

# The Northeast Arctic cod stock's place in the Barents Sea ecosystem in the 1980s: an overview

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Just after World War II the size of the Northeast Arctic cod (*Gadus morhua*) stock was about 6 million tonnes, but at the beginning of the 1980s the stock had been reduced to 1 million tonnes, due mainly to the excessively high fishing-mortality. Nevertheless, the stock produced strong year classes at the 0-group stage in the relatively warm period 1983–1985. At the same time, individual growth in the cod stock was good, and in 1986 the stock size increased to over 1.5 million tonnes.

However, the cod preyed increasingly on the capelin (*Mallotus villosus*) present, and by the end of 1986 the capelin stock was seriously depleted. The cod compensated for the loss of capelin by preying more intensively on other food items, including smaller cod. Cannibalism increased by a factor of three from 1984 to 1986, and this is one important reason why the 1984 and 1985 year classes did not recruit to the fisheries as expected. Individual growth was dramatically reduced, and the average fish weight decreased by about 50% in most age groups. Because the quotas are in tonnes, more fish than expected were caught.

This resulted in serious management problems and led to reductions both in stock size and quotas compared to the optimistic prognosis of the mid-1980s.

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## Introduction

The Northeast Arctic cod (*Gadus morhua*) stock is one of the dominant fish stocks in the Barents Sea, both in the ecosystem and in the fisheries. The stock is distributed from Novaja Zemlja in the east to Spitsbergen in the northwest and Lofoten in the southwest. The main area of distribution and migration routes are shown in Fig. 1 (Bergstad et al. 1987; unpubl. survey reports).

Just after World War II the size of the cod stock was about 6 million tonnes. Since then the stock has been decreasing, and by the early 1980s the stock size had declined to less than 1 million tonnes (ICES Arctic Fisheries Working Group reports) (Fig. 2A). The main reason for this was a more or less constantly increasing fishing mortality during the whole period (Fig. 2B). With a fishing mortality of 0.9 and natural mortality of 0.2, a year class is reduced by two-thirds in one year and by 99% in 4 years.

The recruitment to the fishable part of the stock has been quite variable (ICES Arctic Fisheries Working Group reports) (Fig. 3). The fish start to recruit to the fishery as 3-year-olds, and the normal overall mean of 3-year-olds in a year class

has been 600 million individuals. Since 1975 only the 1983 year class has been above average, and this is also an important factor in the decline of the stock in the last 15 years.

## The first (good) half of the 1980s

The second half of the 1970's was very cold, but through the beginning of the 1980s the temperatures increased and the period 1983–1985 was relatively warm (Midttun & Loeng 1987).

During the period 1983–1986 the cod stock produced good year classes at the 0-group stage, actually the best series observed since the 0-group survey started in 1965. Fig. 4 presents the logarithmic index for 0-group cod in the period 1965–1989 (ICES CM 1989a). This index is based on the number caught during a standard trawling haul of one nautical mile (Randa 1984).

There had been an increase in mean length for all year classes following the 1975 year class (ICES CM 1985), and at the beginning of the decade the individual growth in the cod stock was good. Therefore the prospects for the cod stock looked very good in the middle of the 1980s, when the

