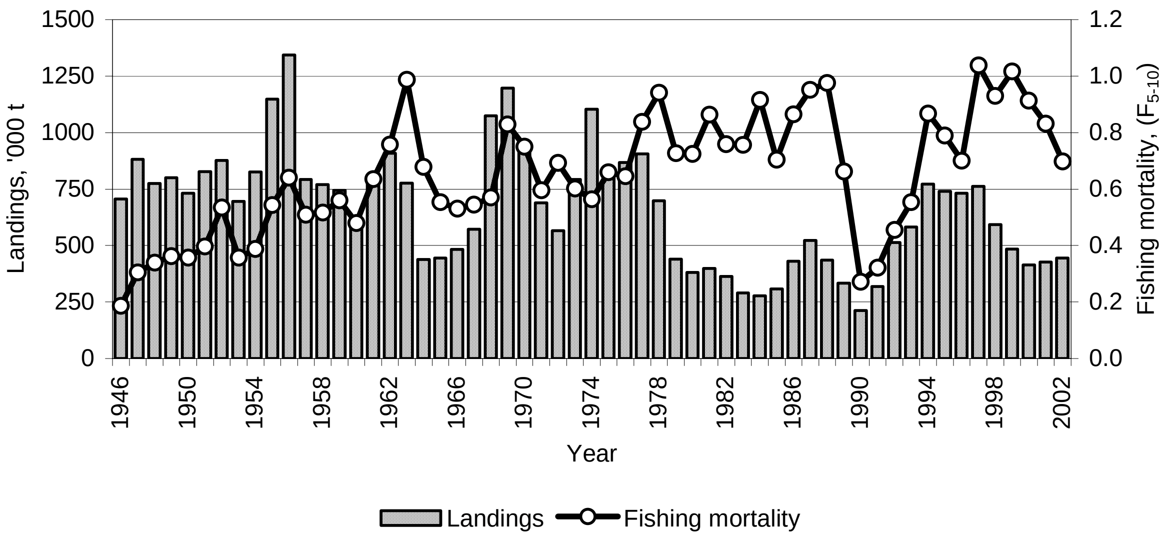

Figure 3. Landings of Northeast Arctic cod and fishing mortality (F_{5-10}) in 1946-2002.

The modern conventional cod fishery is conducted by both international trawl fleets and coastal vessels using active (bottom trawl, Danish seine) and passive (long-line, hooks) fishing gears.

Fishermen of Russia (former USSR), Norway, the United Kingdom, Germany, Poland, Iceland, Spain and other countries fish cod. Historically the main cod fishing counties were Norway, the USSR, UK and Germany, but their role in fisheries has been changing.

Cod are fished throughout the whole of the Barents Sea. The main fishing grounds are off the northeast coast of Norway (subarea IIa), waters near the Spitsbergen archipelago and Bear Island (subarea IIb) and the southern part of the Barents Sea (area I). Mature and large immature fish ("loddetorsk") is mainly caught near the Norwegian coast. A significant proportion of the cod catches taken in the southern part of the sea and in the Spitsbergen-Bear Island area consists of immature fish eight years of age and younger.

During 1946-2002 about 60% of the total catch was taken in feeding areas 45% of which were in the southern part of the Barents Sea and 15% in the Spitsbergen-Bear Island area. However, the importance of the various sea areas was subject to great fluctuations estimated by years and decades.

The significance of the Spitsbergen-Bear Island area for the cod fishery is less than two other areas mentioned above. However, its contribution to the total cod catch in some years can be quite considerable (1946, 1957-1959, 1961-1962, 1974). It is probably caused by the distribution of feeding cod in the north-western parts of the sea due to migrations determined by the stock size and length at age composition of the stock, as well as specific features of oceanographic processes and abundance of prey species.

Since the end of the 1940's until now the fishery has been a robust factor, which generally impacts all commercial fish stocks, and cod stock dynamics in particular.

Thus, unlike changes in natural factors that influence the dynamics of cod stocks, the extremely high fishing mortality, which has been growing for more than 50 years while fish stocks have been decreasing, can be regarded as a factor with a major impact on cod stocks.

The Management System

Stock assessment and advice

The first meeting of the ICES Working Group on Arctic Fisheries was in 1959 and, with the exception of 1961, the working group has met at least once a year ever since (Hylen, 2002). In its first years, AFWG reported the status of research and described recent trends in catches and stock condition. The first "Virtual Population Analysis" of Barents Sea cod was made in 1965 (Gulland, 1965), and this led to recommendations for measures to improve catch selectivity and limit fishing mortality.

Quantified advice on the following year's catch has been provided by ICES since 1975 (Anon, 1975). Table 3.1 shows the total allowable catch (TAC) advice since 1978. Over the years the internal ICES rules regarding the Form of the Advice have become more detailed and specific in order to ensure consistency between stocks and management areas and to meet new management objectives.

Fishing mortality (F) reference points based on theoretical yield-F relationships were often used to provide advice for F-levels capable of maximising long-term yield (and thereby avoiding growth overfishing). It was also recognised that several stocks could be in danger of recruitment overfishing, and rebuilding of the spawning stock biomass (SSB) was recommended when the SSB was observed to approach historic low levels.

In the late 80s the SSB of Barents Sea cod was estimated to have declined to very low levels and severe reductions in catches were recommended with the aim of rebuilding the stock.

In 1991 ICES introduced the term "minimum biological acceptable level" (MBAL) (Anon, 1992). This was defined as the spawning stock biomass below which recruitment decreases. MBAL was quantified for stocks for which there were sufficient data to indicate a biomass level where recruitment was impaired, but not defined when there was lack of clear evidence. For stocks assessed as being below MBAL the advice from ICES was to restrict the fishery in order to allow them to rebuild above MBAL. In other cases no specific advice was given, but (for stocks with an analytical assessment) a range of options showing the short-term consequences of various TACs would be presented.

Table 3.1 Advised, agreed and actual catches of North-East Arctic cod ('000 tonnes) since 1978. Actual catch is as estimated by AFWG. (Partly from Nakken, 1998)

Year	Advised catch	Agreed catch	Actual catch
1978	850	850	699
1979	600	700	441
1980	390	390	382
1981	-	300	399
1982	<432	300	365
1983	<380	300	290
1984	150	220	278
1985	170	220	308
1986	<446	400	430
1987	<645	560	518
1988	530*	590	459
1989	335	300	351
1990	172	160	212
1991	215	215	319
1992	250	356	513
1993	256	500	582
1994	649	700	771
1995	681	700	740
1996	746	700	732
1997	<993	850	762
1998	514	654	593
1999	360	480	485
2000	110	390	415
2001	263	395	426
2002	181	395	445
2003	305	395	
2004	398		

*revised advice May 1988: 320-360 000 tonnes

The 1991 Form of Advice can be summarised as:
SSB>MBAL: No specific advice
SSB<MBAL: Sufficient reduction in fishing to allow for rebuilding of SSB
This Form of Advice was applied for the first time to the advice regarding catches in 1992. At this time the Barents Sea cod had just recovered to above MBAL, which had been set at 500 000 tonnes. For this stock, therefore, no specific advice was given for the whole period 1992-1996. (In 1994-1996 the advice was; "No long-term gains in increased F"). For 1997 and 1998 a specific advice (F below F_{med}) was offered, even though the SSB was still estimated to be above MBAL. The reason for this type of advice in 1997 and 1998 was that the uncertainty of the assessment was regarded as quite high. (The following meeting of the Russian Norwegian Fishery Commission agreed to aim to reduce F to below the recommended F_{med}, but at the same time set a quota for 1998 corresponding to a higher F). Subsequent history has shown that the assessments for those years considerably overestimated the stock.

When the precautionary approach was agreed on by a number of nations, this was considered as a set of additional specifications to the management objectives. There was thus a need to modify the ICES Form of Advice in such a way as to ensure that it would meet precautionary criteria. In particular there was a need to account for the uncertainty in the stock assessment/prediction. The new precautionary framework was put in operation in 1998 when the advice for 1999 was being formulated (Anon, 1999). The main criteria were that the advice should ensure a high probability both that the true spawning biomass was kept above a minimum limit (B_{lim}) and that the true fishing mortality should be kept below a maximum limit (F_{lim}). In order to take uncertainty into account, the precautionary limits for biomass (B_{pa}) and fishing mortality (F_{pa}) were defined. These precautionary limits were intended to ensure a high probability that the true stock would remain on the safe side of B_{lim} and F_{lim} when the TAC was set according to B_{pa} and F_{pa} applied to the predicted stock.

The main conceptual change in the 1998 Form of Advice is that uncertainty is taken into account. A limitation on fishing mortality is also now advised, regardless of the stock condition. This means that ICES now attempts to offer specific advice in all cases. Even in data-poor cases where stock size and fishing mortality are not estimated, advice is usually given, partly based on trends in catches and size composition and partly on knowledge of the life history of the species.

The 1998 Form of Advice can be summarised as:

$SSB>B_{pa}$: Restrict TAC so that $F<F_{pa}$

$SSB<B_{pa}$: Sufficient reduction in fishing to allow for rebuilding of SSB

The 1998 assessment of the Barents Sea cod represented a considerable downward revision of the stock size. The new F_{pa} was applied, resulting in a TAC advice of 360 000 tonnes for 1999, compared to an agreed TAC of 654 000 tonnes for 1998. In the subsequent three years the stock was estimated to be below B_{pa}. The advice for 2000 and 2002 was aimed at rebuilding after one year, while the advice for 2001 was aiming at rebuilding over a two-year period. For this reason, the advices for these three years varied more than the assessed status of the stock. The two most recent assessments have predicted an $SSB>B_{pa}$ when fishing at F_{pa}, and the advice for 2003 and 2004 has been to reduce F to below F_{pa}.

The conceptual definition of B_{lim} is the same as that of the former MBAL. They both refer to a spawning stock level at which recruitment is decreased or impaired. However, neither in 1991 nor in 1998 was "impaired recruitment" clearly defined, and it is worth noticing that in most cases B_{lim} was set differently from MBAL. In some cases (such as the Barents Sea cod) B_{pa} was in fact set equal to MBAL. In 1998 the safety margin between "lim" and "pa" values was based on some rough rules of thumb and did not take the particular uncertainty of each stock sufficiently into account. Experience over the six years when these reference points have been used is that at least some of them need to be improved. An ICES study group (Anon, 2003c) has suggested some new guidelines for calculating reference points, and ICES is now trying to apply these to most stocks. Two important achievements have been incorporated into the new guidelines; a more objective way of defining "the biomass below which recruitment is impaired" and a procedure to quantify the uncertainty in assessment and prediction.

For the Barents Sea cod the need for revision of reference points became obvious when the historic time series of SSB was revised in 2001. Here new reference points were calculated in 2003 on the basis of these new guidelines (Anon, 2003b). Table 3.2. summarises the most important reference points.

Table 3.2. The most important reference points used for the ICES advice on North-East Arctic cod

Advice for catch in:	Main reference points for advice	Additional reference points used
1978-1991	F_{low}=0.32 (for rebuilding)	F_{max}(~0.25),$F_{0.1}$(~0.15)
1992-1998	MBAL=500,000 tonnes	F_{med}=0.46
1999-2003	F_{pa}=0.42 B_{pa}=500,000 tonnes	F_{lim}=0.70 B_{lim}=112,000 tonnes
2004-	F_{pa}=0.40 B_{pa}=460,000 tonnes	F_{lim}=0.74 B_{lim}=220,000 tonnes

Data used for assessment

Landings in tonnes have been available at least since 1900. Since 1946 all the most important nations fishing in the Barents Sea have sampled their cod landings, either at sea or in landing ports. This sampling forms the basis for calculating annual catch at age. A reasonable Norwegian sampling coverage also exists for the period 1932-1945, and some more sporadic and less consistent sampling data exist for 1900-1931. Most meetings in AFWG have used catch at age data starting in 1946 to describe the history of the stock. Hylen (2002) has combined the available sampling information and presented a catch at age analysis (VPA) extending back to 1900.

The marine research institutes in Russia, Norway, Spain and Germany currently report landing statistics and sampling data to AFWG. Both sales-note statistics and logbooks are available to the institutes. The fisheries are sampled both by observers onboard vessels and by sampling at landing ports. Sampling information is also obtained by direct contact with fishing vessels and through reports from the coastguards. Landings by nations not reporting any sampling are usually distributed by age group, by using the distributions observed in the sampled fisheries.

The models used for the cod assessment are catch-at-age analyses belonging to the "VPA family". In principle, these models are bookkeeping of catches which, combined with an assumed (or externally estimated) value of natural mortality gives a historic estimate of the year-classes, when they are fully fished out. The models estimate the historic stock numbers needed to explain the observed catches. Therefore, some additional stock indicators are needed in order to provide information on the most recent development of the stock. Such indicators are used to "tune" the VPA, which means that the indicator is scaled to the historic VPA so that the recent values of the indicator become estimates of recent stock size.

In the 60s and 70s catch per unit effort (CPUE) for various fishing fleets was the main stock indicator used for tuning. The use of CPUE by the fishing fleet, however, has proven to be problematic due to changes in the fleet (technological development and learning). Each unit of effort is fishing more efficiently every year. For this reason, standardised surveys were initiated in order to provide tuning series independent of the development in the fleet. In the early 80s the USSR had an annual survey in late autumn (October-December) and Norway started an annual winter survey (February) and later an autumn survey (September) as well in the Bear Island-Spitsbergen area. In the main spawning areas there was an annual monitoring survey (March), which was subsequently also used in stock assessment. Since the late 80s, these survey results have been the main input for the stock assessment, and gradually less information based on CPUE has been used.

In the two most recent assessments (2002 and 2003) the bottom trawl results from the October-December survey and both bottom trawl and acoustic results from the February survey were used. The acoustic results of the February survey (which since 2000 has been a joint Russian-Norwegian survey) are added to the acoustic results of the spawning survey before it is used in the tuning. Since these surveys do not fully cover the oldest fish, CPUE information for age groups 9-12 in the Russian trawl fleet is still used. The CPUE from the Norwegian trawl fleet has been disregarded since this fleet started to use double trawls. The Bear Island-Spitsbergen survey has also been disregarded, because it covers a rather small but variable part of the sock. The acoustic estimates from the October-December survey was also left out some years ago due to some methodological changes.

Shortcomings and improvements of the assessment

A crucial point in stock assessment is quantification of the sources of mortality. In particular, when giving advice on fisheries it is important to properly quantify the mortality caused by the fishery. In the period when cod trawlers in the Barents Sea used rather small-meshed trawls, discards of small cod were quite significant. Large discards of small cod have also occurred in the shrimp fishery, before area closures and sorting grids came into operation. Some discarding of cod may still take place in all cod fleets. Cases of underreporting and black landings have also been raised and this was paid a great deal of attention in the Norwegian press in 2000-2001. The cod assessment is based on the official landing statistics (except for 1990-1994, when some additional catch was estimated). The errors caused by incomplete information on real catch are still unknown. AFWG is working on available information on discards in the trawl fisheries for cod and shrimp. When a time series of realistic discard estimates becomes available, the assessment will improve.

Predation is the other main cause of mortality. Predation by large cod on smaller cod has been quantified and used in the assessment. Some data on predation by marine mammals is also available, but are not yet used in the assessment. More data and some realistic modelling are still required in this field of research.

Ongoing research on improved survey methodology is expected to improve assessments in the future. A new assessment model (Fleksibest), (Frøysa et al., 2002) has been developed and applied on the Barents Sea cod data. This model makes better use of the available information on fish length and allows for uncertainty in the catch data. The three latest AFWG meetings have run this model in parallel with the standard assessment and obtained satisfactory agreements in the results obtained.

TAC settings and Management Strategies

Nakken (1998) states that "the first TAC for cod which was introduced in 1975 was far too high and it seems fair to conclude that no effective management measures had been in operation for demersal fish in the area prior to the establishment of the national economic zones (NEZ) in 1977". For 1975 and 1976, a TAC was set by the North-East Atlantic Fisheries Commission (NEAFC). At that time, the Mixed Soviet-Norwegian Commission had already been established (Zilanov, 1984), and after the introduction of the 200 nautical mile Economic Zones in 1977, this Commission decided the TAC for cod. Table 1 shows the advice and recommended quotas and observed catch for the years after 1978. This is an updated version of the table in Nakken (1998).

Since about 1980 the quota shareout has been as follows: First a total TAC of North-East Arctic cod is agreed. Then approximately 10% is set aside for third countries, and 40 thousand tonnes of Murmansk cod are set aside for Russia. The remaining quota is shared half and half between Russia and Norway. The TAC for Norway is then increased by 40 thousand tonnes of Norwegian coastal cod. It should be noticed that in the ICES advice the North-East Arctic cod stock covers both the "oceanic" Barents Sea cod and the Murmansk cod, while Norwegian coastal cod are not included. In some years, various transfers of quotas have been agreed between the parties, which means that the actual shares have varied slightly from one year to another. The quota set aside for third countries has also varied somewhat. Over the period 1986-2003, their quota has been between 7% and 13% of the total cod quota (North-East Arctic cod plus Norwegian coastal cod).

The agreements of the Fishery Commission since the early 80s focus on protecting young fish. Although this is not stated explicitly, the underlying objective has obviously been to better utilise the growth potential of the fish, thereby increasing the long-term yield in the fishery. A number of important regulations have been agreed on and put into effect (see section 3.5).

The agreements for 1985-1996 use the phrase "improve long-term regulations". In 1997-2001, this was changed to "further develop agreed long-term strategies". In 1997 it was added that until this has been achieved it is agreed to keep SSB>500,000 tonnes and F<0.46 (but the same meeting set a TAC for 1998 corresponding to a higher F). This was repeated in 1998, with the modification that F should be brought below 0.46 before 2001. In 1999 it was agreed to quickly rebuild SSB to 500,000 tonnes and bring F below F_{pa}=0.42. In 2000 this was repeated and it was agreed to fix the total quota for three years, unless later stock assessments showed dramatic changes. In addition, ICES was asked to re-evaluate B_{pa}.

At the 2002 meeting of the Joint Norwegian-Russian Fishery Commission the Parties agreed that a new harvesting strategy for Northeast Arctic cod and haddock should incorporate the following considerations:

- to prepare the basis for long-term high yield of the stocks
- the desirability of obtaining a high annual degree of stability in the TAC
- full utilization of the most recent information available on stock development

On this basis, the Parties agreed on the following decision rule for setting the annual fishing quota (or TAC) for Northeast Arctic cod from 2004 onwards:

- estimate the average TAC level for the coming 3 years based on F_{pa}. TAC for next year will be set to this level as a starting value for the 3 years period
- the year after, the TAC calculation for the next 3 years is repeated based on updated information about the stock development, though such that the TAC should not be changed by more than +/- 10% compared with the previous year's TAC
- if the spawning stock falls below B_{pa}, the Parties should consider a lower TAC than according to the decision rule above

ICES has made the following comments on the above decision rule: "The 2004 catches calculated by applying the harvest rule imply a fishing mortality above F_{pa}. However, the Precautionary Reference Points as currently used by ICES are defined in the context of advising on an annual TAC based on a predicted catch based on a maximum F. The objective of this harvest control law is to have a low risk of SSB dropping below a B_{lim} point. The proposed harvest control rule or modifications of it may actually secure a low probability of SSB dropping below a B_{lim} point and hence be in accordance with the Precautionary Approach because the decision rule is different from that implied in calculating F_{pa}. Simulation studies are needed to reveal if this is the case. ICES is prepared to review and evaluate results of such studies."

The above description shows that the management objectives have progressively been formulated in a more detailed and specific manner: starting with some general statements on improved regulations, which in the 80s led to a number of important regulations protecting young fish, later specifying reference points for TAC settings, and finally developing the decision rule agreed for setting the TAC for 2004. The comments to this rule made by ICES may lead to some further specifications or modifications in order to ensure that the rule agrees with the Precautionary Approach.

Other regulations and enforcement

Along the Norwegian coast a wide range of regulations has been in effect for more than 100 years. The purpose of those early regulations was to coordinate the activity on space-limited fishing grounds. Conflicts between fishermen using different fishing gears are an important reason for many of these regulations, and some of them are still in operation in the spawning-season fishery in Lofoten and Vesterålen.

Mesh size regulations in the international trawl fishery were introduced as a result of the "Convention for the regulation of the meshes of fishing nets and the size limits of fish" signed in London in 1946 and which came into force in 1953. The minimum allowable mesh size was increased several times (Table 3.3). The minimum landing size of cod was initially implemented in 1967 and set at 34 cm. This was raised in 1981 to 39 cm, in 1982 to 42 cm, and to 47 cm in the Norwegian economic zone on January 1, 1990. Fifteen percent of undersized fish are permitted in the catches. Discarding cod has been prohibited since 1977 following the implementation of the complex system of fishery regulations in the Barents Sea. In 1997 sorting grids (min 55 mm spacing between bars) were made mandatory in the trawl fisheries for cod and haddock. In the shrimp trawl fishery the use of sorting grids to reduce the bycatch of fish has been mandatory since 1992.

Table 3.3. Minimum mesh size* in the trawl fishery for cod in the Barents Sea by Norwegian and Russian (Soviet) trawlers (partly from Dingsør, 2001 and Ponomarenko et al., 1978).

Year of coming into force	Minimum mesh size (mm)	
	Norwegian trawlers	Russian (Soviet) trawlers
1946	80	90
1954	110	
1961		110
1963	130	120
1967		120
1981		125
1982	135**	
1997	135 plus sorting grid, 55 mm bar spacing**	
1998		125 plus sorting grid, 55 mm bar spacing

* mesh sizes applied to manila nets before 1966 and to nylon since 1967

** applied to all vessels in Norwegian economic zone

In order to further protect young cod and haddock (and later also young redfish) a closed area system was introduced in the trawl fisheries for cod, haddock and shrimp in the early 1980s. Areas are closed and reopened according to the percentage of small fish in the catches taken in monitoring surveys. The area within 20 nautical miles of Bear Island is permanently closed for fishing. In the REZ some areas are also closed for fishing, either permanently or during certain seasons.

Mesh-size regulations are also in effect for Danish seine and gill net. For gill net there are also limitations on the number of nets per vessel. By licensing vessels, participation in the cod fishery has been limited since 1972. Control and enforcement is exercised at sea by the Norwegian Coast-Guard and Russian fishery inspectors and by observers, and on landing by government officers.

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S. H. í Jákupsstovu, J. Reinert and P. Steingrund: Cod in Faroese waters

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Introduction

There are two self-contained cod stocks within Faroese waters (Figure 1). One is on the Faroe Plateau and the other on the Faroe Bank; both are fished in a multi-fleet and multi-species fishery. The fisheries regulation in force in Faroese waters, which is a combination of access limitation, technical measures, closed areas and effort limitations, is primarily aimed at regulating the demersal fisheries in Faroese waters, especially the fisheries for cod, haddock and saithe.

This paper offers descriptions of the life history of the Faroe Plateau cod stock, the fisheries for cod and the regulatory regime.

Cod stock characteristics

The two stocks of cod in Faroese waters are regarded as two separate management units. This concept is supported by numerous tagging studies, (Jákupsstovu and Reinert, 1994; Steingrund, unpublished material), which have shown that only about 1 in 1000 cod tagged and released are recaptured outside the area of tagging, *i.e.* the two stocks are stationary. Morphometric, biometric and biochemical studies also support the existence of two separate stocks (Jákupsstovu and Reinert, 1994). Joensen *et al.* (2000) were also able to demonstrate significant differences in the fatty acid compositions of the two stocks. Recent tagging experiments also suggest that the majority of cod on the western parts of the Faroe-Icelandic ridge within Faroese waters (which is considered as Vb1 – Faroe Plateau) are of Icelandic origin (Steingrund, unpublished data).

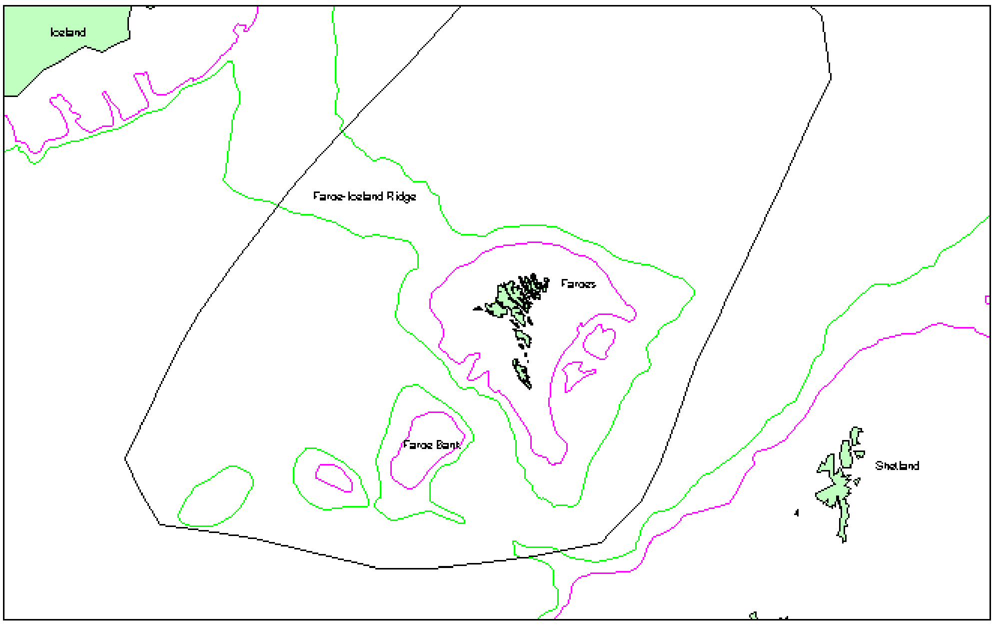

Figure 1. Map showing the Faroese waters.

The Faroe Plateau cod, however, constitute by far the majority of the cod landed from the Faroe area, and as this is the only cod stock where an age-disaggregated stock assessment is available, we will deal only with this stock in this paper.

There are two main spawning grounds on the Faroe Plateau: one north of the Faroe Islands and one to the west (Figure 2.). There are also other smaller spawning areas. The depths of these spawning areas range from 80 to 140 m. Extensive tagging experiments in recent years (Steingrund, unpublished data) suggest the existence of sub-populations, as cod from the eastern and northern area spawn on the northern spawning site, whereas cod from western and southern areas mainly spawn on the western spawning site. Spawning begins in late February and ends in April, the peak being in late March. After spawning, cod migrate back to their original feeding sites. Cod mature in three to four years, at a length of 52-60 cm (Fig. 3). Cod smaller than 70 cm are mainly found in shallow waters (< 200 m) whereas larger fish are found in deeper areas as well. Their main prey in shallow water are sandeels (*Ammodytes spp.*) and benthic crustaceans such *Hyas coarctatus*, *Galathea spp.*, *Pagurus ssp.*, shrimp (Pandalidae), and swimming crabs (Portunidae). In deeper waters, fish like Norway pout (*Trisopterus esmarkii*) and blue whiting (*Micromesistius poutassou*) dominate as food sources. Benthic crustaceans like *Munida spp.* are also important (Faroese Fisheries Laboratory, unpublished data). Calculations of production suggest that cod larger than 30 cm normally are in the third trophic level (Steingrund and Gaard, *submitted*).

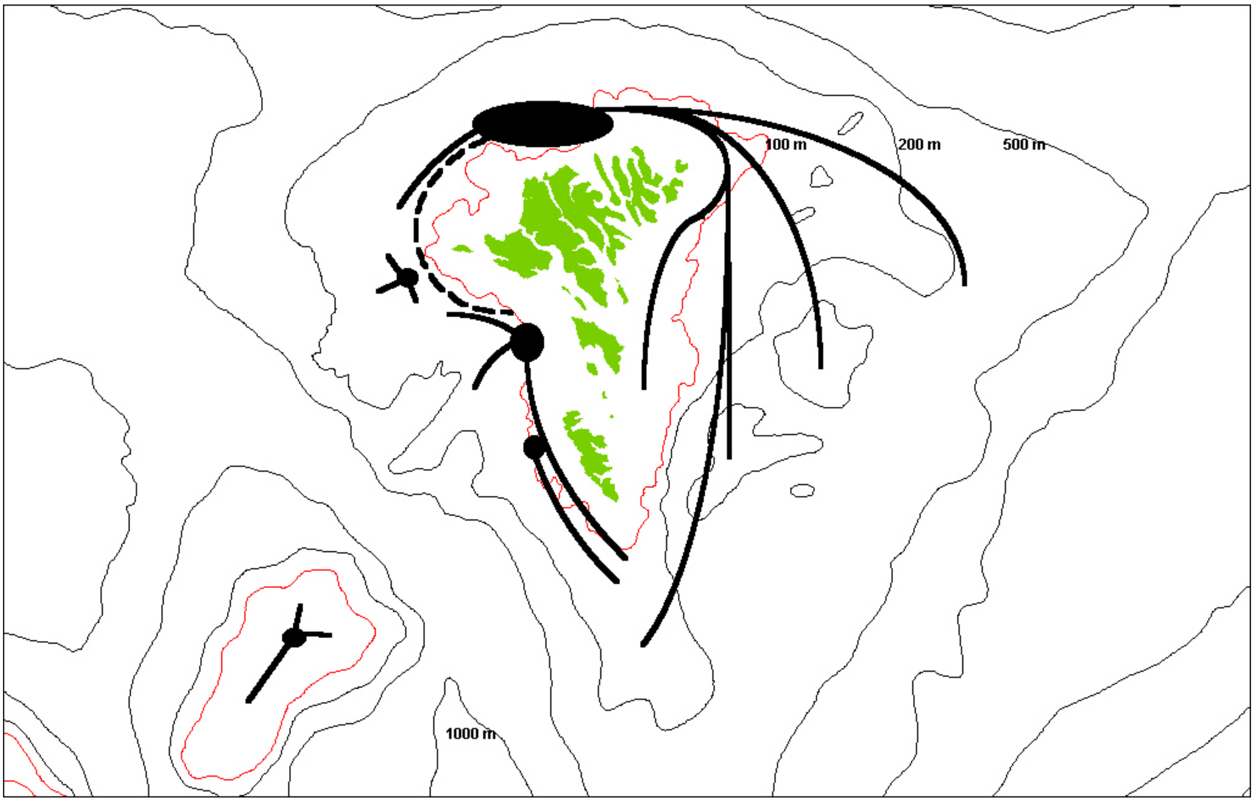

Figure 2. The main spawning areas of cod on the Faroe Plateau. Migration routes to and from the spawning areas are shown. Dashes indicate minor routes.

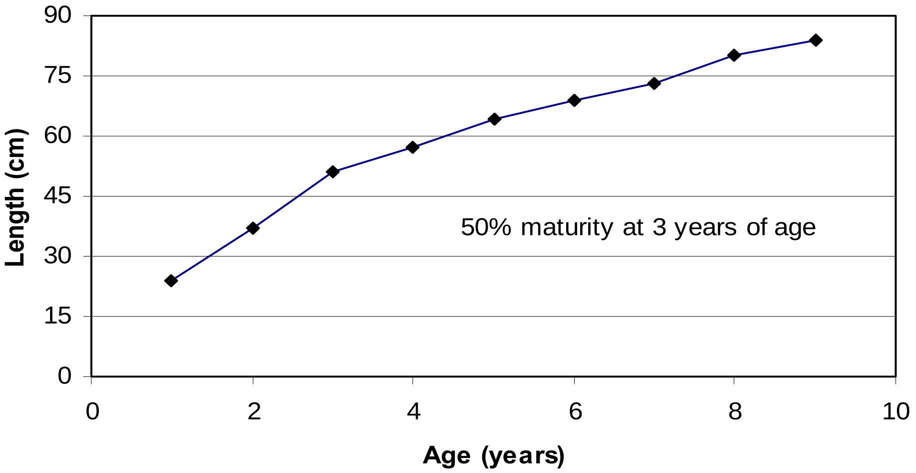

Figure 3. Mean length at age for Faroe Plateau cod; 50 % maturity at three years of age is indicated.

History of the fishery

Landing statistics are available back to 1903 (Figure 4). English and Scottish vessels (trawlers) took the majority of the catch up to the 1960s. In 1977, the 200 nm EEZ was introduced, and since then Faroese vessels have dominated the cod landings, which (ICES statistical areas Vb1+Vb2) have fluctuated between 6 000 and 45 000 tonnes a year (excluding 1903-1905), the average being around 25 000tonnes. There was a slight drop in the landings during the First World War 1914-1918, but landings fell to 12 000 tonnes in 1921. In 1923-1937 landings were high (more than 25 000 tonnes) but during the Second World War (1939-1945), landings dropped below 10 000 tonnes. After a long period of regular fluctuations between 20 and 40 000 tonnes, landings fell below 10 000 tonnes during 1991-1994. These low catches added significantly to the severe financial crisis, which occurred in the same period in the Faroe Islands. Landings have since reverted to the traditional pattern.

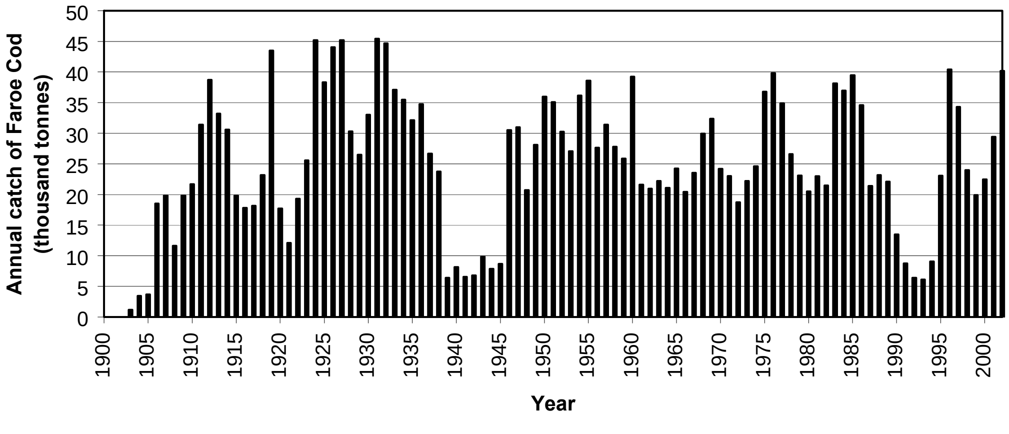

Figure 4. Landings of cod from the Faroe area 1903-2002. For the period 1903 –1960, Faroe Bank and Faroe Plateau statistics are combined; for 1961-2002 the statistics are from the Faroe Plateau only.

The stock size decreased during the 1920s and 1930s as indicated by catch per unit effort (CPUE) series (Jákupsstovu and Reinert, 1994). After the Second World War, CPUE indices were very high, but they fell rapidly during the 1950s to their lowest level around 1960 (Jákupsstovu and Reinert, 1994). Results of the analytical assessments (available from 1961)

(Figure 5) indicate that stock sizes increased until the mid-70s, but decreased after the introduction of the EEZ. After a rise at the beginning of the 80s, the stock size decreased steadily to 1992 when the spawning stock biomass reached its lowest level ever assessed at around 20 thousand tonnes. The stock size increased spectacularly from 1992 to 1995 due to good recruitment and growth, which is also the current situation.

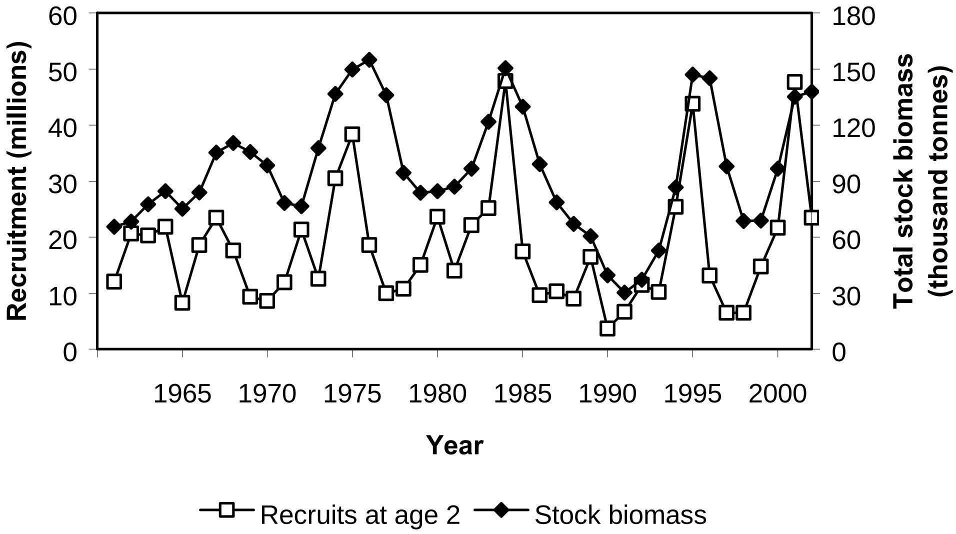

Figure 5. Total stock biomass and recruitment of Faroe Plateau cod (ICES, 2003).

Since 1990, primary and secondary production on the Faroe Plateau has been monitored annually (Gaard, *et al.*, 1998). From these studies, it is apparent that the fluctuations in the cod stock are linked to productivity in the Faroe Plateau area (Gaard, *et al.*, 2002; Steingrund and Gaard, *submitted*). When the production of phytoplankton is high, there is high production of cod in the following 12 months, which is demonstrated by good recruitment of two-year-old cod, as well as rapid growth of older cod. Thus, recruitment and growth appear to be positively related to phytoplankton production.

History of the management system

Before 1977 (introduction of the 200 nm EEZ), there was no formal regulation of the demersal fisheries in the waters around the Faroe Islands. However, 12 nm limits for trawl fishery and for non-Faroese vessels had been introduced. The fleets, Faroese and foreign, moved freely to other areas when catches in Faroese areas were low. Most other Faroese fisheries also took place outside Faroese waters, *i.e.* off Iceland, in the Barents Sea, near Greenland, in the Western Atlantic from the Gulf of Maine to Labrador and in the North Sea.

With the general extensions of national fishery limits, a large part of the Faroese fishing fleet reverted to fishing within the Faroese 200 nm limit.

It quite soon became apparent that the area was unable to support this increased effort, and during the 1980s the Faroese authorities attempted to regulate the fishery and investment in fishing vessels. In 1987, a system of fishing licenses was introduced, and, in addition, regulation of capacity was attempted by technical measures such as minimum legal mesh sizes, permanent and temporarily closed areas for trawling, an import ban on fishing vessels and buy-back of fishing licenses.

Following the deep crisis in the fisheries in the late 1980s and early 1990s, the need for stricter measures was realised, and in 1994 a system with TACs was introduced for the main demersal stocks, *viz*. cod, haddock, saithe and redfish. There was deep scepticism on the part of fishermen and many politicians regarding the practicality of a quota system in a multi-fleet and multi-species fishery. The bycatch problem was also difficult to manage via regulation. Furthermore, an unexpectedly good recruitment of cod from the 1992 and 1993 year classes, combined with higher availability and catchability of older cod than foreseen in the assessments, made the bycatch problem so large that the system had to be abandoned in 1996.

A new system, a transferable (within fleets) effort quota system, was introduced on 1 June 1996. The system was planned in co-operation with various groups of fishermen, long-liners, trawler operators, coastal fishermen, etc., the Fisheries Laboratory and the Fisheries Ministry. Finally, with some amendments and the introduction of wider area closures in the political process, the new system came into force and is still working. The following paragraphs attempt to describe the whole range of regulations of the demersal fisheries in Faroese waters.

All vessels fishing in Faroese waters need a license to fish, and they are grouped into several fleet categories. The main fish stocks, which the regulation process attempts to protect, are cod, haddock and saithe. In addition, there are special regulations for the gillnet fishery for Greenland halibut, anglerfish, and the trawl fishery for lemon sole and plaice and greater silver smelt. There are also special mesh size allowances for directed fishery for black scabbard fish and blue ling.

The demersal fishing fleet

The fishing fleet is comprised of several groups of vessels that use trawls, on the one hand, and passive gear, such as hand-line/jigging, long line and gill nets, on the other.

Figure 6. *Brestir* is one of the larger demersal single trawlers.

The larger stern trawlers (in total 13) operate as single trawlers (Figure 6). They are usually powered by engines of more than 1000 HP and fish mainly in deeper waters. The vessels are not regulated by the effort quota system, but are allowed an annual quota of 100 tonnes of cod and 100 tonnes of haddock on the Faroe Plateau. Their main targets are redfish, saithe, cod on the Faroe-Iceland Ridge, which is not under the regulation; blue ling, black scabbard fish, grenadiers and other deep-water fish species.

The pair trawlers (31 licenses) are all powered by engines of more than 400 hp (Figure 7). These vessels are regulated by the effort quota system and operate on the Shelf proper with saithe as their main target species. However, depending on availability, they also have significant bycatches of cod and haddock.

Figure 7. The "Cuba" trawlers operate as pair-trawlers

The long-liners (19 licences) are larger than 110 GRT (Figure 8). These vessels are regulated by the effort quota system, and operate all over the Shelf and on the Faroe Bank, targeting cod and haddock and, off the Shelf, tusk and ling.

Figure 8. *Mascot* is a typical Faroese long-liner.

The coastal long-liners and jiggers between 15 and 110 GRT (Figure 9) are 72 in total. They operate mainly on the Shelf and on the Faroe Bank, targeting cod and haddock and are regulated by the effort quota system.

Figure 9. *Hovnin* is a traditional coastal long-liner. Some of this group of vessels also operate as single trawlers

Single trawlers powered with engines of less than 400 HP total 14. These vessels operate on the Plateau only. Their main targets are cod and haddock; however, they also fish for anglerfish and other demersal species. They are regulated by the effort quota system. During the summer, 11 of these vessels are specially licensed to fish lemon sole and plaice within specified areas inside the 12 nm limit. However, this has to be done within their effort quota. Coastal long-liners and jiggers of less than 15 GRT are divided into two groups. There are 179 full-time fishing vessels and they are allocated individual effort quotas. Part-time fishing vessels (in total 1,040) have a combined effort quota. This fleet, which fishes mainly for cod and haddock on the Shelf, comprises a variety of different types of boats - from the traditional Faroese open boats (Figure 10) to sophisticated high-powered fibreglass boats equipped with automatic baiting devices.

Figure 10. A traditional Faroese open boat used for hand-line, jigging and shorter long-lines.

Gill-netters A few vessels have special licenses for gillnetting Greenland halibut and anglerfish. In these fisheries, there are stipulations on the number of nets operated, and on bycatch of non-target species.

The effort quota system

As mentioned earlier, the catch quota management system introduced in the Faroese fisheries in 1994 was not very successful and resulted in substantial misreporting of catches. As a result, the Faroese Parliament adopted, in close co-operation with the fishing industry, a new system based on individual transferable (within fleet categories) effort quotas measured in days. The new system entered into force on 1 June 1996.
The within-fleet category individual transferable effort quotas apply to:

- *Pair trawlers*
- *Long-liners larger than 110 GRT*
- *Long-liners of less than 110 GRT*
- *Jiggers and single trawlers of less than 400 HP*
- *Long-liners and jiggers of less than 15 GRT*

The single trawlers larger than 400 HP are not subject to effort limits, but are not allowed to fish within the 12 nm limit and in the areas closed for trawling outside this limit. Their fishery for cod and haddock is limited by maximum bycatch allowances of 4% and 1.75%, respectively. In addition, in the present fishing year, they are allowed individual catch quotas of 100 tonnes each of cod and haddock on the Plateau. The single trawlers < 400 HP are given special licenses to fish inside 12 nm, targeting lemon sole and plaice with bycatch allowances of 30% cod and 10% haddock (Table1).

Table 1.
Number of allocated days by fleet group and number of licenses since the management scheme was adopted

Group no	Fleet category	1996/1997	1997/1998	1998/1999	1999/2000	2000/2001	2001/2002	2002/2003	No of licenses
1	Single trawlers > 400 HP	Regulated by area and bycatch limitations only							13
2	Pair trawlers > 400 HP	8225	7199	6839	6839	6839	6839	6771	31
3	Longliners > 110 GRT	3040	2660	2527	2527	2527	2527	2502	19
4	Longliners and jiggers 15-110 GRT. Single trawlers < 400 HP	9320	9328	8861	8861	8861	8861	8772	86
5	Longliners and jiggers < 15 GRT	22000	2365	22444	22444	22444	22444	22220	1219
	Gillnetters Greenland halibut	Regulated by area, no. of nets and bycatch limitations only							
	Gillnetters Angler fish	Regulated by area, no. of nets and bycatch limitations							

An integral part of the regulations is the system of closed areas. Some of these are closed for trawling either throughout the year or for parts of the year and some are spawning areas closed for all fisheries during the spawning season. An overview of the closed areas is shown in Figure 11, and the timings in Table 2. However, no areas are protected from all fishing during the whole year.

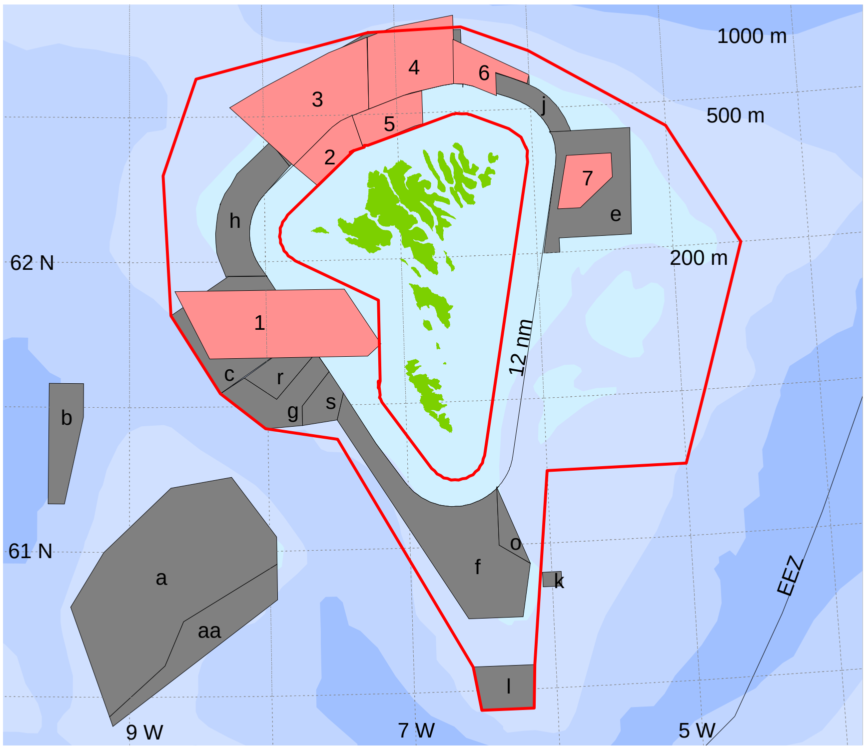

Figure 11. The closed areas in Faroese waters.

Table 2. Timings of the area closures.

Closed areas to trawlings

Areas inside the 12 nm zone closed year round

Area	Period
a	1 jan- 31 des
aa	1 jun – 31 aug
b	20 jan- 1 mar
c	1 jan- 31 des
d	1 jan- 31 des
e	1 apr- 31 jan
f	1 jan- 31 des
g	1 jan- 31 des
h	1 jan- 31 des
i	1 jan- 31 des
j	1 jan- 31 des
k	1 jan- 31 des
l	1 jan- 31 des
m	1 feb- 1 jun
n	31 jan- 1 apr
o	1 jan- 31 des
p	1 jan- 31 des
r	1 jan- 31 des
s	1 jan- 31 des

Spawning area closures

Area	Period
1	15 feb-31 mar
2	15 feb- 15 apr
3	1 feb- 1 apr
4	15 jan- 15 mai
5	15 feb- 15 apr
6	15 feb- 15 apr
7	15 jan- 1 apr

Holders of individual transferable effort quotas who fish outside the thick line encircling the shallower parts of the Faroe Plateau, an area where cod and haddock are normally found, can fish for three days for each day allocated within the area. One fishing day by long-liners smaller than 110 GRT is considered to be equivalent to two fishing days for jiggers in the same gear category. Therefore, long-liners of less than 110 GRT (and single trawlers < 400 HP) may double their allocations by converting to jigging. The effort quotas are transferable within gear categories.

In addition to the number of days allocated, the law also states what percentage of the total catches of cod, haddock, saithe and redfish each fleet category on average is allowed to fish (Table 3).

Table 3. The percentage catch by species and fleet group aimed at in the regulation.

Fleet category	Cod	Haddock	Saithe	Redfish
Long-liners < 110 GRT, jiggers, single trawl < 400 HP	51	58	17.5	1
Long-liners > 110 GRT	23	28	0	0
Pair-trawlers	21	10.25	69	8.5
Single trawlers > 400 HP	4	1.75	13	90.5
Others	1	2	0.5	0.5

The calculations of fishing days was based on:
1) a reappraisal of the North Western Working Group (NWWG) assessment of the demersal fish stocks in Faroese waters (ICES, 1995, Maguire, *et al*,, 1995); and
2) the goal that the allocation of the number of fishing days by fleet categories, together with other regulations of the fishery aimed at ensuring an average fishing mortality on each of the three stocks of 0.45, should result in catches corresponding to average annual catches of 33% of exploitable stocks.

Built into the system is an assumption that the day system is self-regulatory, on the expectation that the fishery will move between stocks according to the relative availability of each of them, thus preventing any stock from being overexploited.

Mesh size regulations. A general minimum legal mesh size of 145 mm stretched mesh is in force. However, for directed fisheries for fish species other than cod and haddock exceptions are allowed under bycatch stipulations and in some cases also area restrictions.

Juvenile protection in addition to mesh size regulations is attempted by means of short-term closures of areas with high concentrations of juvenile fish.

The performance of the effort quota system

In this discussion, the main emphasis will be on the performance of the system with respect to the cod stock.

An inherent feature of any effort regulation scheme is the incentive to overinvest in vessels and gear in order to maximise the catch by a given effort. There is no system at present in place for monitoring the efficiency of individual vessels, and it is therefore impossible to quantify any changes in the fleet's current overall efficiency relative to 1996. There has been some modernisation of older vessels and replacement by new vessels, and there may also be a better utilisation of the available number of fishing days. At present, it is impossible to quantify the effects of this on overall capacity.

The fishing mortality estimates by the North Western Working Group for cod on the Faroe Plateau for the period 1983-2002 are shown in Figure 12 as F_{3-7} and F_{3-6}.

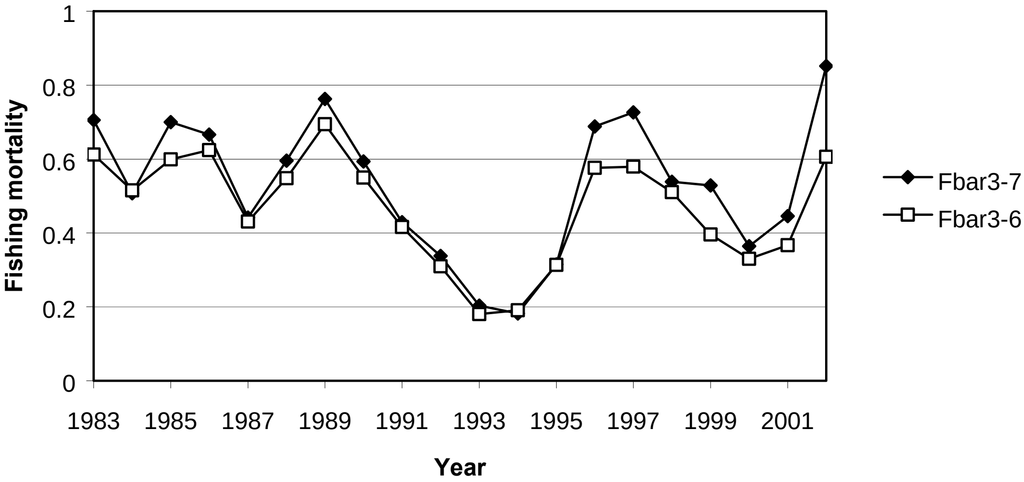

Figure 12. Average fishing mortality on Faroe Plateau cod 1983-2002.

The low recruitment in the late 1980s and the simultaneous high effort significantly reduced the fishable stock, with the result that the profitability of the fishery and the effort declined. At the peak of the crisis in 1992 and 1993 the F ofcod was only 0.2. Following the recovery, the F increased again, but apparently with wide fluctuations and at a lower level than before (Table 4).

Table 4. Average fishing mortality (F_{3-6} and F_{3-7}) for Faroe Plateau cod for 1983-1990 and 1995-2002.

	1983-1990	1995-2002
F3-7	0.62	0.56
F3-6	0.57	0.46

The catch control rule of F= 0.45 refers to the age group of three- to seven-year-olds. Due to the relatively few seven-year-old cod found in the catches, however, the fishing mortality on this age group is poorly defined, and the Fbar 3-6 is therefore presented as well.

From Figure 12 and Table 4, it can be seen that the average fishing mortality of cod has been higher than that intended by the Faroese Government. In recent years, the NWWG overestimated the F's on the three- to seven-year-olds, and in the most recent years, the average F (in Table 3) might be an overestimate. It is unlikely, however, that any corrected value would be as low as 0.45.

Biological reference points were established by ICES in 1998, on the basis of the report of the Study Group on the precautionary approach (ICES 1997).These reference points are presented in Table 5. According to these values, the present F of cod is significantly above F_{pa} and also above the stipulated target.

Table 5. Biological reference points set by ACFM (ICES, 2003)

$\mathbf{B_{lim}}$ is 21,000 t, the lowest observed biomass	$\mathbf{B_{pa}}$ be set at 40, 000 t
$\mathbf{F_{lim}}$ is 0.68	$\mathbf{F_{pa}}$ be set at 0.35

The NWWG (ICES, 2003) stated that "over the period covered by the assessment, fishing mortality has been equal to or less than the proposed $\mathbf{F}_{pa}$ in only 6 of 40 years of available data. This suggests that $\mathbf{F}_{pa} = 0.35$ may be overly conservative". However, the Working Group agrees with the SG on Precautionary Reference Points for Advice on Fishery Management (SGPRP – February 2003) that there is no basis to change the existing $\mathbf{B}_{lim}$ for Faroe cod.

The main closed areas forbid trawling within the areas. However, fishery with hook and line is permitted. In addition, there are spawning season closures that forbid all fisheries during defined periods. The area closure system was significantly increased with the introduction of the new regulatory system. The impact of the closed areas on the stocks and fisheries has been modelled by Zeller and Reinert (2003) and is currently being studied in more detail. Violations of the closed area system have been claimed. However, satellite monitoring of all large fishing vessels introduced in 2003 aims to reduce this problem

Pope (2000) examined changes in stock sizes and price and could not find relationships that would support the hypothesis that the economics of the fishery would prevent overfishing of the stocks by shifting the fishing effort to the most abundant species. The number of days fished by gear category since 1985 is presented in Table 6.

Table 6. Number of fishing days used by various fleet groups in Vb1

	Long-liners 0-110 GRT, jiggers, trawlers < 400hp	Long-liners <110 GRT	Pair-trawlers > 400 HP
Average 85-95	22333	3023	10778
1998	23971	2519	6209
1999	21040	2428	7135
2000	24820	2414	7167
2001	29560	2512	6771
2002	30333	2680	6749
Average 98-01	25945	2511	6806

As this table gives the number of days used on an annual basis rather than on the basis of fishing year, it is not possible to compare the number of days used with the number of days allocated. While the number of days used has decreased in the period 1998-2001 in comparison with 1995-1998, the number of days used by the smaller vessels has increased.

Comparing the fishing mortality on cod, haddock and saithe during the period 1993-2002 (Figure 13) the F of cod increased from a low level in the early 1990s to values above 0.5 in the period 1996-1998. This was followed by lower F values in the following three years, but a significant increase in 2002.However, as mentioned above, this might be an overestimate. The F values for haddock similarly increased from a low level of less than 0.2 in the early 1990s to peak values in 1998-1999 of above 0.5, but have decreased somewhat since. The fishing mortality of saithe decreased from 0.4-0.5 in the early 1990s to about 0.3 in the period 1997-1998, but has since increased to 0.4-0.5.

These variations reflect, to a certain extent, the variations in the state of the stocks. Stocks of cod and haddock were at low levels in the early 1990s, and the fishery by the larger vessels and pair trawlers was targeted at saithe. Very good recruitment of cod and haddock increased stocks to high levels in the latter half of the 1990s, when the saithe stock at the same time was at a low level. The effort on the stocks switched accordingly. In later years, recruitment to all three stocks has been good. The fishing mortality of cod varies more than that of haddock and saithe. This is most probably due to increased effort on cod on the part of the coastal fishing vessels, which increase their effort significantly when large year-classes of cod recruit to the fishery. This was particularly the case in 1996, 1997 and 2002. The catchability factor of long line for cod also appears to have varied significantly with the availability of food for cod (Steingrund, *unpublished data*).

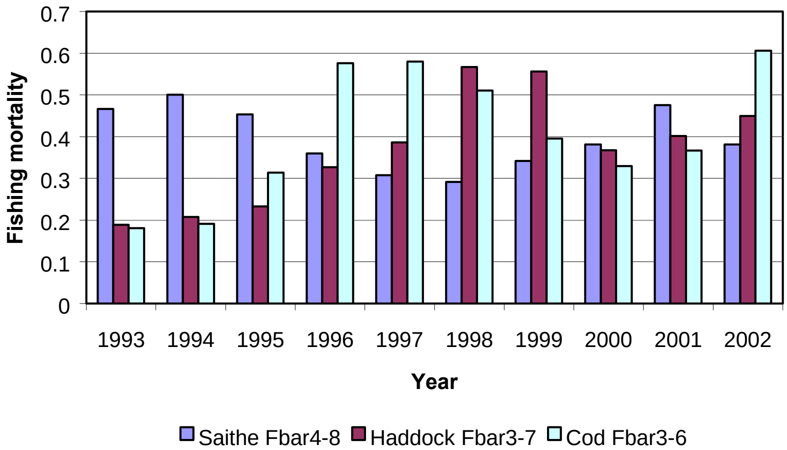

Figure 13. The fishing mortality on cod, haddock and saithe for the period 1993-2002

Concluding remarks

The benefits of the effort quota system in Faroese waters are:

A. The system has a high degree of legitimacy, as it was designed in co-operation with the industry.
B. All fish caught, apart from undersized fish, are legal and can be landed. There is little temptation to legally or illegally discard fish, as in a TAC system. All discarding of fish is forbidden by law.
C. Reliable catch statistics.

The drawbacks of the system are:

A. The system encourages over-investment in vessels and vessel capacity in order to increase the catch obtained by any given effort.
B. The system invites fishermen to focus on the size of the catch rather than on its value.
C. The fishing industry and the politicians are very reluctant to decrease the number of fishing ays. This may lead to a gradual build up of a large surplus capacity, which would then have to be reduced in larger steps.

In addition to traditional fish stock assessment there is a need for better monitoring of the fishing capacity.

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J. Sigurjónsson: Cod in Icelandic waters: Biology, exploitation and management

Marine Research Institute, P.O. Box 121, Reykjavik, Iceland

See PowerPoint presentation on enclosed CD.

W.R. Bowering and D.B. Atkinson: Cod stocks in Canadian and NAFO waters

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Abstract

Cod (*Gadus morhua*) has been the most important groundfish species in the Northwest Atlantic for centuries and has been credited with as the reason for the settlement of much of Atlantic Canada, particularly Newfoundland and Labrador. Cod are distributed from as far north as West Greenland to as far south as Cape Hatteras off the northeastern United States. There are twelve stocks of cod throughout the area, of which nine occur in Canadian and NAFO waters. However, due to the poor state of most of these stocks, only two of the nine remain open to directed commercial fishing. Three of the stocks are dealt with in detail here. They are; 1) northern cod (NAFO Divisions 2J, 3KL); 2) southern Newfoundland cod (NAFO Subdivision 3Ps) and 3) southern Grand Bank cod (NAFO Divisions 3NO).

Northern cod (the 2J3KL stock) grow more slowly than those in warmer areas. For example, a five-year-old cod is presently about 50 cm in length. Females mature at about the age of five, and age at maturity has been falling since the early 1980s. Cod feed on a wide variety of food items, with capelin traditionally being the major prey of adults. Historically, many northern cod migrated between over-wintering areas offshore and summer feeding areas inshore. Northern cod have supported a commercial fishery since the 16th century, with annual catches prior to 1960 being generally less than 300 000 t. With higher catches in the late 1960s (max. 800 000 t in 1967), mainly by non-Canadian fleets, the stock declined until the mid-70s. After the extension of jurisdiction in 1977, the stock increased until the mid-80s, but then collapsed in the late 80s and early 90s, at which time a moratorium on commercial fishing was declared (July 1992). A small inshore quota was reintroduced in 1998 but the fishery again closed in 2003.

Cod from the southern Newfoundland stock (3Ps) grow more rapidly than northern cod. Here an five-year-old cod is currently about 54 cm (about 22 inches) in length and as with northern cod, females mature at about the age of five, and age at maturity has declined since the early 1980s. The cod feed on a wide variety of food items. While capelin historically has been an important prey of adults, sand lance is also an important prey item, particularly for those distributed on St. Pierre Bank. Some offshore cod migrate from offshore over-wintering areas in to summer inshore feeding areas along the southern Newfoundland coast. This stock was not in as poor shape as the northern cod when a moratorium on commercial fishing was introduced (1993). Good individual growth and survival of two relatively large year-classes (1989 and 1990) resulted in fairly rapid rebuilding of the stock. The stock supported a commercial fishery for decades with catches during 1960-1970 generally in the range of 60 000 - 80 000 t. The stock was heavily exploited by non-Canadian fleets, particularly from Spain, and the fishery declined throughout the 1970's until the extension of jurisdiction in 1977, whereafter landings increased until the mid-80s. French catches increased in offshore areas throughout the late 80s and the stock declined until the early 90s. Following the moratorium, a quota of 10 000 t was reintroduced in 1997 and was restricted to inshore fishing grounds and to vessels less than 65 feet in length. The current TAC is 15 000 t.

Southern Grand Bank (3NO) cod are very similar in growth, maturity and foraging patterns to southern Newfoundland cod noted above. Some offshore cod over-winter along the continental slope edge of the southwest Grand Bank and migrate into the shallower parts

of the Grand Bank and to inshore feeding areas during the summer. Some seasonal mixing also occurs between southern Grand Bank cod and southern Newfoundland cod. This stock also supported a commercial fishery for very many years. During the 1950s, reported catches were variable, ranging from 40 000 - 140 000 tonnes. Large otter-board trawlers have replaced hand-line fisheries on the shallowest areas of the Grand Banks in recent decades, after which non-Canadian fleets, particularly from the former USSR and Spain, heavily exploited the stock. Catches peaked at 227 000 t in 1967 and the fishery declined steadily thereafter to a low of 15 000 t in 1978. From 1979 to 1991 reported catches ranged from 20 000 to 50 000 t. The stock declined rapidly in the late 80s and early 90s and a moratorium on directed commercial fishing was imposed in 1994. Although the stock remains at an extremely low level, reported by-catches of cod have increased ten-fold since the moratorium was introduced and are at levels that are impeding stock recovery. Heavy and illegal directed fishing on the "tail" of the Grand Bank continue outside the Canadian 200-mile limit in the NAFO Regulatory Area (NRA).

ICNAF, NAFO or Canadian scientific committees, depending on the stock and year, have made assessments of these stocks on a regular basis since the early 1970s. Traditionally, the management strategy was based on yield per recruit and initially the attempt was to fish at F_{max} or the fishing mortality that maximized yield per recruit to the fishery. This was later reduced to $F_{0.1}$, which represented a much lower fishing mortality which was considered to be more conservative, but without losing significant yield. Other controls on by-catch of cod in other fisheries through spatial/temporal closures/gear restrictions (mesh sizes and amounts of gear, Nordmøre grates, etc.) were also implemented. In Canada a dockside monitoring program to monitor landings more carefully (paid for by industry) was added. Fishing regulations are enforced via spot checks by fisheries officers on patrol, 100% observer coverage on larger offshore vessels (Canadian and NAFO), and by surveillance over-flights/aerial photography and patrols/boardings of vessels in NAFO Regulatory Area (NRA).

J. V. Tagart: Pacific cod in Alaskan waters

Washington Department of Fish and Wildlife, Seattle

See PowerPoint presentation on enclosed CD.

Greenland halibut

K. Nedreaas[1] and O. Smirnov[2]: Stock characteristics, fisheries and management of Greenland halibut (*Reinhardtius hippoglossoides* Walbaum) in the northeast Arctic

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Authorship equal

Abstract

Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)) are widely distributed over wide geographic areas of the Northeast Atlantic Ocean, with no break in the continuity of the distribution from the arctic Frans Josef Land and Novaya Zemlya archipelagos in the north and east to beyond the boreal Shetland Islands in the south. Although the entire Greenland halibut resource in the North Atlantic is genetically homogeneous, they comprise a single interbreeding stock in the Barents Sea and Norwegian Sea areas, which is known as the Northeast Arctic stock. In general, and for most of the year, larger fish become more abundant and smaller fish less abundant in progressively deeper water with peak abundance occurring over a depth range of 400-1 000 m. But during the spring and summer, the mature and bigger fish may be shallower. Greenland halibut in the Northeast Atlantic were observed to be most abundant in bottom temperatures mainly between 0º C and 4º C.

The fishery for Greenland halibut in the Northeast Arctic was unregulated until 1992, although since 1995 catches have substantially exceeded those advised. The spawning stock size reached historically low levels during the 1990s and recruitment to the spawning stock remained uncertain. The stock is now showing clear signs of improvement, and is at present rebuilt to above the long-term average of the past 20 years.

KEYWORDS: *Greenland halibut, Northeast Atlantic, distribution, biology, fisheries, management*

Introduction

The Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)) is a deepwater flatfish distributed throughout the entire rim of the North Atlantic (Nizovtsev 1989a; Bowering and Brodie 1995; Godø et Haug 1987; Vis et al. 1997). Recent studies of the structure of Greenland halibut stocks using mitochondrial DNA have also indicated that they are genetically homogeneous throughout the North Atlantic (Vis et al. 1997). This is not surprising given it’s the highly migratory nature of the species over extreme distances, as deduced from tagging experiments (Nizovtsev 1974; Sigurdsson 1981; Boje 1994; Bowering 1984). Although it is now recognized that there is an extensive gene flow among populations of Greenland halibut in the North Atlantic, it has been concluded that studies of the distribution of local spawning components are still essential for effective management (Vis et al. 1997).

Greenland halibut in the Northeast Arctic from 1960s have been the subject of considerable study regarding their distribution, biological characteristics and fisheries (Table 1). In 1964-1967 the area of the main spawning grounds was outlined, the period of mass spawning was specified and the first representative data on age-length structure of commercial and spawning stocks were acquired (Sorokin 1967; Nizovtsev 1968; 1969; 1970). Using materials collected and processed in 1964-1970, the feeding of Greenland halibut was analyzed, and the data from tagging experiments conducted in 1965-1973 revealed its seasonal migrations between spawning and feeding grounds (Nizovtsev 1972; 1989). In 1968-1972, issues relative to gametogenesis and the sexual cycle were studied. (Sorokin and Grigoryev 1968; Fedorov 1968; 1969; 1971). As result of expeditions to the northern Barents Sea in 1978-1980, Greenland halibut nursery grounds were found to the northeast of Svalbard and in the area of Franz Josef Land (Borkin 1983). In the 1980s, on the basis of long-term observations the peculiarities of growth and maturation taking into account dimorphism inherent in Greenland halibut were revealed, and the dynamics of length-age structure of stock were retraced (Kovtsova and Nizovtsev 1985; Nizovtsev 1987). The level of knowledge achieved by that time allowed relationships between different stock components and between stock and environment (Kovtsova et al. 1987; Nizovtsev 1985 1989a 1989b) to be sought.

Table 1. Publications regarding, distribution, biological characteristics and fisheries of Northeast Arctic Greenland halibut.

Time period	Objects	References
1964-1967	Area of spawning grounds, period of mass spawning, first representative data on age-length structure of stock	Lahn-Johannessen 1965 1972, Sorokin 1967, Nizovtsev 1968 1969 1970, Hognestad 1969
1964-1970	Feeding	Nizovtsev 1972 1989
1965-1973	Seasonal migrations between spawning and feeding grounds	Lahn-Johannessen 1965 1972, Nizovtsev 1989
1968-1971	Gametogenesis and the sexual cycle	Sorokin et Grigoryev 1968, Fedorov 1968 1969 1971
1978-1980	Nursery grounds to the northeast of Spitsbergen and near Fr. Josef Land	Borkin 1983
1980s	Peculiarities of growth and maturation, dynamics of length-age structure of the stock	Kovtsova et Nizovtsev 1985, Nizovtsev 1987
	Migration and recruitment patterns in the Spitzbergen area	Godø et Haug 1987
	Distribution and feeding of larval Greenland halibut	Haug et al. 1989
1990s	Biological implications of a multi-gear fishery, gear selection	Nedreaas et al. 1996, Huse et al. 1997
	Fecundity	Smirnov 1998, Gundersen et al. 1999
	Spawning, recruitment	Hylen et Nedreaas 1995, Smirnov 1995, Albert et al. 1997, Albert et al. 1998, Stene et al. 1999
	Feeding	Michalsen et Nedreaas 1998, Dolgov et Smirnov 2001

Godø and Haug (1987) reported on migration and recruitment patterns of Greenland halibut in the Spitzbergen area using data available during the early 1980s. Godø and Haug (1989) also reviewed the available literature on the natural history, fisheries and management of the species in the eastern Norwegian and Barents Seas until that time. More recently, Nedreaas et al. (1996) evaluated the biological implications of a multi-gear fishery for Greenland halibut in the Northeast Arctic while Michalsen and Nedreaas (1998) reported on a food and feeding study of Greenland halibut in the Barents Sea and East Greenland waters. A number of other studies on Greenland halibut in the Northeast Atlantic have been presented at recent NAFO or ICES symposia and are currently being reviewed for publication or are in press;. e.g. gear selection (Huse et al. 1997), fecundity (Gundersen et al. 1999), spawning (Albert et al. 1998; Stene et al. 1999) and recruitment studies (Albert et al. 1997).

For Greenland halibut in the Northeast Atlantic, stock status is determined and scientific advice on management is provided annually. This is the responsibility of the Arctic Fisheries Working Group and the Advisory Committee on Fisheries Management of the International Council for the Exploration of the Sea (ICES) (see Anon. 2002).

Bowering and Nedreaas (2001) made a useful comparison of Greenland halibut fisheries and distribution in the Northwest and Northeast Atlantic, which revealed both differences and features in common, and discussed the implications for fisheries management within the individual areas. A Nordic report (Boje et al. 2002) has reviewed the current status of Greenland halibut research and knowledge and made suggestions for future research that would be useful for management.

The aim of the present paper is to review current knowledge about the characteristics of the Northeast Arctic Greenland halibut stock (e.g., its size, distribution, position in the food web, management unit), the history of the stock, its fishery and management system. Current management strategy, including scientific advice (e.g., stock monitoring, stock assessment and prognoses, precautionary reference points, form of advice), TAC decisions and international/national sharing of the TAC, the fishery (fishing methods, fleets), fisheries regulations (legal size, mesh size, selectivity measures, area closures), enforcement, control and collection of fisheries statistics are also described.

Materials and methods

The geographical distribution presented here (see Figure 1) is taken from Nizovtsev (1989a) and Bowering and Nedreaas (2001).

Figure 2 illustrates the **size** of Greenland halibut at depths shallower than 500 metres on the nursery grounds north and east of Spitsbergen and on the shelves and slopes of the Barents and Norwegian Seas, and at depths greater than 500 metres along the continental slope and on the main spawning grounds. The individual **mean size** of Greenland halibut as this varies **with depth** along the continental slope area, as well as north and east of Spitzbergen, and on the Svalbard and Barents Sea shelf, is shown in Figure 3 (based on Norwegian survey data.

Distribution and relative **abundance with depth** are expressed as mean number and weight (kg) per standard set by 100-m depth intervals for depths to 500 m and 250-m intervals for depths greater than 500 m. A cursory examination of the data indicated that for the geographic areas investigated any trends with respect to time were similar. Therefore, data for all years were combined in the analyses. The areas and survey time series that were evaluated are identified in Table 2. Results are shown in Figure 4.

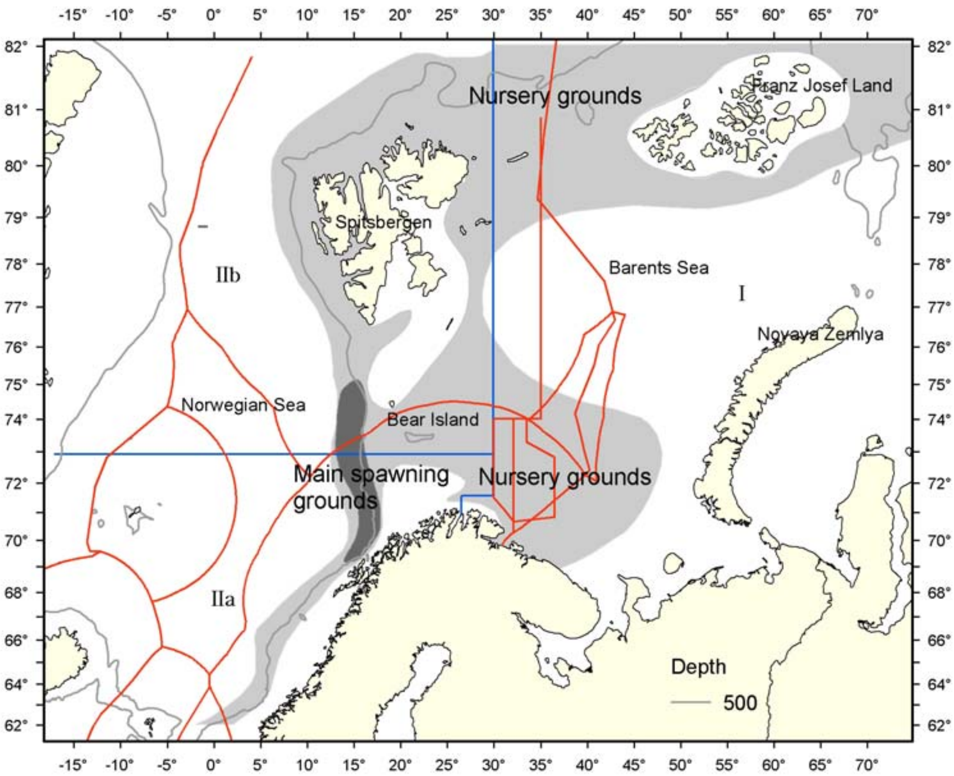


Figure 1. Schematic presentation of the geographic horizontal distribution of Greenland halibut. Nursery- and main spawning grounds are marked. National economic zones, the disputed border areas between Norway and Russian (i.e., the Grey Zone), the international Loophole, and the ICES areas are shown.

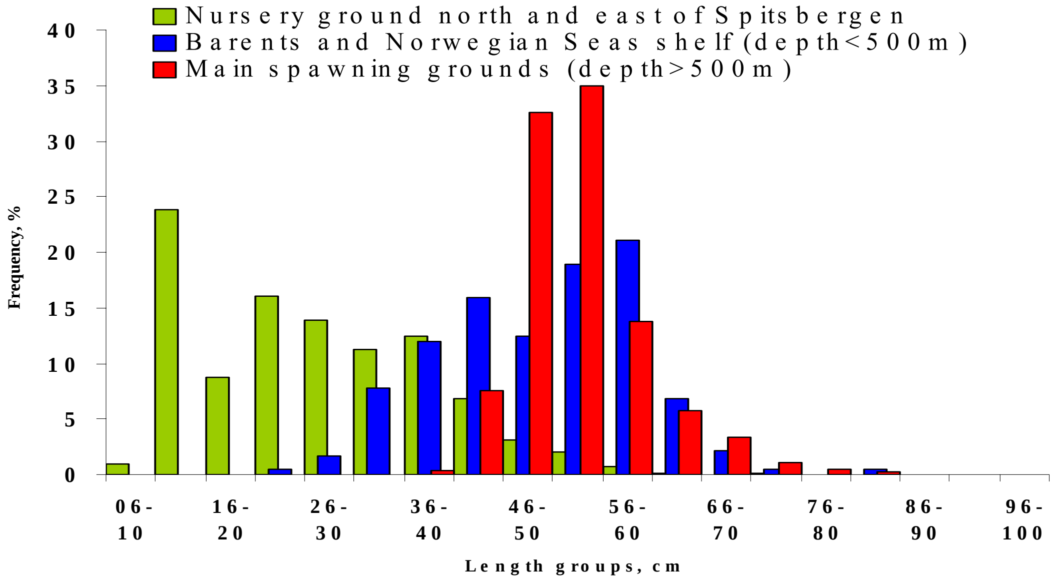


Figure 2. Length distributions of Greenland halibut typical of 1) the nursery grounds north and east of Spitsbergen (depth < 500 m), 2) the Barents and Norwegian Seas shelf areas (depth < 500 m), and 3) along the continental slope and the main spawning grounds (depth > 500 m). Data from Russian surveys in September-December 1999-2000. Small meshed trawls used everywhere.

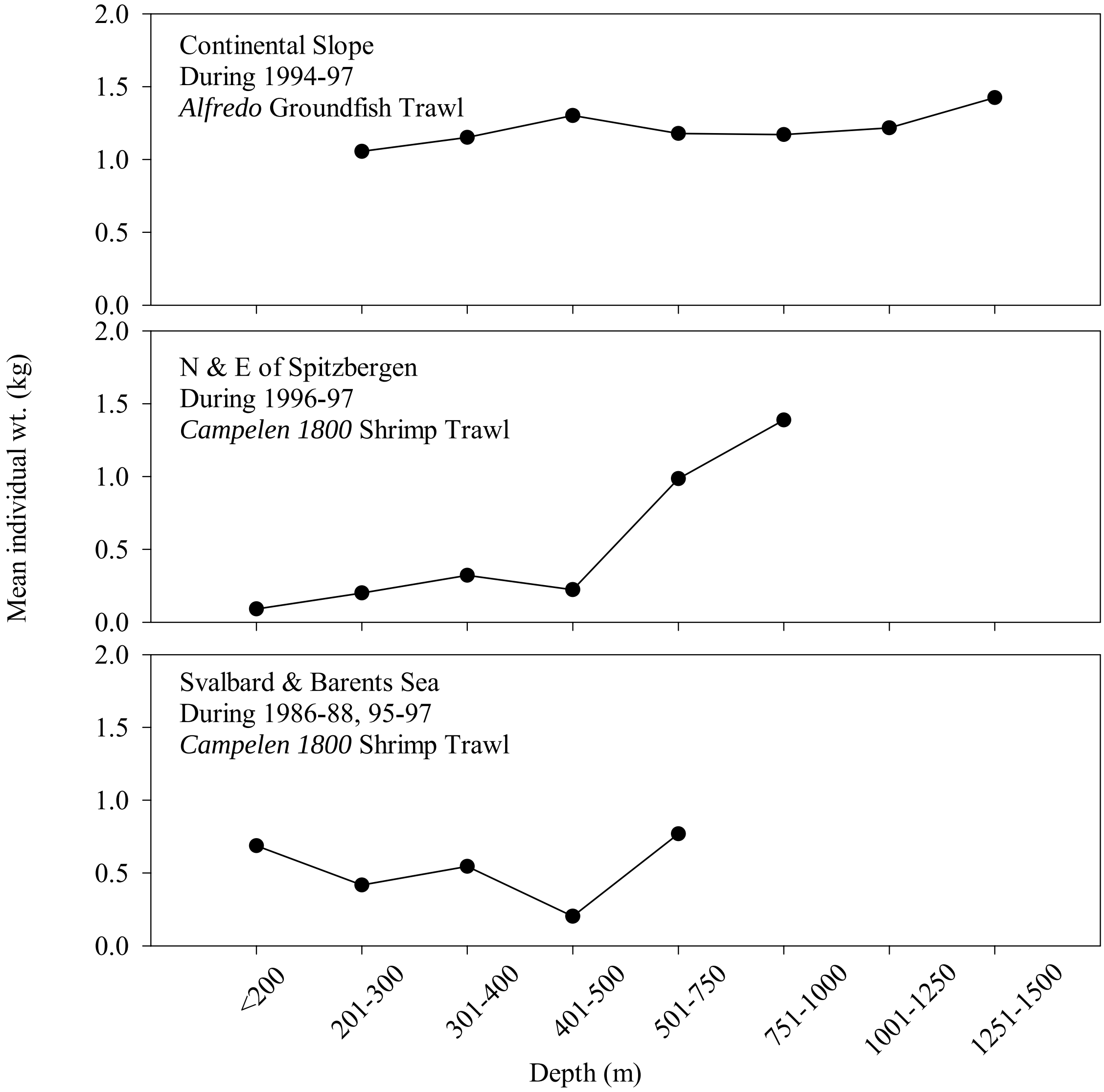


Figure 3. Individual mean size of Greenland halibut at various depths. Data from different years combined and presented for three different survey areas. All data are collected in August-September (source: BOWERING AND NEDREAAS 2001).

Table 2. Research vessel surveys by area, years and depth intervals used to study distribution and relative abundance of Greenland halibut in the Northeast Arctic.

Area	**Combined Survey Years**	**Depth Range (m)**
Continental Slope (62º N to 68º N)	1995	400-1500
Continental Slope (68º N to 80º N)	1994-97	200-1500
N. et E. of Spitzbergen	1996-97	<200-800
Franz Josefs Land (BORKIN 1983)	1978-80	200-1150
Russian Svalbard and Barents Sea surveys	1984-2002	<200-800
Norwegian Svalbard and Barents Sea surveys	1986-88, 1995-97	<200-500

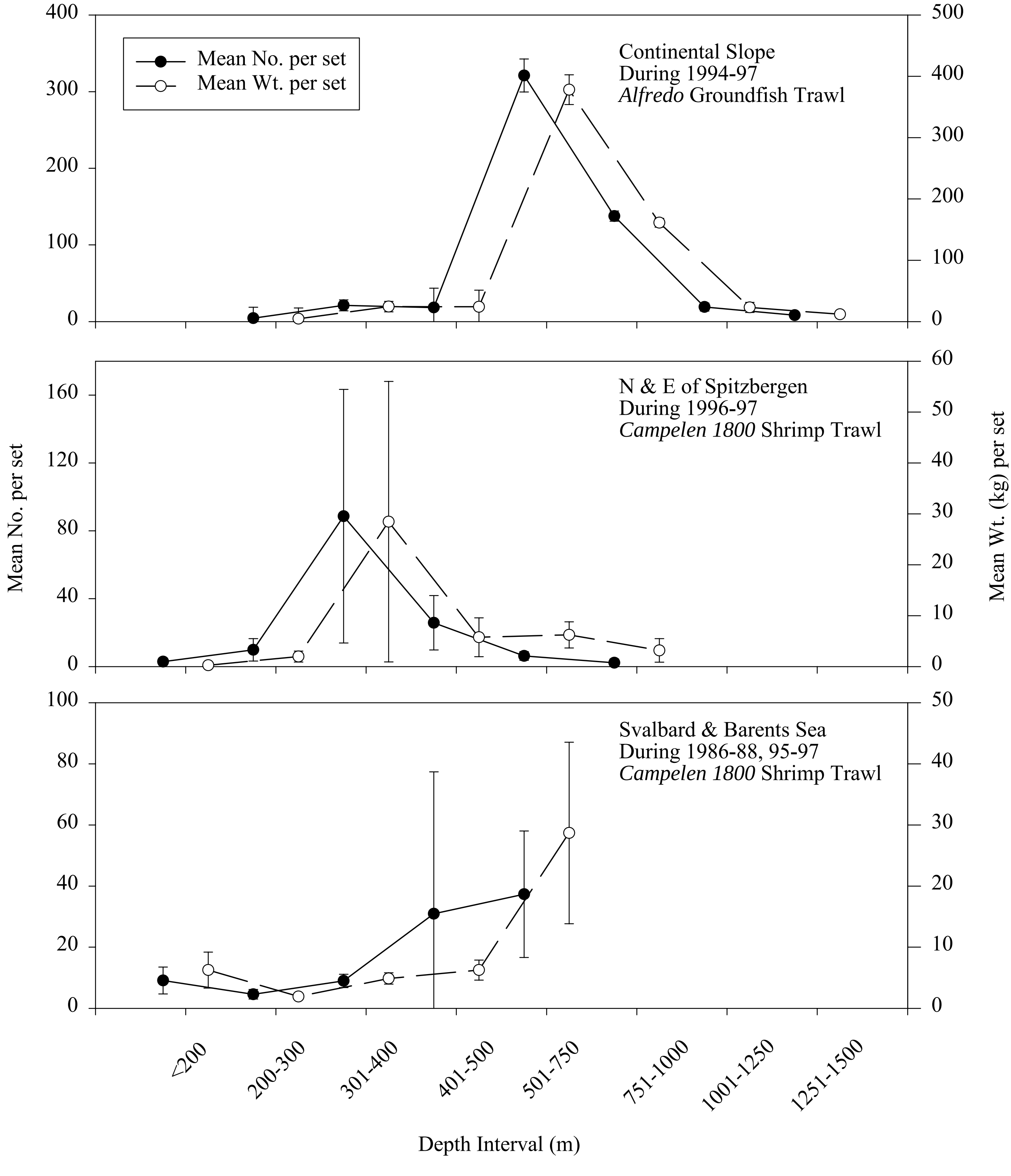


Figure 4. Distribution and relative abundance with depth expressed as mean number and weight (kg) per standard set by depth intervals. Data from different years combined and presented for three different survey areas. All data are collected in August-September (source: Bowering and Nedreaas 2001).

The distribution and relative abundance of Greenland halibut as these vary **with bottom temperature** for the Northeast Arctic data are expressed as mean number and weight (kg) per standard set by 1.0º C intervals for bottom temperatures in the range of –1.9º C to 5.0º C. All catches made at temperatures <1.9º C are grouped as well as those at temperatures >5.0º C. For catch and temperature data analyzed, the areas and survey time series combinations examined were identical to those used in the analyses of distribution with depth (see Table 2). The results are shown in Figure 5.

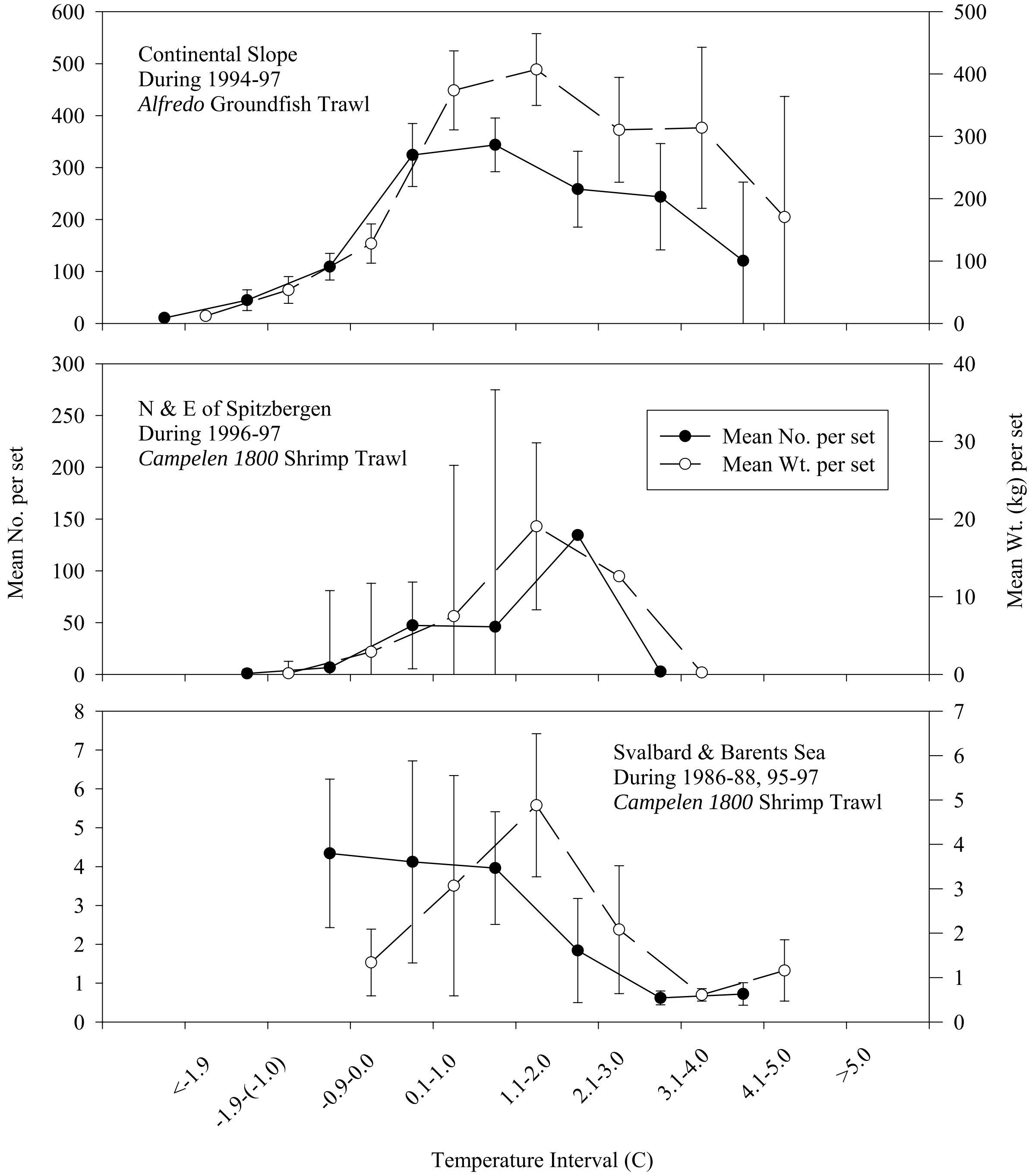


Figure 5. Distribution and relative abundance of Greenland halibut as these vary with bottom temperature expressed as mean number and weight (kg) per standard set by 1.0º C intervals. All data were collected in August-September (source: Bowering and Nedreaas 2001).

Concerning the material and methods used to describe the stock's position in the food web, the authors refer to work done by several authors (e.g., NIZOVTSEV 1989a, MICHALSEN and Nedreaas 1998, Dolgov and Smirnov 2001, Hovde et al. 2002, and Vollen et al. 2003).

The material used for describing and discussing stock assessment, fishery and management are taken from the ICES Arctic Fisheries Working Group reports (e.g., Anon 2002), related reports of the ICES Advisory Committee for Fisheries Management, protocols from the Joint Norwegian-Russian Fisheries Commission, and laws and regulations of the Norwegian and Russian authorities.

Results and discussion

Stock characteristics

Distribution and management units

Greenland halibut in the Northeast Arctic are distributed extensively from south of 62º N along the continental slope near the European Union (EU)-Norway border, continuously to the northeast of Spitzbergen beyond 82º N (Figure 1). They have also been observed as far east as the eastern coast of Franz Josefs Land at 73º E (Figure 1). Catches are highest along the edge of continental slope, although differences in fishing gear in the Northeast Atlantic surveys make it difficult to compare catches accurately. They are abundant in the deep channels running between the shallow fishing banks but are absent from the tops of the banks in the Barents Sea (Figure 1). Relatively large catches have been made northeast of Spitzbergen and are widely distributed east of Svalbard towards Franz Josef Land In the central part of the Barents Sea small quantities occur in catches as far to the east as the Goose Banks (47º E). (Figure 1).

Nizovtsev (1989a), Bowering and Nedreaas (2001) conclude that Greenland halibut appear to be distributed with little or no break in the continuity of the distribution throughout both the Northwest and Northeast Atlantic Ocean. According to the results of earlier investigations, Greenland halibut in the Northeast Arctic spawn along the continental slope primarily between 71º N and 75º N (Nizovtsev 1989a) or between 72º N and 74º N (Godø and Haug 1989), i.e. about the mid-latitude of the distribution range (see Figure 1). Albert et al. (1998) also observed spawning Greenland halibut along the slope between 70º N and 75º N with peak spawning occurring in December. These authors, like Fedorov (1969), however, noted that some spawning occurred in adjacent areas more than six months later, although this was much less extensive.

The main nursery area in the Northeast Atlantic is reported also to be more to the northern end of the distribution surrounding the Spitzbergen archipelago (Godø and Haug 1989). Recent studies have shown that the areas north and east of Spitsbergen and eastwards to Franz Josef Land are important nursery areas. Since the northernmost areas are covered by ice during most of the year the northeastern border of the distribution could not be delineated (IMR/PINRO-report series no. 7, 2002).Young Greenland halibut may occasionally also occur in the eastern part of the Barents Sea towards Novaya Zemlya (Nizovtsev 1983; 1989a).

In the Northeast Atlantic there is no apparent change in individual mean size of Greenland halibut with depth along the continental slope area. However, to both the north and east of Spitzbergen surveys and the Svalbard and Barents Sea surveys indicate an increase in mean individual size in the catches in depths greater than 500 m (Figure 3). Greenland halibut catches exhibited a tendency to increase in size with depth, peak and then decline (Figure 4). However, no latitudinal depth trends in peak abundance could be established.