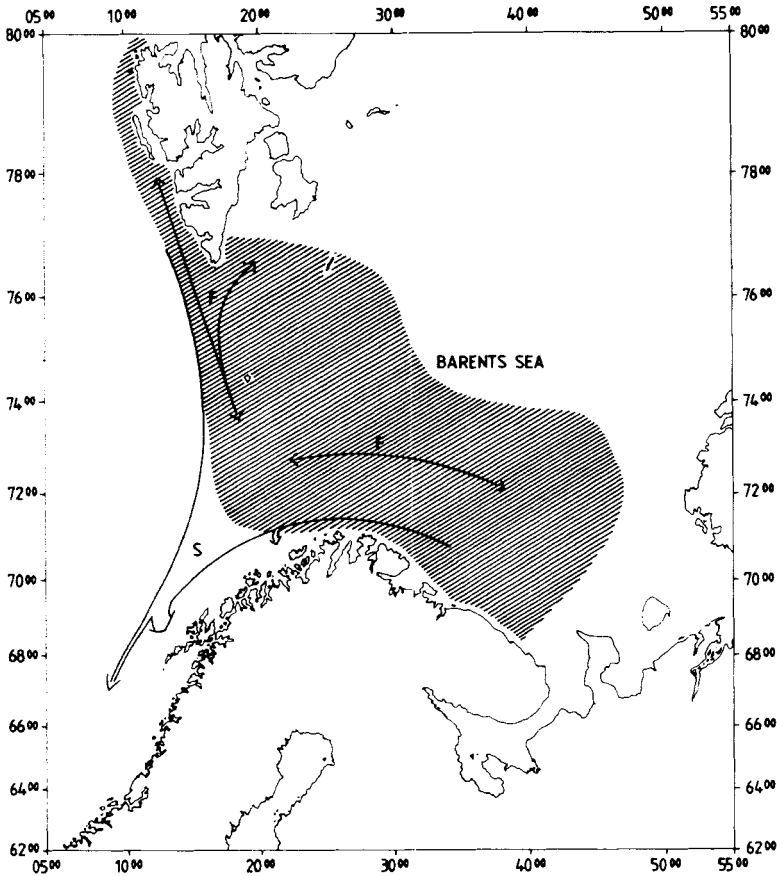


Fig. 1. The Northeast Arctic cod stock's main area of distribution with spawning (S) and feeding (E) migration routes (from Bergstad et al. 1987 and unpubl. survey reports).

coming collapse of the capelin stock and its effects had not yet become obvious. The medium-term projections from 1985 indicated a stock size of 3–4 million tonnes in 1988 and catches of about 350,000–800,000 tonnes, depending on the level of the fishing mortality (ICES CM 1986a).

In 1984 a stomach sampling program on cod was initiated in the Barents Sea. The aim of the program was to produce detailed quantitative data on the food selection of different size groups of cod throughout the area of distribution over the year (Mehl et al. 1985; Mehl 1986). The data were to be used in connection with the development of a multispecies model for the Barents Sea. Since 1987 the Institute of Marine Research in Bergen and the Polar Institute (PINRO) in Murmansk have cooperated in the sampling and exchange of stomach content data from the Bar-

ents Sea (Mehl & Tjelmeland 1988). The joint database now contains information on more than 40,000 cod analysed individually. Fig. 5 shows the geographical distribution of trawling stations where sampling of cod stomachs was carried out during the period 1984–1988.

The spectrum of the prey categories found in the stomachs of cod analysed is broad (Table 1). On the average, only 9 species or groups of categories contribute more than 1% by weight to the food. These are amphipods (Hyperidae), krill (Euphausiacea), deep sea shrimp (*Pandalus borealis*), herring (*Clupea harengus*), capelin (*Mallotus villosus*), polar cod (*Boreogadus saida*), cod, haddock (*Melanogrammus aeglefinus*) and redfish (*Sebastes* spp.). Other species which might provide useful ecological information are also registered.