The affinity for young juvenile Greenland halibut to nursery areas in the north and larger fish to be in deep water along the continental slopes of the Northeast Atlantic might explain some of the variability apparent in the preferred depth range. For example, the distribution data from surveys along the slope of the Norwegian Sea did not demonstrate any change in mean individual fish size over the range of depths fished. Since this survey series includes the spawning area (Albert et al. 1998), young fish would have a tendency to be less abundant here; therefore a change in mean individual size with depth would probably be less apparent. Age compositions from these surveys reported in Anon. (2002), in fact, indicated that very few Greenland halibut less than five years old were caught. On the other hand, unpublished survey and commercial catch rate data from the Institute of Marine Research show that from September onwards there seems to be a clear trend in mean individual size with depth. Larger mature fish appear to migrate to shallower depths and to some extent into regions of the Barents Sea as shallow as 200-metrese. Data from Russian longliners (Popov et al. 2003) demonstrate that some large post-spawning specimens in March - April may migrate to the central part of the Barents Sea (Grey Zone) and stay there at depths of 300-360 metres at least until the middle of summer, then leave this area gradually. This suggests a degree of seasonality in the distribution pattern, which might be associated with feeding or spawning behaviour.

Trends in distribution and relative abundance of Greenland halibut with respect to bottom temperature in the Northeast Atlantic surveys are more evident than in the Northwest Atlantic (Figure 5) (Bowering and Nedreaas 2002). In all the survey series presented, the average weight (kg) per set increases to peak within a bottom temperature range of 1.1º C to 2.0º C, beyond which the average weight (kg) per set declines. The trend is similar for average number per set from the continental slope surveys. However, the peak occurs within a bottom temperature range of 2.1º C to 3.0º C for the north and east of Spitzbergen data and below 0.0º C for the Barents Sea and Svalbard data (Figure 5).

This also agrees with Nizovtsev (1989a), who showed that the distribution of various length groups of Greenland halibut in the continental slope area versus sea temperature confirms a certain regularity, i.e., smaller fish meet at the extreme limits of a temperature range, whereas larger specimens live near the middle of a temperature range (2-3° C).

Nonetheless, Bowering and Nedreaas (2002) found that Greenland halibut in the Northeast Atlantic tend to be more widely distributed at lower bottom temperatures than those of the Northwest Atlantic, rather surprisingly, given the apparent slower growth rate of the latter (Anon. 1997, Bowering and Nedreaas 2002). Peak spawning in the Northeast Atlantic is reported to occur at bottom temperatures of 2.0-3.0º C (Nizovtsev 1989a) or 2.0º C (Albert et al. 1998) compared to 3.0º C to 3.5º C for Davis Strait (Jørgensen 1997a).

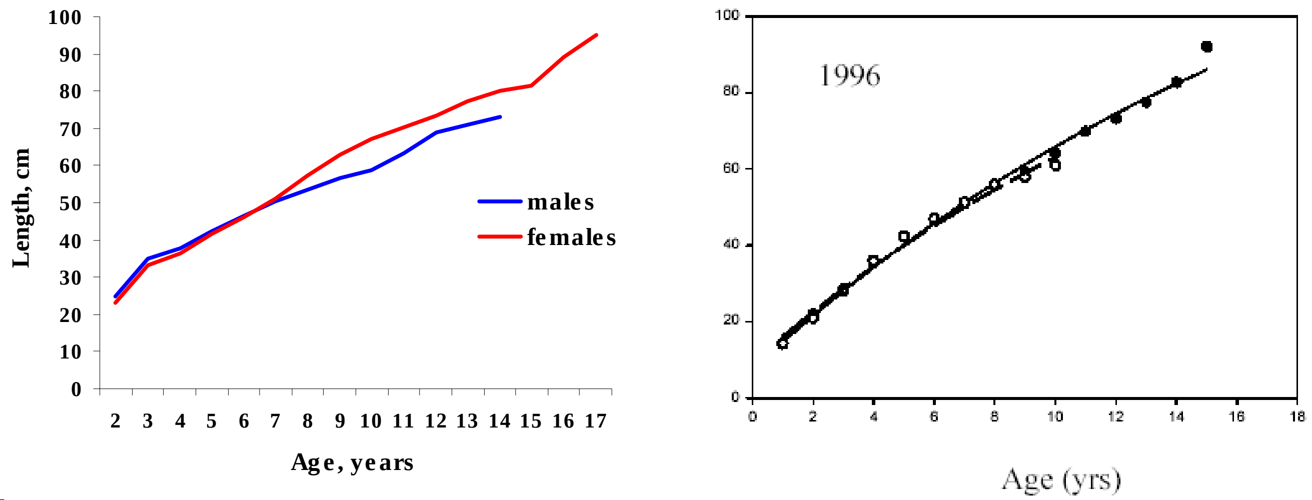
Size, age, growth and maturity

A joint Northwest Atlantic Fisheries Organization (NAFO) – International Council for the Exploration of the Sea (ICES) "Workshop on Greenland halibut Age Determination" was held in Reykjavik, Iceland in 1996 to deal with the age determination of Greenland halibut and standardization of methodology (Anon. 1997). Bowering and Nedreaas (2001B) based their review of age validation and growth upon the results and recommendations from this workshop. In most instances female growth rates are slightly higher than those of males after about six or seven years of age (Figure 6a). The joint NAFO/ICES workshop only discussed otoliths, as these are the most widely used measure and are regarded as the most appropriate structures for age determination. PINRO and Russia, on the other hand, have routinely used scales for age determination. Also on the basis of scale interpretation, females grow faster than males from an age of six to seven years.

Irrespective of geographical areas and method of age determination, it has been confirmed and agreed that females have a longer life-span than males.

Bowering and Nedreaas (2001B) showed that Greenland halibut in the northeast Atlantic are generally larger at age, i.e., display higher growth rates, up to about eight year of age than those of the northwest Atlantic. However, the results suggest that the growth patterns between the two regions may have been converging on a more similar pattern in recent years.

a



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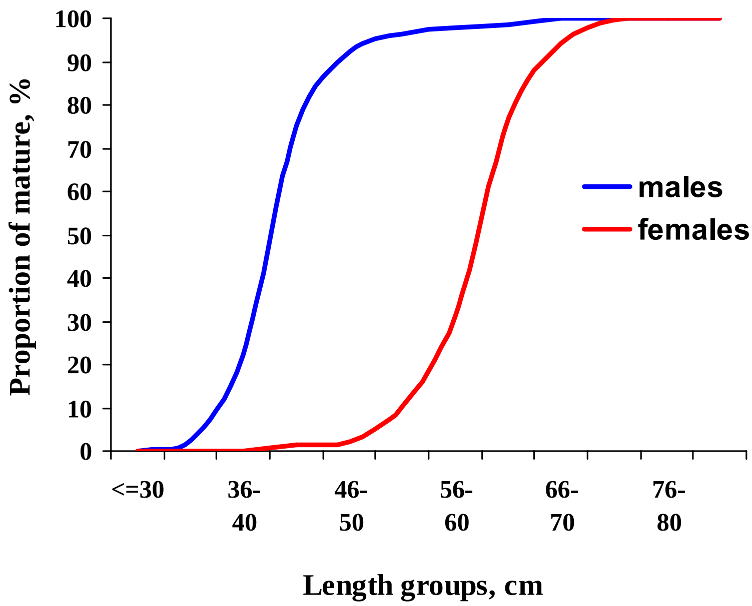

Figure 6. a)-left: Greenland halibut length at age determined by otolith growth rings (example from Bowering and Nedreaas (2001b). a)-right: Mean length at age for the years 1981-1997 as age determined by scales. b) Proportion mature at length (mean for 1984-1998) (Russian scale readings)

According to PINRO data, Greenland halibut in the Barents Sea reach a maximum length of 120 cm and an age of 20 years (Nizovtsev 1989a). Earlier investigations (Kovtsova and Nizovtsev 1985) showed higher growth and maturation rates in the 1970-80s than in the 1940-60s. The reduction of stock abundance is considered to be the main reason for this trend.

This increase in growth and maturation rates continued until the end of the 80s. In the 90s, the average annual length increments began to decrease.

As with other fish species, the length and age at which Greenland halibut reach sexual maturity vary widely (Kovtsova and Nizovtsev 1985), but males become mature when they are younger and smaller than females. In the 80s and 90s, 50% of males had reached maturity at an average length of about 41 cm and at an age of five years, which is close to parameters observed in the 1970ies, and 50 % of the females – likewise at a length of about 59 cm and an age of eight years, which is a little bit earlier than in the 70s (Figure 6b).

The fecundity of Greenland halibut is rather low compared to other flatfish. Estimates ranged from 6.4 to 94.4 thousand eggs per female, depending on body size. Mean fecundity has been evaluated by various authors at 18.1-28.1 thousand eggs per female (Figure 7).

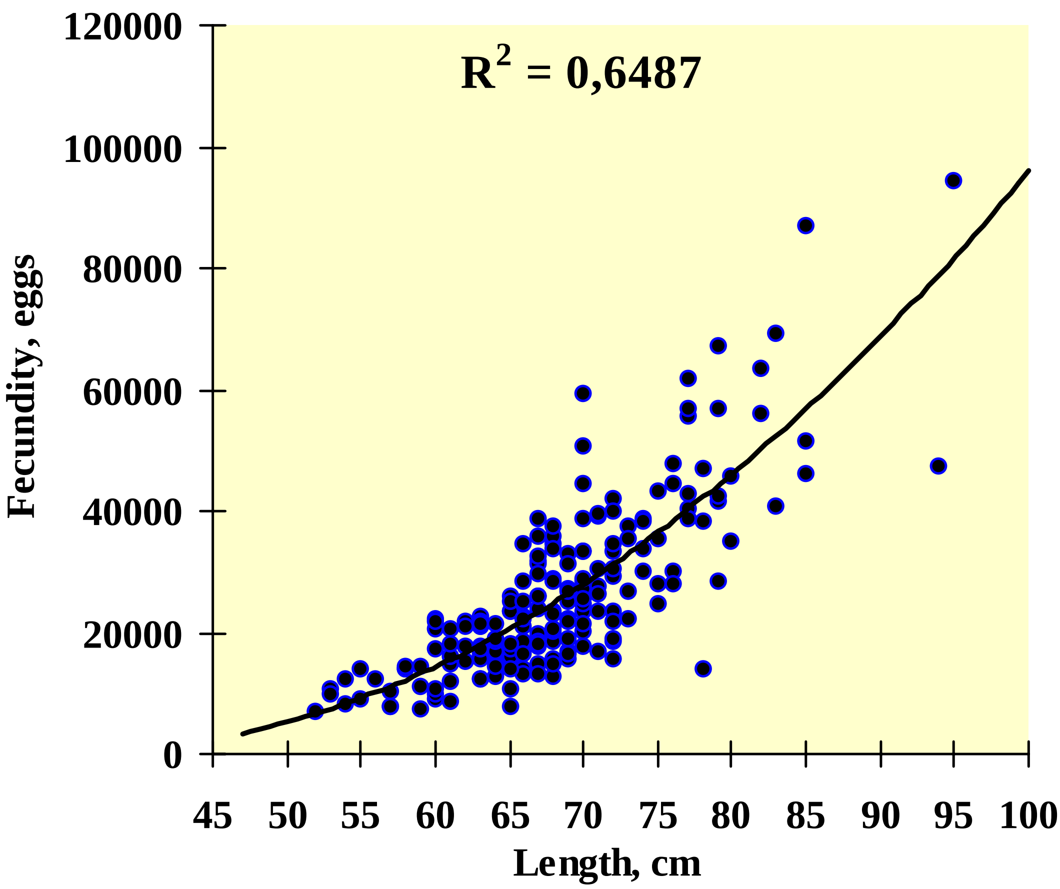

Figure 7. Fecundity of Greenland halibut as function of on body size.

Total egg production (TEP) by the northeast Arctic Greenland halibut stock by age in 1996-1998 is shown in Figure 8 (Gundersen et al. 2000).

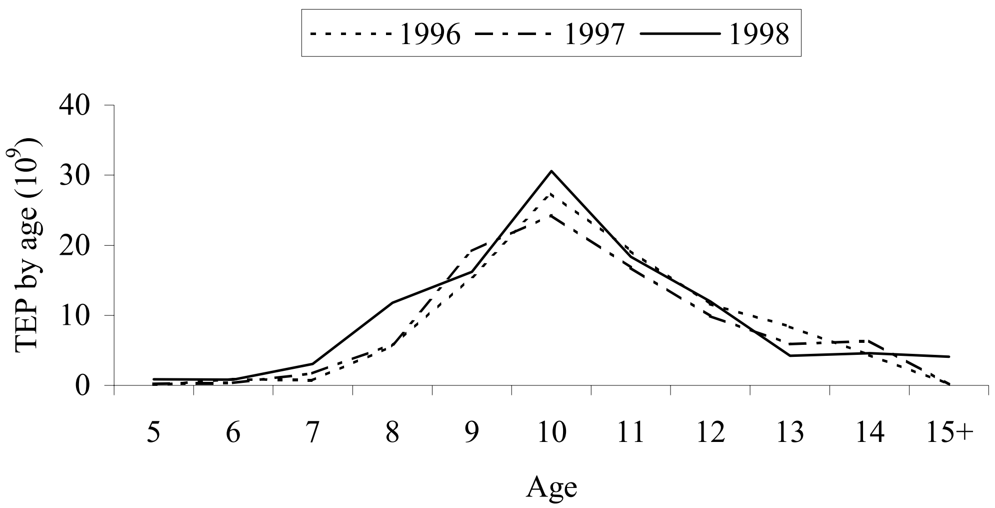

Figure 8. Total egg production (TEP) by the northeast Arctic Greenland halibut stock by age in 1996-1998 (ref. Gundersen et al. 2000).

Position in the food web

As Russian investigations show (Dolgov and Smirnov 2001), among the variety of fish, seabirds and marine mammals, Greenland halibut were found in the diet of just three species - Greenland shark (*Somniosus microcephalus*), cod (*Gadus morhua morhua*) and Greenland halibut itself. The killer whale (*Orcinus orca*), grey seal (*Halichoerus grypus*) and narwhal (*Monodon monoceros*) are other potential predators. However, the role of Greenland halibut in the diets of the above species was minor. Predators fed mainly on juvenile Greenland halibut up to 30-40 cm long.

The mean annual percentage of Greenland halibut in cod diets in 1984-1999 accounted for 0.01-0.35% by weight (0.05% in average). Low levels of consumption are related to the distribution pattern of juvenile Greenland halibut as they spend the first years of their life mainly in the outlying areas of their distribution, in the northern Barents Sea, where both adult Greenland halibut and other abundant predator species are virtually absent.

The level of cannibalism was highest in the 1960s (up to 1.2% by frequency of occurrence). In 80s, in Greenland halibut stomachs the frequency of occurrence of their own juveniles did not exceed 0.1 %. In the 90s, the portion of their own juveniles (by weight) was around 0.6-1.3%.

The composition of the food of the Greenland halibut in the Barents Sea includes more than 40 prey species (Nizovtsev 1989a; Dolgov and Smirnov 2001). The results of monitoring by PINRO of a wide area from the continental slope up to Novaya Zemlya show that the main food of the Greenland halibut consists of fish, mostly of capelin (*Mallotus villosus villosus*) and polar cod (*Boreogadus saida*) as well as cephalopods and shrimp (*Pandalus borealis*). In 1990's an important place in the diet was occupied by waste products from the fisheries for other species (heads, guts etc.). With growth, a decrease in the importance of small food items (shrimp, capelin) in the diet and an increase in the proportion of large fish such as cod and haddock (*Melanogrammus aeglefinus*) were observed.

In a diet study carried out on the continental slope of the Norwegian Sea Michalsen and Nedreaas (1998) found a generally high proportion of empty stomachs, but with decreasing percentage of empty stomachs with increasing predator length. The cephalopod *Gonatus fabricii* was a very important prey item. Of the fish prey, herring and blue whiting were the most important. Much of the prey was pelagic, and few strictly bottom living organisms were found.

Recent studies of diet composition and feeding behaviour of Greenland halibut have also been presented by Hovde et al. (2002) and Vollen et al. (2003). Hovde et al. (2002) found spatial and temporal components to have more influence on the variation in diet composition than biotic variables, although in smaller Greenland halibut (< 50 cm) crustaceans and the cephalopod *Gonatus fabricii* were the prevailing prey, whereas for larger specimens (> 50 cm) teleosts and fish offal were the dominant components.

With a Greenland halibut stock of nearly 100 000 tonnes, the total food consumption by their population comes to about 280 000 tonnes. The biomass of commercial species consumed (shrimp, capelin, herring, polar cod, cod, haddock, redfish (*Sebastes sp*.), long rough dab (*Hippoglossoides platessoides*) does not exceed 5 000-10 000 tonnes per species.

The Greenland halibut as a species thus has a negligible effect on the other commercial species of the Barents Sea, while at the same time it is not subject to their predatory influence.

History of the fishery, the stock and its management

Fishery

Historically, in the Northeast Atlantic there was little demand and poor prices for Greenland halibut compared to other groundfish such as cod, therefore it received little attention from enterprising fishermen. It was not until a trading relationship (known as the Pomor trade) developed between Russia and Norway during the 1760s that Norway began to fish this species commercially using longlines. Greenland halibut were more common in the Russian marketplace and the demand was sufficiently high to warrant the development of the fishery (Ytreberg 1942). The trading relationship eventually collapsed with the arrival of the Russian Revolution in 1917, and the fishery declined. After 1935 the longline fishery once again developed. Catches increased from about 1 000 tonnes at the beginning to 10 000 tonnes by the 1960s (Figure 9). In 1964, dense spawning concentrations of Greenland halibut were found to the west of Bear Island by Soviet fishermen testing new deep-water trawl equipment (Pechenik and Troyanovsky 1970; Nizovtsev 1989a). This provided an incitement for the prompt development of an international trawl fishery. With the introduction of international trawling fleets to the fishery during mid 1960s, catches increased rapidly to peak at 90 000 tonnes in 1970 before declining (Anon. 1998b). The fishery has been regulated since 1992, and from 1992 until 1997 catches averaged around 11 000 tonnes annually, the lowest since the early 1960s. The average annual official catches for 1998-2002 have been 15 000 tonnes (Figure 9). The fishery for Greenland halibut in the Northeast Atlantic has been conducted mainly along the continental slope of the Norwegian Sea between 68º N and 74º N in ICES Division IIa and along the continental slope of southern ICES Division IIb. High variability in catches is generally associated with those proportions taken in ICES Division IIb and it was here that the peak catches were made in 1970-71 (GODØ and HAUG 1989). The Greenland halibut fishery in the Norwegian and Barents Seas in 1970-1980s has primarily been carried out by fishing fleets from the former Soviet Union (about 50% on average), Norway (about 25%), the German Democratic Republic and the Federal Republic of Germany as well as Poland and the United Kingdom (Figure 9) (Anon. 2002). During 1992-1999, however, more than 80% of the catches have been taken by Norway, with Russia accounting for most of the remainder. In 2000-2002, the Norwegian share of the total official catches fell to about 60%.

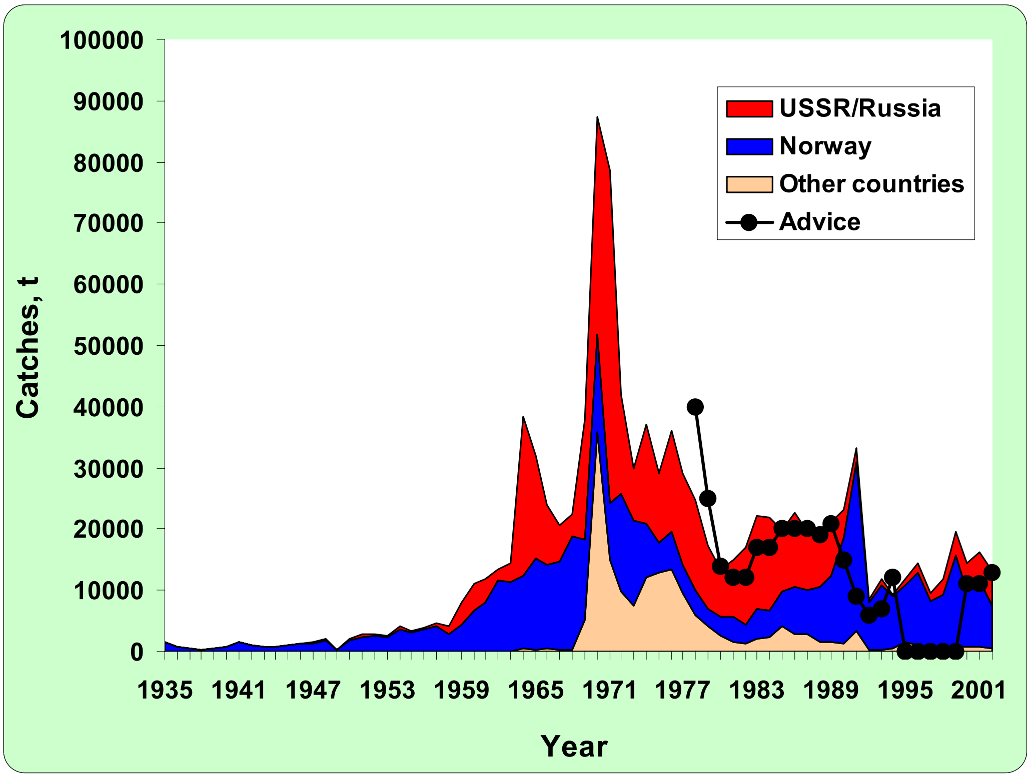

Figure 9. International landings of Greenland halibut from the Barents and Norwegian Seas, 1935-2002.

ICES has provided annual scientific advice on catch levels for this stock since 1978; however, the fishery remained unregulated until 1992. Since most of the Greenland halibut stock is located within the Norwegian Exclusive Economic zone (NEEZ) and Svalbard area, all regulations have been imposed and implemented by Norway. In view of the poor state of the stock, since 1992 the fishery has been regulated by permitting only vessels less than 28 m in length using longlines and gillnets to target Greenland halibut, with a small assigned quota that can only be fished during the month of June. In addition, catches by all other vessels and gears are restricted to by-catch only. The by-catch regulations have also become rather strict. This included a by-catch weight limit on Greenland halibut for other fisheries carried out in the area, which has varied between 5% and 12% since 1992 (Anon. 2002). ICES advised a zero catch for this stock during 1995-2002, on the basis of the low spawning stock and the apparent failure of several pre-recruit year-classes. However, because Greenland halibut is an allowable by-catch in other major groundfish fisheries such as cod and haddock, while a small targeted fishery is permitted, the actual catch substantially exceeded the advised TACs (Figure 9).

Stock

Stock evaluations of the Greenland halibut resource in the Northeast Atlantic indicate that the stock has been declining steadily since the 1970s, and by the early 1990s the spawning stock here had reached the lowest level observed (Anon. 1998b). This was mainly a result of excessive exploitation over the period, given that the fishery was unregulated until 1992. Recruitment failures were deduced from extremely low survey abundance indices of Greenland halibut at ages 0-4 from 1989 onwards. Later estimates of the abundance of these same year-classes aged five or more, on the other hand, suggest that these year-classes may not be nearly as weak as the earlier ages would suggest (Anon. 1998b). It seems clear from recent studies and the data presented here that important areas for young Greenland halibut might be found further north and east of Svalbard than previously considered. These areas would have been outside the former surveyed areas from which the pre-recruit abundance indices were derived (Joint IMR/PINRO report 2002). Albert et al. (1997) also showed that the southwestern end of the distribution area of age one fish was gradually displaced northwards along west and north Spitzbergen in the period 1989-92 (partly outside the former surveyed areas) and southwards in 1994-96. These displacements seem to have corresponded to changes in hydrography, i.e., a more northerly distribution when the temperature in the Barents Sea is high and a more southerly distribution when the temperature is low. It has been hypothesized that this may have caused the main concentrations of at least the 1989-1992 year-classes at early ages to move outside the areas formerly covered by the surveys. If this is correct, the implications for evaluating stock status are particularly worrisome for this resource, bearing in mind the fishery-independent database used in the assessments and advised TACs of recent years. Nevertheless, these year-classes as yet would have little effect on current estimates of the low spawning stock size, which alone would warrant the very strict scientific advice. On the other hand, if the estimates of the 1989-94 year-classes at older ages are confirmed as being more representative of year-class size, then improvements to the spawning stock could occur earlier than previously anticipated, provided that catches are kept low.

Management of the stock

Stock assessment and current management strategy

The stock is annually estimated by the ICES Arctic Fishery Working Group (AFWG) in spring using the XSA-model. The assessment is finally quality checked and recommendations are subsequently provided by the ICES Advisory Committee on Fishery Management (ACFM) at its June meeting.

The basic data for the estimations are the data on annual catches of various age groups (in numbers) and average individual (round) weights of specimens of various age groups. Maturity ogives are necessary for calculations of spawning stock. Table 3 indicates the type of data provided by different countries.

Table 3. Data for stock assessment provided by different countries participating in the fishery.

Country	Kind of data				
	Catch in weight	Catch at age in numbers	Weight at age in the catch	Proportion mature by age	Length composition in catch
Norway	+	+	+		+
Russia	+	+	+	+	+
Germany	+				
United Kingdom	+				
France	+				
Spain	+				
Portugal	+				
Ireland	+				
Greenland	+				
Faroe Islands	+				
Iceland	+				
Poland					

The analytical assessment method XSA (eXtended Survivor Analysis) is used for tuning the model, i.e., matching the catch-at-age data with the scientific survey indices and/or catches per unit of effort. The model produces a diagnostic output to be evaluated and discussed before making any adjustments needed and performing a final run. This enables the quality of the assessment to be estimated.

At present, the AFWG possesses data on catches for the period back to and including 1964, and abundance indices from the following surveys (see also Figure 10):

- Norwegian bottom trawl survey in August in the Barents Sea and Svalbard areas at fishing depths from less than 100 m down to 500 m (since 1984).
- Norwegian Greenland halibut survey in August. The survey covers the continental slope from 68 to 80ºN, at depths of 400–1500 m north of 70º30'N, and 400–1000 m south of this latitude (since 1994).
- Norwegian bottom trawl survey north and east of Svalbard in autumn (since 1996, and conducted since 2000 as a joint Norwegian-Russian survey).
- Russian autumn bottom trawl survey in the Barents Sea and Svalbard in October-December at fishing depths of 100–900 m (since 1984).
- Spanish bottom trawl survey on the slope of Svalbard area in October (since 1997)
- Norwegian Barents Sea bottom trawl survey in February at fishing depths from less than 100 m and down to 500 m (back to 1981, but present design since 1993, and conducted since 2000 as a joint Norwegian-Russian survey).
- International pelagic 0-group survey (back to 1965, but present design since 1980).
- Norwegian experimental commercial fishery (CPUE), two weeks every May since 1992.

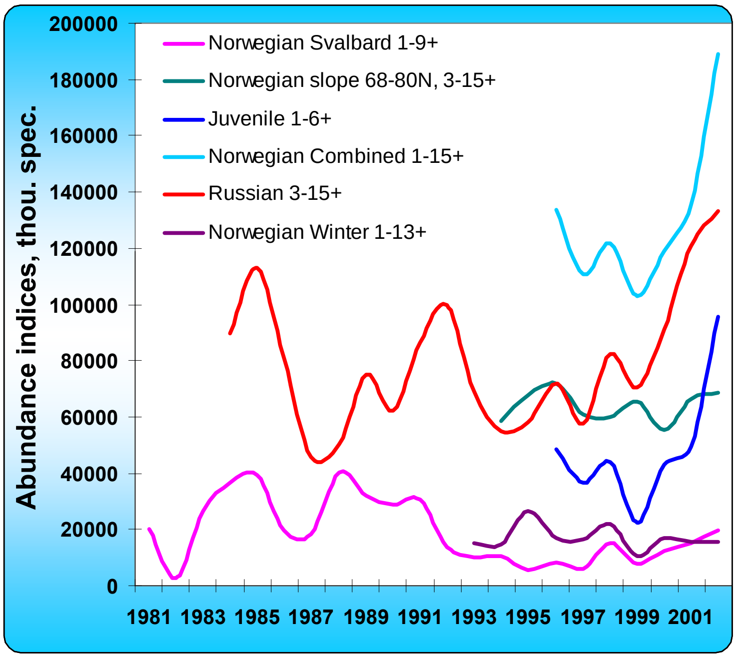

Figure 10. Abundance indices of Northeast Arctic Greenland halibut from different surveys.

During the past two years (2002-2003) three datasets have been used for the tuning: a combined index series of the three first surveys from the list above, indices of the Russian autumn trawl survey, and catch-rates from the experimental Norwegian fishery in spring.

The last stock assessment (2003) estimates the total fishable stock (5 years and older) in 2002 to have been 82 000 tonnes and the spawning stock (biomass of mature females) to 28 000 tonnes (Figure 11). Although commercial and spawning stocks of Northeast Arctic Greenland halibut in 2002 have remained below the long-term mean level for the whole monitoring period since 1964 (121 and 48 000tonnes respectively), both of them already exceed the mean level for the past 20 years (77 and 26 000 tonnes). The level of fishing mortality in 2002 (F=0.20) was the lowest since 1981.

Short-term projection has shown that the fishable and spawning stocks in the beginning of 2003 were predicted to be about 87 and 32 000 tonnes respectively. With an expected catch of 15 000 tonnes (F=0.21) in 2003, the fishable and female spawning stocks will increase up to 90 and 35 000 tonnes respectively, at the beginning of 2004. These assessment results thus confirm the growth of the Greenland halibut stock, which is expected to continue further under condition of catch in 2004 will not exceed 16 000 tonnes.

At the same time, despite the emergence of a slight optimism, the reliability of the received estimates continues to provoke doubts. The reason for this is that there are many assumptions in the basic data used in the assessment. Some doubts regarding the veracity of the given fishery statistics and the data quality of the surveys exist. Other sources of uncertainty are mentioned below. Estimates have been made only for age groups five years and older due to the fact that survey results on fish younger than five years of age inadequately reflect their real numbers. Individual weights at age are accepted as identical "in catch" and "in stock". The natural mortality (M) is set to 0.15 for all ages in all years. Differences between the sexes other than the maturity ogive have not been taken into account.

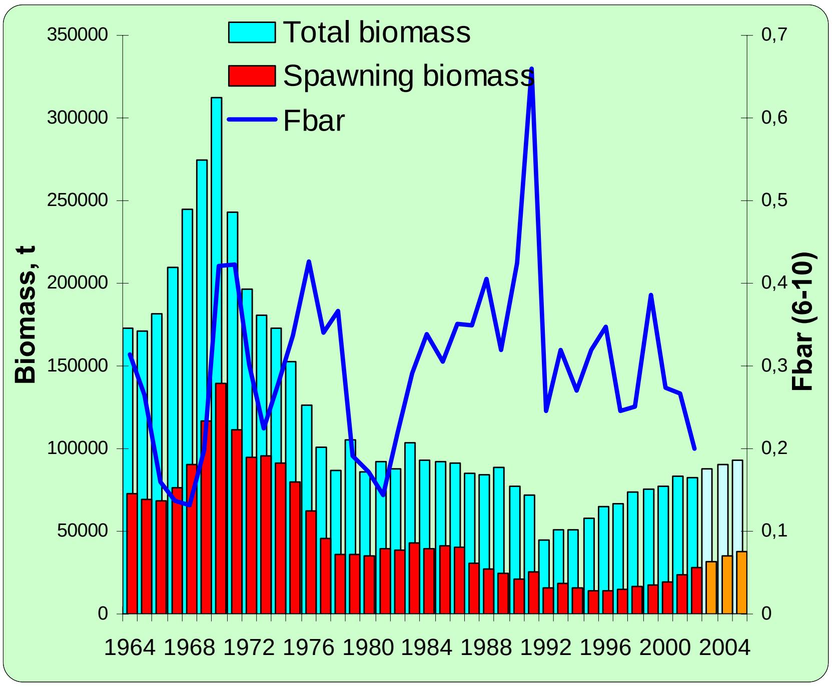

Figure 11. Assessment results of the Northeast Arctic Greenland halibut stock showing the estimated total biomass of five-year-old and older fish, female spawning biomass and the average fishing mortality of ages 6-10. A prediction for 2003-2005 is also shown.

Working Group in 2003 summarized: "Although many aspects of the assessment remain uncertain, nearly all fishery independent indices of stock size indicate positive trends in recent years. However, given the uncertainties in the assessment it is desirable to maintain a relatively low fishing mortality to ensure continued stock improvement. Additional management measures to control catches, e.g. TACs, area closures and reduced by-catch limits, need to be introduced and enforced effectively" (Anon 2003).

Thus, under the existing conditions of uncertainty and, in consequence, the difficulty of defining proper biological reference points, the current strategy of Greenland halibut stock management will be to focus on its rebuilding.

Stock monitoring and form of advice

The Norwegian and Russian authorities have agreed to monitor this stock as a joint stock. The stock is currently being monitored by the scientific surveys listed above, and biological sampling from the international bycatch fisheries and the Norwegian coastal fishery in June.

Currently, a major research and monitoring effort is being devoted to this stock through the three-year (2002-2005) Russian-Norwegian research programme for improvement of future management and advice. This programme is focusing on:

- Distribution and migrations
- Life history, reproductive biology, trophic relations
- Accuracy in determination of age and its influence on the stock assessment
- Improvement of time series by surveys and fishery
- Catchability of research trawls and comparative selectivity of research and fishing trawls and longlines
- Searching the ways of improvement of stock assessment on the basis of fulfilment of all projects
- Development of biological reference points.

Since neither precautionary reference points nor explicit management objectives have been established for this stock, and until the joint Norwegian-Russian research programme is completed, the current form of advice from ICES is to let the stock size further increase. In order to achieve this, landings should be kept at the 2002 level. ICES further advises that additional management measures to control catches, e.g. TACs, area closures and reduced bycatch limits, need to be introduced and enforced effectively.

TAC decision and international/national sharing of the TAC

The Greenland halibut fishery was fully free until 1977 when exclusive economic zones were established in the Barents Sea and the Joint Russian-Norwegian Fishery Commission (RNFC) began to resolve questions concerning exploitation of the Greenland halibut stock. In 1978-1991 Norway allocated annual quotas for the Soviet Union (Russia) in the NEEZ with volumes from 2.0 up to 12.5 thousand tonnes. From 1992, Norwegian and Russian authorities stopped all targeted fishery, except for Norway allowing a limited traditional non-trawl coastal fishery south of 71º30’ N by vessels less than 28 m. The coastal fishery was to be kept at the historic annual level of ca. 2 500 tonnes, but with hindsight, the regulations have not fully succeeded in maintaining the coastal fishery at this low level. The allowable bycatch for other fisheries comes in additional this.

Both countries also catch certain amounts of Greenland halibut during the joint investigations confirmed by the RNFC. Catches taken for scientific purposes are limited by vessel numbers and by the length of time they are present on the fishing grounds. During the past two years restrictions on the catch volume for scientific purposes have been set. In 2002 each of the parties had the right to take 1.5 thousand tonnes, and in 2003 and 2004 - 3 000 tonnes each.

Based on data regarding Greenland halibut distribution and fishery and reference to the historical contribution to research on the stock, the Joint Russian-Norwegian Fishery Commission (RNFC) will make a decision on the future management, utilization and international/national sharing of the TAC of this stock. This will probably take place at the earliest during the 34th Session in 2005, i.e., after the final report from the joint Norwegian-Russian research programme has been submitted. Until then, the present fishery regime will continue in effect. Table 4 shows the recommended, agreed and official catches during the period 1987-2004, while Table 5 and 6 show the decisions made by the Joint Norwegian-russian Fishery Commision in the periods 1978-1991 and 1992-2003, respectively.

Table 4.Recommended, agreed and official catches of Northeast Arctic Greenland halibut in 1987-2004.

Year	ICES advice	Predicted catch corresp. to advice	Agreed TAC	Official catches
1987	Precautionary TAC	-	-	19
1988	No decrease in SSB	19	-	20
1989	F = F(87); TAC	21	-	20
1990	F = F (89); TAC	15	-	23
1991	F at $\mathbf{F}_{med}$; TAC; improved expl.	9	-	33
1992	Rebuild SSB (1991)	6	2.5[1]	9
1993	TAC	7	2.5[1]	12
1994	F < 0.1	<12	2.5[1]	9
1995	No fishing	0	2.5[1]	11
1996	No fishing	0	2.5[1]	14
1997	No fishing	0	2.5[1]	10
1998	No fishing	0	2.5[1]	13
1999	No fishing	0	2.5[1]	19
2000	No fishing	0	2.5[1]	14
2001	Reduce catch to rebuild stock	<11	2.5[1]	16
2002	Reduce F substantially	<11	2.5[1]	13
2003	Reduce catch to increase stock	<13	2.5[1]	
2004	Do not exceed recent low catches	<13	2.5[1]	

For footnote explanation, see Table 6.

Table 5. Decisions made by the Joint Norwegian-Russian Fishery Commission 1978-1991.

Year of regulation, Session #	Main decisions			Details	
	TAC advised by ICES	Total catch in NEEZ	USSR/Russia quota in NEEZ	Other measures	By-catch during shrimp fishery
1978 (4th)	40 000	30 000	12 500	-	-
1979 (7th)	25 000	20 000	7 600	-	-
1980 (8th)	14 000	10 500	2 000	-	-
1981 (9th)	12 000	9 000	2 000	-	-
1982 (10th)	12 000	9 000	2 400	-	-
1983 (11th)	17 000	13 000	5 500	-	-
1984 (12th)	17 000	13 000	5 500	-	-
1985 (13th)	20 000	15 000	7 000	-	-
1986 (14th)	20 000	15 000	7 000	-	-
1987 (15th)	20 000	15 000	7 000	-	-
1988 (16th)	19 000	14 750	6 600	-	-
1989 (17th)	21 000	16 300	8 100 + 3 000	-	-
1990 (18th)	15 000	12 000	4 100	-	-
1991 (19th)	9 000	7 000	2 100	Norway introduced 45 cm as minimum legal catch size for foreign vessels fishing in NEEZ and at Jan Mayen and for Norwegian vessels	300 individuals per tonne of shrimp

Table 6. Decisions made by the Joint Norwegian-Russian Fishery Commission 1992-2003.

Year of regulation, Session #	Main decisions			Details		
	TAC advised by ICES	Total catch in NEEZ[1]	Russian quota in NEEZ	Comments	By-catch during groundfish fishery	By-catch during shrimp fishery
1992 (20th)	6	2 500	-	*Ban placed on the targeted Greenland halibut trawl fishery*	10% in haul	300 spec. per 1 ton of shrimp
1993 (21st)	7	2 500	-	The same	10% in haul	The same
1994 (22nd)	<12	2 500	-	The same	10% in haul	The same
1995 (23rd)	0	2 500	-	The same	5% in haul	The same
1996 (24th)	0	2 500	-	The same	5% in haul	The same
1997 (25th)	0	2 500	-	The same	5% in haul	The same
1998 (26th)	0	2 500	-	The same	5% in haul	The same
1999 (27th)	0	2 500	-	The same	10% in haul	The same
2000 (28th)	0	2 500	-	The same	10% in haul but 5% on board	The same
2001 (29th)	<11	2 500	-	The same	12% in haul but 7% on board	The same
2002 (30th)	<11	2 500	-	The same	12% in haul but 7% on board	The same
2003 (31th)	<13	2 500	-	The same	12% in haul but 7% on board	The same

1 Set by Norwegian authorities. This TAC relates to the traditional non-trawl coastal fishery south of 71°30' N by vessels less than 28 m. Allowable bycatch for others in addition to this. This corresponds also to the regulations set by Norwegian authorities in 1992-1994 although ICES (ACFM) probably included the anticipated bycatch when interpreting the set TAC as being 6, 7 and <12 thousand tonnes, respectively for these years.

Fisheries regulations, enforcement, control and collection of fisheries statistics

Since 1992 the Greenland halibut fishery has been regulated by allowing only a longline and gillnet fishery by vessels smaller than 28 m to be aimed at Greenland halibut. This fishery is also regulated by seasonal closure to keep the total landings comparable to the historic catch level for this group of fishermen. A targeted trawl fishery has been prohibited, and trawl catches are limited to by-catches only. From 1992 to autumn 1994 the by-catch in each haul was not to exceed 10% by weight. In autumn 1994 it was changed to 5% by-catch in each haul, and from January 1999 this percentage was again raised to 10%. In August 1999 it was adjusted further to 10% in any one haul but only 5% of the landed catch. In 2001 the by-catch regulations were again changed to 12% in any one haul and 7% of the landed catch.

The control of by-catches at sea is carried out by the Norwegian and Russian Coast-guards and observers (both military (Russia) and civilian (both countries)) on board fishing vessels, while inspectors audit vessels as they unload their catches in harbour.

A minimum legal catch size for Greenland halibut has not yet been stipulated and implemented in the Russian fishery regulations. In 1992, Norway introduced a minimum legal catch size of 45 cm for foreign vessels fishing in NEEZ and at Jan Mayen and for Norwegian vessels irrespective of fishing area on this stock, with permission to fish and keep up to 15% undersized specimens in each haul. When operating in NEEZ, Russian fishermen are required to follow Norwegian rules.

An additional measure aimed at the protection of young Greenland halibut in the Barents Sea is closing of areas for shrimp fishery in cases of excessive by-catches of

Greenland halibut. Russia and Norway have agreed to close and protect geographical areas from shrimp fishing if the number of Greenland halibut per 10 kg shrimp exceeds three.

Russian fisheries statistics are based on daily reports from the vessels to the All-Russian Research Institute of Fisheries and Oceanography (VNIRO, Moscow). Data are then reported to ICES by ICES areas and gears.

Norwegian fisheries statistics are based on sales notes of landed Greenland halibut at fishing ports reported to the Directorate of Fisheries. For trawlers, the sales note statistics are compared and quality checked with the log-books. Data are then reported to ICES by ICES areas and gears.

Other countries report to Norway when fishing in the NEEZ and at Svalbard, and to Russia when fishing in the REEZ. In cases where third countries have not reported to ICES, scientists use these countries' reports to Norway and Russia to obtain the total international catch to be used as input in the assessment.

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W.R. Bowering and D.B. Atkinson: Greenland halibut stocks in Canadian and NAFO waters

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Abstract

Greenland halibut *(Reinhardtius hippoglossoides)* is a large Pleuronectiform flatfish and because of its unique characteristics, it is the only species in the genus *Reinhardtius*.

Among its more interesting features are 1) dark coloration on both sides, unlike almost all other flatfish species, which are usually white on the underside; 2) that the left eye is not fully migrated, giving it an unusually wide range of peripheral vision; 3) an elongated shape and muscle arrangement which are characteristic of a powerful swimmer (often observed on the surface of the sea) and 4) studies of its physiology indicate it can control its gravitational position when swimming either vertically or horizontally.

Greenland halibut in the Northwest Atlantic are widely distributed from high in the Arctic between Canada and Greenland to as far south as the Scotian Shelf, although it is most abundant from the eastern Grand Bank and Flemish Cap beyond the Canadian 200-mile limit and north to the Davis Strait. The Greenland halibut is a deepwater species with higher densities concentrated primarily at depths of about 500-1200 meters along the continental slope and within the deep channels running between the fishing banks on the continental shelf as well as the deep inshore bays of eastern Newfoundland and the fjords of Greenland and Baffin Island. In recent years, with the advances in modern fishing technology, it has been found to be commercially abundant in some areas as deep as 1500-1800 meters, particularly in NAFO Division 3LMN throughout the Flemish Pass. It has also been caught in longline investigations as deep as 2200 meters, both off West Greenland in the north and in the Flemish Pass. While the more extensive distribution is along the eastern continental shelf, it is also of commercial importance in the Gulf of St. Lawrence and exists in limited quantities along the south Newfoundland coast, Fortune Bay and in the Laurentian Channel.

Although regarded as a single stock complex throughout the Northwest Atlantic it is managed by the several units. The NAFO Subarea 2 and Div. 3KLMNO unit which extends from northern Labrador to the southern Grand Bank including Flemish Cap is the most heavily fished and extensively studied. The fishery essentially began in this area during the 60s in deep Newfoundland inshore bays in Div. 3KL with the development of synthetic gillnets. Large non-Canadian trawlers (mainly from the USSR, Poland and GDR) entered the fishery in the 1970s, fishing the slope areas largely as by-catches in the roundnose grenadier fishery. With the introduction of the 200-mile limit in 1977, most non-Canadian effort was phased out of the Canadian zone. Since then, however, a large non-Canadian fishery developed in the NAFO Regulatory Area (NRA) of Div. 3LM by 1990, primarily by Spain and Portugal, with considerable catches also being taken by Russia and Japan. The fishery in the NRA has comprised the largest component of the SA2 and Div. 3KLMNO since then.

Catches averaged about 30 000 tonnes during the 1970s then declined in the 80s. During the early 90s catches rose to over 60 000 t but in 1995 declined to 15 000 t following the infamous "turbot war" between Canada and the European Union. Since then catches have increased again to 36 000 – 38000 t by 2000-02. Total allowable catches (TAC's) were set unilaterally by Canada from 1974 to 1994 and by the NAFO Fisheries Commission since then.

The assessment of this stock is undertaken by the NAFO Scientific Council on an annual basis. Based on the most recent analytical assessment in June 2003, the fishable stock has declined in recent years and by 2003 it was the lowest ever observed. Fishing mortality peaked in the early 90s then declined substantially in 1995 as the NAFO Fisheries Commission introduced its first TAC, which was well below recent catches. However, fishing mortality has been increasing systematically since then. The fishery in recent years has consisted primarily of the above-average 1993-95 year-classes. Subsequent year-classes are well below average and these are the ones which will make up the fishery over the next several years.

This resource has been managed by annual quotas split between the coastal state (Canada) and various member states of the NAFO Fisheries Commission, with all non-Canadian catches taken in the NRA. The management approach has largely been based on scientific advice from ICNAF since 1974 and NAFO from 1979 on. Within Canadian waters the minimum mesh size is 145 mm for both otter trawl and gillnets, while for gillnets fishing depths of more than 400 fathoms the minimum mesh size is 190 mm. More recently, in order to protect snow crab populations, fishing for Greenland halibut is not permitted in depths of less than 300 fathoms. On the other hand, the minimum mesh size in the NRA is 130 mm with no depth restrictions. Additional measures include a minimum fish size of 45 cm within Canadian waters, whereas the minimum size in the NRA is 30 cm.

A. C. Gundersen[1], E. Hjørleifsson[2] and H. Siegstad[3]: Greenland halibut in the waters of East Greenland, Iceland and Faroe Islands

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Stock perception and status

Distribution

In recent years, the Greenland halibut in the waters of East Greenland, Iceland and the Faroe Islands have been referred to as West-Nordic Greenland halibut. In 1976 ICES defined the Greenland halibut in these waters as a single stock. Their argument for defining this as a separate stock component was: "... based on a strong probability that the spawning grounds [for Greenland halibut in these waters] are the same".

West-Nordic Greenland halibut are widely distributed (Figure 1). In East Greenland waters the main concentrations are found along the continental slope down to about 1600m.The species is also found on the continental shelf and in the fjords of East Greenland from Cape Farvel (60°N) north to Ammassalik (about 66°N) (Gundersen and Woll, 1997; Woll and Gundersen 1997). The Greenland halibut is also observed further north in the fjords of the Scoresbysund area.

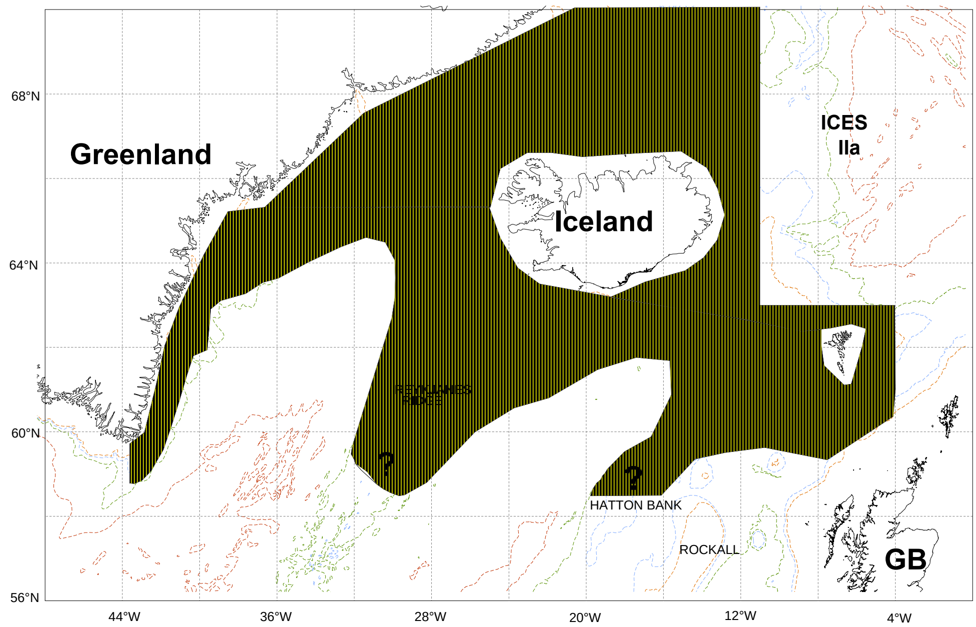

Figure 1. Distribution of West-Nordic Greenland halibut in the waters of East Greenland, Iceland and Faroe Islands.

The Greenland halibut is distributed continuously from the waters of East Greenland eastwards along the slope in the Denmark Strait towards Iceland. In Icelandic waters, Greenland halibut is mainly found in the slope areas. Its main area of distribution is off the west and north-western part of Iceland, but it is found in all areas (Hjørleifsson *et al*. 1999).

In the waters of the Faroe Islands the Greenland halibut is found in the cold water masses that flow southwards east of Faroe Islands, through the channel between the Faroe Islands and Shetland and the Faroe Bank channels. The cold water masses then flow northwest-wards along the Faroe-Ìceland Ridge. It is usually found at depths below 400m (Reinert *et al.* 2001).

Recent years have seen a focus on tagging of Greenland halibut. In Icelandic waters 1786 Greenland halibut were tagged and of these, 57 were recaptured in 2000-2002 (Hjørleifsson and Egilsdottir 2003). Recaptures mainly showed migrations within Icelandic waters. However, five recaptures were made within the Faroese EEZ.

In Greenland tagging of Greenland halibut has been carried out for a long time. Recaptures have indicated extensive migrations, *e.g.* from the Davis Strait to Canada, as well as East Greenland, from Baffin Bay towards inshore waters of the Disco area as well as the Davis Strait, and finally from East Greenland to the Faroe Islands.

Biology

Hjørleifsson *et al.* (1999) summarized the current state of knowledge on West-Nordic Greenland halibut and found that key information on the life cycle was lacking. Since then several studies focusing various life cycle stages have been performed (Boje and Hjørleifsson 2000; Woll, 2000; Gundersen, 2002).

The Greenland halibut is a large flatfish (size ranging up to 120cm) and is one of the top predators in the marine community. It feeds on other fish species as well as crustaceans (*e.g.* Jørgensen 1997; Michalsen and Nedreaas 1998, Woll and Gundersen, *submitted*).

Biological information on the West Nordic Greenland halibut is still insufficient with respect to the reproduction biology, recruitment, size composition and dynamics of the spawning stock.

Information about spawning location and time is limited. In the spring of 1997 an Icelandic scientific bottom trawl cruise was carried out west of Iceland and the results of this survey led to the hypothesis that the major spawning grounds are located on the continental slopes west of Iceland at depths around and below 1 000 m (Magnusson, 1977; Sigurdsson and Magnusson, 1980). In recent years (1995 and 2000), some spawning has been observed in East Greenland waters (62°N and 64°N) in August (Gundersen *et al*., 2002). In Faroese waters no spawning areas have been described so far. However, in 2001 nine females with large eggs (>2.5 mm in diameter) were observed in the gillnet fishery in July on Munkagrunn, south of the Faroe Islands. In addition, one male with fully developed gonads was observed (L.H. Ofstad, Faroese Fisheries laboratory *pers. comm.*). Although actual spawning has not been observed, this indicates that there may be spawning in the Faroese area. In waters off West Greenland Jensen (1935) and Smidt (1969) described spawning in the continental slope, where cold-water masses dominated. A spawning migration has been described as occurring from the fjords of West Greenland to these deepwater areas. However, tagging experiments reported by Riget and Boje (1989) could not verify this spawning migration. Eggs floating freely in the water masses are rarely seen.

Bathypelagic eggs have been observed on the continental slope west of Iceland (Magnusson 1977). Icelandic 0-group surveys have shown the presence of drifting eggs and larvae, mostly in East-Greenland waters (Figure 2). Surveys were conducted as standard 0-group fish surveys and were carried out annually in early fall (mainly in August) in Icelandic and in East Greenland waters during 1970-1996. Since 1996 survey coverage has been reduced, and it now covers only Icelandic waters. Larvae were mainly observed along the shelf region off East Greenland, and in some years were abundant all over the shelf area south to 60°N. The highest abundances were observed on the continental shelf north of 64°N and just east of the continental shelf south of 64°N. 0-group larvae are only occasionally observed on the Icelandic shelf and in very limited numbers. In Faroese waters a few observations of Greenland halibut eggs and larvae have been made in the area west of the Iceland-Faroe-Ridge. These observations are rare and go back in time some years (J. Reinert, Faroese Fisheries Laboratory *pers. comm.*). Existing egg and larval surveys in the Faroese area have been designed for other species than Greenland halibut, so the likelihood of observing Greenland halibut egg and fry has been reduced in recent years.

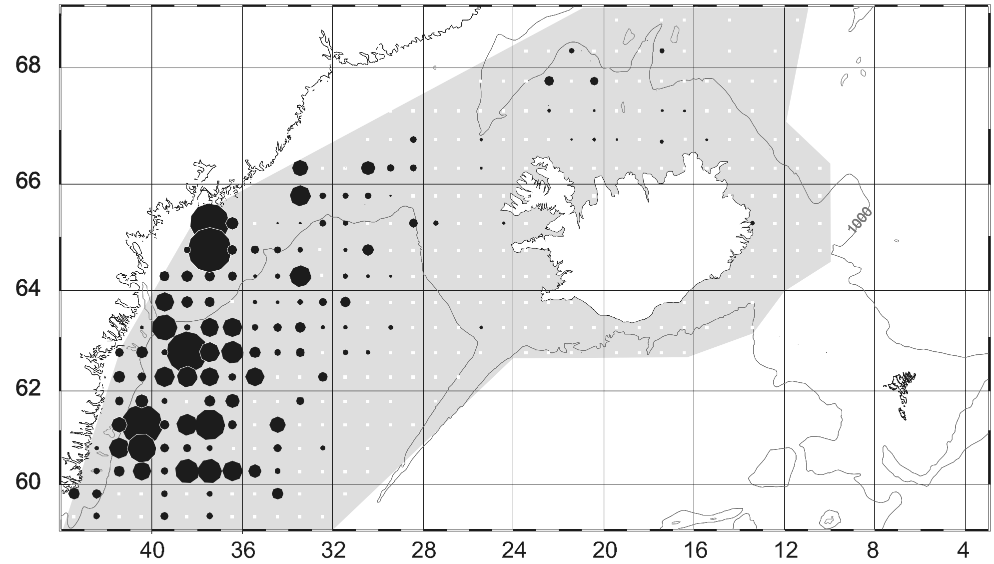

Figure 2. Relative abundance of pelagic Greenland halibut larvae from annual 0-group surveys 1970-1996. The shaded area denotes the coverage of the survey area, black circles the average number of larvae per tow within 1° longitude and 0.5° latitude and the white circles denote areas where Greenland halibut larvae have never been observed (From Hjørleifsson *et al*. 1999)

The nursery grounds are still not completely mapped for the West Nordic stock of Greenland halibut. During a large scale mapping survey in 1998 Greenland halibut aged from one to four years were observed in South-Greenland, on both the western and eastern side, although only in small numbers (Woll *et al.*, 2000). One reason for our lack of knowledge is that areas have difficult bottom topography and steep slopes, which makes it difficult to trawl and to fish with fine-meshed gillnets. Results from historic ichthyo-plankton surveys (Boje, 1997) indicated that larvae were transported to Southwest Greenland waters before settling. Analyses of shrimp surveys in Icelandic and Greenland waters (Boje and Hjørleifsson, 2000) concluded that it was unlikely that the main nursery grounds were to be found neither in Icelandic nor in East Greenland waters. Ådlandsvik (2000) modelled advection of eggs and larvae based on existing knowledge of prevailing current patterns in the area. Spawning products were released into a current model at assumed spawning locations southwest of Iceland (Magnusson, 1977; Sigurdsson and Magnusson, 1980) and at 62°N off East Greenland where spawning has been observed (Gundersen *et al.* 2002). A drift period of five to six months was assumed and the model output indicated that larvae would settle on the banks of West-Greenland, possibly mixing with specimens from the Greenland-Canadian stock complex.

In recent years the reproductive biology of West-Nordic Greenland halibut has been focused on (Tuene *et al.* 2002 a,b). In general, the onset of sexual maturity is often determined by the length of the fish. Greenland halibut are described as maturing at the ages of four to six and nine to ten years of age for males and females respectively (Millinsky, 1944; Smidt, 1969; Kovtsova and Nizovtsev, 1985). This corresponds to overall lengths of 40-60 cm and 60-80 cm respectively. In the Barents Sea (Fedorov 1968; Albert *et al*, 2001; Gundersen *et al*., 2001a) and in the Flemish Pass area (Junquera and Zamarro, 1994).

Greenland halibut are described as having a peak spawning period. However, in the same areas spawning is found nearly all year round, although to a limited extent. A less extensive second peak spawning period may be seen four to five months after peak spawning (Fedorov, 1968; Junquera *et al.* 1994; Gundersen *et al.* 2001a). Junquera *et al* (2003) found that the there was some variability between years with regards to when mass spawning occurred in the Northwest Atlantic.

History of Fisheries

The Greenland halibut fishery is a targeted fishery. No extensive bycatch is taken in the fishery. In the longline fishery one may see bycatch of Roughhead grenadier (*Macrourus berglax*) and some Blue antimora (*Antimora rostrata*) when fishing at a particular location starts, but after a few days catches consist almost entirely of Greenland halibut (Gundersen *et al.* 1997).

In the waters of East-Greenland, Iceland and Faroe Islands, the highest aggregation of commercial-sized Greenland halibut is found just south of the Greenland-Iceland ridge (Figure 3). In this area most of the annual catch has been taken during the past 10 to 15 years. Most fishing takes place at depths of 500 and 1 000 metres. Other locations where Greenland halibut are found in exploitable densities for trawl fisheries are found along the north and east coast of Iceland, mainly at depths of between 500 to 700 metres, in the waters of the Faroe Islands, as well as along the continental slope off East Greenland. The size of the Greenland halibut in the trawl fisheries depends largely on location and depth and to a certain extent on the season. In Icelandic waters, smaller fish are found along the east and north coast, with somewhat larger fish in the deeper waters south of the Faroe-Iceland ridge. However, the largest fish are always found on the main fishing grounds between Iceland and Greenland.

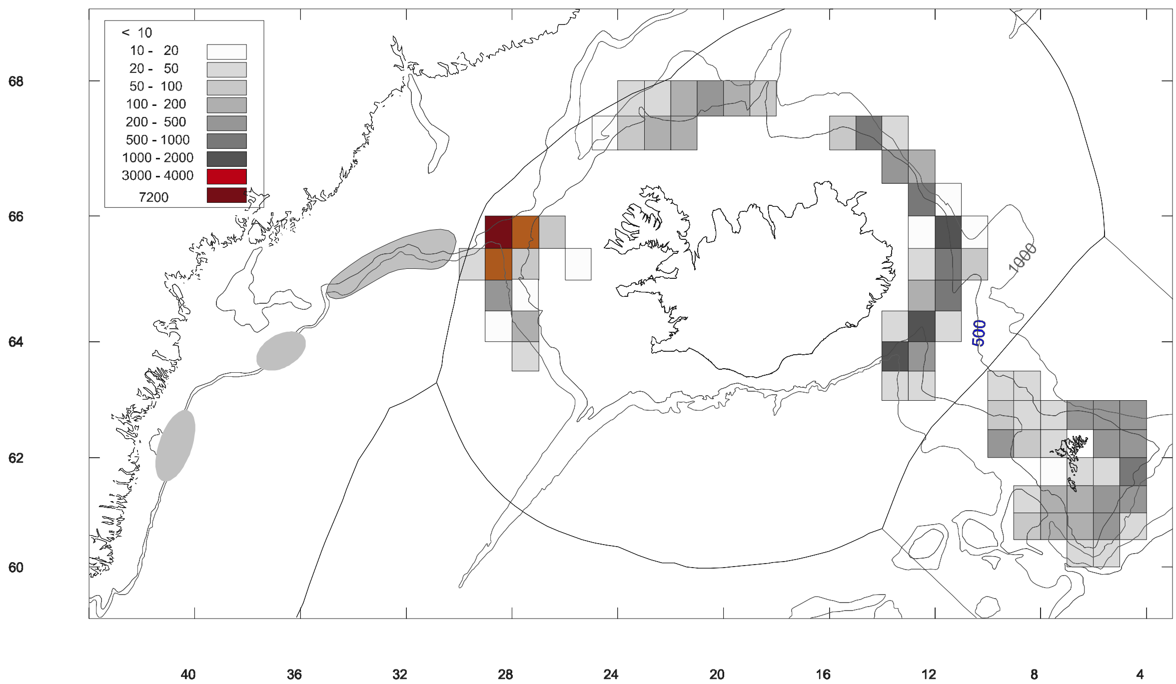

Figure 3. Main fishing locations for West-Nordic Greenland halibut (From Hjørleifsson *et al*. 1999).

Landings of the West-Nordic Greenland halibut have varied. In 1987–1989, landings reached a maximum of about 61 000 tonnes, followed by a decrease to about 35-40 000 tonnes during 1992-96 (Figure 4). After 1996, landings declined to 20 000 tonnes in 1998 and 1999. Since 2000, landings have increased again, reaching 29 000 tonnes in 2002 (ICES 2003). The observed reduction in landings in the late 90s was primarily due to the reduced TAC for fleets operating in Icelandic waters. Landing from Icelandic waters thus declined from 37 000 tonnes in 1990 to 11 000 tonnes in 1998-1999. Faroese landings have been of the order of 1 000-6 500 tons; whereas the landings reported in the East-Greenland zone have been in the range 1 000-8 500 tonnes, with a maximum in 1997.

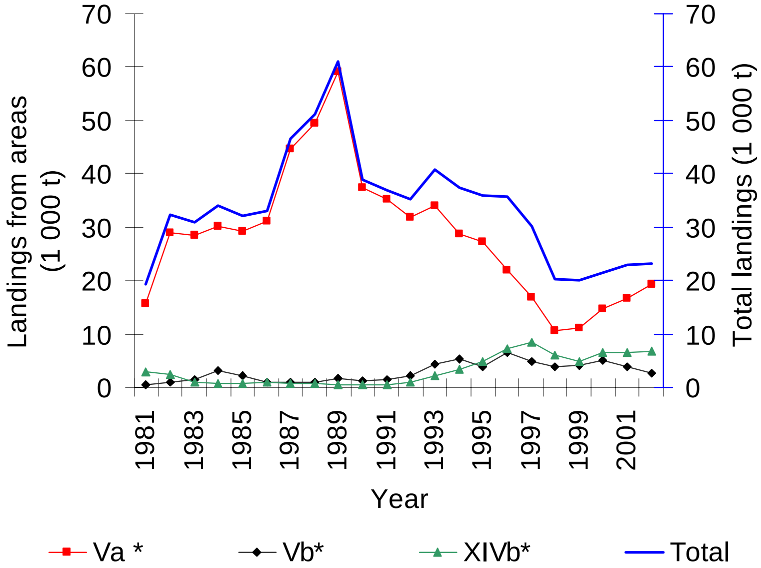

Figure 4. Landings of West-Nordic Greenland halibut related to the three main areas (Iceland (Va), Faroe Islands (Vb) and East Greenland XIVb). Numbers include landings as reported by national authorities and ICES (ICES 2003).

In **East Greenland waters** (ICES XIVb) the main trawling grounds are found along the continental slope between 63°N and 65°N in the areas of Heimland Ridge and Dohrn Bank. Some trawling also takes place further south on the slope west of Kap Bille Bank (62°N). Longliners mainly fish along the slopes and on the bank plateaux below the slopes. The main fishing areas are Kap Bille Banke (62°N), Fylkir Banke (63°N) and Heimland Ridge (63°-64°N). Examples of length distributions from longline and trawl catches of Greenland halibut from ICES XIVb are shown in Figures 5 and 6. The fishery in XIVb is a new fishery which has increased from below 500 tonnes annually before 1991 to about 7000 t during 1999-2002.

For Division XIVb, logbook data were available from German, Norwegian, Faroese, Russian, Japanese and Greenland fleets (Figure 7). The CPUE derived from logbooks was standardised using a multiplicative model (ICES 2003). Effort increased continuously between 1991and 1997, after which a decline was seen until 1999 (30%). Effort has increased again since then. However, as the fishery must be described as being in the process of learning in the early years where logbooks are available log-books, one should not conclude that increased CPUE necessarily means an increase in stock.

In **Icelandic waters** the main fishing grounds are located in the western parts of the Icelandic zone in the Denmark Strait (Figure 3). However, fishing is also carried out along the northern and eastern side of Iceland. The fishery is almost entirely carried out by the Icelandic trawl fleet (Figure 8).

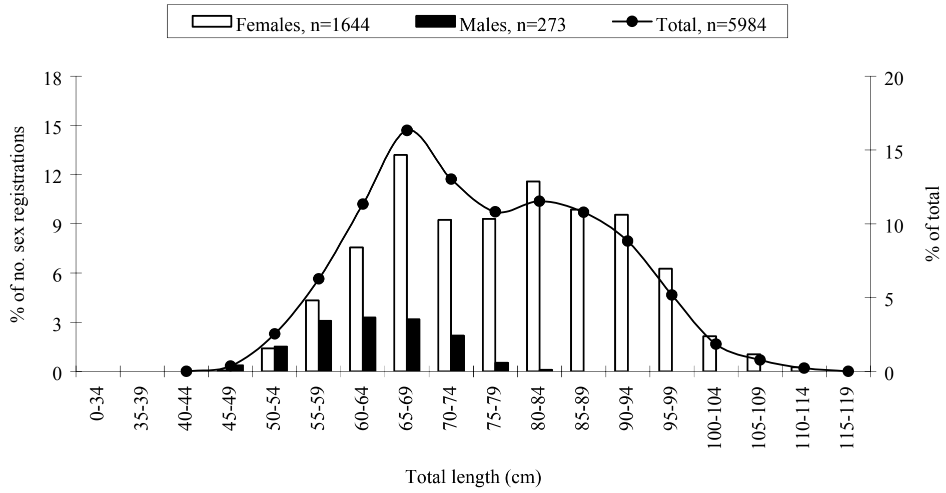

Figure 5. Length distribution of Greenland halibut, males and females, taken by longlines in the Kap Bille Bank 62°10N-40°12W in ICES-area XICb in July-August 1996.

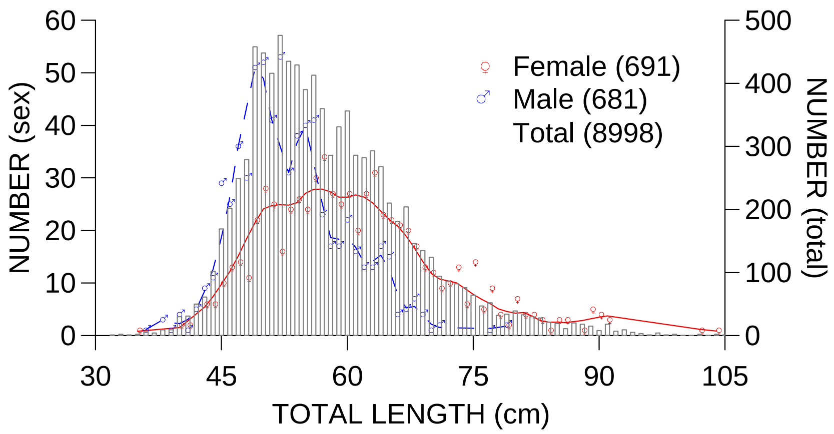

Figure 6. Length distribution of Greenland halibut caught by trawl in ICES XIVb in August 2000.

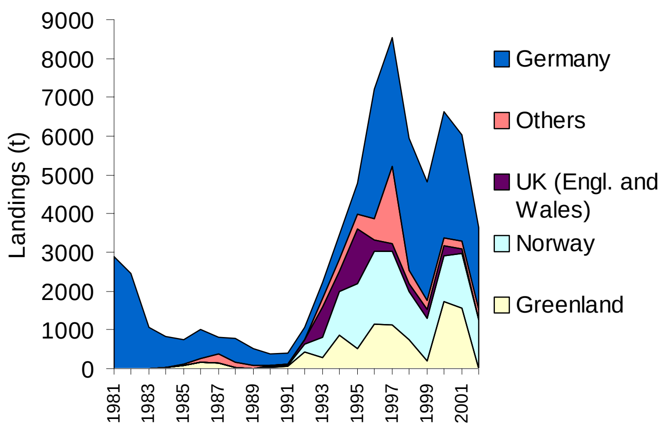

Figure 7. Landings in ICES XIVb by nation. Other countries include Denmark, Faroe Islands, Iceland, Portugal, Russia and Spain (ICES 2003).

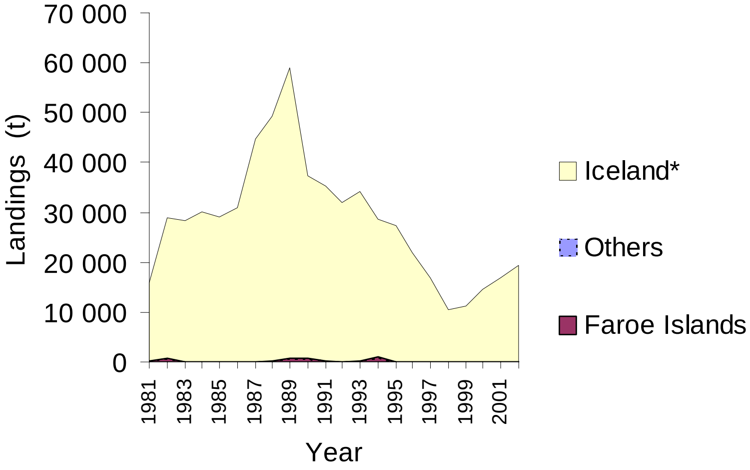

Figure 8. Landings in ICES Va by nation. Other countries include Germany, Greenland, Norway, and UK (ICES 2003).

ICES (2003) describe trends in landings and fisheries for the stock. A CPUE series for the Icelandic trawl fleet has been derived using a GLIM multiplicative model. The period of studies was 1985-2002. A fall in catch rates was seen during the early 90s. In 1995-1997 they stabilised. In 1998 effort was reduced by about 60 % leading to an increase of 60% in CPUE. In 1999-2001 CPUE increased slightly (4-15%). In 2002 effort whereas CPUE decreased by more than 50 % leading to a reduced CPUE by 24%.

In **Faroese waters** the Greenland halibut fishery is rather new. The fishery has taken place on both the eastern and the western sides of the islands. Catches are mainly taken by the Faroese fleet, but other nations also participate (Figure 9). Log-book series are available as far back as 1991 (ICES 2003). During 1995-1998 the fishery mainly occurred in the eastern side of the Islands, but since 2000 fishing has moved to the western side.

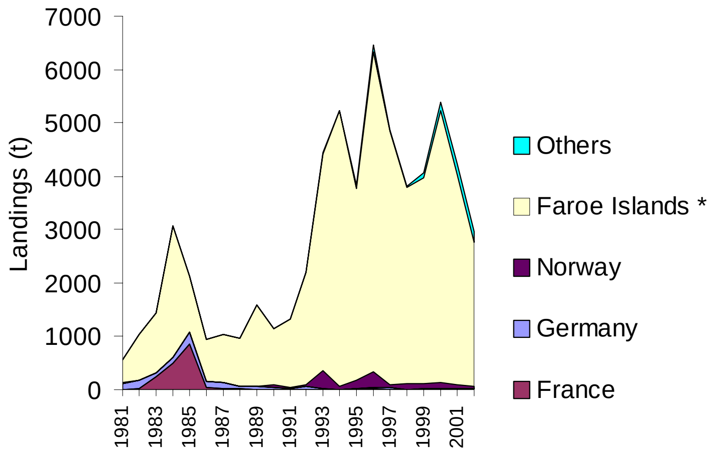

Figure 9. Landings in ICES Vb by nation. Othercountries include Denmark, Greenland, Iceland, Ireland and the UK (ICES 2003)

Based on log-book information from Faroese trawlers (otter-board trawlers > 1 000 hp) a CPUE series has also been established for the Faroese waters (ICES 2003). The logbooks were standardised with a multiplicative model using logCPUE as the dependent variable and taking into account locality, vessel, month, and year. As the fishing locations have changed during the period and as the fishery is new, growing from about 1 500 t in 1991 to 5 000 t in

2000 it has been regarded as being in the processes of learning for at least parts of the period. CPUE decreased in the early period by about 10% coinciding with a significant increase in effort. Since 1994 CPUEs have been stable and effort has thus followed the development of the catches.

Assessment

Traditionally, the stock was assessed using XSA. The XSA for 2000, however, was regarded as being unreliable due to poor diagnostics. XSA was therefore rejected by ACFM as a basis for advice.

Greenland halibut are currently assessed by means of a stock production model (ASPIC). In such models the development of the population is described by only two parameters: i) a growth parameter which is supposed to handle the bookkeeping of growth, natural mortality and recruitment, and ii) a constraint parameter, often referred to as maximum carrying capacity. The former parameter describes the increase in biomass at low stock size. The latter in essence puts a constraint on the increase in biomass when the stock size is high. The employment of a stock production model may be a reasonable approach for long-lived species with relatively little variability in recruitment between years. Such models are often the only alternative to more data-intensive models such as catch at age models, particularly in cases when age determination is regarded as unreliable. Age determination has been problematic for the Greenland halibut (ICES 1997). Recent development in the implementation of stock production models have been the inclusion of some estimates of the variability in the data which allow some description of the uncertainty in the biomass and exploitation rate.

The input data to the stock production model are the annual yield that is removed from the population and indices that describe the changes in population size. In the current assessment of Greenland halibut the indices used to reflect changes in population size are CPUE by the Icelandic trawler fleet (1985 onwards) and biomass indices from the Icelandic autumn survey (1996 onwards). The most critical aspect of the model is the assumption that stock biomass (B) is directly proportional to the abundance indices (I, ie B=qI). It is not known if this assumption holds true, particularly when one uses non-standardized indices, such as the one from the Icelandic trawl fleet. Although the commercial indices are to some extent standardized with regards to location, season and vessel, the standardization does not capture changes in gear development or other technological improvements that are not systematically recorded in logbooks. Such factors may contribute to keeping CPUE high even though the actual biomass may be declining. It should be emphasized that violations in the assumptions of the model are not reflected in the description of the uncertainty in the current model implementation. This implies that uncertainty related to running ASPIC is related to input data.

According to both the former XSA and the recent stock production model (ASPIC) it is evident that the Greenland halibut stock biomass has been falling since the late 80s (ICES 2003). Since 1998 the observed decline in biomass has halted. However, stock biomass is still well below $\mathbf{B}_{MSY}$. F (fishing mortality) has been above what is defined as $\mathbf{F}_{pa}$ for the past ten years. ICES (2003) states that both unreliable maturity data and age readings from recent years impede any age-disaggregated assessment. In turn this impedes any estimate of SSB. ACFM (2003 spring) states that the stock is being harvested beyond safe biological limits.

In 2003 MSY was estimated at 35 000 t and B_{msy} at 114 000 tons. Total biomass estimated in 2003 is about 22% below $B_{msy,}$ and fishing mortality in 2002 is estimated to be 10% above F_{msy}. Biomass was at a record low in 1998. Since then it increased by about 25% until 2003. During the 90s fishing mortality has been high. In some cases it has been 60%

above F_{msy}. However, since 1998 fishing mortality has been more stable, at a level close to or above F_{msy}.

Management and advice

During its spring 2003 meeting ACFM stated that the recommended fishing mortality should be reduced to below 0.67 * F_{MSY}. This corresponds to F_{pa} which is the upper boundary for F.

If F is kept at the F_{PA} it is likely that the biomass will increase. The probability of reaching B_{MSY} by 2005 is 50%.

Fishing at the level of today (F status quo) which is near $F_{MSY,}$ corresponds to a catch close to 33 000 tonnes. At this level it is likely that the biomass will remain low and not reach $B_{MSY,}$ and there is a risk that the stock will collapse.

ACFM also points out that due to our lack of knowledge concerning nursery grounds, combined with the fact that Greenland halibut is a slow-growing species which first appears in catches at the age of five, possible recruitment failures will not be detected until 5-10 years after their occurrence.

While no joint management agreement among the three nations exists, it is very likely that total yield will consistently exceed future advice. If future recruitment, growth and mortality are similar to what they have been in the past, the current management practice will probably lead to a stock size that is below that capable of generating an optimum yield in the long term.

How can we improve management?

Establishment of a common agreement among coastal nations is essential to improve the current situation. Spawning entities often constitute one of several baselines for establishing regulation regimes between coastal states. The definition of West-Nordic Greenland halibut as a single stock in 1976 by ICES was based on the probability of one common spawning ground. A spawning ground was described west of Iceland (Magnusson, 1977; Sigurdsson and Magnusson, 1980). In recent years spawning has been observed in East Greenland waters (Gundersen *et al*., 2002). The extent of spawning has not been well described in either of these areas. This probably makes the situation more complex and it is evident that focus should be put on these topics in order to improve our basic knowledge of the biology of Greenland halibut.

The data that form the basis for stock assessments have been of variable quantity and quality. Data have not been collected from all sub-areas in all years, which means that data from other sub-areas have to be employed. Maturity data have been insufficient and of variable quality. In some years a running average or the previous year’s data have been used because of a lack of field observations. Inconsistent determinations of maturity may be a problem for Greenland halibut. Comparisons between macroscopically determined maturity in the field and in the laboratory have shown differences, which are also found when macroscopic and microscopic maturity determinations are compared (A.C. Gundersen, unpublished data). Studies involving comparisons between the different methods and considering alternative ways of measuring maturity should be emphasised. Alternative methods might include gonadal indices, for example.

Estimates of spawning stock size or biomass are the one of the assumptions employed for making projections and predictions of stock development. Inconsistency in maturity determinations may therefore lead to bias in spawning stock estimates. Attention needs to be paid to sampling strategies and to timing of sampling. Experience gained in large-scale maturity studies in the Barents Sea has shown the presence of an annual maturity cycle

(Gundersen *et al*, in prep) with the majority of the ovaries preparing for a peak spawning season in November - January. However, females in maturing and spent condition are seen throughout the year. This has also been found in other areas such as the Flemish Pass area (Junquera and Zamarro, 1994). Even if spawning does occur year around it is likely that the peak spawning event will be the major contributor to the maintenance of stock size. Timing of sampling may therefore be important in improving maturity data. To pick up the spawners that will contribute during the next peak spawning period it is essential to conduct sampling just prior to spawning e.g. during the previous two to four months. If this is done at other times we may pick up females in maturation for off-season spawning and at present we do not know the significance of their contribution to stock production. This may lead to overestimates of the spawning stock which is actually contributing to the main spawning. To be able to determine time of sampling studies focusing on determining peak spawning seasons and reproductive behaviour should be emphasised.

Recently, fecundity (potential egg production) data have been made available for several components of the Greenland halibut stock in the area (Gundersen *et al.*, 2001b, Gundersen 2002). Fecundity may provide a link between spawning females and the forthcoming offspring. Implementations of egg production may be an interesting approach in future stock assessments. Estimates of total egg production of Greenland halibut have been carried out both for West-Nordic Greenland halibut (Gundersen *et al*. 2002) and in the Barents Sea (Gundersen *et al.,* 2000). When it comes to collecting data for fecundity studies, timing of sampling should betaken into consideration. Degeneration of developing oocytes in Greenland halibut ovaries has been well described (*e.g.* Fedorov, 1971; Walsh and Bowering, 1983*;* Junquera *et al.* 1999; Tuene *et al*., 2002 a,b; Gundersen *et al.* in prep). Atresia has also been observed in relatively well-developed ovaries (Gundersen *et al.* in prep) and it is important that ovaries are collected not too early in the maturity process, as it is that sampling should not overlap with peak spawning.

As ageing Greenland halibut is still a challenge (ICES 1997), it is important to develop ageing techniques further. Ageing is particularly difficult for older individuals.

Alternative models in assessment may be something to look into in the future, *e.g.* length-based assessments (*e.g.* BORMICON*)*. Splitting spawning stock by sex, implying that the spawning stock consists only of females, may be something else to look into in more detail .

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SESSION 3: Crustaceans

Shrimp

M. Aschan[1], S. Bakenev[2], B. Berenboim[2] and K. Sunnanå[1]: Management of the shrimp fishery (*Pandalus borealis*) in the Barents Sea and Spitsbergen area.

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Stock characteristics

The shrimp (*Pandalus borealis*) is a protandric hermaphrodite that changes sex from male to female at an age of four to seven years in the Northeast Atlantic (Nilssen and Hopkins 1991). The shrimp spawns in autumn and the females carry their eggs as out roe until spring, when the larvae hatch. Within a period of two to three months the shrimp larvae pass through seven developmental stages whereafter they settle on the bottom (Shumway et al. 1985, Bergstrøm 2000).

The shrimp is an opportunistic omnivorous feeder and its food may consist of polychaetes, mollusca, crustaceans as well as detritus. It is an important prey for cod, ray, long rough dab and Greenland halibut. In the Barents Sea it is distributed from the North Norwegian coast to North and East of Svalbard at depths of 100-600m. The highest historical densities have been observed in the Hopen deep.

Genetic investigations have demonstrated that there are no distinct sub-populations in the open sea, and that there is a high degree of genetic variance among individuals within each location (Drengstig *et al.* 2000, Martinez *et al.* 1997). Shrimp in the North Norwegian fjords are considered to be isolated populations. Genetic gradients related to geographic distance and sea currents have been identified in the open sea. Data on larval hatching, development, and behaviour of shrimp larvae have been obtained from field and laboratory experiments and have been used as input data for particle tracking and biological models. This reveals that the majority of shrimp larvae settle approximately 80 km from the spot where they have hatched (Pedersen *et al.* 2002). For this reason, the shrimp in the Barents Sea and Svalbard area is considered as one stock.

History of the Fishery

Norwegian vessels began to exploit the shrimp fisheries in the Barents Sea and Svalbard area in 1970. Russian vessels entered the shrimp fishery in 1974. The catches increased continuously (Figure 1.) until 1984 when the total catch reached a maximum of 128 000 t. By that time vessels from other countries had entered the fishery. Since then, biomass and catch levels have fluctuated due to variation in recruitment, predation by cod and fishing effort. The catch peaked at 81 000 tonnes in 1990 and at 82 000 tonnes in 2000, and the lowest catch was 25 000 tonnes in 1995.

Reported landings for 2002 for all countries are 60 000 tonnes, however, the preliminary estimate for 2003 is around 36 000 tonnes.

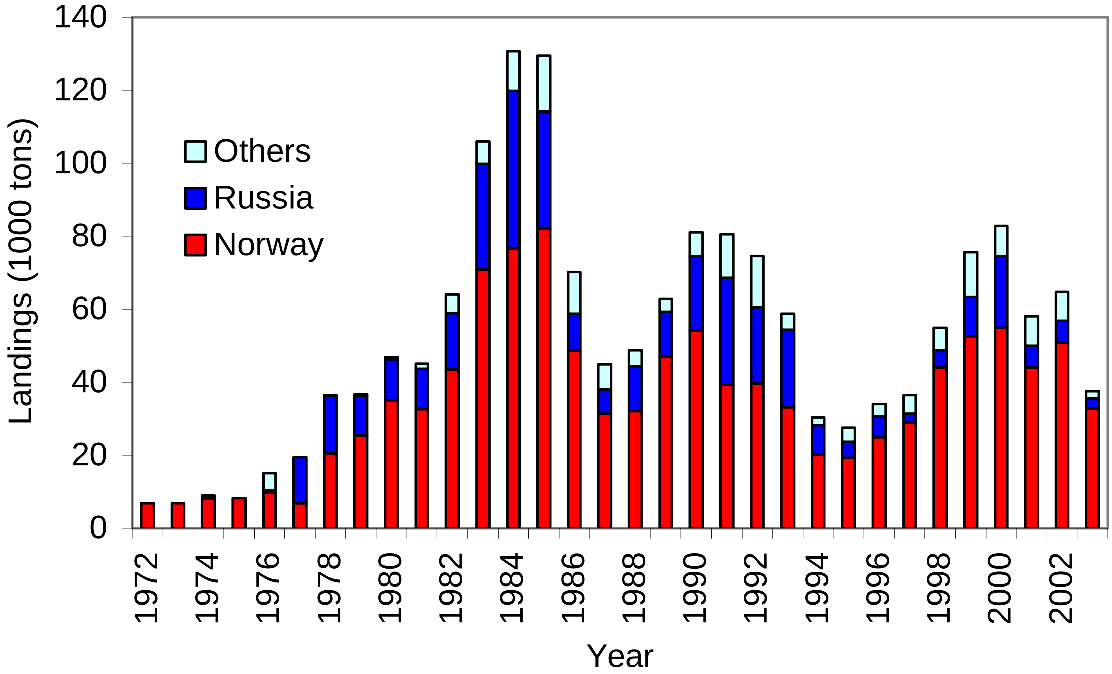

Figure 1. Shrimp landings from ICES areas I, IIa and IIb by Norway, Russia and other countries in the period 1970–2003.

Management strategy

Fisheries regulation

There is no direct regulation of the shrimp fishery with the aim of maintaining a stable standing stock and a good annual catch. In the Svalbard area the shrimp fisheries are regulated by number of effective fishing days and number of vessels by country. Fishing grounds are closed if by-catch limits defined as number of individuals of other species per 10 kg of shrimp are exceeded. In 2003 the values of permitted by-catch were set at eight for the sum of cod and haddock, ten for redfish and three for Greenland halibut. The Norwegian shrimp fishery is also regulated by smallest allowable shrimp size (maximum 10% of catch weight may be < 15 mm carapace length, CL) and by provisions of the fishing licences. In the Russian Economic Zone, a TAC is established each year by the Russian authorities. The assessment and prognosis are based on analysis of logbook statistics from the shrimp fishery and annual surveys.

Fishing effort and CPUE

Catch, effort, and annual CPUE series for Norway and Russia are presented in Figure 2. Since the late 90s, the Norwegian shrimp fleet has been upgraded by the introduction of new vessels and multi-trawl systems. In the logbooks, the use of these trawl types have been difficult to register and thus make them available for further use. This problem has now been overcome and revised series of catch per unit of effort (CPUE), effort and corresponding catch have been made. The Norwegian data show a peak in effort in 2000, at the same level as the earlier peaks in 1985 and 1990. The Norwegian effort decreased in 2001. The Russian series of effort data is unchanged and both series show an increase in effort in 2002. The CPUE of the Russian fleet (vessels<1300hp) has fluctuated in accordance with the shrimp biomass (Berenboim *et al.* 2001, Figure 2). The revised Norwegian series show the same trend. It should be noted that the Russian fleet is also under development and the effort is thereby likely to increase.

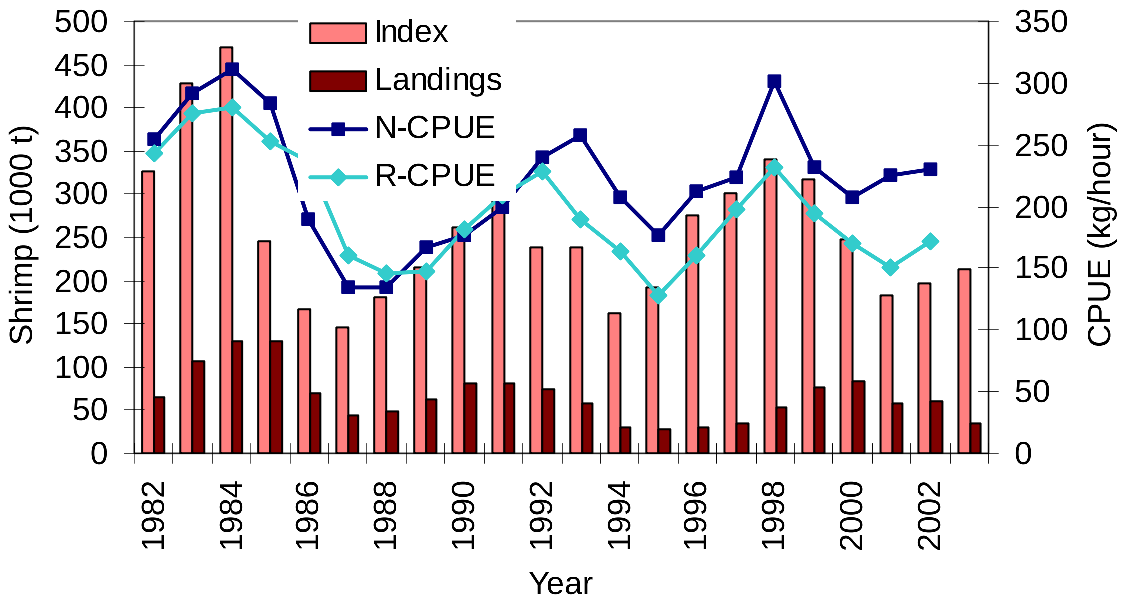

Figure 2. Biomass indices from the Norwegian surveys, total landings and Norwegian and Russian CPUE for ICES areas I, IIa and IIb.

Survey results

The shrimp surveys have been conducted since the early 80s and are believed to provide a good swept area index of the shrimp stock size (Aschan and Sunnanå 1997). There is a strong correlation between the Norwegian and the Russian survey results (Figure 3).

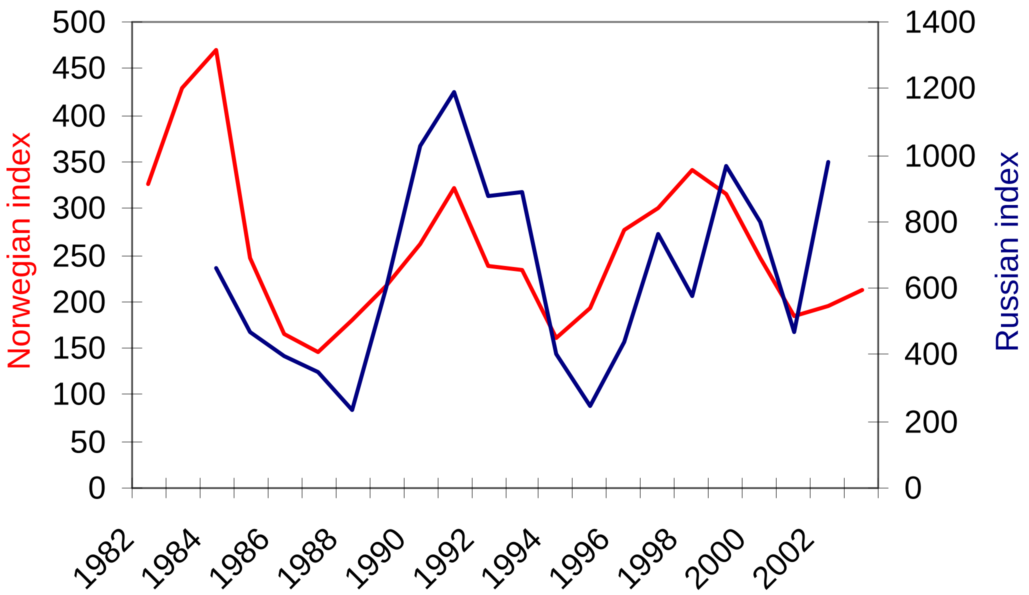

Figure 3. Shrimp biomass indices from Norwegian and Russian surveys in the Barents Sea and Spitsbergen area in 1982-2003. The Russian survey was not conducted in 2003

Unfortunately, no Russian shrimp survey was conducted in 2003. Biomass indices were highest in 1984, and have since fluctuated between 30% and 60% of this level, with peaks in

1991 and 1998-1990 and low values in 1987-1988, 1994-1995 and 2001. Norwegian and Russian bottom trawl surveys indicate an increase in shrimp biomass in the Barents Sea and Svalbard area of 6% and 109% respectively from 2001 to 2002 (Tables 1 and 2). The main survey areas are shown in Figure 4. The increase in biomass may be explained by the average strength of the 1998 and 1999 year-classes following the weak 1996 and 1997 year-classes (Table 3, Aschan *et al.* 2000) and a decline in predation by cod (Korzhev and Berenboim 2003; Berenboim *et al*. 2001) (Figure 5).

Table 1. Indices of shrimp biomass from Norwegian surveys in 1982-2002 by main areas.