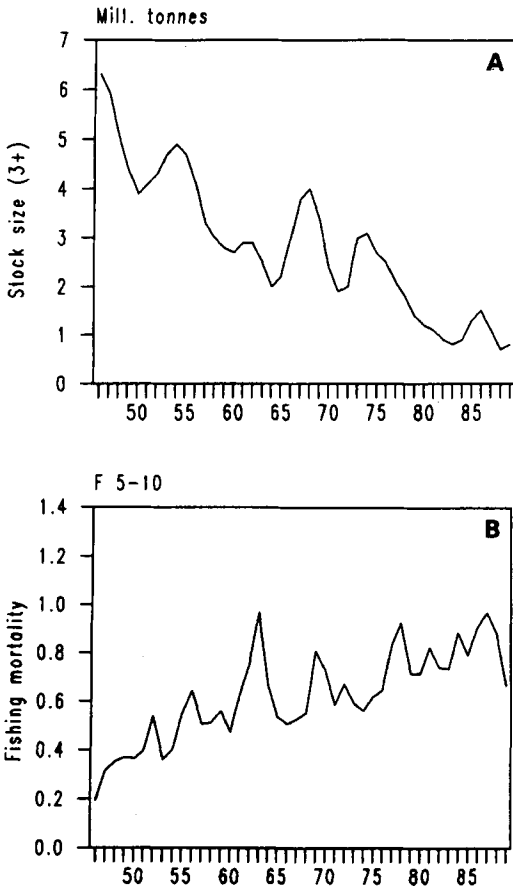


Fig. 2. The Northeast Arctic cod stock. Stock size (A) and fishing mortality (B) in the period 1946–1989 (from ICES Arctic Fisheries Working Group reports).

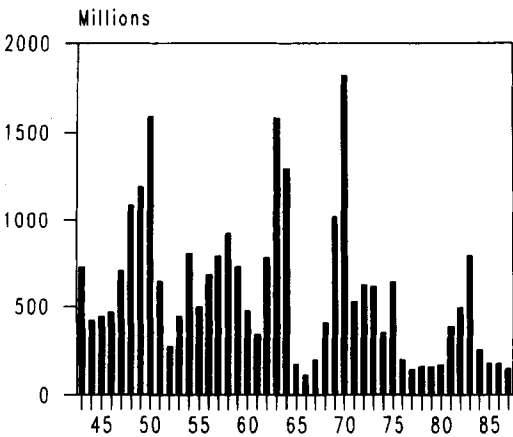


Fig. 3. Year class-strength (1943–1987) in the Northeast Arctic cod stock, measured as number of 3-year-old fish (from ICES Arctic Fisheries Working Group reports).

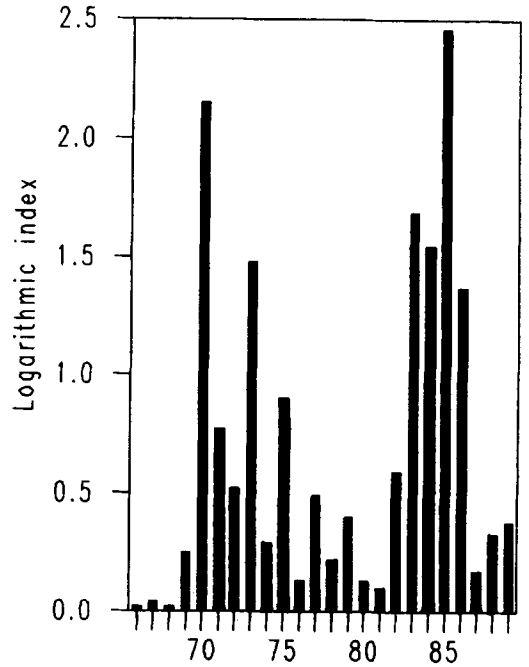


Fig. 4. Logarithmic indices of year class abundance for 0-group cod in the Barents Sea in the period 1966–1989.

The diet of the Northeast Arctic cod shows individual, spatial, seasonal, and year-to-year variations (Mehl 1986). The general trend is that crustaceans, mainly copepods, krill, and amphipods, are the dominant food of smaller cod, and fish the major prey of larger cod (Fig. 6). Capelin is the main fish prey and the most important prey for medium-sized cod. Crustaceans such as deep sea shrimp and amphipods also are important for medium-sized cod. Large cod prey more upon larger fish such as haddock, larger redfish, blue whiting, flatfish, and cod (cannibalism).