Main area	A East Finnmark	B Tiddly Bank	C Thor Iversen Bank	D Bear Island Trench	E Hopen	F Bear Island	G Storfjord Trench	H Spits-bergen	Total	Sum. A,B,C, E
Strata	1 - 4	6 - 7	10 - 12	5, 8, 9, 13	14 - 18, 24	19 - 22 31 - 40	41 - 50	51 - 70		
1982	35	34	44	53	66	56	17	22	327	179
1983	40	57	61	53	112	52	21	33	429	270
1984	40	51	64	60	141	66	20	29	471	296
1985	23	17	27	18	96	31	17	17	246	163
1986	10	7	13	25	57	34	10	10	166	87
1987	29	13	18	23	31	10	9	13	146	91
1988	26	18	18	36	32	24	13	14	181	94
1989	41	17	13	17	33	53	22	20	216	104
1990	31	13	25	42	58	43	27	23	262	127
1991	22	28	22	54	120	44	21	10	321	192
1992	18	22	33	37	62	38	14	15	239	135
1993	17	19	32	29	85	20	12	19	233	153
1994	19	8	13	15	52	33	9	12	161	92
1995	10	10	11	17	83	33	16	13	193	114
1996	21	8	26	26	110	42	21	22	276	165
1997	24	34	20	34	116	44	12	16	300	194
1998	18	24	41	26	120	72	12	28	341	203
1999	17	19	23	21	169	31	21	16	316	227
2000	14	29	25	26	102	29	10	12	247	170
2001	*18*	10	30	15	61	25	*10*	*17*	**184**	118
2002	*11*	18	28	16	86	18	*9*	*10*	**196**	143
2003	15	17	36	12	94	15	8	15	**212**	162
% 03/02	*38*	-3	30	-22	9	-19	-12	49	**6**	14

Table 2. Indices of shrimp biomass (1000 t) from Russian survey in the 1984-2002 by main areas. Catchability of 0.182 is used in the estimate.

Main Area	A	B	C	E	F	G	H	I	K	Total	Sum.
	East Finmark	Tiddly Bank	Thor Iversen Bank	Hopen	Bear Island	Storfiord Trench	Spits-bergen	Kola coast	Goose Bank		A,B,C,E
Strata	1-4	6,7,1s	10-12,25	14-18	38-40, 43-45	48-50	53-55,58-60,63-65, 58-70	2s-6s	7s-8s		
1984	38	137	99	254				133		661	528
1985	14	45	74	255		6	46	19	9	468	388
1986	9	19	44	140		42	127	9	9	399	212
1987	16	17	59	107	45	36	27	25	14	346	199
1988	14	31	39	49		22	29	36	13	233	133
1989	70	128	57	132	6	60	25	105	20	603	387
1990	90	195	119	259	14	110	30	196	15	1028	663
1991	90	153	104	541	9	70	27	155	43	1192	888
1992	80	153	92	409				65	77	876	734
1993	45	91	159	382	9		58	37	111	892	677
1994	4	35	48	255	21			14	27	404	342
1995	5	28	15	80	33	53		16	18	248	128
1996	20	98	127		21			67	108	441	245
1997	26	108	130	341				108	52	765	605
1998	14	106	136	172				108	41	576	427
1999	43	139	107	523				93	61	966	812
2000	29	73	109	328	9	39		72	141	800	539
2001	11	52	105	185	19	14	13	14	55	468	353
2002	30	129	198	353	15	39	51	70	105	980	710
% 01\00	-62	-29	-4	-44	111	-64		-81	-61	-42	-35
% 02/01	173	148	89	91	-21	179	292	400	91	109	101

Length distribution data and by-catch data have been gathered by the Norwegian monitoring programmes since 1995. In 2002 observers on board commercial Spanish vessels collected samples in the Svalbard zone. Length and sex distribution data and data on by-catch were obtained. However, such sampling is not continuous in time and space.

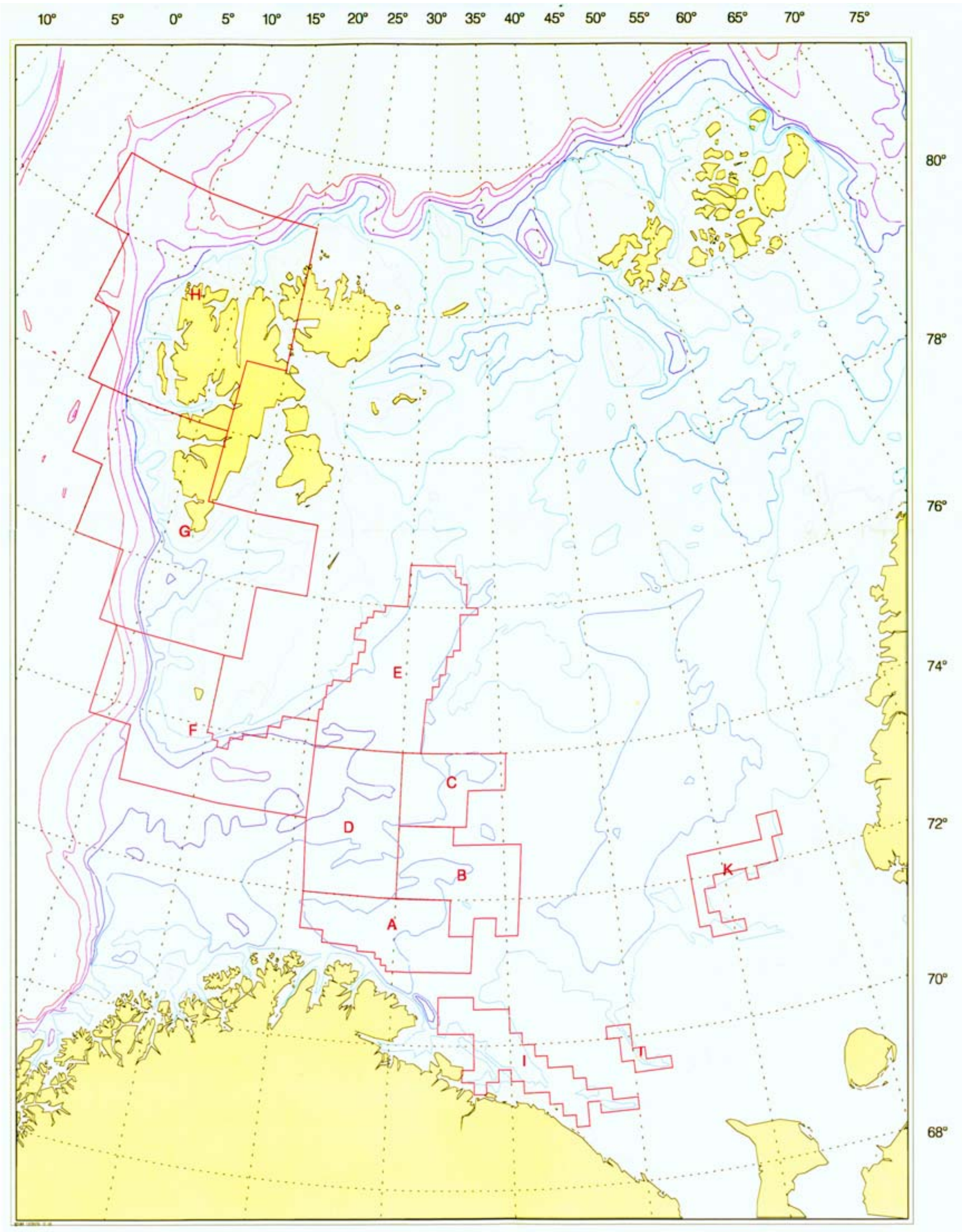

Figure 4. Survey strata are combined into 10 larger areas marked A to K. East Finnmark (A), Tiddly Bank (B), Thor Iversen Bank (C), Hopen (E), Bear Island (F), Storfjord Trench (G), Spitsbergen (H), Kola coast (I) and the Goose Bank (K).

Status of the Stock

Norwegian and Russian CPUE and survey biomass indices indicate an increase in CPUE and stock from 2001 to 2002 (Table 1 and 2, Figure 3). The Russian survey in 2002 and Norwegian surveys in 2002 and 2003 indicate a slight increase in the stock. Unfortunately, Russian scientists conducted no shrimp survey in the area in 2003. The CPUE series show that the Norwegian series is above the average and the Russian is below the average. The 1998 and 1999 year classes of average strength have probably resulted in the slight growth of the survey index in year 2002 and 2003. The 2000-2001 year classes are of uncertain strength but may contribute to some increase in shrimp stocks in 22004 if they turn out to be of average size. The decrease in shrimp consumption by cod will probably result in an increase in the shrimp stock biomass.

Table 3. Recruitment index for shrimp in the Barents Sea defined as index of numbers in size groups according to carapace length at age in the Norwegian Barents sea survey (whole mm).

CL (mm)	age	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
<9	1	0.2	4.2	2.8	3.8	4.2	0.1	0.2	0.2	0.1	0.9
9<cl<12	2	4.5	28.1	42.9	31.7	16.1	12.3	14.0	13.7	2.8	7.4
12<cl<15	3	32.6	92.1	127.9	112.8	60.6	66.9	77.9	84.4	85.7	26.4
15<cl<18	4	343.0	299.6	361.9	415.7	247.2	305.5	468.0	561.2	544.7	342.5

CL (mm)	age	2000	2001	2002
<9	1	0.5	0.0	0.2
9<cl<12	2	21.1	12.2	14.6
12<cl<15	3	70.6	44.6	54.7
15<cl<18	4	191.2	163.3	323.2

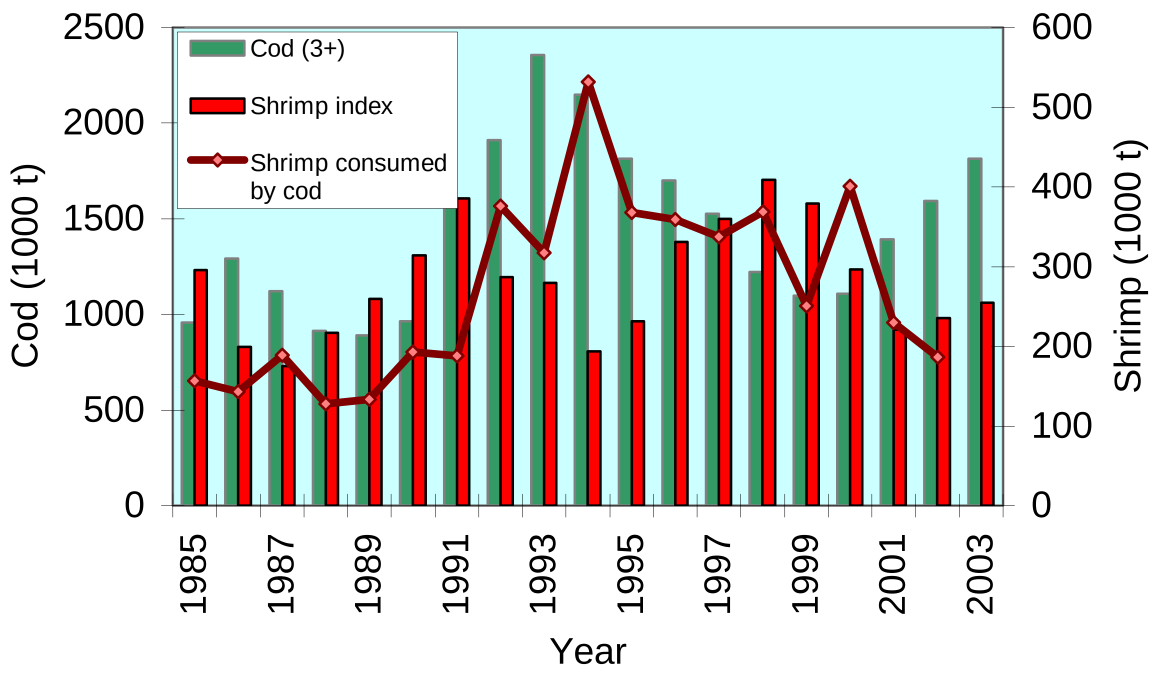

Figure 5. Shrimp biomass indices from the Norwegian surveys, biomass estimate for cod (age 3 years and older) and shrimp consumed by cod in the Barents Sea.

Assessment methods under progress

The great plasticity in shrimp growth rates and in age at sex change, as well as a lack of biological data and length distributions from the catches make it difficult to apply traditional analytical fishery assessment methods to the data. Therefore, a spreadsheet performance report (Caddy 1999, Koeller *et al.* 2001) has been used to assess the available information.

Other models have been used in assessing shrimp and some of these are listed below together with the experience gained by their use.

Production models

1) Shaefer and Fox stock models;
2) Stock production model, including predation (Stefánsson *et al.* 1994, Berenboim and Korzhev 1997);
3) Age-structured production model (Shepherd 1991);
4) Biomass dynamic models (Hilborn and Walters 1996).
5) Dynamic production model (Babayan and Kizner, 1998).

The dynamic production model introduced by Babayan and Kizner was used to assess the MSY of the Barents Sea shrimp, but since cod consumption is not included in this model the Stefánsson production model is to be preferred.

The production model elaborated by Stefánsson *et al*. (1994) for shrimp in north Icelandic waters was applied to Barents Sea shrimp data (Berenboim and Korzhev, 1997). This model considers cod and shrimp populations without dividing them into age or length groups.

Catch-at-age analysis (cohort models)

1) Single-species virtual population analysis;
2) Multi-species virtual population analysis.

For these models it is important to apply reasonable values for the natural mortality coefficient as a function of age and year, because these parameters are important in shrimp models due to high predation by cod.

Single-species VPA

Single-species VPA (Lowestoft ICES) may be used in two ways:

- To estimate total natural mortality in advance (for example with the help of a multispecies model), or
- To introduce the predator as an additional “fleet”.

Multispecies model MSVPA

The MSVPA is developed in the MAWG ICES (Sparre 1984). Cod stomach data are obtained from the Joint Russian-Norwegian stomach database. Methods used in parameter estimation and preparation of input files are described in Bulgakova *et al.* (1995) and Anon. (1996).

Length at age analysis

1) Jones´ analysis (for sustainable stock);
2) Analysis including stochastic growth (Sullivan *et al.* 1991, Kunzlik 1991);
3) Fleksibest (Frøysa *et al.* 2002);
4) Bormicon – multispecies analysis (Stefánsson and Pálsson 1997).

Conclusions

Since there is no direct regulation of the shrimp fishery with the aim of maintaining a stable standing stock and a good annual catch, annual catches have fluctuated between 27 and 83 000 tonnes. The predicted great increase in the biomass of the stock due to good recruitment in 1998-2001 has not come to pass, due to greater fishing effort and higher fishing pressure on younger year classes (3-4-year-olds). Since 2000, management advice has been supplied by the ICES Arctic Fisheries Working Group, but in 2004 the advice will be prepared by the *Pandalus* Assessment Working Group, which will hold a joint meeting with the NAFO Scientific Council. The aim is to gather all scientists responsible for *Pandalus borealis* stocks in the North Atlantic in order to give the best advice.

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U. Skúladóttir and J. Sigurjónsson: Pandalus stocks in Icelandic waters: biology, exploitation and management

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Introduction

An inshore fishery for shrimp (*Pandalus borealis)* was first launched in Isafjardardjup, in one of the main fjords in the Northwest peninsula, in 1923 when some handpeeling and canning took place (Hallgrímsson 1993). The fishery was not industrialised until 1935 in Isafjardardjup, and spread to other fjords and inshore areas southwest to north Icelandic waters in the following decades. Ever since, the shrimp fishery has been an important activity in local communities, particularly in the Northwest peninsula (Hallgrímsson and Skúladóttir 1981; Skúladóttir *et al.* 2001). An offshore shrimp fishery developed in the early seventies off the north coast of Iceland and in the late seventies off the Northwest peninsula, in the Denmark Strait area, which lies between Iceland and Greenland.

This paper briefly summarises the main characteristics of the populations of shrimp exploited in these waters; their biology, identification and development as well as the history and management of the shrimp fishery.

Biology and life history

The shrimp caught in Icelandic waters is the northern shrimp of the species *Pandalus borealis,* while another species *Pandalus montagui* is also caught but comprises less than 0.1% of the shrimp catch and is only found in inshore waters.

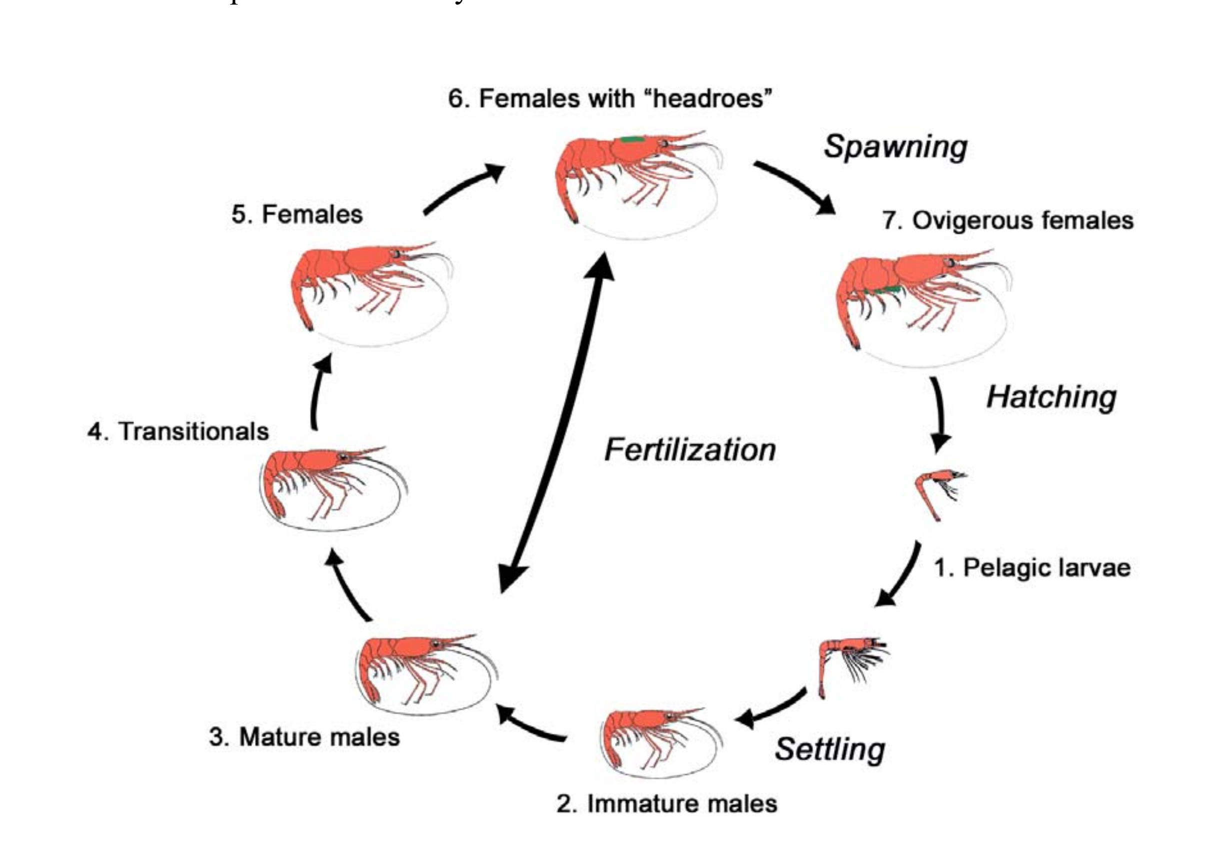

Figure 1. Life cycle of the northern shrimp (courtesy of Hjalti Karlsson, MRI).

The life cycle of *Pandalus borealis* in Icelandic waters is shown in Figure 1. The mature females spawn just after copulation and carry the eggs for 5.5-10 months. The shrimp in the warm south western Icelandic waters, where the mean near-bottom temperature is about 6° C, has the shortest egg carrying period, whereas the shrimp furthest north, where the mean near-bottom temperature is 0-1.2° C, carry their eggs for ten months. The inshore shrimp spawn every year while the offshore population spawns only every second year (Skúladóttir *et al*. 1991). At hatching the larvae become pelagic. The larvae settle on the bottom after two to three months in the pelagic phase. In Icelandic waters the young larvae are male at first but develop into females at an age of three to five years (Skúladóttir 1981; Skúladóttir *et al*. 1991). The age at sex change depends on the temperature. The higher the temperature the younger the shrimp are when they change sex. Thus the shrimp are oldest at sex change in the offshore area north of Iceland and youngest in the warmer inshore areas. As age determination of shrimp is difficult, peaks in length distribution are used for studying variations in cohort strength. The length at which the shrimp change sex varies considerably between areas (see below).

Stock identification

For management purposes the inshore shrimp off Iceland are divided into separate components where each fjord has traditionally been treated as a separate management unit. The offshore stock and the Denmark Strait stock are also traditionally treated as two separate management units (Figure 2).

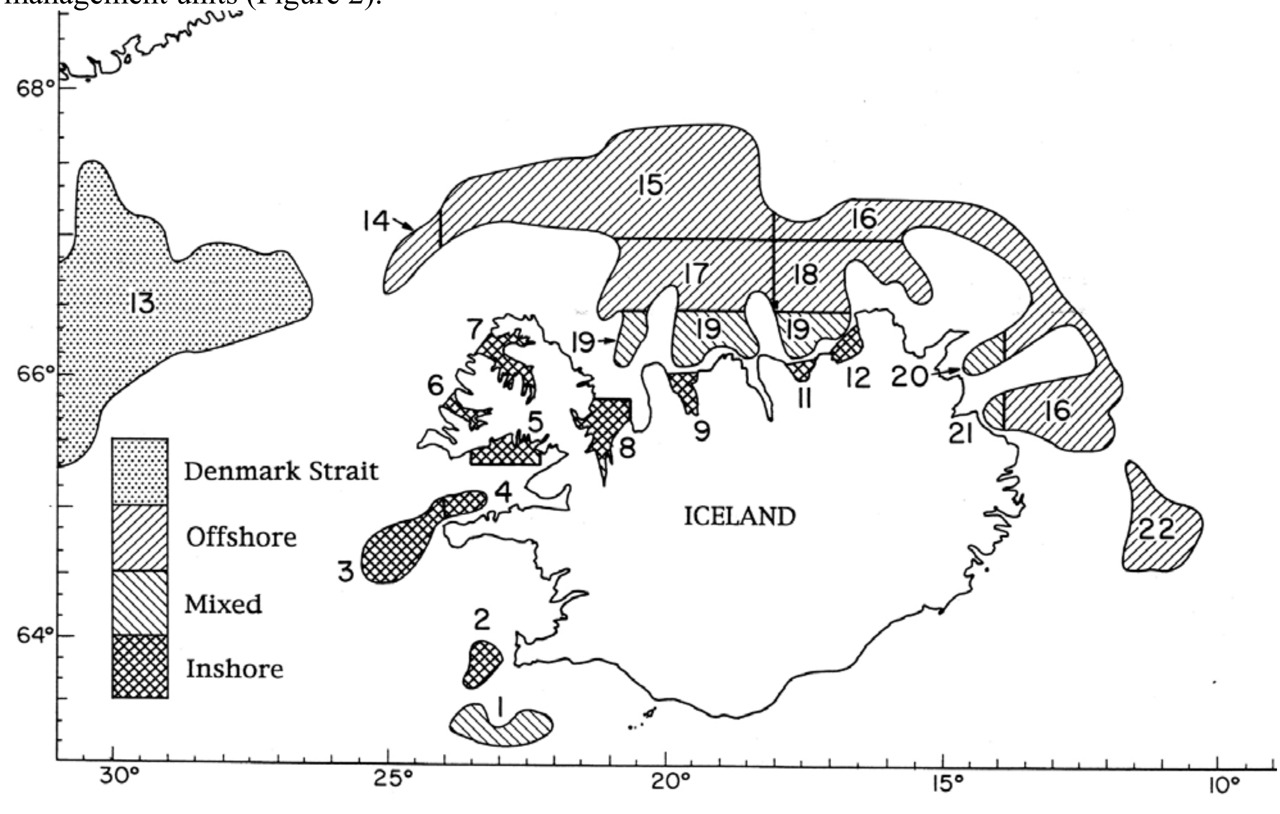

Figure 2. Based on statistical analysis of both L_{50} and L_{max} in 21 separate areas, three main shrimp stock components were identified, namely Denmark Strait, offshore and inshore stocks (several separate sub-units). Intermediate values were found in "Mixed" areas.

The inshore stocks occur at depths of 50-150 m and reach a maximum age of five years, while the offshore stocks (including the Denmark Strait) occur at depths of 200-1000 m and reach seven or eight years of age. Moreover, there are variations in maximum lengths and length at sexual change (males become females) between the Denmark Strait, offshore and inshore stocks, respectively. After distinguishing sexual characteristics and measuring all the shrimp within an area, the shrimp can be grouped according to maximum length L_{max} and the length at which 50% of males become mature females (L_{50}) where the criteria for the attainment of sexual maturity in females is the disappearance of sternal spines (McCrary 1971). Skúladóttir *et al.* (1991) adopted this approach and plotted and calculated L_{50} and L_{max} per sample. The result of this exercise pointed to the existence of three populations, namely the Denmark Strait, offshore and inshore stocks. In 1999 Skúladóttir and Pétursson measured and analysed 900 000 shrimp for seven years in 21 areas by using a S-curve to calculate L_{50} in each sample, and recorded L_{max} . In statistical comparisons of the shrimp samples (see Figure 2) no difference between the inshore areas was found but both the offshore and the Denmark Strait represented separate populations. The largest L_{50} was always found in the Denmark Strait and the smallest in inshore areas (Figure 3). The size at L_{50} and L_{max} was consistent through all the years studied.

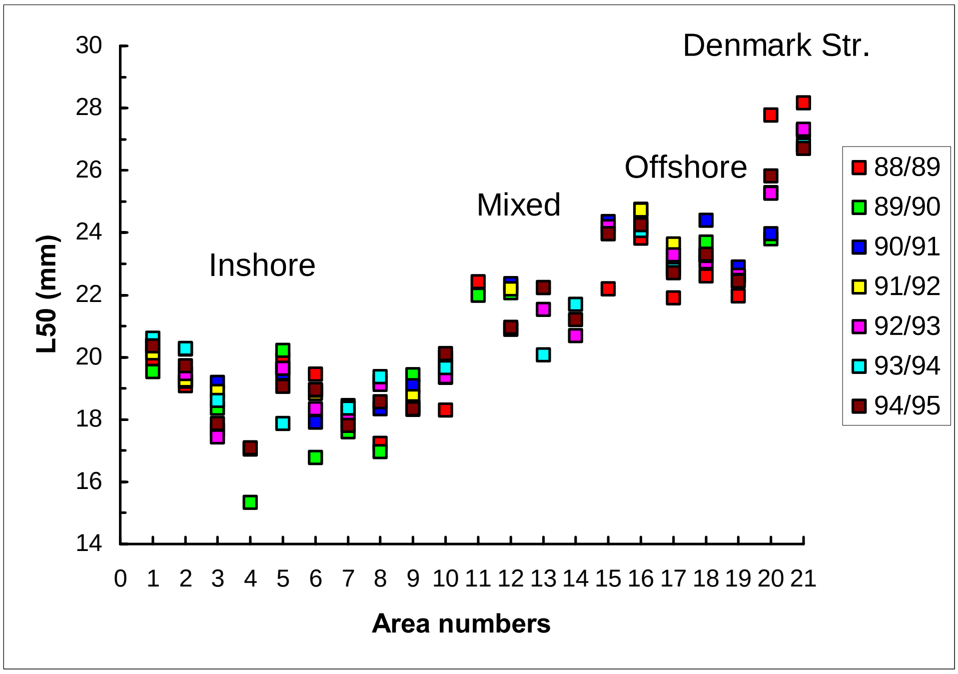

Figure 3. The size at sex change L_{50} is shown by years and areas. The area numbers are the same as shown in Figure 2

Both L_{50} and L_{max} can thus be used as meristic phenotypic descriptors of populations. Indeed the distinctiveness of different stock components is even clearer when the L_{50} is plotted against L_{max} by area (see Figure 4). On the basis of this methodology, Charnov and Skúladóttir (2000) postulated a universal rule that the L_{50} is about 80% of L_{max} per area. Thus a log L_{50} divided by log L_{max}, which is 1 for northern shrimp, would be the same for other marine species that change sex.

However, the relationship between near-bottom temperatures and the size at L_{50} as well as L_{max} is rather complicated. Thus, the largest L_{50} and L_{max} are found at the lowest temperatures (0°-1.2° C, offshore) but the smallest at medium temperatures (4.5° C). At the highest temperatures (6.0 - 7° C, inshore), L_{50} and L_{max} tend to increase somewhat again.

Jónsdottir *et al.* (1998) studied shrimp from the three main areas above and found by genetic analyses the same main population components by using allozyme (15 enzymes) electrophoresis, namely the inshore, offshore and the Denmark Strait components, respectively. The greatest difference was found between the Denmark Strait shrimp and the inshore components. The offshore and Denmark Strait were not as different genetically as was the inshore compared to the offshore stock.

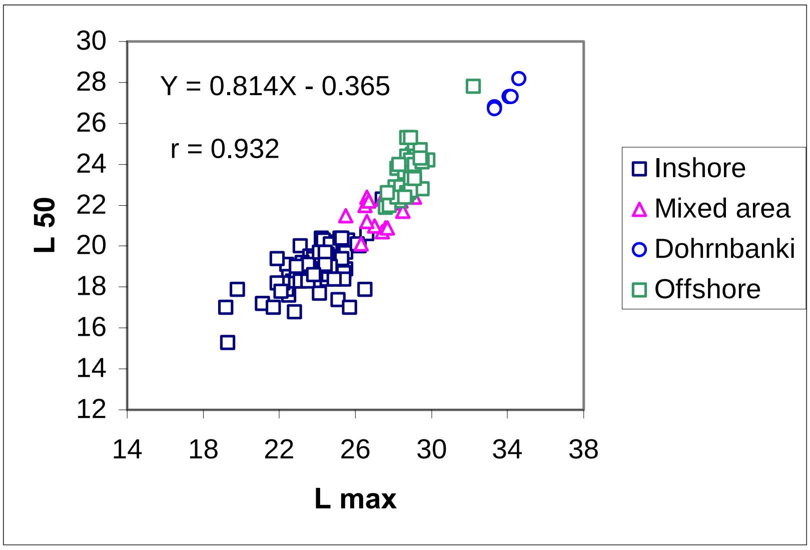

Figure 4. Mean L_{50} plotted against mean L_{max}, denoted by four different markers for the three main stock components; Denmark Strait, offshore and inshore areas.

Development of the inshore fishery

Figure 5 shows the expansion of the inshore shrimp fishery off Iceland during the past 40 years. Since the start of the fishery in the mid 1930s until the early 60s the catches were limited to Isafjardardjup and Arnarfjord areas in the Northwest peninsula but until 1990 new inshore grounds were located one after another clockwise from the southwest to the east of Iceland.

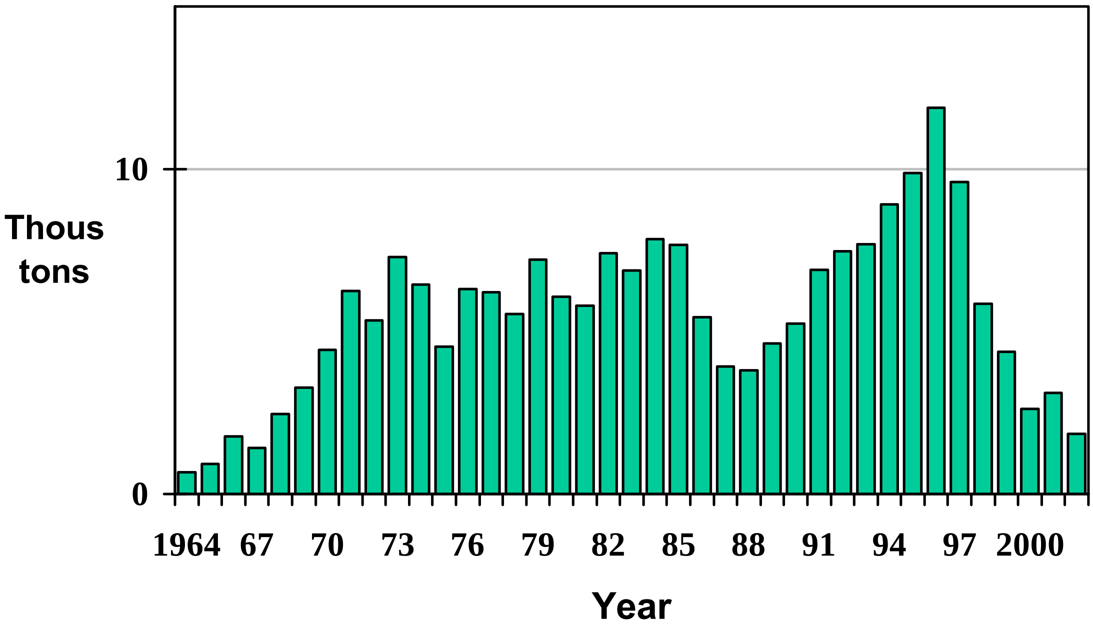

Figure 5. Total nominal catch in inshore areas, 1964-2002.

In most years, inshore catches have been less than 10 000 tonnes, usually 5-7 000 tonnes (Figure 5). The development of the catches and biomass indices by area in western and northern catch areas, respectively, are shown in Figures 6 and 7. Six of eight inshore areas have been closed in recent years to the shrimp fishery, due to stock depletion. The depleted status of the stocks has been linked to increased abundance of cod and other haddock in inshore areas in recent years. Although this development has been clear in the Northwest, such as in the Isafjardardjup area (Figure 8a), it has been even more evident in all inshore areas in North Iceland where shrimp have almost completely disappeared (Figure 8b). The temperature change which has occurred in recent years following a stronger influence of warm, saline Atlantic water mass in the area north of Iceland since 1997 (Valdemarsson, personal communication), has evidently influenced the migrations of cod to the northern and eastern Icelandic waters but may also have directly influenced growth and recruitment of shrimp.

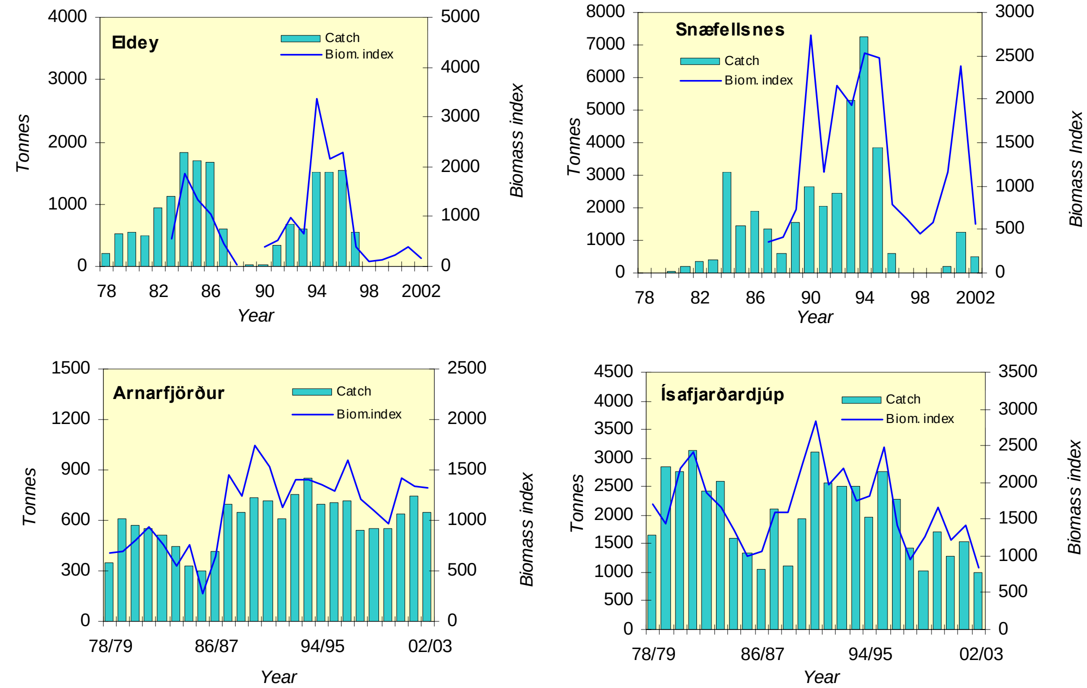

Figure 6. The catch and biomass in four inshore areas at the west coast of Iceland 1978-2003.

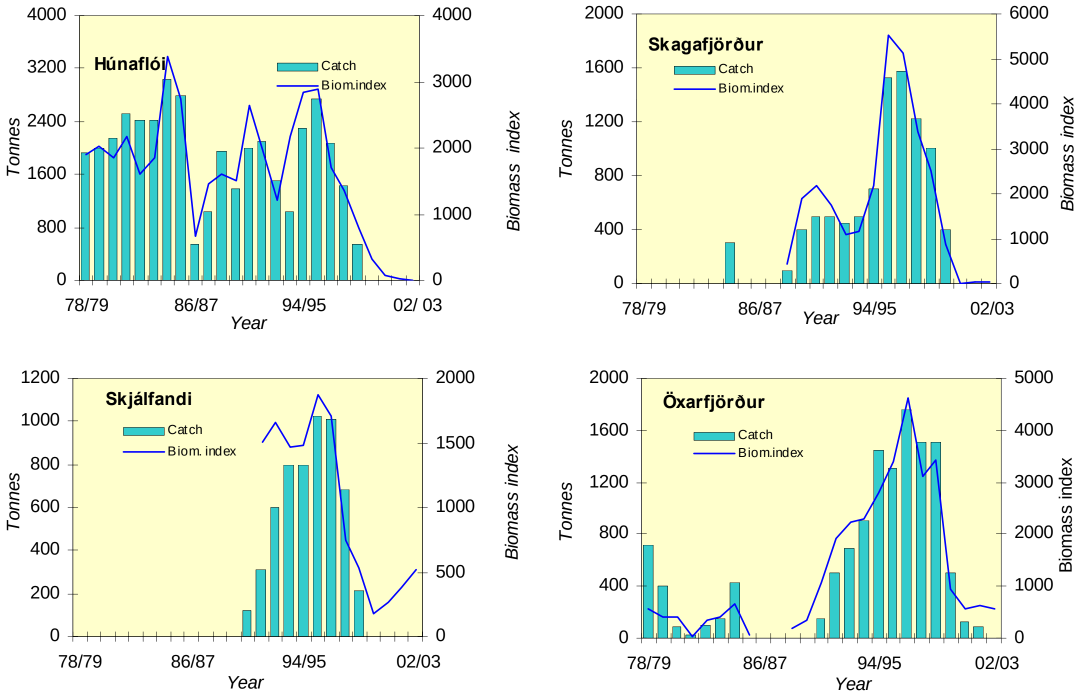

Figure 7. Catch and biomass in four inshore areas off the northern coast of Iceland, 1978-2003

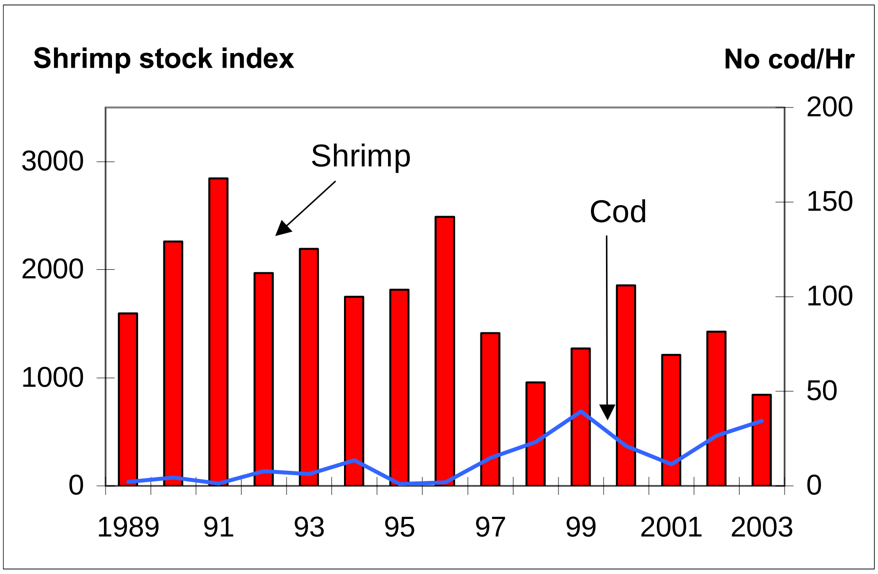

Figure 8a. Number of cod (>30cm) caught in the February shrimp biomass survey in the Isafjardardjup NW Iceland, compared to shrimp biomass index

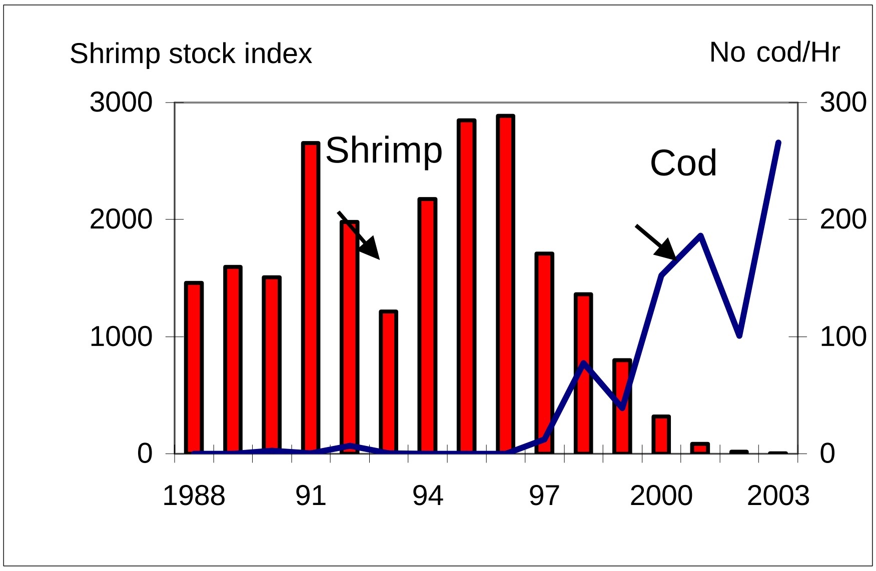

Figure 8b. Number of cod (>30cm) caught in the February shrimp biomass survey in Hunafloi, N Iceland, compared to shrimp biomas index.

Inshore fishery: Monitoring and management

The inshore fishery is subject to licensing like all other commercial fishing activities in Iceland. In short, the fishery was managed on basis of TAC during the period 1962-1967 with no allocation to vessels or area. During the period 1968-1973 there were in place effort regulations by season. Again TAC was introduced in 1974 with allocations to vessels, inshore areas and landing restrictions by areas (landing outside respective fjord was not permitted). In the mid 1990's the vessel quota allocations were made transferable in general line with the ITQ system in the Icelandic demersal fishery, while earlier landing constraints were lifted.

As for other fisheries, the Marine Research Institute (MRI) is responsible for providing the Ministry of Fisheries with recommendations on TAC for each area (fjord). Samples have been gathered since 1959 and logbooks were introduced in 1960 (Hallgrimsson and Skuladottir 1981). Since 1973 inshore trawl surveys have been carried out once a year, i.e. in September/October and in some areas twice, i.e. with a second survey in February each year. These surveys have been standardised since 1988 with respect to locations (fixed stations), fishing gear and trawling speed. On basis of the biomass indices of the last two surveys a preliminary TAC (2/3 of last season's catch) is recommended to the Ministry of Fisheries for each area in June for the following fishing year starting 1 September. A revised, final TAC, is then set in October after conclusion of the fall surveys (occasionally adjusted after the February survey).

The harvesting strategy is based on the relationship between the biomass indices from the two most recent surveys and historical catches, where attempt is made to secure a long-term optimum catch and sustainability of the resource.

Apart from the above regulations, strict by-catch regulations are in place, where only a defined maximum number of juvenile fish in the shrimp catch (mainly cod and haddock) is permitted. A great number of juvenile fish sometimes turn up in the autumn so it happens that an area (fjord) has to be closed for as much as two months. An additional survey is then required before an area can be opened to the fishery. In the inshore fishery sorting grates are usually not mandatory as the youngest cod and haddock (0-group) that are found in the inshore pass through the grate and get caught anyway along with the shrimp.

Development of the offshore fishery

Figure 9 shows the development of the shrimp fishery off Iceland with the start of the offshore fishery in the mid 1970's. A rapid expansion took place in the 1980's and until 1997 when the catch reached the maximum of 65 000 tonnes. A dramatic drop followed in the 1998-1999 seasons and in the most recent seasons catches have been 20-30 000 tonnes. The Denmark Strait catches ranged from a few tonnes up to 2 900 tonnes.

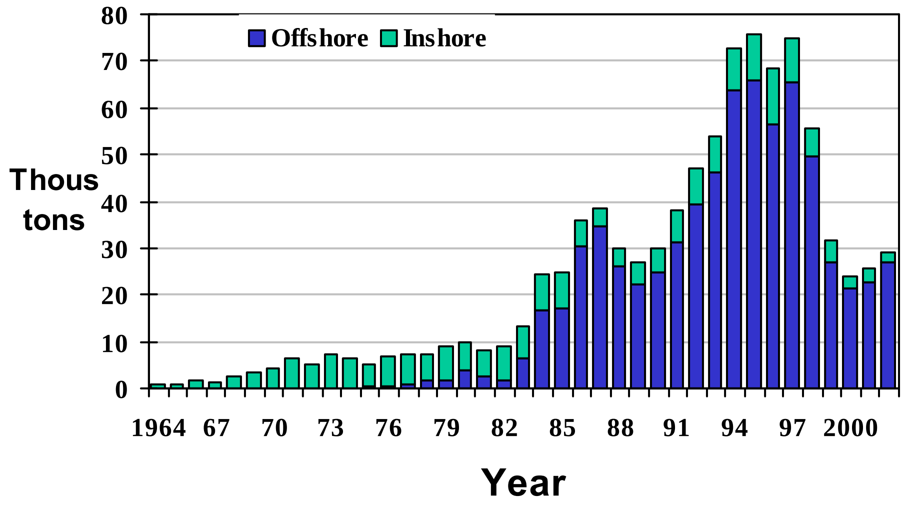

Figure 9. Nominal catches of inshore and offshore shrimp; 1964-2002.

Offshore stock: Monitoring and management

Apart from detailed logbook information, which is mandatory for all licencees in the offshore fishery and which provides standardized CPUE indices (where the circumference of the trawl is 1600 meshes), annual standardized offshore trawl surveys (190 fixed stations) have been conducted in July-August every year since 1988. The survey provides indices of abundance and biomass throughout the stock area. A juvenile bag (a small meshed bag) attached to the trawl provides information on the abundance of one- and two-year-old shrimp where the latter isare used as a recruitment index. A maximum likelihood procedure developed by MacDonald and Pitcher (1979) is applied to the length frequency distributions in order to assess the age and the frequency of the youngest age-classes of shrimp that are taken by the juvenile bag.

The offshore trawl survey also adds to our understanding of the sustenance of the stock in the offshore area north of Iceland. It has been noted that in every years since the start the offshore surveys that the larger shrimp (also females), have been in greatest abundance in deep water off North and Northwest Iceland (Figure 10a). In fact 60-80% of the annual catch is fished in this area while the smaller shrimp have always been most prevalent in the eastern part. Thus the juveniles, one-year-olds, seem to be carried by the main current from the northwestern part to the eastern part, to judge from the occurrence of one-year-olds on the northeastern grounds (Figure 10b). The 2 year olds also have a more easterly distribution than the females but with a little more spread towards the west and the east than the one-year-olds (Figure 10c).

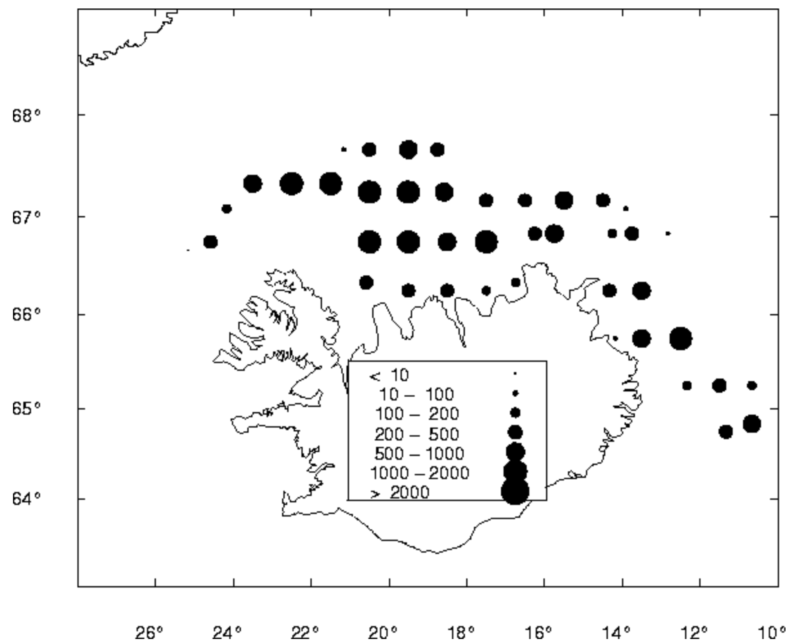

Figure 10a. Average annual biomass index from standardized trawl surveys (15 years) on offshore Icelandic shrimp grounds: a) females, b) one-year-olds, c) two-year-olds.

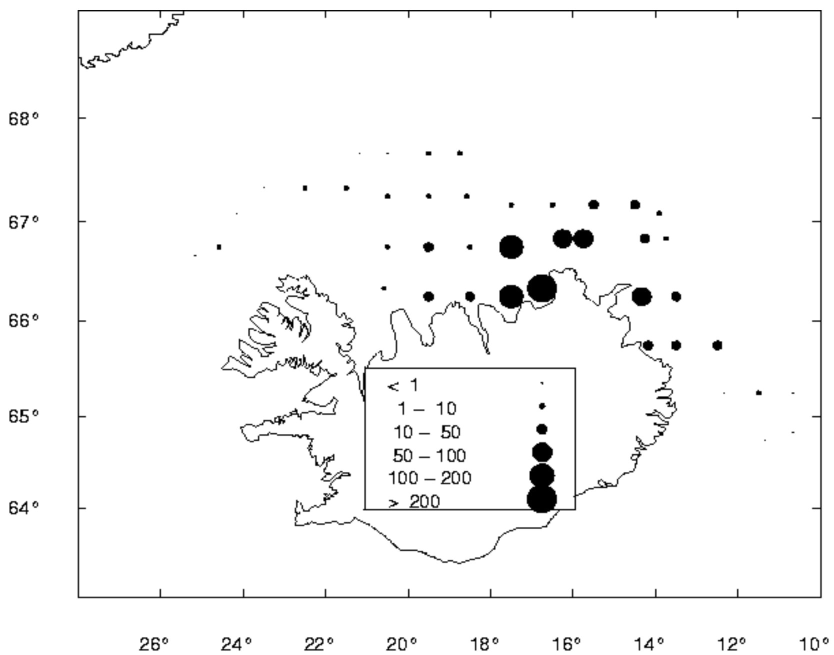

Figure 10b.

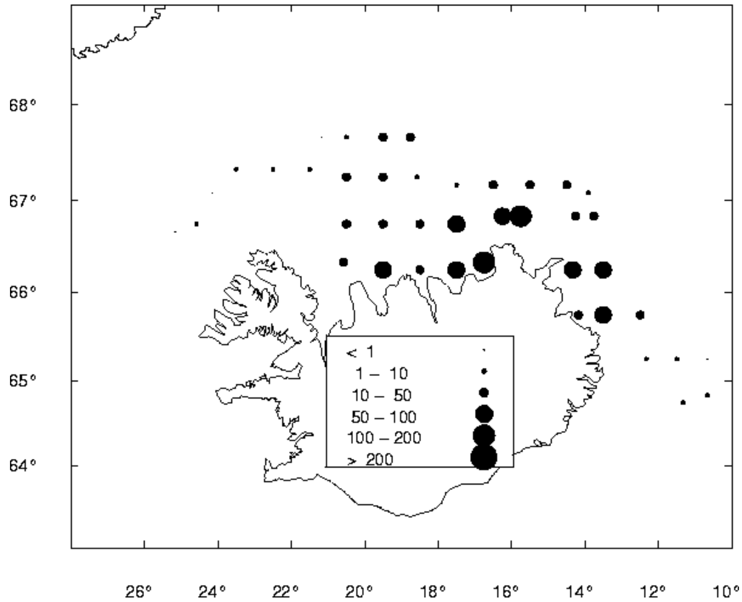

Figure 10c.

The stock size has been assessed by a stock production model (Stefansson, Skuladottir and Petursson 1994), in which the inputs are recruitment (by weight), shrimp catch and cod abundance index (Figure 11). In order to forecast recruitment the following year the cod index is regressed against the tvo-year-old shrimp index a year later (Figure 12). The biomass is then calculated by a least-squares fit of CPUE against average biomass in two successive years. Long-term sustainability of the stock seems to lie in the lower range of the past harvesting rate (recently near 20% of biomass), while periodic high predation by cod (Figure 13) appears to influence both shrimp recruitment and the yield of the shrimp stock (Stefánsson *et al.* 1998).

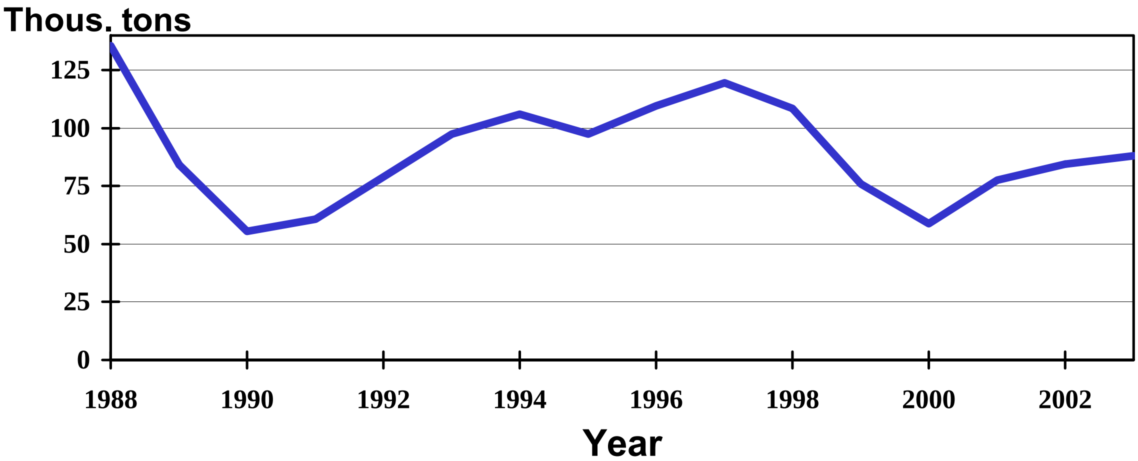

Figure 11. Offshore shrimp biomass 1988-2003 as estimated by the stock production model.

A multistock model of cod, capelin and shrimp for development of harvest control regulations for the cod fishery off Iceland (Stefánsson *et al.* 1994; Baldursson *et al.* 1996) assumed that via gradual recovery of the cod stock, a reduction of yield in shrimp would result in a reduction from the maximum of 60-70 000 tonnes catch to a long-term stable yield in the range of 20-30 000 tonnes. From the point of view of national economic interests it was found to be advantageous to secure a large cod stock at the cost of a smaller shrimp stock, and this multistock utilization strategy was therefore adopted by the authorities in the mid 90s.

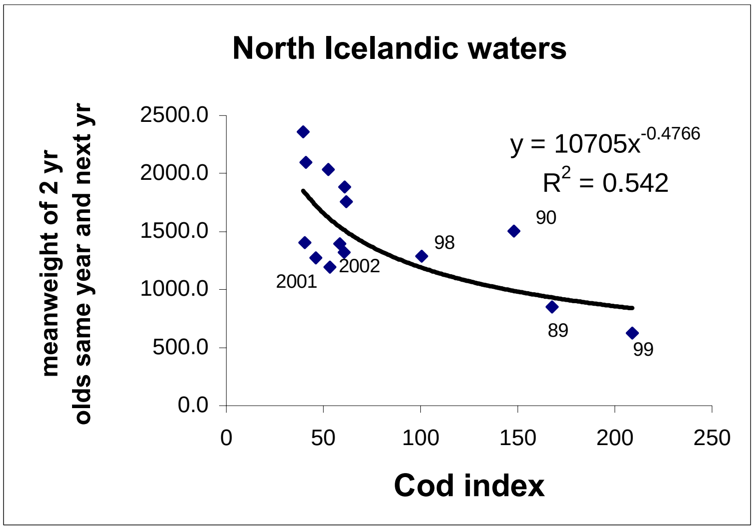

Figure 12. Relationship between cod index from demersal surveys and biomass of two-year-old shrimp.

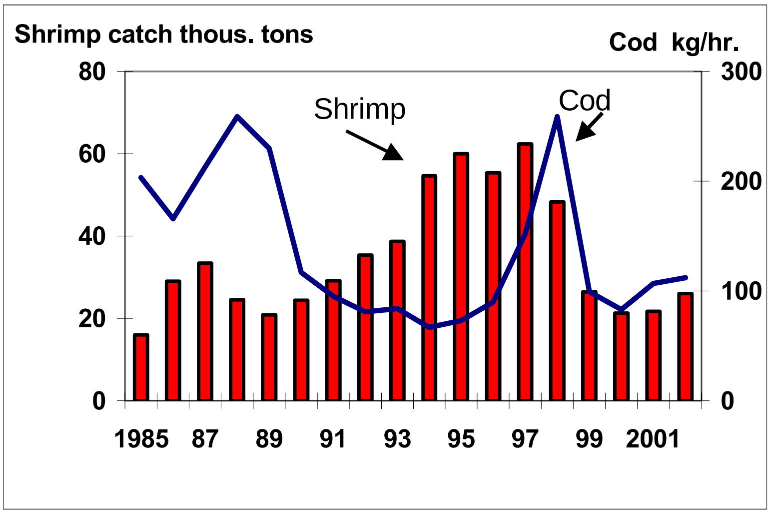

Figure 13. Offshore shrimp catch and cod kg/hour in the Icelandic groundfish survey; 1985-2002.

Another model used to assess the offshore shrimp stock is the Gadget model (Anon. 2003), which is a length and age-based multispecies, multi-area, multifleet model. The settings used in the assessment of offshore shrimp are one area, one natural predator, i.e. cod, one fleet, one survey and a residual natural mortality of 0.1. The dynamics of the cod are not modelled by a cohort model but abundance is modelled as proportional to the abundance index from the groundfish survey in March. Estimated variables are growth parameters, selection pattern for the cod, the commercial fleet and the survey and the size of each year-class. The model results have been used to estimate yield as a function of shrimp fishing mortality (F) and abundance of cod. F consists of mortality caused by the shrimp fishery and mortality due to consumption by cod (Figure 14). In the absence of cod the yield-per-recruit analysis indicates that $F_{max} \cong 0.6$ ($Z_{max} \cong 0.7$). Based on these findings a Z=0.7 has been used as a harvest control law. The model is then used to predict the size of the shrimp stock two years ahead, on the basis of estimated shrimp recruitment and predicted abundance of cod in the area, and the catch that yields Z=0.7 is the TAC for the next year. The uncertainty in the predictions is high, especially in the prediction of predation by cod.

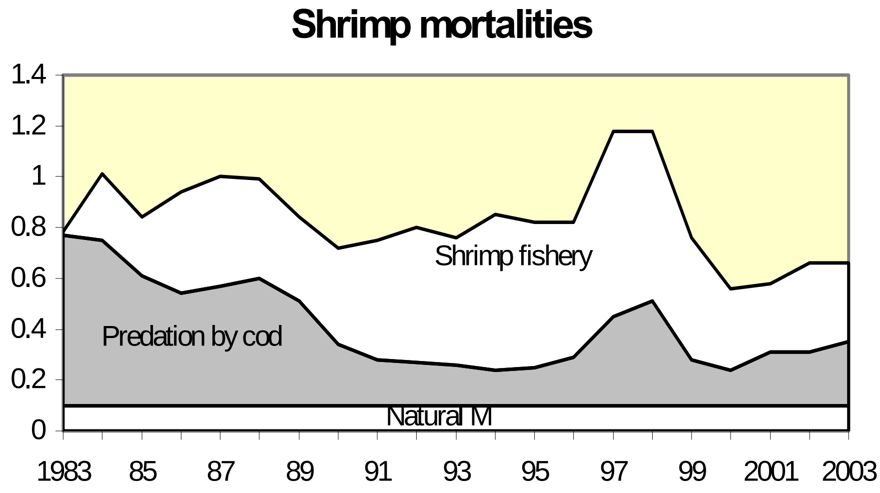

Figure 14. Mortality coefficients of shrimp from the Gadget model in northern and eastern Icelandic waters.

Apart from the annual shrimp TACs, protective measures for demersal fish (cod, Greenland halibut and redfish) in terms of mandatory sorting grates (22mm) have been in place in all offshore shrimp fisheries since 1995, resulting in only small bycatches in recent years. The only other management measures enforced have been permanent or temporary closures of offshore shrimp grounds because of excessive proportions of juvenile shrimp in the catch.

Conclusions

The biology of shrimp in Icelandic waters is now quite well known. Investigations have revealed distinct stocks or stock components both by genetic methods and meristic findings, revealing great differences in L_{50} and L_{max} between stocks. The management of different areas is based on these findings, while standardized trawl surveys also play a key role. Ageing is rather difficult in shrimp and cannot be relied upon. However, although the Gadget model uses age estimation the stock production model used for the offshore shrimp generally does not rely upon ageing.

It is clear that during certain periods, shrimp in Icelandic waters are heavily preyed on by cod. Most inshore areas are now depleted because of cod predation. As long as the long-term harvesting strategy is to secure as large a cod stock as the ecosystem is able to support, shrimp will suffer. The determination of TACs often seems to be difficult in this species, not only because of problems of age determination and in estimating absolute stock sizes, but also not least since shrimp stocks are evidently subject to greater fluctuations in natural mortality than most exploited stocks, due to high cod predation. For these reasons, the management strategy for shrimp is still under consideration, given that economic and operational (e.g. effort) aspects need to be explored for any future management scheme.

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W.R. Bowering and D.B. Atkinson: Shrimp stocks in Canadian and NAFO waters

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Abstract

In the Northwest Atlantic, commercial shrimp populations consist primarily of *Pandalus borealis* and to a much lesser extent *Pandalus montagui*. In the Northwest Atlantic they are distributed from the Davis Strait in the Arctic to the Gulf of Maine off the Northeastern United States, usually in areas where the ocean floor is soft and muddy and where temperatures near the bottom range from about 2 to 6^{o} C. These conditions are very common particularly throughout the Newfoundland and Labrador offshore area within a depth range of about 150 - 600 m, thus providing a vast area of suitable habitat. Both species are known as protandric hermaphrodites which means they first mature as males, mate as males for one to several years and then change sex and spend the rest of their lives as mature females. Although the age of shrimp is difficult to determine, they have been estimated to live for more than eight years in some areas. Some northern populations exhibit slower rates of growth and maturation but greater longevity results in larger maximum size. Being at the lower end of the food chain they are important prey for many species such as Atlantic cod, Greenland and Atlantic halibut, skates, wolffish, snow crabs and harp seals.

There are five management areas from Baffin Island in the Arctic to the Grand Bank in the south, referred to as "Shrimp Fishing Areas" or SFAs. The most northerly area, SFA 1 off northern Baffin Island, straddles the boundary between Canada and Greenland and is therefore managed bilaterally by the two countries on the basis of scientific advice received from the NAFO Scientific Council. SFAs 2 and 4-6 are distributed from southern Baffin Island to eastern Newfoundland and are exclusively within Canadian waters. They are managed by Canada as the coastal state on the basis of scientific advice from the Science Branch Sector of the Canadian Department of Fisheries and Oceans. SFA 7 straddles the Canadian 200-mile limit on the eastern Grand Bank adjacent to Flemish Cap, which comprises another shrimp management area. The latter two areas are managed by the NAFO Fisheries Commission on the basis of advice of the NAFO Scientific Council. With the exception of the Flemish Cap management area, which is managed by effort limits, all other areas are managed using quotas.

The fisheries for shrimp originated in the most northerly area and expanded southward. In SFA 1 the fishery began in the 1970s, in the late 1970s in SFAs 4, 5 and 6 and in the late 1980s in SFA 2. On Flemish Cap and the northern Grand Bank (SFA 7) the fisheries began in the early and late 90s, respectively. Over the last few years the cumulative catch for quota in the management areas has reached about 100 000 tonnes while the Flemish Cap produces catches of around 50 000 tonnes.

The stock status for each SFA is determined by monitoring the performance of the fishery within and between years, distribution of fishing effort and the size/sex composition of the catches. Research vessel (RV) trawl surveys since 1995 provide data on stock size and structure for SFA 5, 6 and 7. Using both sources of information, inferences can be made regarding the state of spawning stock (female abundance), potential for future recruitment to the fishery (male abundance) and an index of exploitation (ratio of commercial catch to lower 95% confidence interval of biomass index from the previous year's RV survey). The shrimp resource in the northwest Atlantic has increased significantly during the 90s, in part due to release from predation by groundfish. The resource remains healthy in all areas in spite of

increases in catches, and in fact stock assessments would indicate that at present, catches do not seem to have had any negative impact.

H. Siegstad and C. Hvingel: Shrimp in Greenland waters.

Greenland Institute of Natural Resources, Nuuk

See PowerPoint presentation on enclosed CD.

King crab

B. I. Berenboim[1], A. M. Hjelset[2], M. A. Pinchukov [1] and J.H. Sundet[2]: Red king crab (*Paralithodes camtschaticus*) in the Barents Sea

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Abstract

The distribution range of the red king crab in the Barents Sea continues to expand in eastern, northern and western directions. In autumn 2002 the recruitment to the legal size stock was good in the eastern part of the distribution area in the Russian Economic Zone (REZ) and in Tanafjorden in the Norwegian Economic Zone (NEZ). The total harvest of crab in 2002 was 400 000 individuals. In REZ the mean catch per day harvested by Japanese conical traps was 1.4 legal males, and 8.5 using American square traps. In NEZ the mean catch by Norwegian square traps increased considerably between 1999 and 2001. In REZ the bycatch of red king crab in the bottom trawl fisheries was steadily increasing, being estimated at 77 000 in 2001 and 417 000 in 2002. In NEZ, bycatch in the gillnet fishery for cod and lumpsucker has been observed to decline in the Varangerfjord and to increase in the Tanafjord in recent years.

Introduction

The red king crab was introduced to the Barents Sea by Russian researchers during the 1960s. By the mid-90s the crab sustained a self-reproducing population there (Bakanev et al., 1997; Gerasimova et al., 1997). However, the distribution area is continuously expanding westwards as new areas are invaded. In the light of this, scientists from both countries conduct regular research surveys to study the biology and distribution of the stock, and to assess it.

From 1994 onward, Russia and Norway have been conducting a research fishery on this introduced species, and the size of this fishery has been increasing with the growth of the stock size. Increased abundance and distribution have created a bycatch problem in other fisheries.

This paper reviews specific features of biology and distribution of the red king crab in Russian and Norwegian waters of the Barents Sea in 2001-2002. Its basis is a joint Russian-Norwegian research progress report for 2002 (Hjelset et al., 2002).

Materials and Methods

In 2002 the Russian research cruises for the red king crab were performed in April/May and August/September, while Norwegian cruises were carried out in August and September. Experimental tagging with external tags in the Norwegian zone was performed in order to study crab migration and as a complementary method for estimating stock size. In addition, tagging experiments with T-bar tags were carried out in Tanafjorden and Laksefjorden for studies of growth and moulting frequency.

Data from the research fishery were collected in September-December 2002 in the Norwegian zone in January-June, and in September-December 2002 in the Russian zone.

Two different types of traps are used to catch crabs in the Barents Sea. In the Russian exploratory fishery Japanese conical traps (standard gear) and American square traps are used, while square collapsible traps have been used in the Norwegian fishery since 1999. Square collapsible traps are used as a standard catching gear on Norwegian research cruises and both conical and square collapsible traps are used on Russian research cruises. Stock assessment in the Russian and Norwegian zones of the Barents Sea in 2002 was carried out applying a swept area method, where a scientific bottom trawl was used by Russian scientists and an Agassiz trawl in the Norwegian zone.

For practical reasons Russian and Norwegian scientists have agreed on a number of definitions to describe different biological groups of the red king crab in the Barents Sea:
Total stock: All size-groups of the red king crab that are likely to be caught in representative numbers according to the stock, in the trawl devices used.
Legal males: All male crabs with carapace length greater than or equal to 132 mm, or carapace width larger than or equal to 150 mm.
Pre-recruits: Male crabs with a carapace length greater than or equal to 115 mm and carapace length smaller than or equal to 131 mm.
Mature crabs: All crabs with a carapace length greater than or equal to 110 mm. This is also the basis for the estimation of the stock of egg-carrying females, and for the calculation of the sex-composition in the stock from the research cruise data.

Results

Data from research fishery

For 2002 the quota was set to 400 000 individuals, with 300 000 allocated to Russia and 100 000 to Norway. In the NEZ the fishery started 21st of October and the number of participating vessels increased to 127.

In the REZ the fishery was conducted in January-March and September-December and 14 vessels participated.

During the Russian research fishery in 2002, crabs were harvested using Japanese conical traps (22 823 trap-days) and American square traps (29 852 trap-days). The total fishing effort in the REZ was estimated to be 52 675 trap-days.

Fishing area

In the Russian coastal zone in 2002, crabs were harvested from Varangerfjorden in the west to the Seven Islands Archipelago (40°E) in the east. Other fisheries took place at a considerable distance offshore along the northern slope of the Rybachaya Bank (70°20’N), in the East Coastal area and on the Murman Rise (70°N). The area of crab fishery in the REZ is tending to expand to the north and east of earlier crab fishing areas.

In 2001, the whole Varangerfjord area was exploited as fishing area, coastal waters close to Vardø and Kiberg included. Some vessels tried to take their quota in Tanafjorden and the area known as Østhavet. During the fishery in 2002, the same areas as in 2001 were utilized as fishing areas in the Norwegian fisheries.

CPUE – index from traps

In January - March 2002 experimental fishing was conducted in the REZ in order to compare catch rates using conical, collapsible and American square traps. The average catch per day harvest by the first type was 1.7±0.4, by the second, 3.0±0.39 and the third, 9.0±0.49 legal males. Overall, the average catch per day harvest in the exploratory fishery in 2002 was 1.4 legal males by conical traps and 8.5 by American square traps.

There has been a general increase in catch per unit of effort (CPUE) of all sizes of males in the Norwegian research fishery (Table 1).

Table 1. CPUE (catch per unit effort) data from Varangerfjorden, Tanafjorden and Østhavet; 1999 – 2001. CPUE data from square collapsible traps.

CPUE value for males	1999	2000	2001
Varangerfjorden	3.8	6.4	14.6
Tanafjorden	0.4	1.3	12.4
Østhavet	1.1	2.0	3.7

Size of legal males

In the Russian zone, the mean weight of legal males was about 3.0 kg, according to information provided by research surveys in 2000 - 2002, while mean carapace width for crabs in the research fishery varied from 168 to 188 mm and the mean weight varied between 3.1 and 4.3 kg.

The mean individual weight of landed crabs in the Norwegian fishery decreased from 5.5 kg in 2000 to 4.3 kg in 2001. This was probably due to a higher exploitation rate in 2001. In 2002 the exploitation rate was at the same level as in 2001, and the mean individual weight of landed crabs was 4.1 kg.

Bycatch in other fisheries

Bycatches of red king crab in Russian waters are mainly taken during the trawl fishery for demersal fish. In 2001, the mean bycatch of crabs was 2.4 individuals per tonne of fish, and the total bycatch was estimated to be approximately 77 000 crabs (10 000 legal size males). In 2002, the average bycatch of the king crab was 10.88 individuals per tonne of fish, and the total bycatch was estimated to be approximately 417 000 crabs (175 000 legal size males).

The most serious bycatch problems of red king crabs in Norwegian waters are in the gillnet fishery for cod and lumpsucker during the winter and spring (Figure 1). The bycatch problem in the Varanger area has decreased, while it has increased in Tanafjorden. Bycatches of crab in the Norwegian trawl fishery offshore are so far poorly documented, but efforts to obtain such data will be increased in the future.

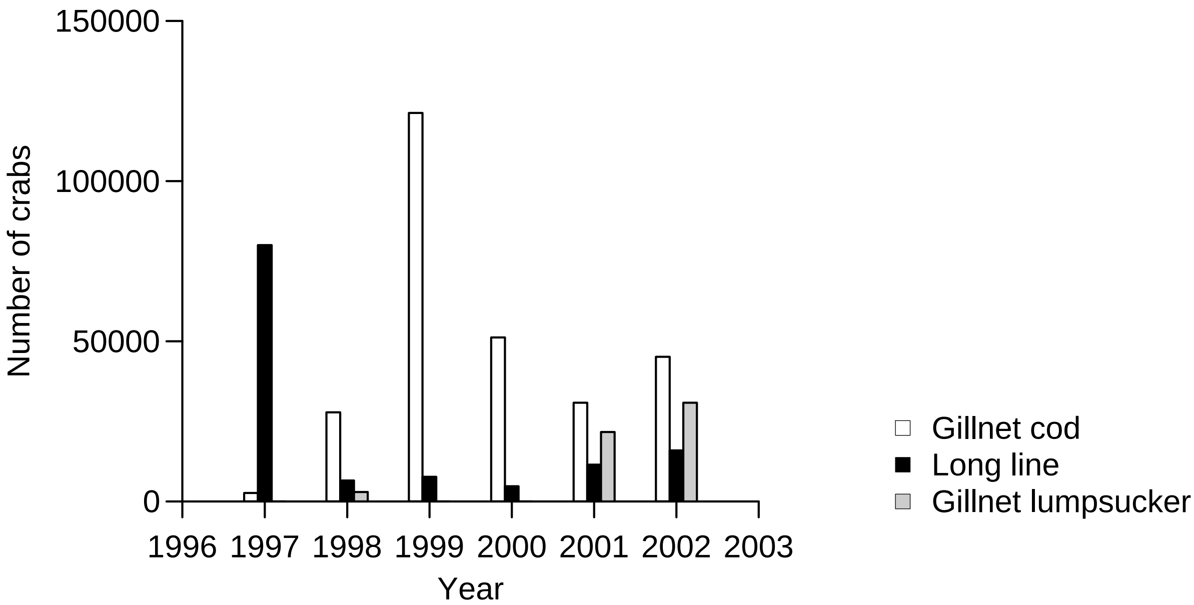

Figure 1. Estimated bycatches of red king crab-; 1997 – 2002, for three types of fishing gear.

Data from research cruises

Distribution area

According to Russian data from 2001, the densest concentrations of legal size males were found west and east of the Rybachy Peninsula. In 2002 a large area of dense concentrations developed in the eastern part of the crab habitat (Figure 1). In 2001, egg-carrying females were distributed over the entire area surveyed, while in 2002 they were only found in the near-coastal region (Figure 2).

The red king crab is continuously invading new areas along the coast of Finnmark as well as along deeper slopes 10 – 12 nm offshore. The crab has been recorded in Tanafjorden for many years now, and it the stock appears to be well established there. A survey carried out in autumn 2000, together with the research cruise in September 2002 and the research fishery in 2001, showed that the species is quite abundant in several places along the eastern side of Laksefjorden. Østhavet could not be examined sufficiently in 2002 due to bad weather conditions and loss of equipment during the cruise. In the winter of 2001/2002 there were additional cases of crab bycatches in the gillnet fishery for cod, west of the North Cape.

Stock structure

Analysis of the size distribution of red king crab in 1998-2002 in Russian waters showed that in 2002 a strong year-class recruited to the commercial stock (Figure 3). Males were most abundant in the size group from 150 to 180 mm carapace width (CW), while females were mainly 120 - 140 mm CW.

The size distribution of the crab stock in Varangerfjorden in 2002 showed that the abundant year-classes recorded for the first time in 1997 are now dominating the stock of legal males. Only a few small crabs were caught during the cruise in 2002. The absence of strong year classes means that recruitment to the legal male component of the stock will be negligible in the next few years (Figure 4).

In Tanafjorden the size distribution is different from that of the Varangerfjord area. Legal males with carapace length larger than 132 mm are quite abundant, while pre-recruits are found in only small numbers. A new year class of crabs with a carapace length of about 90 mm is abundant in the Tana stock, and will contribute significantly to the fishery within a few years.

The size distribution in Østhavet is unknown due to crab cruise failure in 2002.

Total stock index

Estimates of the total red king crab stock for the two national zones in the Barents Sea are presented in Table 2. However, the smallest size groups are not fully represented in the trawl catches, which provide the basis for the estimates. The smallest size groups (<50 – 60 mm carapace lengths) inhabit water depths that are not fully covered during trawl surveys. Therefore it was found necessary to agree upon a precise definition of what is meant by the term “total stock”.

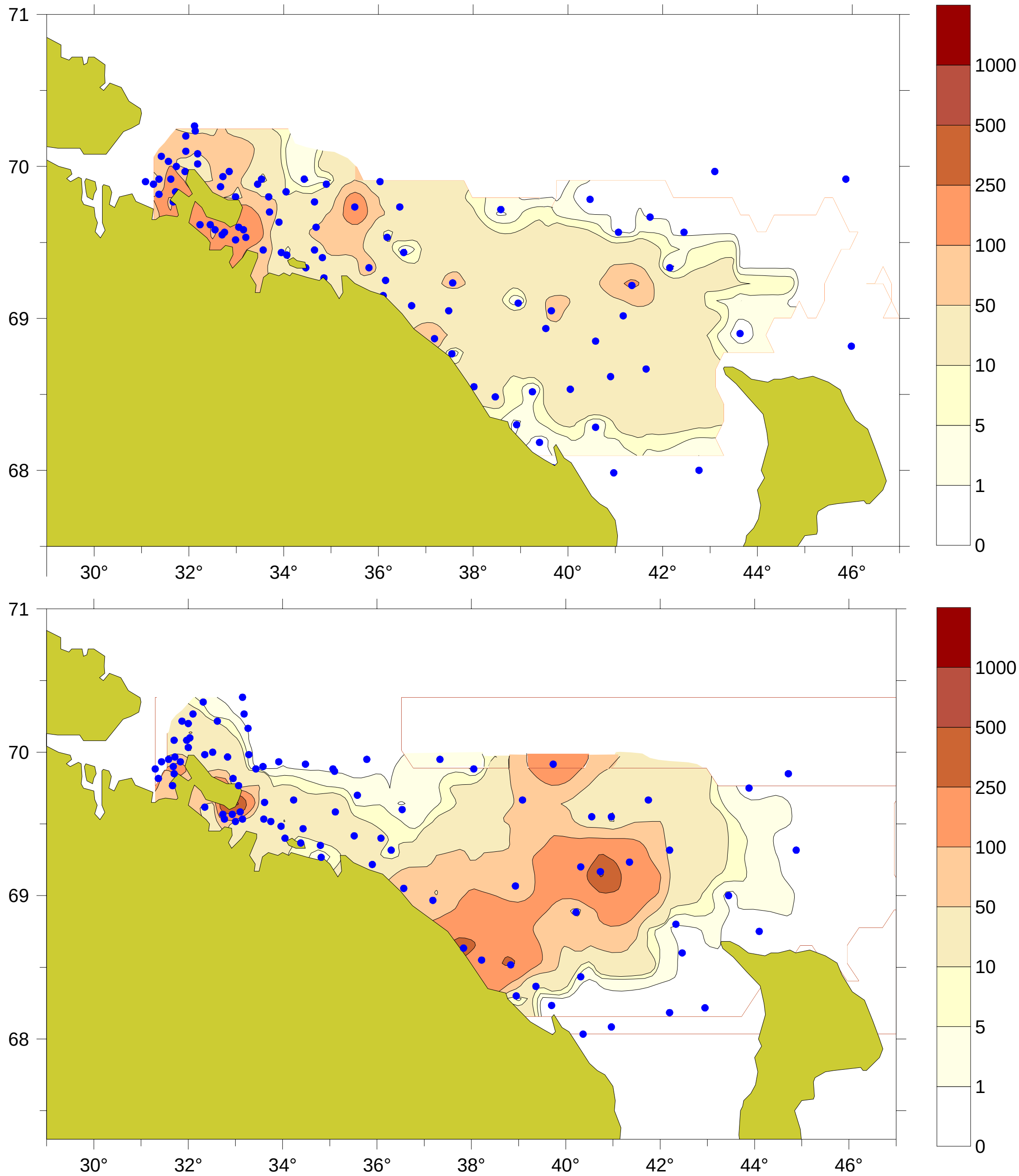

Figure 2. Distribution of legal males (spec/square km) in REZ in autumn 2001 (top) and in autumn 2002 (bottom).

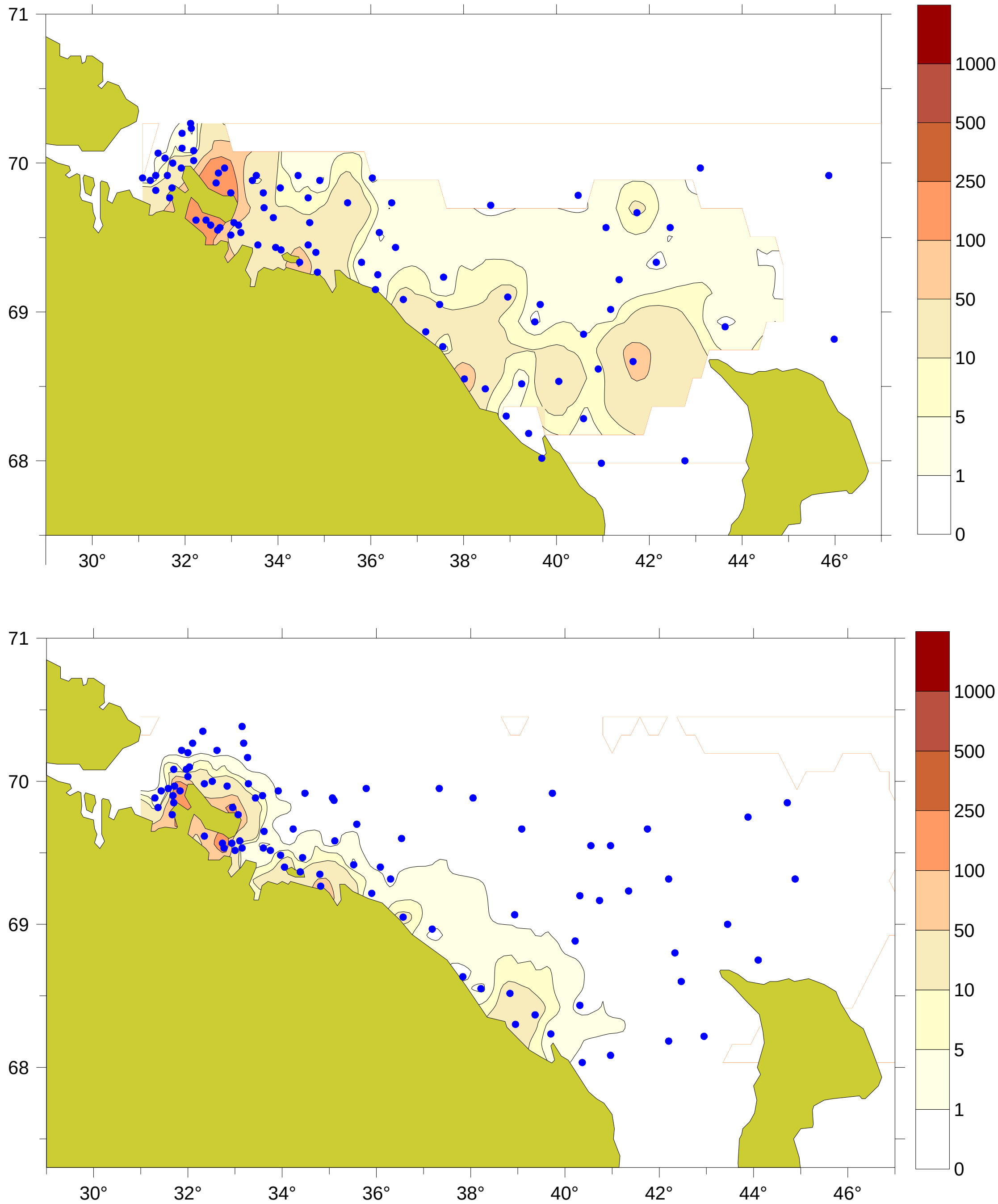

Figure 3. Distribution (spec/square km) of egg-carrying females in REZ in autumn 2001 (top) and autumn 2002 (bottom).

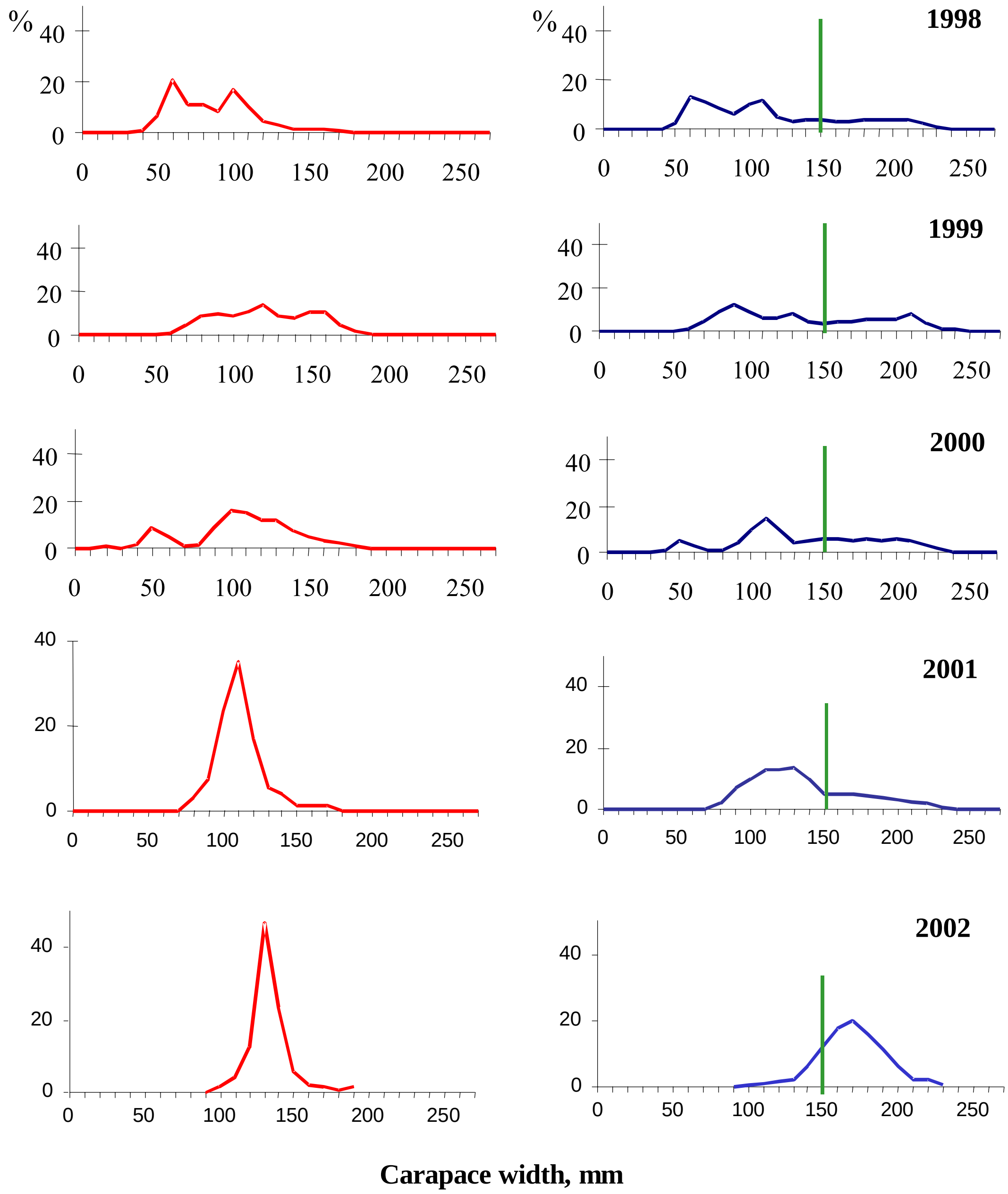

Figure 4. Carapace width distribution of red king crab in REZ from research cruises; 1998-2002. Red line – female; blue line – male; green bar – legal size limit.

the total stock index in the REZ in 2002 was 4 315 900 individuals and 12 100 000 in 2001. This reduction is probably related to underestimation of females and young crabs due to their mainly coastal distribution (see Figure 2); areas that are impossible to survey with a trawl.

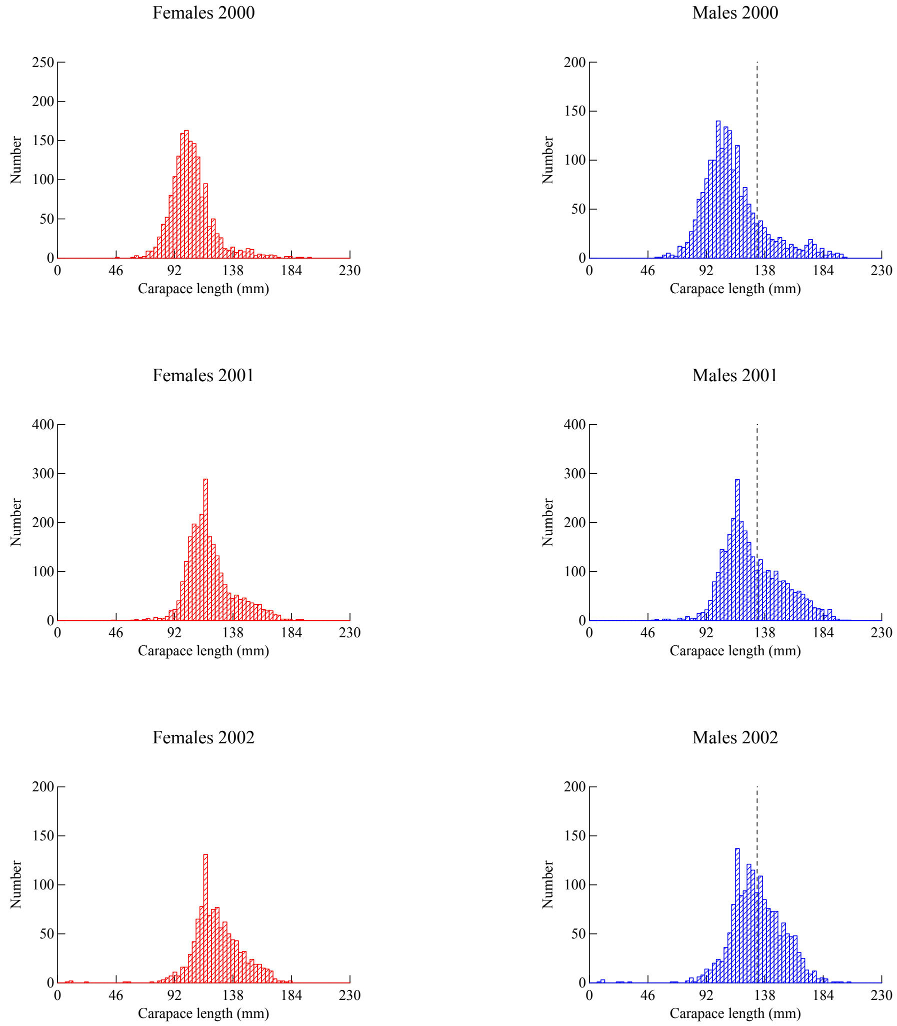

Figure 5. Carapace length distribution of red king crab caught in the Norwegian part of Varanger, in the period 2000 – 2002. Right-hand part of the figure - males and left-hand part - females. Dotted line indicates minimum legal size for males.

Table 2. Total red king crab stock index in the Russian economic zone (REZ) and Norwegian economic zone (NEZ), 2001 and 2002; swept area method.

Economic Zone	Year	Total stock index
REZ	2001	12 210 000
	2002	4 316 000
NEZ	2001	2 970 000
	2002	3 180 000

Stock index of legal males

A considerable recruitment to the legal males stock in REZ in 2002 led to an increase of the stock (Table 3).

The stock index of the legal males in the NEZ in 2002 was estimated only for the Varangerfjordn and Tanafjord. Only areas deeper than 100 m were included, since legal males rarely occurred in samples taken at depths of less than 100 m. The stock index estimate is based on a total of 81 trawl hauls in Varangerfjorden and 23 trawl hauls in Tanafjorden (Table 3).

Table 3. Estimates stock of legal males (CaWi ≥ 150 mm or CaLe ≥ 132 mm) for 1995 – 2002 in REZ and NEZ.

Year	REZ	NEZ	REZ + NEZ
1995	250 000	54000	304 000
1996	155 000	87000	242 000
1997	316 000	110000	426 000
1998	801 000	150000	951 000
1999	1 508 000	not estimated	
2000	1 513 000	676 000	2 189 000
2001	1 494 000	446 000	1 940 000
2002	3 271 000	799 000	4 070 000

Stock index of pre-recruits

The pre-recruit component of the crab stock was estimated for the first time in 2001. In the REZ the pre-recruit abundance in 2001 was estimated to be 2 220 000 crabs. In 2002, it decreased to 488 000 crabs. In West Murmansk waters - in the Russian part of the Varangerfjorden and Motovsky Bay - the stock index for pre-recruits remained almost unchanged from 2001 to 2002 at 109 400 and 95 300 crabs, respectively. On the northern slope of the Rybachy Peninsula and in the East Murmansk region the total abundance of pre-recruits was estimated to be 1 220 900 crabs in 2001 and 392 600 in 2002. The stock index of pre-recruits decreased 2-14 times in various areas (northern part of the Rybachaya bank, Kildin bank, West and East Costal areas, Murmansk Shallows).

As seen in the length distribution figure (see Figure 3) the pre-recruits make up a large proportion of the immature component of the male crab stock in the Norwegian part of Varanger, while they were almost absent in the Tanafjord in 2002. In NEZ the mean stock index of pre-recruits in 2002 was 445 572.

Recruitment to the crab stock

Juvenile red king crabs inhabit shallow waters during the first years of their life. This means that these year-classes do not appear in trawl catches before they migrate to deeper areas. Indices of the recruitment to the crab stock may therefore not be obtained before crabs reach about 50 – 70 mm in carapace length, when they begin to be caught in the trawl samples.

In Russian and Norwegian areas, high abundance of these age groups was observed only in 1997. Since then, there has been no evidence of good recruitment to the crab stock in these waters.

In Tanafjorden, there will probably be a good recruitment to the stock within about three to five years, since a large group of the stock was around 90 mm carapace length in 2002.

Moulting frequency of male red king crab

Male red king crabs skip moulting as they become older. The moulting frequency in each size-group depends on food availability, temperature etc., and may vary between years and areas. In the Norwegian investigations we use two different methods to reveal moulting; tagging experiments with T-bar tags in the isthmus, and a subjective judgment of the carapace age.

During the period from 1997 to 2001 the rate of moulting in the pre-recruit group varied between 70 and 90% in the Norwegian part of Varanger. Based on the subjective judgment of carapace age, the moult rate rose to about 94% in 2002. It may therefore be concluded that most of the pre-recruits will become legal males within the next year.

The meat content of harvested males was low in the Norwegian research fishery in 1999. This was assumed to be a result of a high moult rate of about 36 % among legal males that year. In 2000 this fell to about 21%, while it increased again to about 43% in 2001. In 2002 a total of 65 % of the legal male stock had moulted. Low meat content in catches during autumn 2002 was therefore also a significant problem. However, the fishermen seem to be able to sort out crabs with low meat content from the catch.

According to Russian research, mature females moult once a year. Mature males with a carapace width of less than 150 mm moult once a year, among males with a carapace widths of more than 150 mm individuals are found which moult every second year, and among those with a 170 mm carapace width, every third year. Crabs with a carapace width of more than 190 mm moult only every fourth year. According to research surveys, the moulting frequency of legal males in Russian waters was close to that in Norwegian waters. In 1999 the number was 50%, in 2000 48%, in 2001 68% and 86% in 2002. A considerably higher proportion of moulted legal males appeared in 2002 than in 2001, probably due to increased recruitment to the legal stock.

Ecological effects

So far, there have been no reports of any ecological effects of the red king crab on the ecosystem in the Norwegian zone. Some people, however, maintain that the crab ruins scallop beds in its areas of distribution and that it affects the habitat of flatfishes. In co-operation with the Norwegian College of Fisheries, a project was launched in 2001 with the main aim of studying possible impacts of the crab on the species diversity associated with scallop beds.

Studies of various aspects of red king crab feeding in the REZ suggest that competition between the crab and benthos-eating fish is insignificant. The crab feeds, primarily, on benthos and offal from the fisheries. In 2003, the Institute of Marine Research (IMR) launched a comprehensive research and surveillance programme to study any ecological effects. This is planned to be carried out in cooperation with other research institutions and will last for at least ten years.

Marine climate

Marine climate data such as temperature and salinity have been recorded in the Norwegian part of Varanger since 1994, but no main changes in these parameters have been found during this period.

In the past two years bottom water temperature in the REZ exceeded the long-term mean level by 0.5-1.0° C in 2001 and by 1-3°C in 2002.

Perspectives for the fishery

The red king crab fishery in both the Russian and Norwegian zones of the Barents Sea has been organized as an exploratory fishery, where the fishermen were subject to instructions from the research institutions in charge until 2001. In 2002 the fishery became an ordinary commercial fishery in Norway as decided by the RNFC (Joint Russian-Norwegian Fisheries Commission) in 2001. However it was decided to ensure that fishery and biological data would be collected from the fishery under the new fishing regime.

It is also necessary to increase scientific efforts to study the role of the red king crab in the Barents Sea ecosystem as an introduced species.

The decision regarding the TAC in the Barents Sea king crab fishery is made in late autumn (November) every year. Choosing this particular time of the year means that data from the fishery to be used in the stock assessment will be one year old, since the crab fishery takes place in the autumn. We therefore recommend that the time of year to decide upon a TAC be changed to spring of the following year, so that all the data from the latest fishery can be used in the crab assessment.

Stock status

The red king crab stock in the NEZ is still growing in numbers particularly in areas outside Varanger, such as Tanafjorden. Most of the abundant year classes, which in recent years have made up a large part of the stock, have now recruited to the legal size stock. Recruitment to the legal size stock was high in the NEZ also in 2002, but will decline in 2003 and the following years. No new recruitment to the crab stock in Varanger has been recorded since 1997 in the NEZ. In Tana, recruitment to the legal male stock will be negligible in 2003, but will increase again in 2004. There are no indications of any effects of the male-only harvest strategy in Norwegian zone.

The total crab stock index in the REZ in 2002 was low because of considerable underestimation of females and young crabs. The legal male stock increased to more than twice the 2001 level. We have no data available on recruitment of younger crabs.

Conclusions

The distribution area of red king crab in the Barents Sea is tending to expand westwards in Norwegian waters and northwards and eastwards in Russian waters.

Stock of legal males in Russian and Norwegian waters nearly doubled in 2002 compared to the previous year. Catch per unit of effort in the Norwegian crab fishery in 1999-2002 increased considerably. Bycatches of crabs in the trawl fishery in Russian waters increased from 2.4 to 10.9 crabs per tonne of fish from 2001 to 2002. In 2003 and subsequent years recruitment to the legal size stock is anticipated to decline.

The fishery management of this stock should ensure maximum long-term sustainable yield via a rational multi-species fishery over a long period of time. However, there is a need for continuous evaluation of king crab management due to the crab being an introduced species. Knowledge of any serious impacts of the crab on the ecosystem should trigger a new discussion on how this species should be managed.

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J. V. Tagart: Red king crab in Alaskan waters

Washington Department of Fish and Wildlife, Seattle

See PowerPoint presentation on enclosed CD.

SESSION 4: Marine mammals

T. Haug[1] and V. Svetochev[2]: Seals in the Barents Sea

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Introduction

Six seal species occur regularly in the Barents Sea. Three of these have adapted to life in the Arctic such that they spend their entire lives in the northernmost (Svalbard – Franz Jozef Land) and east-southeastern (Novaja Zemlja – Pechora) range areas of the sea: walrus, bearded seals and ringed seals. In the southern areas, grey and harbour seals reside on the Norwegian and Murman coasts. Following severe overexploitation, walruses were given total protection in the area in 1952. For ringed, bearded, grey and harbour seals, a certain amount of game hunting has continued in some areas to the present day. Only one seal species in the area has been subject to large-scale commercial exploitation: the harp seal*. The species is by far the most numerous and ecologically also the most important seal in the Barents Sea ecosystem. It has been exploited and managed jointly by Norway and Russia during the past two centuries. In the following, therefore, we focus only on harp seals.

Stock characteristics

Distribution

Harp seals are a wide-ranging, migratory species. Three stocks (Figure 1) inhabit the North Atlantic Ocean, whelping on the pack ice off Newfoundland and in the Gulf of St. Lawrence (the Northwest Atlantic stock), off the east coast of Greenland (the Greenland Sea or West Ice stock), and in the White Sea (the Barents Sea or East Ice stock) (Lavigne and Kovacs 1988). During the spring, harp seals display a set sequence of activities - whelping (in March-April), followed by 12 days of intensive lactation, then mating, after which the females wean their pups. Adults and immature seals moult north of each whelping location after a further lapse of approximately four weeks. The location of these events in the Northeast Atlantic is either the fringe of winter ice, lying seawards of the heavier Arctic ice off the east Greenland pack, located between the latitudes 69°N and 75°N (the West Ice stock, Øritsland and Øien 1995), or the White Sea and south-eastern parts of the Barents Sea (the East Ice stock, Haug et al. 1994). When the moult is over, the seals disperse in small herds to feed. Their location at this time of the year is heavily dependent on the configuration of the drifting sea ice. Seals from the West Ice disperse over the drift ice along the east coast of Greenland, from the Denmark Strait or farther south, northwards towards Spitsbergen, and into the Barents Sea. The East Ice seals follow the receding ice edge during summer, gradually moving northwards and north-eastwards in the Barents Sea. Overlap between harp seals from the West Ice and East Ice occurs in the northern Barents Sea during summer and autumn, which are the most intensive feeding periods for the species. The movement towards the breeding areas (in the Greenland Sea and White Sea for the West Ice and East Ice stocks, respectively) begins in November-December.

Figure 1. Locations of North Atlantic harp seal stocks. Green spots mark the whelping and moulting areas for the Barents Sea/White Sea (also called the East Ice) stock (the White Sea), the Greenland Sea or West Ice stock (West Ice), and the northwest Atlantic stock (Front and Gulf areas). Dark blue marks the entire area of distribution.

Size

The Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP) met at ICES headquarters, Copenhagen, Denmark, on 2-6 October 2000 to assess the most current status of the stocks of Barents Sea/White Sea and Greenland Sea harp seals (ICES 2001a).

Russian aircraft and helicopter surveys of Barents Sea/White Sea harp seal pups were conducted in the White Sea in March 1998 and 2000 using traditional strip transect methodology and multiple sensors (ICES 2001a, Poteov et al. 2003). Black and white, ultraviolet and thermal infra-red scanners were employed. The estimates are considered to be negatively biased since they were not corrected for pups, which might have been hidden from the camera, or for pups missed by the readers. Furthermore, the survey estimates were not corrected for the temporal distribution of births.Actual pup production may therefore be higher than the estimates presented below:

Year	Pup production estimate	c.v.
1998	286 260	.073
2000	322 474	.089
2000	339 710	.095

These pup production estimates were used by WGHARP to assess the entire population on the basis of a population dynamics model that estimated the development of future population size, for which statistical uncertainty was provided for various catch options (ICES 2001a). The age structure of the model was restricted to two age classes, 0 (pups) and 1+ (one year old or older), because of limited information on catch at age and age structure for the populations in question, and because of the fact that catches were rather small compared to population size in the years for which catch at age is known. The model requires estimates of mortality and reproductive parameters that include variance. Using the historical catch data and estimates of pup production, the model estimates mortality (M_0 and M_{1+}) and a birth rate in the 1+ population of females (f). The freedom with which the model can estimate these parameters is dependent upon the standard deviations provided. The model is fitted to pup production estimates weighted inversely to their variance in cases where more than one estimate is available.

The possibility of including multiple pup production estimates in the assessment model is an improvement on previously used estimation programmes. However, models of this nature do not estimate parameters well when pup production estimates are derived from a limited period in time compared to generation time. The model has the option of allowing estimates of population size and sustainable catch to be made, but when given no prior information about M_{1+} and f, the model treats these parameters as independent parameters. To stabilize the model, the range of these parameters had to be constrained. As a result, the estimates of uncertainty may be negatively biased, and the confidence intervals for future population sizes may be too narrow.

There are reports that pup mortality rates may vary substantially in the White Sea region, and that in recent years these rates have been very high. For this reason, the abundance of White Sea/Barents Sea harp seals in 2000 was estimated under two different assumptions about the ratio M_0/ M_{1+}:

Parameter	Estimate	95% CI
$M_0/ M_{1+} = 3.0$		
1+ population in 2000	1 727 000	1 550 000 – 1 910 000
Pup production	319 000	286 000 – 351 000
M_{1+}	0.10	0.07 – 0.12
M_0/ M_{1+}	3.0	Fixed
F (birth rate for 1+ females)	.42	Fixed
$M_0/ M_{1+} = 5.0$		
1+ population in 2000	1 676 300	1 500 000 – 1 850 000
Pup production	314 000	283 000 – 346 000

M_{1+}	0.09	0.07 – 0.11
M_0/ M_{1+}	5.0	Fixed
F (birth rate for 1+ females)	0.42	Fixed

When the Advisory Committee on Fishery Management (ACFM) reviewed the results of the WGHARP assessments at its autumn 2000 meeting (ICES 2001b), the conclusion was that the stock was within safe biological limits, that numbers were estimated to be increasing, that catches through the 1990s had been below quotas, and that there was some evidence that densities may have been so high that biological processes such as rate of maturation may be showing density-dependent effects.

During the period 1977-1991, about 17 000 harp seal pups were tagged in a comprehensive mark-recapture experiment in the Greenland Sea (Øien and Øritsland, 1995). Updates of the mark-recapture-based pup production estimates indicated a pup production in 1991 of 67 300 (95% CI 56 400-78 113) (NAFO, 1995). Aerial surveys performed in 1991 suggested a minimum pup production in this year in excess of 55 000 (Øritsland and Øien, 1995). When assessing the present status of the stock, WGHARP used the new population dynamics model described above, and calculated a projected 2000 pup production estimate of 76 700 (95% CI 48 000 – 105 000) and a total size of the 1+ population of 361 000 with a 95% confidence interval ranging between 210 000 and 629 000 animals (ICES, 2001a). In its review of the WGHARP assessment, ACFM concluded that the Greenland Sea stock of harp seals was within safe biological limits, and that recent removals had been well below the recommended sustainable yields (ICES 2001b).

Position in the food web

Barents Sea harp seals display opportunistic feeding patterns in that different species are consumed in different areas and at different times of the year. However, the bulk of the harp seal diet is comprised of relatively few species, in particular capelin, polar cod, herring *Clupea harengus*, krill *Thysanoessa* spp. and the pelagic amphipod *P. libellula*. The crustaceans appear to be of particular importance as food for harp seals during their summer and autumn feeding in the northern parts of the Barents Sea (July-October). As the ice cover expands southwards in late autumn and winter, the southward-migrating seals appear to switch from crustaceans to fish (particularly capelin and polar cod) as their preferred food (Nilssen et al. 1995a; Lindstrøm et al. 1998). In the southernmost areas of the Barents Sea, where the seals occur during winter and early spring, herring is also an important forage fish (Nilssen et al. 1995b). Several fish species may serve as prey for harp seals during the late autumn and winter. Nilssen et al. (2000) calculated the total food consumption by harp seals in the Barents Sea using data on energy intake, diet composition, energy density of prey and predator abundance. The food consumption of around two million harp seals was calculated for periods with a high and low capelin stock (both situations occurred in 1990-1996, the period during which the seal diet data was collected). Assuming that there are seasonal changes in metabolic rate associated with changes in body mass (blubber deposition), and that the field metabolic rate of the seals corresponded to two times their predicted basal metabolic rate, the annual food consumption of the harp seals was estimated to be within a range of 2.69 - 3.96 million tonnes of biomass. Distribution of the harp seals' energy requirements across a representative mix of prey species gave point estimates of 1.22 million tonnes of crustaceans, 808,000 tonnes capelin, 605,000 tonnes polar cod, 212,000 tonnes herring and a mixture of gadoids and other more Arctic fishes of circa 500,000 tonnes (Figure 2). A low capelin stock (as in 1993-1996) led to a switch in harp seal diet, with increased consumption of other fish species, in particular polar cod, other gadoids and herring.

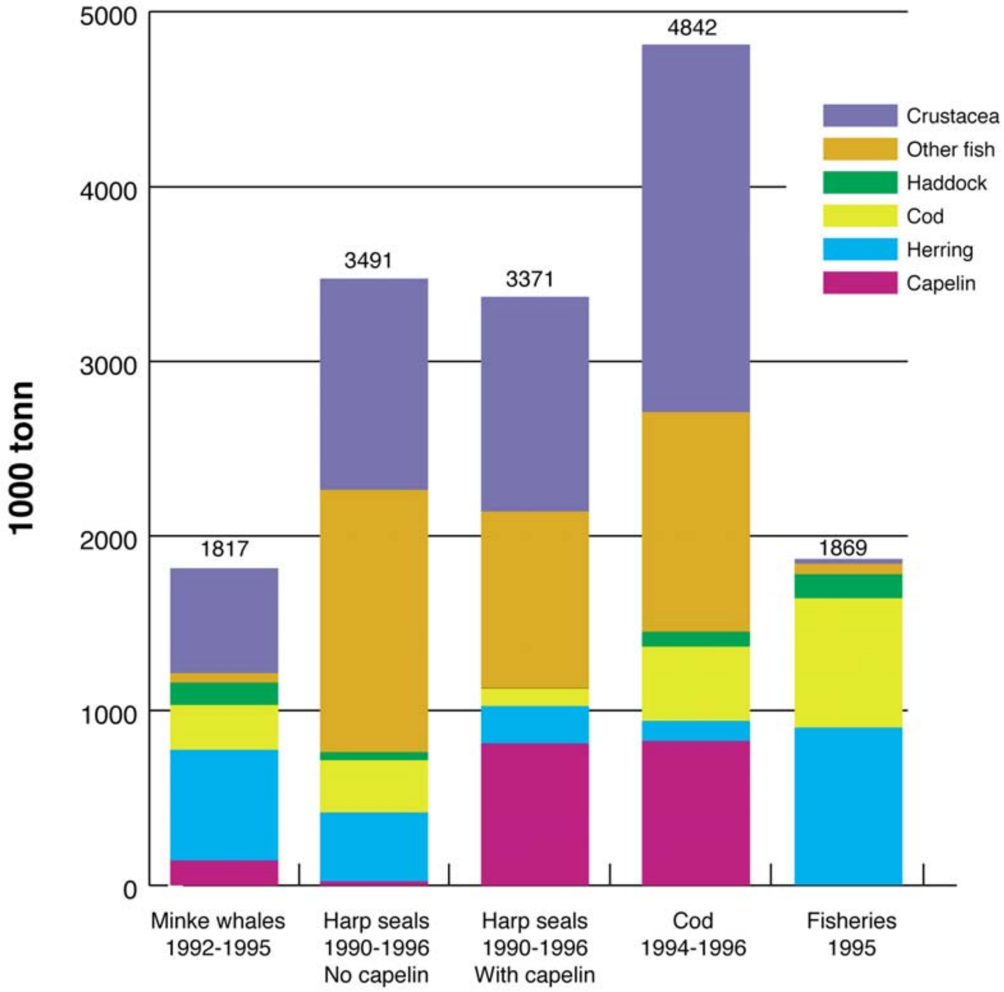

Figure 2. Estimated annual consumption by East Ice harp seals in the Barents Sea in the early 1990s. Scenarios with and without capelin are shown, and comparison is also made with the annual consumption of minke whales and cod, and with total fishery removals in 1995. Based on data provided by Bogstad et al. (2000).

Recent observations from satellite tagging experiments suggest that Greenland Sea and Barents Sea harp seals likely overlap in their feeding range during the summer and autumn (June-October) in the northern Barents Sea (Lars P. Folkow, University of Tromsø, Norway, pers. comm.). This means an additional pressure on the Barents Sea resources which need to be added to the results given by Nilssen et al. (2000).

Due to seasonal variation in food availability the body mass of many marine mammals feeding in the Arctic, including harp seals, varies substantially in an annual cycle. There is a regular seasonal pattern of deposition of energy reserves as fat in the subcutaneous blubber layer. This is well illustrated in Barents Sea/White Sea harp seals (see Nilssen et al. 1997), which are generally thin in spring and early summer (May – June). Their condition improves over the summer, and they are quite fat by September – October. The energy stores built up during the summer and autumn are maintained until February, but then the seals become thinner as their stores of blubber diminish rapidly during the breeding and moulting period (March-June). How these variations in deposited fat affect body weight is illustrated by the case of harp seals - an adult (165 cm long) harp seal which would weigh 80 kg in June weighs 145 kg in October, a change of 81.5% (Nilssen et al. 1997). The ability to store large amounts of energy and sustain significant periods of fasting is an essential adaptation for most Arctic mammals.

Ecosystem changes and density dependency

Ecosystem changes that may affect marine mammal populations, e.g., through changes in food or habitat availability. The winter/spring harp seal invasions to coastal areas of North Norway may serve as a useful example of one type of interaction (see Haug et al. 1991, Haug & Nilssen 1995). Since 1978, Barents Sea harp seals have appeared in large numbers in Finnmark, North Norway, from February until May. The size of the seal invasions increased dramatically in 1987 and 1988 when huge herds of seals (hundreds of thousands) were observed along the coast of North Norway between January and August. The seal invasions gave rise to seal-fisheries conflicts. In addition to consuming fish, the seals caused substantial damage to gill nets and gill net catches. The presence of seals may also have resulted in the emigration of commercial species from traditional fishing grounds to deeper strata or areas unsuitable for fishing. Reduced recruitment to the seal population seems to have prevailed during most of the seal invasion period, particularly during 1986-1988, when first-year mortality may have been almost total. Food shortage, particularly of the three important prey species capelin, polar cod and herring, probably caused the coastal invasions. The following scenario has been suggested as an explanation of this phenomenon. A series of cold years in the Barents Sea initially led to a more westerly winter distribution of a growing population of harp seals. A food shortage, possibly resulting from the 1985-1986 collapse in the capelin stock and a generally low stock of polar cod, following intensive fisheries for both species in the 1960s and 1970s, may have intensified the problem by forcing large numbers of harp seals to leave their traditional wintering areas in the south-eastern Barents Sea in favour of the coast of North Norway in 1987 and 1988. Mortality, particularly of young animals, appears to have risen, leading to reduced recruitment to the population. Substantial increases in the abundance of immature Norwegian spring spawning herring in the south-eastern Barents Sea may have resulted in the establishment of a suitable alternative winter food resource for the harp seals, thereby contributing to the reductions in the size of the seal invasions observed since 1988. In the 1990s, improved stocks of capelin and polar cod may also have contributed to reducing the seal invasions (Nilssen et al. 1998).

Pinniped age is usually estimated from counts of growth layers deposited in teeth, and the longevity of harp seals is 20-40 years (Bowen et al. 1983, Kjellqwist et al. 1995). In stock assessment, age at maturity is a parameter of vital importance. Age at maturity is not an absolute value in animal populations in that it varies in response to environmental changes. This is nicely exemplified in the northwest Atlantic population of harp seals, where a significant decrease in mean age at maturity from 5.8 years in the early 1950s to 4.6 years in the early 80s coincided with a harvest-driven reduction in population size from three to 2.4 million animals with an intermediate low of 1.8 million animals in the early 1970s (Shelton et al., 1996; Sjare et al., 2000). Some early studies suggested that this was a simple density-dependent relationship between population size and age at maturity in harp seals, which might then serve as a convenient indicator of trends in stock abundance (Bowen et al., 1981; Lett et al., 1981). However, a substantial increase in the Northwest Atlantic harp seal population to 5.3 millions in 1997 was only accompanied by a modest increase in mean age at maturity to 5.6 years in 1995-97 (Sjare et al., 2000), suggesting that a more complex relationship exists. The essential principle of density dependence is one of resource limitation. In an ice-breeding species like harp seals the limiting resource is probably food rather than breeding space, as is also suggested by observations of negative correlations between body growth rates and age at maturity in both Northwest Atlantic and Barents Sea (East Ice) harp seals (Innes et al., 1981; Kjellqwist et al., 1995, Chabot et al., 1996). Food limitation might result from an increase in population size as well as changes in ecosystem carrying capacity due to density independent changes in prey availability or levels of competition from other consumers, including man.

Starting from similar values (5.4 - 5.6 years) in the early 1960s, age at sexual maturity appears to have followed different trends in the two stocks of Northeast Atlantic harp seals (Frie et al., 2003). In the West Ice stock no long-term trend was found whereas in the East Ice stock mean age at maturity had increased to 8.2 years in the early 90s (Figure 3). Present knowledge of population fluctuations and general ecology of these two stocks is too incomplete to fully understand the possible causes for the observed differences, but both density-dependent and density-independent factors are likely to be involved. The different trends in age at sexual maturity (and also growth rates) between the two Northeast Atlantic harp seal stocks indicate that maturing animals from the two stocks have experienced different food-availability scenarios in the 80s and perhaps even before that time. In the case of the Barents Sea stock, it is generally thought that the implementation of a series of catch regulations allowed the stock to increase from a historical low in the early 1960s (Sergeant 1991, ICES 2001a), and this may have contributed to the observed changes in growth and age at maturity. However, Frie et al. (2003) emphasize that the observed changes may be due to changes in the Barents Sea ecosystem, in particular occasional low availability of important forage fish such as capelin *Mallotus villosus* and polar cod *Boreogadus saida* during the winter and early spring. Little is known about the ecology and trends in abundance of the West Ice stock, although it is acknowledged that the stock must have increased since the early 1960s (Ulltang and Øien, 1988; Øien and Øritsland, 1995, ICES 2001a).

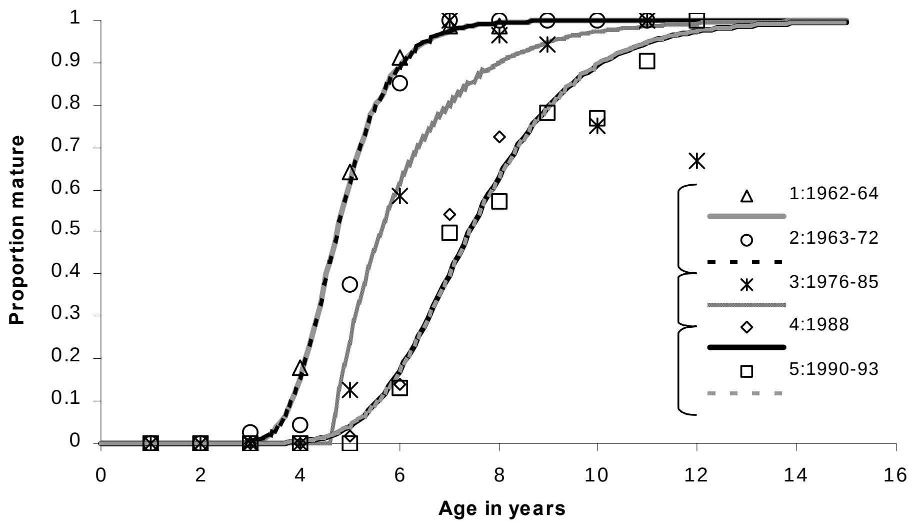

Figure 3. Changing age at sexual maturity in East Ice harp seals. An increase in mean age seems to have prevailed from 5.6 years in the two first periods (1962-64 and 1963-72) to 8.2 years in the last (1990-93) period. From Frie et al. (2003).

Catch history

In their historical assessment, Skaug and Øien (in prep) noted that the Barents Sea/White Sea (East Ice) stock of harp seals had been hunted by Norwegian and Russian sealers over a long period of time, probably since the 12th century, and that documentation of these catches was scarce. The fishery was originally shore-based, taking place along the coasts of the White Sea and around the Kanin Peninsula (see Sergeant 1991). Offshore hunting started when vessels from North Norway caught harp seals in 1867 (Iversen 1927); they were joined by vessels from Western Norway from 1919 onwards and by Soviet vessels during the 1920s. Prior to 1875 there were many years without catch information at all, but Iversen (1927) assumed that the catches were probably quite small, supposedly annually in the hundreds. After 1875 total catches increased, with levels of between 15 000 and 60 000 up to around 1900, above 100 000 after that year, and with the largest catches taken in the 1920s and 1930s (annual average of 200 000 - 300 000 animals, and a top in 1925 when nearly 470 000 seals were taken) (Iversen 1927, Sivertsen 1941, Nakken 1988, Skaug and Øien in prep.).

In 1924-1939, Norwegian seal hunting in the White Sea and in the southeastern part of the Barents Sea was conducted under Soviet licence, and up to 1933 the Norwegian harvest exceeded that of Soviet sealers. Mean annual Norwegian harp seal catches in 1920 -1933 were 170 000 animals, whereas the Soviet mean catch was about 102 000 animals. During 1934 – 1939, the Norwegian annual harvest was reduced to 43 000. According to Surkov (1957), the distribution of harp seal whelping patches changed within the White Sea area from the mid 1930s. Simultaneously, the number of sealing vessels was reduced. Nevertheless, Soviet catches rose. After World War II the seal catch licences for Norwegian vessels in the White Sea region were not renewed. For this reason, Norwegian catches began to be based on taking animals on drifting ice in the Barents Sea. The mean annual Norwegian seal harvest in 1946 - 1964 was 15391 animals, the results of each year's harvest being particularly dependent on effort (number of vessels and trips), hydrometeorological conditions (weather, current and ice) and various features of breeding ground distribution.

While exploitation was low during World War II, the total hunting pressure increased substantially from 1946 onwards (Figure 4), and the population was probably reduced from 1.25-1.5 million individuals in the 50s (numbers based on aerial surveys on the moulting grounds in 1952-1953 and in 1959; (Surkov 1957, 1963)) to less than 500 000 in the mid-60s (Bowen et al. 1981). According to Dorofeev (1939, 1956), aerial surveys performed on the moulting grounds in 1927-1928 suggested that the population at that time may have been 3.0-3.5 million individuals. Quotas for the Soviet catches were introduced unilaterally in 1955 (100 000 seals, Yakovenko 1963) and were gradually reduced until 1965, when a quota of 34 000 seals was imposed for the total catch (taken by Norway and Soviet together). Adult females were protected in the whelping patches in 1963, and Soviet catches of 1+ seals stopped in 1965 (Kjellqwist et al. 1995). Minimum pup production was estimated at about 100 000 in 1965 (Benjaminsen, 1979), which by projection of population models gave an estimated pup production of 170 000 in 1978, corresponding to a total population of around. 800 000, which was estimated to increase by 5% per year. This projection assumed a median age at first whelping of five years. Assuming a median age at first whelping of six years, which is more in line with recent estimates (Frie et al. 2003), the projected pup production in 1978 was 141 000. However, as the 95% confidence interval of the 1965 pup production estimate ranged from 74 000-221 000 these calculations can hardly be taken to indicate an increasing trend in pup production. In the 1980s, Russian aerial surveys of whelping females and age composition data indicated reduced recruitment (Krylov, 1986; Ulltang and Øien, 1988; ICES, 1992, 1994; Kjellqwist *et al.*, 1995; Timoshenko, 1995), which was corroborated by the near absence of the 1986-1988 year-classes in later Norwegian catches from the moulting grounds (Kjellqwist *et al.*, 1995, Nilssen *et al.*, 1998). Some caution is warranted, because surveys of whelping females rely heavily on the accuracy of correction factors for the proportion of females in the water, which may vary considerably with time of day, meteorological conditions and perhaps also local food availability, since female harp seals have been found to feed opportunistically during lactation (Nilssen et al. 1995b, Lydersen and Kovacs 1996). Increased catches in the late 70s and in 80s (annual quotas increased to 50 000 in 1977, 60 000 in 1981, 75 000 in 1982, reaching a maximum of 82 000 in 1983, then decreasing to 80 000 in 1984-1987) and large bycatches of harp seals in Norwegian gill net fisheries in the period 1986-1988 may also have influenced the status of the stock (Haug and

Nilssen, 1995; Kjellqwist *et al*., 1995). The total quota was reduced to 70 000 in 1988 and further down to 40 000 in 1989-1998. Although there is no hard evidence of changes in the siz of the population of Barents Sea/White Sea harp seals from the 60s onwards, there may be some reason to expect an increase in numbers, owing to the implementation of several catch regulations such as full protection of whelping females from 1963, a stop in Soviet catches of 1+ animals and a general decrease in catches due to a new quota system from 1965 (Benjaminsen, 1979, Sergeant 1991). As seen from Figure 4, the majority of catches in 1965-2002 were pups.

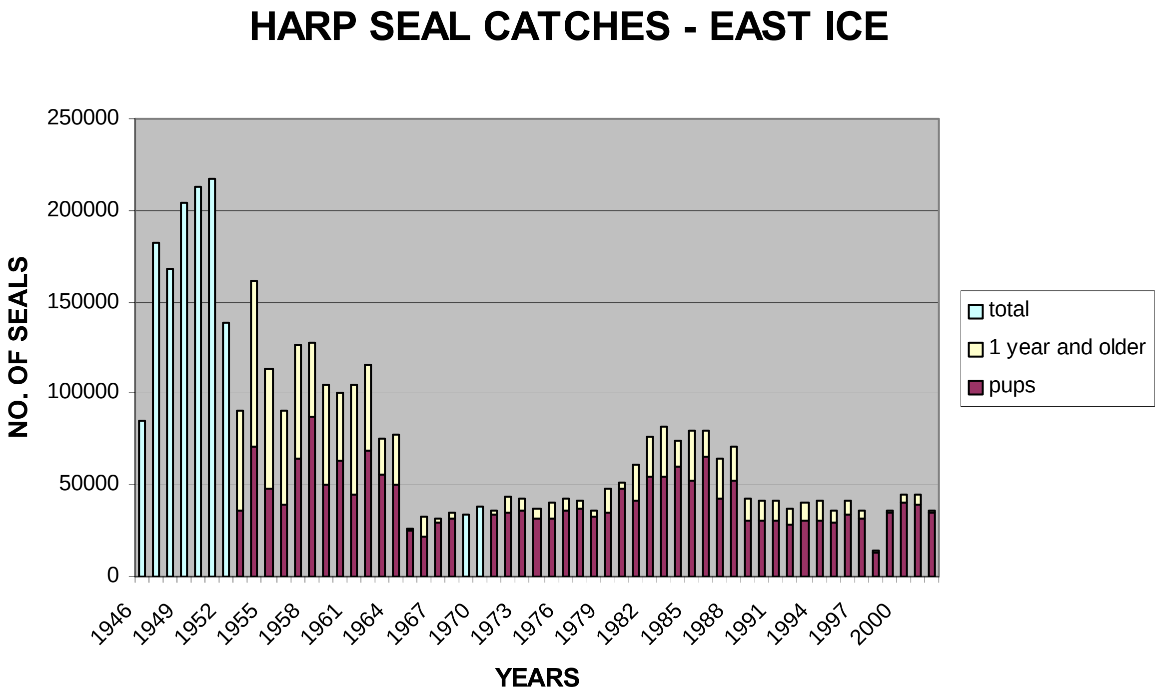

Figure 4. Annual catches of East Ice harp seals after World War II (1946-2002). Whenever possible, the total catches are split into pups of the year and animals one year old and older.

Aerial surveys of pup production in 1998 and 2000 indicated a total population of Barents Sea/White Sea harp seals of about 2 million animals in 2000 (CI: 1.8-2.3 million) (ICES, 2001a). However, the recent estimates are not necessarily comparable to earlier estimates obtained by other methods and thus tell us little about the population trajectory. Nevertheless, they have formed the basis for ACFM's advice on TACs from 1999 onwards (ICES 1999, 2001a, 2001b). For 1999 and 2000, the recommended TAC was 31 600 1+ animals, or an equivalent number of pups (one 1+ seal should be balanced by 2.5 pups). Russian authorities chose to set the quotas lower (21 400 and 22 700 1+ animals in 1999 and 2000, respectively). The recommended 2001-2003 quotas were 53 000 1+ animals (again one 1+ seal should be balanced by 2.5 pups). The quotas for the last period were similar to the recommended TACs, but catches (which have virtually all been of the same magnitude, i.e., 36 000 – 42 000 animals of which the majority were pups, since 1989) were only 31-39% of the recommended sustainable level that would stabilise the population.

The Greenland Sea (West Ice) stock of harp seals has been subject to commercial exploitation for centuries (Iversen, 1927; Nakken, 1988; Sergeant, 1991). The Greenland Sea hunt started as an offshoot of the Spitsbergen hunt for bowhead whales (*Balaena mysticetus*) in the late 17th century. Knowledge of the Greenland Sea catches in the 18th and the first two-thirds of the 19th century, made by Dutch, British, German and Danish ships, is poor.

Norwegian sealers appeared for the first time in the Greenland Sea in 1846, and have subsequently participated with increased effort. Exploitation levels reached a historical maximum in the 1870s and 1880s when annual catches of harp seals (pups and adults) ranged from 50 000 to 120 000 (Iversen, 1927). This assumed overexploitation probably drove the stock to an all-time low, and the competition for a limited supply of seals in the 1870s resulted in the disappearance of all non-Norwegian fleets (Sergeant 1991). It was evident that the catch levels in the 1870s were higher than the stock could sustain, and some regulatory measures (mainly designed to protect adult females) were taken in 1876 (Iversen, 1927). In the first decades of the 20th century, annual harp seal catches varied between 10 000 and 20 000 animals, whereas an increase to around 40 000 seals per year occurred in the 1930s (Iversen, 1927; Sergeant 1991). After a five-year hiatus in sealing during World War II, total annual catches rapidly rose to a post-war maximum of about 70 000 in 1948, but then followed a falling trend until quotas were imposed in 1971 (Sergeant 1991, ICES 2001a). From 1955 to 1994 a small proportion of the catches was taken by the Soviet Union/Russia, and the total annual catches have varied between a few hundreds to about 17 000 from 1971 until the present day (ICES 2001a).

Management history

In no population of harp seals were conservation measures introduced in time to prevent depletion (Sergeant 1991). In the history of exploitation there was a tension between the need to take the young as the most valuable product and the need to prevent undue disturbance of whelping and moulting and to conserve the stock; this generally resulted in the adoption of starting dates and closing dates as first conservation measures. Most early decisions concerning harp seal management were made on a unilateral basis. Since 1959, however, Norwegian and Russian sealing has been regulated on the basis of recommendations from annual meetings of the Norwegian-Soviet Sealing Commission, which were succeeded in 1984 by consultations under the Joint Norwegian-Soviet Fisheries commission (later the Joint Norwegian-Russian Fisheries Commission) (ICES 1987).

Current management of harp seals is based on assessments performed by the Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP). The history of WGHARP is not particularly long (1984 until the present). Nevertheless, the group has been, and still is, crucial in the management of harp (and hooded) seals in the North Atlantic. The group started with a restricted geographical mandate (harp and hooded seals in the Greenland Sea) but expanded to include all harp and hooded seal populations in the north Atlantic (since 1989). Major topics included assessment of the status of the populations, provision of advice on sustainable harvest levels, and assessment of interactions with prey (i.e. ecological role of seals). Terms of reference (TORs) given to WGHARP are based on requests for information and advice related to management of the seal stocks, as provided to ICES or NAFO by commissions (e.g., NAMMCO) or member governments. Formulation of the TORs is the responsibility of the ICES Advisory Committee on Fisheries Management (ACFM) and the NAFO Scientific Council (NAFO SC). After its meetings, WGHARP reports the results of its deliberations to ACFM and NAFO SC. Subsequently, ACFM and NAFO SC provide the advice requested for the northwestern and northeastern stocks, respectively. At present, WGHARP is made up of 25 appointed members from Canada, Denmark (Faroe Islands and Greenland), Germany, Iceland, Norway, Russia, UK and USA.

Since the establishment of a working group to deal with issues related to the management and harvest of harp and hooded seals in the North Atlantic within the ICES framework in 1984, there has been an improvement in the availability of necessary assessment data. From an initial situation in which almost no relevant data were available for some of the stocks in question, the present state of the art is that at least some assessment data (certainly with variable quality) are available for all stocks.

In 1984-1988, the group met under the name Working Group on Harp and Hooded Seals in the Greenland Sea (ICES 1987, 1988), reflecting its geographical mandate. In meetings in 1985 and 1987, the group had to conclude, however, that due to the unavailability of historical data and information about current pup production and stock size for the two stocks in question, no sustainable or replacement yields could be calculated. The group was thus unable to provide scientific advice on catch options. Furthermore, the group noted that current information on the ecology of harp and hooded seals was insufficient to determine the extent of their interaction with commercial fisheries.

In 1988, the working group was renamed as the ICES Working Group on Harp and Hooded Seals, which meant that from now on it was given the additional task of examining data from the Barents Sea/White Sea harp seal population. When the renamed group met in 1989 (ICES 1990), it still had to admit that even though some results from aerial surveys and mark-recapture experiments were now available for harp seals both in the Greenland Sea and in the Barents Sea/White Sea, the uncertainties involved in both data collections and subsequent analyses were too large to allow calculations of sustainable or replacement yields to be made. Thus, the group was still unable to provide scientific advise on catch options. Although it was noted that greater efforts had been devoted to answering questions relating to seal–fisheries interactions, the group concluded that basic information on these issues was still insufficient to address these questions satisfactorily.

From the establishment of the working group in 1984, the possibilities of including the northwest Atlantic stocks of harp and hooded seals had been discussed. This would require coordination with NAFO. In its 1989 meeting, the working group concluded with satisfaction that ICES had officially recommended the establishment of a Joint ICES/NAFO Working Group on Harp and Hooded Seals (WGHARP). The group was established, with the following mandate:

" ... for the purpose of assessing the status of these stocks and providing related advice and information in the areas of both organizations. Contracting Parties to either organization or regulatory commissions who might desire advice on harp and/or hooded seals in a particular geographical area must refer their request to the organization (NAFO or ICES) having jurisdiction over or interest in that area. Advice based on reports of the Joint Working Group would be provided by ACFM in the case of questions pertaining to the official ICES Fishing Areas (FAO Area 27) and by NAFO Scientific Council in the case of questions pertaining to the legally-defined NAFO area. ICES will administer the Joint Working Group in terms of convening meetings, formulating terms of reference, handling membership and chairmanship, and processing, printing, and distributing Working Group reports."

The working group concluded that these developments should improve the basis for future work in assessing the status of any stock of harp and hooded seals and give management advice.

WGHARP met for the first time in 1991 (ICES 1992). At this meeting it became clearthat data from recent aerial surveys of pup production were available for both harp seal stocks in the northeast Atlantic. The Barents Sea/White Sea data, based on surveys of breeding females, were presented in a relatively incomplete form, without information about uncertainty, and could not be used in assessments either. For the Greenland Sea harp seals, however, information was now available both from mark-recapture experiments and from an aerial survey of pups, which enabled WGHARP to calculate reasonable minimum estimates of removals, which would stabilize stock size. Although the amount of data necessary to assess the ecology of harp and hooded seals had increased, WGHARP was still unable to determine the effect of seals on fish stocks or fisheries.

When WGHARP met in 1993 (ICES 1994), it considered the results of both mark-recapture experiments and aerial surveys to estimate the 1991 pup production of Greenland Sea harp seals. The former estimates were considered to be the most reliable and were therefore used to model stock status and catch options for the 1994 season. The group also called for greater efforts to evaluate the ecological role played by the seal stocks in the Barents Sea.

At a WGHARP meeting in 1997 (ICES 1998), updated pup production estimates, based on mark-recapture experiments in 1977-1991, were presented for the Greenland Sea harp seal stock, but these were within the range investigated at the WGHARP 1993 meeting and no new catch options were therefore calculated. Preliminary results of recent aerial surveys of harp seal pups and subsequent population modelling were presented for the Barents Sea/White Sea stock. However, these new results were in a rather preliminary form and could not yet be used by WGHARP to provide catch options.

At its 1998 meeting (ICES 1999), WGHARP concluded that no new estimates of pup production were available. However, revised updated pup production estimates for 1991 (based on mark-recapture experiments) were used to model the 1999 population size by extrapolation, and new catch options were given for the stock. For the Barents Sea/White Sea stock, the first complete aerial surveys of pup production had been conducted in 1998, and WGHARP was able to provide new catch options for the 1999 season based on these results.

At its 2000 meeting (ICES 2001a), using a new population model that estimates the development of future population size, WGHARP was able to provide advice on catch options for 2001 for both harp seal stocks in the northeast Atlantic. For Greenland Sea harp seals, updated values from the 1977-1991 mark-recapture experiments were used as input values. For harp seals belonging to the Barents Sea/White Sea stock, new results from aerial pup production surveys conducted in 2000 were applied. During the meeting, WGHARP held a preliminary discussion of the appropriateness of current and other possible biological reference points for harp seals. Recent diet and consumption studies on harp seals were also considered.

Current management regime

Management agencies have requested advice on "sustainable" yields for the harp seal stocks in question. ACFM noted that the use of "sustainable" in this context is not identical to its interpretation of "sustainable" as employed in advice on fish and invertebrate stocks (ICES 2001b). "Sustainable catch" as used in the yield estimates for seals means the catch that is risk-neutral with regard to maintaining the population at its current size.

The most current advice on harp seals for ACFM come from its autumn 2000 meeting (ICES 2001b). Based on the most recent assessments (ICES 2001a), ACFM offered catch options for two different catch scenarios for the Barents Sea/White Sea harp seal stock: current catch level (average of the catches in 1996 – 2000) and sustainable yield. The sustainable catches were defined as the (fixed) annual catches that would stabilise the future 1+ population. These were calculated under the assumptions that the ratio M_0/M_{1+} was either 3 or 5. The catch options were further expanded using different proportions of pups and 1+ animals in the catches.

As a measure of the future development of the estimated population, a quantity that related future (2010) to the current (2000) 1+ population was used:

$$D_{1+} = \frac{N_{2010,1+}}{N_{2000,1+}}.$$

Option #	$M_{0/}M_{1+}$	Catch level	Proportion of 1+ in catches	Pup catch	1+ catch	D_{1+}	Lower 95% C.I. for D_{1+}	Upper 95% C.I. for D_{1+}
1	5	Current	12.5% (current level)	35000	5000	1.16	0.80	1.52
2	5	Current	100%	0	40000	1.09	0.73	1.45
3	3	Sustainable	12.5%	95000	14000	1.02	0.62	1.42
4	3	Sustainable	100%	0	82000	1.02	0.61	1.45
5	5	Sustainable	12.5%	69100	9900	1.02	0.68	1.35
6	**5**	**Sustainable**	**100%**	**0**	**53000**	**1.01**	**0.66**	**1.37**

Given recent reports of possible high pup mortality rates in the White Sea, ACFM recommended that managers considered the higher pup mortality options (catch options 5 and 6) when setting catch quotas, and concluded that a catch of 53 000 1+ animals, or an equivalent number of pups in 2001, would be sustainable (ICES 2001b). If a harvest scenario including both 1+ animals and pups was chosen, one 1+ seal should be balanced by 2.5 pups.

Using the same approach for the Greenland Sea stock of harp seals, ACFM defined the following catch options:

Opt. #	Catch level	Proportion of 1+ in catches	Pup catch	1+ catch	D_{1+}	Lower 95% C.I for D_{1+}	Upper 95% C.I for D_{1+}.
1	Current	14% (1996-1999 level)	3600	600	1.31	0.88	1.75
2	Current	51% (2000 level)	2000	2200	1.30	0.86	1.74
3	Current	100%	0	4200	1.28	0.84	1.72
4	Sustainable	14%	17600	2900	1.00	0.52	1.49
5	Sustainable	51%	8500	9000	1.01	0.51	1.50
6	**Sustainable**	**100%**	**0**	**15000**	**1.00**	**0.50**	**1.50**

ACFM emphasized that in 2001, a catch of 15,000 1+ animals (catch option 6), or an equivalent number of pups, would be sustainable. If a harvest scenario including both 1+ animals and pups is chosen, one 1+ seal ought to be balanced by 2 pups.

As illustrated by the lower confidence interval in the D_{1+} values in the analyses, when "sustainable" catches were removed annually, in ten years the stocks might have fallen by sometimes as much as 50%, compared to size of the stock at present. The stock might also be as much as 50% larger. The crucial point was even at the lower confidence bound the population was so large that its future viability would not have been impacted. This contrasts with ICES use of "sustainable" in fisheries contexts, where ICES takes a risk adverse approach, to achieve at least a 95% probability of a population being above precautionary reference points (ICES 2001b). Future use of reference points in seal management is being discussed in WGHARP (ICES 2001a).

The advice given by ACFM in 2000 (ICES 2001b) has subsequently been used to set TACs and the national (Norway vs. Russia) shares of TACs for 2001-2003 by the Joint Norwegian-Russian Fisheries Commission. The Commission also sets opening and closing dates and areas of the catches, which in 2003 were: from 28 February to 20 April for Russian coastal catches in the White Sea, from 23 March to 20 April for Norwegian sealing ships in the southeastern Barents Sea, and from between 1 and 10 April until 30 June in the Greenland Sea. Adjustments of time periods are permitted in the case of difficult weather or ice conditions. Also, exceptions from opening and closing dates could be made, if necessary, for scientific purposes. There is a ban on killing adult females in the breeding lairs, and Norway does not permit any take of suckling pups.

WGHARP will meet again in Archangelsk, Russia, in September 2003 in oder to make a new assessment of Barents Sea/White Sea and Greenland Sea harp seals, and new advice from ACFM can therefore be expected for the 2004 season.

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W.R. Bowering and D.B. Atkinson: Seal stocks in Canadian and NAFO waters

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Abstract

There are six species of seals (*Phoca spp.*) in Atlantic Canadian waters, all of which occur around Newfoundland and Labrador. There are two Arctic Species (Ringed, Bearded), two temperate species (Grey, Harbour) and two migratory species (Harp, Hooded). With the exception of bearded seals, which appear to feed mostly upon benthic invertebrates such as crabs and clams, seals feed upon a wide variety of finfish and invertebrate prey. Diets vary both geographically and temporally, with pelagic forage fish such as capelin and herring, along with sand lance being the most common prey types. In most studies, commercial fish species make up a relatively small proportion of the diet.

Bearded seals are not well studied and no estimates of population size are available. Nevertheless, abundance is known to be generally low. Only a few are harvested during the traditional Labrador hunt, and then mostly for subsistence purposes.

Ringed seals are generally found close to shore but have been observed in offshore areas. They whelp in dens built into the shorefast ice. No estimates of abundance are available but this species is relatively common in much of northern Labrador, where some are harvested during the subsistence hunt. They comprise one of the major food species identified in the Labrador Inuit Association (LIA) land claims.

Harbour seals are commonly found along shores and in bays. At present, harvesting of harbour seals is not permitted even for personal use. Although no estimates of abundance are available the population is probably around 20- 30 000 animals in Atlantic Canada. The numbers were reduced significantly during a directed bounty hunt in the 40s - 60s and they were also exploited during the grey seal bounty hunt from the 60s until 1990. Since they usually remain close to traditional haul-outs local areas could be severely affected by hunting. They have been known to travel up rivers to prey on fish and have been identified as the most common species preying upon salmon.

Northwest Atlantic grey seals form a single stock although this is often treated as two management groups based on the location of major whelping sites. Whelping occurs from late December until early February, with the largest group whelping on Sable Island, Nova Scotia. The second group, referred to as Gulf animals, whelp primarily on the pack ice in the southern Gulf of St. Lawrence and on some small islands along the Nova Scotia Shore. Recently, small numbers also have colonized areas of the New England States. Animals from both areas summer in nearshore and offshore areas throughout Atlantic Canada from the US border to mid-Labrador with the highest concentrations found on the Scotian Shelf, along the south coast of Newfoundland and in the Gulf of St. Lawrence.

Grey seal numbers in Canada were reduced to extremely low levels during the 19th century and the continued to be rare until the 1960s. Between the early 70s and mid-90s, the Sable Island colony increased rapidly at an annual rate of approximately 13% while the Gulf population displayed a different trend. Estimates of pup production from mark-recapture and aerial surveys indicate that the Gulf segment increased from around 7 000 pups in the mid-80s to 11 000 in 1996 and then declined rapidly to 7 300 in 1997 and 5 400 in 2000. Since 1996, there has been a sharp decline in the quantity of suitable ice breeding habitat in the southern Gulf of St Lawrence. This loss of breeding habitat has led to an increase in pup mortality and/or to the movement of large numbers of animals to other sites. During the early 1970s, the

Gulf component accounted for 70-80% of the total grey seal population, whereas currently they account for < 20%. The last estimate of grey seal abundance was based upon pup production surveys carried out in 1997, at which time the population was estimated to be 195 000 animals. Projections estimate that the herd on Sable Island has been growing and may have more than doubled, but the Gulf herd has declined by 33% since 1997. Given the marked changes observed in the Gulf of St. Lawrence since the last population survey and the absence of recent information from Sable Island, no estimates of replacement yield can be calculated.

Grey seals were the subject of a bounty program from the 1960s until 1990 although some were also taken during the harbour seal bounty hunt prior to that time. A directed cull of grey seals was carried out in the Gulf of St. Lawrence during the 80s but in recent years only small numbers are hunted and a TAC has not been established. Harvesting is now limited to a small traditional commercial hunt in an area off Magdalen Islands and to commercial hunts of small numbers in other areas, except Sable Island, where no commercial hunting is permitted. Since 1998, commercial sealers have taken only 819 grey seals.

Hooded seals are the second most abundant, and individually the largest, seal species in the Northwest Atlantic. There are two populations in the North Atlantic. The Northeast Atlantic population whelps on pack ice near Jan Mayen (north of Iceland), off the east coast of Greenland, and the Northwest Atlantic population whelps off the coast of southern Labrador or northeastern Newfoundland (the 'Front'), in Davis Strait, and in the Gulf of St. Lawrence (the 'Gulf'). It is not known if interbreeding occurs among Northwest Atlantic whelping areas, but seals from all three areas are known to mix during the non-breeding period. They are seasonal migrants, spending most of the year near slope edges in offshore waters. Northwest Atlantic hooded seals spend the summer off south and west Greenland or in Canadian Arctic, and migrate to whelping areas during late fall or early winter. Satellite telemetry indicates that Front hooded seals move off the Continental Shelf towards either Flemish Cap or the Reykjanes Ridge southwest of Iceland, and eventually migrate to the Denmark Strait near southeast Greenland to moult in late June or July. Those from the Gulf move to the north slope of the Laurentian Channel where they feed before migrating out of the Cabot Strait and along the shelf-edge of the Grand Banks en route to the Denmark Strait.

The abundance of Northwest Atlantic hooded seals is estimated from a population model that incorporates information on the number of pups, reproductive rates and catches. Only two estimates of pup production of NW Atlantic hooded seals are available from aerial surveys conducted in 1984 and 1990, when total abundance was estimated to be 450 000 and 475 000 animals, respectively. As there are no estimates of abundance since 1991, no reliable estimates of the current size or status of the NW Atlantic hooded seal population are available.

Commercial sealing at the Front was reported as early as 1874, but records of catches are lacking because no distinction was made between harp and hooded seals for many years. Following a shift to hunting for fur in the 1940s, hooded seal pups, or bluebacks, became the most valuable of all pelts and hunting effort increased accordingly. Prior to 1974 there were no TACs although there were restrictions on hunting season. In 1974, a TAC of 15 000 was implemented for Canadian waters, accompanied during the late 1970s by a number of regulatory changes in order to limit the percentage of adult females harvested. From 1974-82 the harvest was fairly constant, averaging 12 800 per year, and made up primarily of pups taken during the large vessel hunt. The TAC was reduced to 12 000 in 1983 and further reduced to 2 340 in 1984. Following the demise of the large vessel hunt, commercial catches varied from a low of 33 in 1986 to a high of 6 425 in 1991, averaging 1 048 for the period 1983-92. Hunting bluebacks for commercial purposes and the use of vessels over 18 m was prohibited in 1987. The TAC has fluctuated over the past 10 years but has remained at 10 000 since 1998. In recent years annual catches have continued to vary greatly, with over 25 000 reported harvested in 1996. Highly variable numbers taken in any one year are probably due to the accessibility of seals to land-based hunters. Currently, the hooded seal hunt is only a minor part of the commercial and personal use hunts. In recent years the number harvested has been less than 200 animals per year.

Hooded seals from all three NW Atlantic whelping areas are hunted in Greenland although there is no joint management plan between Canada and Greenland.. Catches there have remained fairly consistent at 6 000 – 10 000 seals per year since the 1970s. Historically, Northwest Atlantic hooded seals were also hunted at the moulting concentrations in the Denmark Strait, but this ended in 1967.

Harp seals are medium-sized seals, which migrate annually between Arctic and sub-Arctic regions of the North Atlantic. There are three populations, of which the Northwest Atlantic stock is largest. Others are the White Sea and Jan Mayen or Greenland Sea populations. The Northwest Atlantic stock spends the summer in the Canadian Arctic and Greenland, begins its southward migration in early fall and by late November reaches the southern Labrador coast. About one third of the mature seals enter the Gulf of St. Lawrence while the rest migrate southwards along the East Coast of Newfoundland. Following breeding in March, they form large moulting concentrations on sea ice off northeast Newfoundland and in the northern Gulf of St. Lawrence in April and May. After moulting, they disperse and eventually migrate northward, although small numbers may remain in southern waters throughout the summer.

The harp seal is the most abundant pinniped in the Northwest Atlantic. The total population size is estimated using a population model that incorporates information on pup production, reproduction rates and known mortalities. The population declined during the 1960's and reached a minimum of less than two million in the early 70s and subsequently increased steadily until its 1996 level, at which it remained stable due to the large harvests in recent years. The most recent estimated population (1999 survey) is 5.2 million (4.0 – 6.4 million) seals.

Harp seals have been hunted commercially since the early eighteenth century. About 250 000 animals were harvested per year at the beginning of 20th century but the hunt declined during the First World War and averaged 150 000 a year from 1919 to 1939. Commercial harvesting almost stopped completely during World War II but increased rapidly afterwards, reaching 450 000 in 1951 and averaging about 288 000 seals per year from 1952 to 1971. Land-based sealers in both the Gulf and Front areas currently hunt harp seals during the winter. The first TAC for harp seals was set in 1971 at 245 000 and varied until 1982 when it was set at 186 000. During this period, the average annual harvest was approximately 165 000 seals.

Before 1983, the large-vessel harvest of pups on the whelping patch accounted for most of the harvest. However, a ban on the importation of whitecoat pelts implemented by the European Community in 1983 severely reduced the market, ending the traditional large-vessel hunt. From 1983 to 1995 catches remained low, averaging 52 000 per year. However, catches have since increased substantially as demand increased. The Canadian catch in 2002 was 312 000 animals. A new management plan was implemented in 2003 which allows for a harvest of 975 000 over the next three years with a maximum of 350 000 in any one year, provided that the combined TAC over three years is maintained by a reduction in the TAC in other years.

Young of the year seals that have moulted their whitecoat (‘beaters’) make up the majority of recent catches. Harp seals are also hunted in the Canadian Arctic and Greenland.

Greenland catches have increased steadily since the mid-70s and are currently estimated to be over 100 000 a year. No recent statistics are available for the Canadian Arctic but in the late 70s catches were thought to range between 1 200 and 6 500 per year. Total removals of Northwest Atlantic harp seals including reported catches, estimates of bycatch in the Newfoundland lumpfish fishery and estimates of seals killed but not recovered during the harp seal hunts in Canada and Greenland are estimated to be over 500 000 annually.

Current regulations do not allow hunting of whitecoats or the use of vessels longer than 20m. Since 1995, residents adjacent to sealing areas are allowed to hunt up to six seals for personal use. Aboriginal people and non-Aboriginal coastal residents who reside north of 53°N can hunt for subsistence purposes without a license. No joint management plan for harp seals exists between Canada and Greenland.

SESSION 5: Ecosystem approaches to fisheries management

Å. Bjordal[1] and A. Boltnev[2]: An ecosystem approach to fisheries management in the Barents Sea.

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INTRODUCTION

The Barents Sea, named after the Dutch explorer Willem Barents (1549-97) covers an area of about 1,4 million km2, with water depths mainly between 200- and 500 m. Being a relatively shallow ocean and due to the inflow of warm and nutritious Atlantic water, the Barents Sea ecosystem has a very high productivity – as compared with other arctic ocean areas.

The first large scale exploitation of living marine resources of the Barents sea was the catch of marine mammals like whales, seals and walrus from the 17th century as well as cod that mainly was fished in coastal waters during the spawning migration. In the early 20th century, most of the large whale species were overexploited and there was also a strong exploitation pressure on the seal stocks. After World war II, there was a rapid development of offshore fishing operations in the Barents sea – not only for cod, but also for several other target species like haddock, redfish, Greenland halibut, polar cod, capelin and shrimp. Over the same period the exploitation of marine mammals was gradually reduced to zero or very low levels. At present the harvest of marine mammals is limited to the traditional Norwegian whaling for Minke whale in accordance with recommendations from the Scientific committee of the International whaling commission and Norwegian and Russian hunt for harp seals in accordance with recommendations from the International Council for Exploration of the Sea (ICES). ICES also provides quota recommendations for sustainable development of the Barents Sea fisheries on the different fish stocks mentioned above.

With a steady increase in fishing effort from the 1950-ies, driven by technological developments of fishing vessels and fishing methods, signs of over-exploitation of several stocks became apparent. The most dramatic case was that of the Norwegian spring spawning herring (spending the juvenile stage in the Barents Sea), with a total stock collapse in the late 1960-ies as a result of hard fishing pressure combined with adverse climatic conditions. Similar signs were also observed for other stocks – and in the late 1970-ies the first quota or Total Allowable Catch (TAC) was set for the Northeast arctic cod fishery – and later this was followed by TACs for most of the commercially harvested fish stocks in the Barents Sea. In addition, different technical measures have been introduced, mainly to protect juvenile fish, as regulations on mesh size, use of sorting grids, temporarily closed areas, by-catch limitations and different control and enforcement measures.

Since the introduction of Exclusive Economic Zones (EEZs), the management of the fisheries in the Barents Sea including decisions on TACs, different technical measures and development of harvest strategies have been conducted by the Joint Norwegian-Russian Fisheries Commission. Scientific advice - from ICES and directly from the scientific institutions in the two states is the basis for most management decisions made by the joint commission.

Scientific assessments of- and forecasts for the development of fish stocks are hampered with uncertainty and hence, management of fisheries is always based on decision making under uncertainty. Despite a series of advancements in scientific methodology during the last decades, there is still a significant component of uncertainty linked to the scientific advice on fisheries management. The uncertainty is linked to the real harvest quantities of different species, but mainly to the great natural biomass fluctuations, which are characteristic for the Barents Sea ecosystem.

A main objective of an ecosystem approach to fisheries management is a more holistic approach to advice on management of ocean related human activities. For advice to fisheries management this means that incorporating data on ocean climate should reduce uncertainty of scientific recommendations for sustainable harvest levels, lower trophic level bio-production as well as species interactions on higher trophic levels in catch recommendations for target species.

For figures linked to this paper, see the corresponding power-point presentation given at the 10th Norwegian-Russian Symposium – that can be found on the compact disc enclosed in the Symposium proceedings.

ECOSYSTEM APPROACH TO FISHERIES MANAGEMENT

The concept of ecosystem approach to fisheries management is still being developed globally, with no clear definition of the concept. As marine ecosystems dynamics are very complicated the concept of ecosystem approach can also be made very complicated. However, to make it operational, it is necessary to simplify and focus the approach – which can be summarized in the following main elements:

- Improved advice for sustainable fisheries: Better knowledge and understanding of marine ecosystem dynamics – for improved advice to management for sustainable exploitation of living marine resources.

- Reduced ecosystem effects of fishing: Develop fish capture technology for reduced ecosystem effects of fishing. This means technology for aimed harvest of target species and sizes with least possible effects on other components of the ecosystem.

- Clean and healthy marine ecosystems: Develop indicators for "ecosystem health" – which can be monitored as basis for assessment and advice on ecosystem effects of fishing and other human activities related to the marine ecosystems. Important aspects will be the assessments of marine pollution and marine biodiversity with corresponding advice to secure clean and healthy oceans as a fundamental basis for marine life and food production.

ECOSYSTEM APPROACH TO SCIENTIFIC ADVICE FOR MANAGEMENT OF THE BARENTS SEA FISHERIES

Status and basis for an ecosystem approach

An ecosystem approach does not represent something fundamentally new in marine and fisheries research. We do not start from scratch, but the ecosystem approach represents a new focus and direction for a more holistic and interdisciplinary way of understanding ecosystem dynamics and corresponding reductions of uncertainties in advice to fisheries management.

Jointly, IMR and PINRO have developed long time series for the main components of the Barents Sea ecosystem. One of the PINRO hydrographical sections (the Kola section) can be dated more than 100 years back and is among the oldest global marine data time series. In addition there are other long time series on hydrography, plankton, fish and marine mammals that are important elements of a future ecosystem approach to management advice for the Barents Sea fisheries. Further, there are time series on species interactions – particularly on the diet of North-east arctic cod. Models exist both for single stock and multi-species assessments. In a global perspective, the capelin stock assessment is one of few where multispecies considerations are used in an operational way. For the Barents Sea fisheries there are numerous regulations to promote sustainable harvest of the living marine resources. The precautionary approach to fisheries management has been adopted for the management of the Barents Sea fisheries and management strategies for sustainable fisheries have been developed.

Improved advice for sustainable fisheries

Despite all existing knowledge about the Barents Sea ecosystem and development of management strategies for sustainable fisheries, the ecosystem approach calls for a considerable increase of data (in time and space) as well as integrated operational models that are able to include both quantified and not quantified ecosystem information in the assessments and advice for TAC decisions.

To obtain the necessary data input it will be important to develop new platforms for data collection. In addition to surveys with research vessels, data should be supplied from platforms like satellites, buoys and permanent installations for data collection. It will also be of high importance to develop the fishing fleet for data collection – either trough scientific observers and / or direct data collection and reporting of catch-, biological and environmental data from the fishing fleets. The latter demands development of automatic and semi-automatic systems for data collection. In this context PINRO has for many years used observers on commercial fishing vessels to collect data for scientific purposes, while IMR recently has established a so called Reference fleet of fishing vessels reporting catch and biological data on an agreed format – for use in stock assessments.

In addition to increased data in time and space, there is a need for new systems for data handling and quality control as well as development of models that can incorporate ecosystem information in regular stock assessments. Over the past two decades, multi-species models aimed at optimizing the fisheries management have been developed for the Barents Sea ecosystem. MULTSPEC, AGGMULT and Bifrost are major multi-species models developed by IMR for the Barents Sea, and MSVPA and STOCOBAR have been developed by PINRO. To co-ordinate efforts in developing the multi-species models for the Barents Sea scientists from PINRO and IMR are working collaboratively in integrating the two models Bifrost and STOCOBAR.

For implementing the ecosystem approach to fisheries management, further improvement of assessment models and management schemes should be supplemented by modification of the overall system of data sampling and processing. Preference should be given to ecosystem surveys allowing comprehensive sampling, rather than single-species surveys.

Reduced ecosystem effects of fishing

An important aspect of the ecosystem approach is to harvest given TACs of certain target species and size with lowest possible by-catch of non target species, least possible effect on bottom habitats and in an energy effective manner to reduce fuel consumption and corresponding pollution per catch unit. Several measures have been introduced to mitigate unwanted by-catch in the Barents Sea fisheries. In the trawl fisheries for shrimp and groundfish, sorting grids to release by-catch of juvenile fish are mandatory. Another example is the introduction of a bird-scaring device, which effectively reduces the by-catch of sea birds in the long-line fisheries. Still there are challenges to make most fishing gears more "ecosystem friendly" and research is needed such improvement. As a basis for this research – an evaluation of the total ecosystem effects of different fishing gears should be made.

Clean and healthy marine ecosystems

The oceans have for decades been recipients for pollution from different sources of land- and ocean related activities. In addition to natural substances in seawater, we have during the last decades experienced an increasing amount of pollutants like PCB, PAH, dioxine and heavy metals in the sea. These harmful substances are absorbed in the marine food chain and accumulated as they pass from lower to higher trophic levels. Although the Barents Sea is regarded as a relatively clean area, it is of utter importance to monitor the state of pollution and identify and advice against activities being main sources of pollution.

Research organization

Organizational approaches to ecosystem based fisheries management.

From 2003 IMR in understanding and co-operation with PINRO changed the survey program in the Barents Sea from pure single stock surveys to integrated multispecies and ecosystem-oriented surveys. The ecosystem approach has also inspired organization changes of the institutions. Thus, IMR reorganized in 2003/2004 from a thematic to an ecosystem based organization structure – where the thematic model with departments for marine resources and marine environment is replaced with ecosystem based advisory programs – for the Barents Sea, Norwegian and North Seas, the coastal zone and mariculture.

L.N. Bocharov, V.P. Shuntov, E.P. Dulepova: Status and objectives of ecosystematic research of biological resources in Russian far-eastern seas

TINRO-Centre, Vladivostok, Russia. Translated by Oleg Katugin. Edited by Sharon Hawkins

The history of research activities in the Russian far-eastern seas dates back to the early 20th century. At first, studies were of a geographic, hydrographic, faunal and biogeographic nature. Later, from the 1920s to the 50s, biological (including ecological) research became more important, as it was called upon by the needs of the developing commercial fishery.

In general, the beginning of ecosystem-based biological research in the Far-Eastern seas dates from the late 1940's, when the first cruises of the renowned Soviet research vessel "**Vityaz**" started. The scale of this research was significantly increased during the 50s and 60s, when scientists from the central research institutes – VNIRO, Institute of Oceanology and Zoological Institute – joined the far-eastern fisheries specialists in their studies.

With due regard to the ecological nature of those studies, they could hardly be considered ecosystem-based in the strict sense. Indeed, at that time scientists were not able to make accurate biomass and productivity estimates for all groups of marine organisms.

More advanced ecosystematic investigations were carried out in the bays and gulfs of the Sea of Japan in the 80s and 90s by the Institute of Marine Biology and TINRO, though they never resulted in models or patterns capable of demonstrating trophic and energetic relationships between all biotic elements.

Ecosystem-based studies of the far-eastern seas began in the TINRO Centre in 1980 in the newly organized Laboratory of Applied Biocenology and the Laboratory of Plankton Research. From the very beginning, we understood that to cover all biotic elements even within a selected area would be impossible. It was therefore decided to look at macro-ecosystems, with the basic objectives of studying meso- and macroplankton, meso- and macrobenthos, nectobenthos and nekton, including higher trophic level groups such as mammals and birds. Sufficient research vessels were available to allow us to conduct large-scale surveys simultaneously, such as nekton and nektobenthic trawl surveys, hydrobiological and hydrological surveys and sometimes acoustic surveys. As a result, by the mid-80s research activities covered all of the Russian Exclusive Economic Zones (REEZ) outside territorial waters. The priorities were set at studying macro-processes and patterns, and at acquiring information to compare extensive data on biota from different areas, different landscapes, current systems, etc. All the information was collected and summarized by standard bio-statistical regions. Inter-regional borders were determined according to current patterns, surface water modifications and bottom topography (Figure 1). Although only 20 years have passed since the beginning of consistent ecosystematic research in the Russian far-eastern seas, our ideas on the nature of the area have significantly changed, and new problems have been outlined.

We believe that an ecosystem approach to investigations of the Russian far-eastern seas has proven successful. Since the early 1980's, we have provided large-scale monitoring of the composition and structural dynamics of pelagic and bottom communities within macro-ecosystems in Russian waters. Many expeditions (50 pelagic and 23 bottom surveys) have been made. Large-scale biocenological studies provide useful background information for investigations of commercially important species. In order to process the large amounts of resulting data in a timely fashion, the following principles were used:

1. Plankton samples were divided into groups by size (small, medium and large) with subsequent processing of each group separately by classical and express methods;
2. Different catchability coefficients were used for different (size) groups of plankton;
3. Correction coefficients for daily changes in zooplankton abundance were applied.

We applied correction coefficients on the amount of catch for basic nekton groups, including highly abundant species, as well as for prey organisms in order to obtain reliable assessments of their total number and biomass. Geometric parameters of midwater and bottom trawls that affect the volume of water coming through a net were also considered in estimating nekton abundance.

We used GIS technology to create a database for quantitative distribution of nekton and nektobenthos, and to examine the composition of their communities including abundance and biomass for every species. Maintenance of this north-western Pacific Ocean database has continued since the early 1980's. As a result, we are planning to create a number of atlases of the quantitative distribution of nekton and nektobenthos in different regions of the far-eastern REEZ and adjacent waters of the north-western Pacific Ocean. All calculations have been performed on one-degree squares, and based on long-term data from the trawl surveys (Figure 2).

During the first stage of ecosystematic research, we primarily analysed the composition, biomass and production of zooplankton, benthos, nekton, and nektobenthos were. Results indicated high levels of bioproductivity (and hence, fish productivity) in the far-eastern seas. The highest fish productivity within our region occurred in the 1980s. Our data showed that stock abundance estimates for most of the commercial species (walleye pollock, flatfish, crab, salmon, cod, etc.) were underestimated by ecological studies. New information has provided a solid basis for expanding the commercial fisheries, which resulted in a million-tonne increase in catches that reached a maximum of five million tonnes in 1988. At that time, the biomass of fish and large invertebrates in Russian waters was assessed at about 90-100 million tonnes (with almost one half of the estimate attributable to small mesopelagic fishes), the biomass of macrobenthos at 408 million tonnes, that of meso- and macroplankton at 1206 million tonnes, and a number of both residential and migrating animals: whales;100-120 000 individuals, dolphins; 250 000 individuals, and sea birds; 40-50 million individuals.

Even the first tentative estimates of food consumption by higher trophic level animals suggested that such high abundance of plankton consumers does not correlate with the known estimates of zooplankton biomass and the amount of primary production. Walleye pollock alone consumed an estimated 350 million tonnes of zooplankton, 11 million tonnes of squid and 30 million tonnes of small fish annually in the Bering and Okhotsk Seas in the 1980's. This posed a question concerning the reliability of the methods of collection and processing of zooplankton, phytoplankton, bacterioplankton, and benthos data.

During the next decade (1990-2000) of ecosystematic research, large-scale studies of the Russian EEZ were continued, and these resulted in a number of important findings. One of the most important was the finding of a decrease in fish productivity in the far-eastern seas. During the 90s, there was a 30% decrease in total fish production in the region. The decline was related to considerable changes in the marine ecosystem. In the early 90s, a decline in pelagic fish biomass was accompanied by a rise in the abundance of predatory zooplankton. In the late 90s, fish biomass continued to decrease, and extended to include bottom species, while zooplankton communities became stable and predatory zooplankton abundance returned to levels found in the 1980's.

The decrease in fish abundance was largely due to a major drop in Pacific sardine (pilchard) abundance and a three- to four-fold drop in walleye pollock abundance. At the same time, the abundance of a number of commercial species such as Pacific herring, Japanese anchovy, and some populations of Pacific salmon, Atka mackerel, Japanese common squid, several species and populations of shrimp, and some non-commercial species increased by 5-10 million tonnes.

No concurrent decrease in abundance of either plankton or benthos was observed, though there were certain annual changes in planktonic community structure. The sharp increase in the amount of predatory zooplankton reached 50-60% of meso- and macroplankton biomass in the early 90s, and returned to normal levels of 20-25% of the total biomass by 1995. Unfortunately, large-scale observations on plankton communities were thereafter continued only in the Okhotsk Sea. In 1997 and 1998, the amount of zooplankton dropped sharply in the Okhotsk Sea, and a comparison between zooplankton abundance and biomass of fish and squid, in conjunction with estimates of their feeding ratios, suggested that the food supply of nekton was low. That observation was an indication that a less productive period had begun. Nevertheless, in the spring of 1999, the amount of plankton in the Okhotsk Sea increased, largely due to euphausiids and copepods, back to the level of the 80s.

As a result, we managed to summarize and analyse all the data on the structural features of the bottom and pelagic communities we had obtained during 1980-2000. This enabled us to suggest a schematic pattern of organic matter production in these communities.

High plankton abundance resulted in enhanced food consumption by fishes. In 1999, walleye pollock consumption increased by a factor of three to seven and herring by a factor of one and a half to two in comparison with 1998. In the Navarin-Anadyr area of the Bering Sea, there was an almost three-fold increase in zooplankton abundance, and a decrease in pollock abundance from 3.5 million tonnes in 1998 to 1.2 million tonnes in 1999, while annual consumption rates remained approximately the same at 15.5 and 14 million tonnes, respectively. Therefore, the decrease in nekton abundance was accompanied by an increase in the nekton feeding rate.

Biotic changes in the North Pacific Ocean occur successively. For example, the last "wave" of decrease in pollock abundance started in the Gulf of Alaska and in the eastern Bering Sea in the 1980s, then spread into the western Bering Sea, and by the mid-90s it had appeared in the Okhotsk Sea. This trend was also observed in some sea birds. We believe that the North Pacific Subarctic Gyre system provides an environmental background for these events. It first affects the eastern Bering Sea, then the western Bering Sea, east Kamchatka and north Kurile regions, and only then the Okhotsk Sea. This is the way in which some environmental anomalies are spread. Different zoogeographic provinces react differently to those anomalies. New data on marine communities, together with retrospective statistical analysis of the fishery, suggested a "warm period" from 1970-1980, similar to that of 1920-1930, giving way to a "cold period" that started in mid-1990, and is similar to that of 1940-1960. The concept of systemic organization of natural processes led us to forecast this scenario in the1980s.

The current fall in fish production and commercial catches in the Russian far-eastern seas is frequently blamed on anthropogenic impacts on marine ecosystems, caused directly or indirectly by human influence (over-harvesting, pollution, etc.), and/or the Russian economy. Nonetheless, in spite of increased human impact on marine ecosystems, annual and long-term ecosystem dynamics are still primarily influenced by climate and oceanographic factors. Research data collected by scientists from STA (Scientific Technological Association) "TINRO" suggest that in Russian waters, high pollution rates are found primarily within isolated areas, for example, in Peter the Great Bay (Figure 3). This factor does not significantly affect macro-ecosystems.

Though large-scale poaching in Russian waters creates additional pressure on biological resources, significant over-harvesting has been detected in only a few populations of crab, trepang, scallop, rock-fish, and southern populations of salmon. Until recently, the initial cause of most changes in marine organism abundance was associated with natural factors such as climate, oceanographic and biological conditions rather than on anthropogenic factors. Commercial fisheries also contribute direct and indirect impacts on the resource. High fishing pressure significantly reduces the recovery time of even the most high-yielding generations within a stock. On the other hand, extensive elimination of predators results in an increase in abundance of their prey. For example, shrimp abundance rises when gadoid abundance decreases.

Quantitative changes in nekton and nektobenthos abundance in the Far-Eastern seas in the 90s were accompanied by a rearrangement in the composition and structure of pelagic and bottom communities. Such rearrangements were most evident in the offshore areas of the Bering and Okhotsk seas. During the 1980s, walleye pollock was highly abundant and migrated into deep-water regions to feed, making up a large portion of the biomass. By the 90s, this species had almost disappeared from deep-water areas (Figure 4).

At that time, the structure of pelagic and bottom communities acquired polydominant characteristics, which means that changes spread from pelagic layers down to the nektobenthic life zone. For example, Pacific cod was most abundant in the bottom communities in the western Bering Sea in the 1980s, when cod accounted for almost 69% of the total bottom fish biomass. This species is known for its high rate of growth and productivity. In the 90s, cod abundance sharply decreased, and bottom fish communities became polydominant. This affected the productivity of bottom communities, and resulted in a decrease the rate of turnover of biomass. It is worth mentioning that the cod fishery at that time remained within permitted catch quotas.

Networks and patterns of trophic relationships for bottom and pelagic communities over vast areas and seas, together with schemes for substance and energy transport (for the Bering and Okhotsk Seas), were constructed on the basis of large amounts of data. These patterns should be regarded as generalized and rather rough, reflecting the current status of our knowledge of functional relationships among biotic components in the far-eastern seas. These patterns made it possible to analyse the effectiveness of macro-ecosystem processes within the Bering and Okhotsk Seas. It appears that in the 1980s, lower trophic levels were most effective in energy transport in the Okhotsk Sea, while upper trophic levels dominated in the Bering Sea. The energy utilization efficiency on the part of bottom communities (transferring energy down to nektobenthos) in the Bering Sea is more than twice as high as in the Okhotsk Sea. Severe hydrological conditions, in particular, permanent cold-water cores over large areas throughout the year in the Okhotsk Sea could be a contributing factor for such differences. Calculations suggest that deep-water seas in the Far East utilise primary production as well as highly efficient shallow seas.

Estimates of plankton and benthos consumption by nektonic animals revealed variability in food utilization in different seas and in different areas of each sea. This may trigger a density factor (e.g., in the Karaginsky Gulf of the Bering Sea). Recently, retardation of growth rates at high abundance has been noticed in some generations and populations of fish. In such cases of trophic relationships "bottom up" community control is usually weakly expressed. Our estimates show that in most cases food resources are under-utilised by nekton and nektobenthos. Nektonic and nektobenthic animals together consume no more than 5-10% of non-predatory zooplankton and benthos in both pelagic and bottom communities. This item definitely needs further investigation and new ideas. Annual dynamics of nektonic and nektobenthic communities from highly productive regions such as the western Kamchatka

Shelf could serve as good illustration of the problem, when both fishery and natural dynamics have simultaneous impacts on resources. By the late 1990s, there was a considerable decrease in the abundance of walleye pollock, Pacific cod, red king crab and flatfish. The first three species are prone to fluctuations in abundance and are under long-term fishery pressure. Flatfish biomass decreased to 473 000 tonnes, the lowest estimate for the last 20 years, although their commercial catch did not reach TAC. At the same time, there were no significant changes in benthos biomass. Until the mid-90s, flatfish accounted for 69-79% of the bottom fish biomass, while in recent years they were only 59-65%. The decrease in total flatfish biomass on the western Kamchatka Shelf (Figure 4) was due to a decrease in the biomass of two predominant species: the yellow-bellied flounder and the yellow-finned sole, - and was accompanied by a rise in the biomass of sculpin (Cottidae), codfish (Gadidae), eel-pout (Zoarcidae), and prickle-back (Stichaeidae) (Figure 5).

Among the possible natural causes of the decrease in flatfish biomass, we can suggest low survival rates of juvenile fish as a result of weak stability of plankton communities in the early 1990s. The subsequent stabilization of plankton communities led us to suggest that flatfish resources would gradually rise. Indeed, a considerable increase in the biomass of Sakhalin sole was reported in 2001. It continued to grow in 2002 (Figure 6). At the same time, the biomass of yellow-bellied flounder and yellow-finned sole, stable during 2000 and 2001, subsequently decreased, and today is lower than the biomass of Sakhalin sole and rough dab. Such a flatfish species ratio on the western Kamchatka shelf has not been observed since the 1960s, when there was considerable over-harvesting.

We think that “bottom up” limiting factors could be associated with meroplankton, in other words, with early life stages of most planktonic, nektonic, benthic and nektobenthic species. This “microcosmos” provides subtle background for differences in abundance of higher-level community representatives. In turn, meroplankton are supported by poorly-known groups of piko- and nanophytoplankton, bacteria and protozoans, the basis for trophic pyramids.

This problem could be considered as a priority in further fundamental ecosystematic research activities. Without such basic knowledge, no attention can be paid to problems of the carrying capacities of marine and oceanic communities. Data on ecological capacity should serve as a basis for management of biological resources.

We currently possess information that enables us to look at the carrying capacity of the Russian far-eastern seas. Important results were obtained from analyses of the relationships among plankton and nekton in the Bering and Okhotsk Seas. In the Bering Sea, where there is a high abundance of nektonic animals and a low planktonic food supply, food competition is intense. This may explain why in the Bering Sea, there are more so-called “alternative” species, in which abundance fluctuates in counter-phases. One well-known pair of species is the Pacific herring and walleye pollock. When pollock abundance is high in the Bering Sea, herring abundance is low, and vice versa. Plankton availability is much higher in the Okhotsk Sea, and pollock abundance goes in counter-phase only with the Gizhigin-Kamchatsk population of herring. This population occupies the north-eastern Okhotsk Sea, an area in which pollock are highly abundant.

As for other items related to ecosystem-based investigations of the Russian Far-Eastern biological resources in the near future, and considering our restricted technical support, we believe that it is important to continue regular large-scale field monitoring in order to keep an eye on macroecosystems. Our experience tells us that the most effective research activities are those relating to production and population biology, trophology, differentiation and dynamics in the abundance of different commercial species, i.e. in those research fields that provide us with parameters for ecosystem modelling (theoretical aspect) and for rational fishery management, particularly for multi-species fisheries. Ecosystematic research should also contribute significantly to general problems of relationships among fishery, aquaculture and wildlife conservation activities.

J. V. Tagart: Ecosystem management in Alaskan waters

Washington Department of Fish and Wildlife, Seattle

See PowerPoint presentation on attached CD.

W.R. Bowering and D.B. Atkinson: Ecosystem approaches in Canadian waters

Dept. of Fisheries & Oceans; Science, Oceans & Environment Branch, NW Atlantic Fisheries Center

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Abstract

In the Canadian Department of Fisheries & Oceans (DFO), management focus has expanded to encompass more highly integrated management of human activities in the oceans. This was a logical progression as knowledge of links between climate, ecosystems and fishery productivity increased and the need for a much broader knowledge of ocean ecosystems (predator and prey species, indicator species, plankton, climate, currents and production processes) had become apparent. It is clearly necessary to monitor and understand the dynamics of a wider range of marine organisms, develop our knowledge of marine climate and its effects on ecosystems, and broaden our understanding of human impacts (e.g. oil and gas activities) on all parts of marine ecosystems. However, developing the knowledge necessary for integrated management requires that ecosystem objectives be defined, especially for ecosystem components impacted by human activity.

Canada, through DFO, has now adopted ecosystem-based management (EMB) as a basis for managing human activities in the oceans under the Oceans Act (1997) and related policy instruments such as the DFO Strategic Plan and Canada's Oceans Strategy (COS). EMB means that all activities are consistently managed against a backdrop of ecosystem considerations, which sets the direction for getting where we need to go. DFO has put objectives at the centre of its approach, which include: 1) focusing on defining desired future states of ocean ecosystems; 2) setting up indicators to show whether desired states are being achieved; 3) reporting on the status of the indicators in relation to defined objectives; and 4) ensuring that any changes we are causing in ecosystems are within the ability of the ecosystem to maintain within its limits. The ecosystem approach to date focuses on the natural sciences, although it is recognized that work on social and economic objectives will also be necessary in order to provide comprehensive scientific support for ecosystem-based management.

Objectives will be defined within three "realms" identified as i) conservation of components of biological diversity, ii) conservation of ecosystem function and iii) conservation of sediment and water quality. The process of defining objectives will begin with conceptual objectives that state general goals, and continue as these are unpacked or refined to produce operational objectives against which performance can be assessed. Operational objectives are to be associated with specific management plans (sectoral or of limited geographic scope) or with broader integrated management plans. Indicators associated with these conceptual objectives will be selected to support performance assessment, and regular reports will be produced on indicators in relation to objectives to provide a "State of the Oceans" report. Reference points will probably be a feature of the approach as well, as they relate to the operational objectives.

Five particular items are regarded as representing a required "short list" of measurements for the assessment of marine ecosystem health. These are: a) contaminants, which are the presence of harmful synthetic or natural chemicals that have been released by human activity; b) pathogens, biotoxins, and disease which may harm marine biota and human populations; c) species diversity and size spectrum, which are core measures of ecosystem structure; d) primary productivity and nutrients, which are core measures of ecosystem function and e) instability or the ability of the ocean "climate" to have different states.

While this approach is already being pre-tested in integrated ocean management initiatives in Canada, DFO is now at the stage of wider and more formal piloting of the approach. However, there are several issues that require further work at this point in time. These are; finalizing the definition of large ocean management areas, defining the best operational objectives and indicators for use, developing scientific programs to support the definition of objectives, identification of indicators, monitoring and reporting, and developing a reporting framework.

There are many challenges associated with the development of such a far-reaching approach, not the least of which is dealing with the complexities of natural and human systems that interact in oceans. It will introduce a very different way of conducting science and providing scientific advice such as expanding from single-species targeted fisheries management to integrated management planning with objectives that may include target, non-target and other species, and other marine uses and users. Reduced effort in stock assessment may be resisted by industry or managers who are used to having detailed short-term forecasts which can lead to intense political pressure. Internally as well, some DFO staff may not favour reducing effort in certain areas. Nevertheless, Canada, through DFO has embarked on this major initiative and is determined to see it succeed. This indeed is necessary if we are to make progress in managing Canada's oceans efficiently, given the complexities of their structures and the pressures placed upon them by their users.

APPENDIX I: Symposium program

The 10th Norwegian-Russian Symposium
on

MANAGEMENT STRATEGIES FOR COMMERCIAL MARINE SPECIES IN NORTHERN ECOSYSTEMS

Bergen – Norway, 27-29 August 2003

Organized by
The Institute of Marine Research (IMR), Bergen, Norway,
and
The Polar Research Institute of Marine Fisheries and Oceanography (PINRO), Murmansk, Russia

Co-sponsored by the Nordic Council of Ministers

Participation
The symposium will address scientists, fishery managers and representatives of the fishing industry. Expected number of participants: 100.

Scope
The symposium will focus on management strategies for the most important commercial stocks in the Barents Sea ecosystem. However, presentations of management strategies for exploited stocks in other northern marine ecosystems will be emphasised. The programme will be based on presentations by invited speakers.

Proceedings
The proceedings of the symposium will be edited by the co-conveners and published in the IMR/PINRO Joint Report Series.

Co-conveners:
Åsmund Bjordal, Research director, IMR
Alexander Boltnev, Director, PINRO

Symposium programme committee:

From Norway:	From Russia:
Å. Bjordal	A. Boltnev
A. Bjørge	V. Borisov
S. Mehl	S. Dyagilev
S. Engesæter	K. Drevetnyak

Local organizing committee:
E. Eriksen
V. Eriksen
L. Edstrøm
M. von Minden

Deadlines:
Final programme: 30 May 2003
Final registration: 15 June 2003

Guide to authors:
Each presentation on fisheries management (Sessions 1-5) should provide a brief outline (20 minutes), including:

- Stock characteristics (size, distribution, position in the food web, management unit, etc.) and history of the stock.
- History of the fishery.
- History of the management system.
- Current management strategy, including scientific advice (e.g. stock monitoring, stock assessment and prognoses, precautionary reference points, form of advice), TAC decision-making and international/national sharing of the TAC, the fishery (fishing methods, fleets), fisheries regulations (legal size, mesh size, selectivity measures, area closures, etc.), enforcement, control and collection of fisheries statistics.

Symposium venue:
SCANDIC HOTEL, BERGEN /BERGEN KONGRESS SENTER,
STREET ADDRESS:HÅKONSGT. 2, BERGEN

PROGRAMME

Wednesday, 27 August

09.00 Registration
10.00 Welcome and introduction

SESSION 1: Pelagic fish
10.20 Capelin in the Barents Sea, by H. Gjøsæter and N. G. Ushakov
10.40 Capelin in Icelandic waters, by J. Sigurjonsson
11.00 Capelin in Canadian waters, by B. Atkinson/R. Bowering

11.20 PANEL DISCUSSION on management strategies for different capelin fisheries.
12.00 LUNCH

SESSION 2: Demersal fish
Cod
13.00 Cod in the Barents Sea, by A. Aglen , K. Drevetnyak and K. Sokolov
13.20 Cod in Faroese waters, by H. Jakupsstovu
13.40 Cod in Icelandic waters, by J. Sigurjonsson
14.00 Cod in Canadian waters, by B. Atkinson/R. Bowering
14.20 Cod in Alaskan waters, by J. Tagart

14.40 COFFEE BREAK
15.00-16.00 PANEL DISCUSSION on management strategies for different cod fisheries.

19.00 RECEPTION at Institute of Marine Research.

Thursday, 28 August

09.00 Introduction and information
SESSION 2: Demersal fish (continued)
Greenland halibut

09.10 Greenland halibut in the Barents Sea, by K. Nedreaas and O. Smirnov
09.30 Greenland halibut in Canadian (NAFO) waters, by R. Bowering
09.50 Greenland halibut in Bering Sea, by J. Tagart
10.10 Greenland halibut in Faroese/Icelandic/Greenland waters, by A. C. Gundersen, E. Hjørleifsson and H. Siegstad.

10.30 COFFEE BREAK

11.00 PANEL DISCUSSION on management strategies for different Greenland halibut fisheries.
12.00 LUNCH

SESSION 3: Crustacean fisheries
Shrimp
13.00 Shrimp in the Barents Sea, by M. Aschan and B. Berenboim
13.20 Shrimp in Icelandic waters, by J. Sigurjonsson
13.40 Shrimp in Canadian (NAFO) waters, by B. Atkinson/R. Bowering
14.00 Shrimp in Greenland waters, by H. Siegstad

14.20 PANEL DISCUSSION on management strategies for different shrimp fisheries.

15.00 COFFEE BREAK

SESSION 4: Marine mammals
15.20 Seals in the Barents Sea, by T. Haug and V. Svetochev
15.40 Seals in Kamtsjatkan waters, by A. Boltnev
16.00 Seals in Canadian waters, by B. Atkinson/R. Bowering

16.20 PANEL DISCUSSION on management strategies for exploitation of marine mammals.
17.00 SYMPOSIUM DINNER – and mini-cruise on the S/S “Statsraad Lehmkuhl”.

Friday, 29 August
SESSION 3: Crustacean fisheries (continued)
King crab
09.00 King crab in the Barents Sea, by B. I. Berenboim, A. M. Hjelset, M. A. Pinchukov and J. Sundet
90.20 King crab in Alaskan waters, by J. Tagart
09.40 PANEL DISCUSSION on management strategies for different crab fisheries.

10.30 COFFEE BREAK

SESSION 5: Ecosystem approaches to fisheries management

11.00 An ecosystem approach to fisheries management in the Barents Sea, by Å. Bjordal and A. Boltnev
11.20 Ecosystem approach to fisheries management in Kamtsjatkan waters, by L. Bocharov, V. Shuntov and E.P. Dulepova.
11.40 Ecosystem approach to fisheries management in Alaskan waters, by J. Tagart

12.00 LUNCH

13.00 Ecosystem approach to fisheries management in Canadian (NAFO) waters, by B. Atkinson/R. Bowering
13.20 Ecosystem approach to fisheries management in Icelandic waters, by J. Sigurjonsson

13.40 PANEL DISCUSSION on Ecosystem approaches to fisheries management

14.30 Summing up and concluding remarks

15.00 END

APPENDIX II: List of participants

Participants	Affiliation	Country		E.mail addresses
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APPENDIX III: Power Point Presentations (CD)

JOINT REPORT

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