Capelin is subject to predation primarily in the southern part of the Barents Sea during the first half of the year in connection with the capelin's spawning migration. Redfish is subject to predation by larger cod in a larger area throughout the year, mostly as juveniles (0–4-group) less than 15 cm, but also up to 25 cm. Haddock and young cod are taken mainly at 0- and 1-group stages, after they have settled on the bottom. Polar cod is preyed upon in the eastern part of the Barents Sea and also to some extent in the Svalbard area, while herring is preyed upon mainly in the southern–southeastern Barents Sea when young

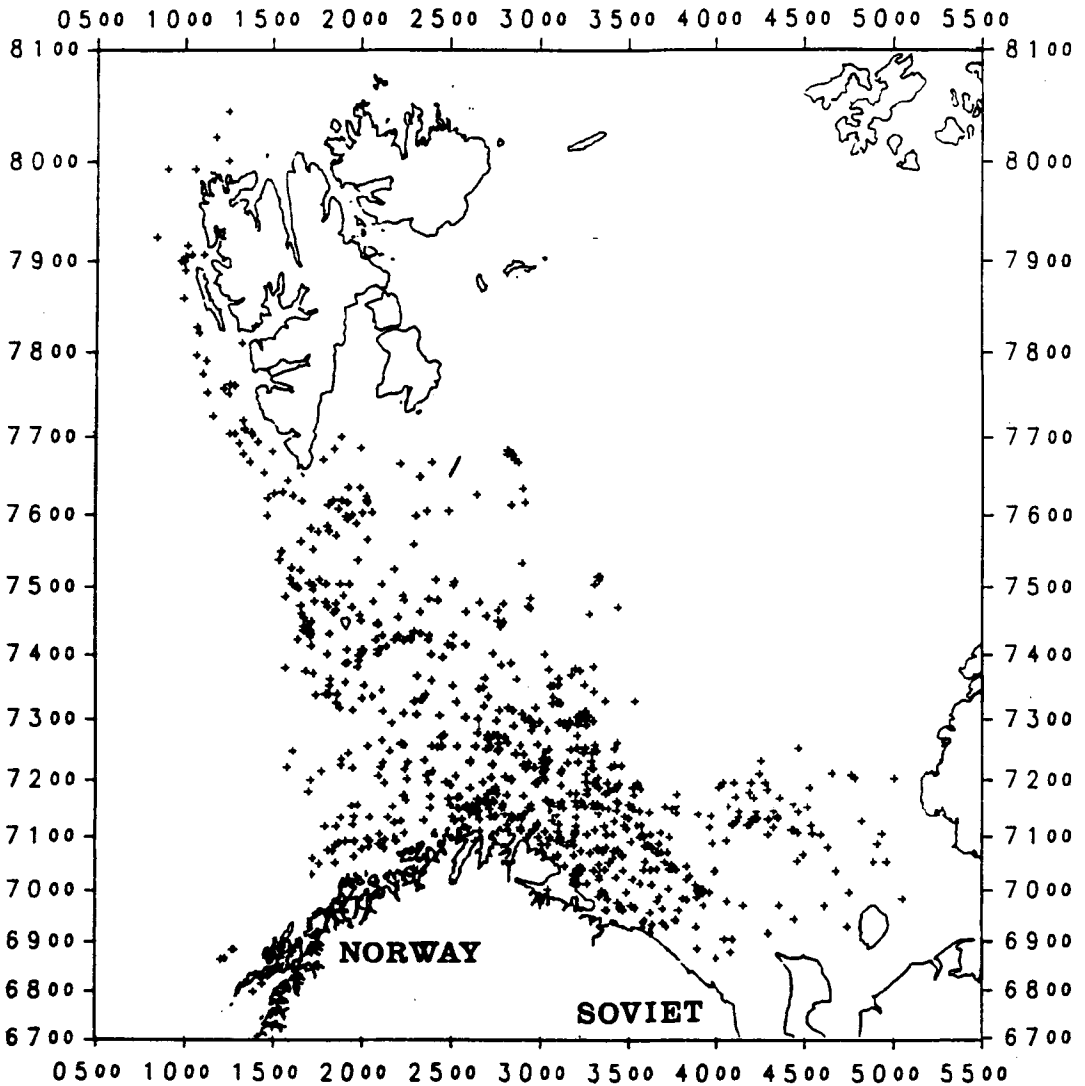


Fig. 5. Geographical distribution of trawling stations in the Barents Sea and Svalbard area with sampling of cod stomachs carried out in the period 1984–1988.

year classes of herring are present. Deep sea shrimp is preyed upon all year in most of the area, amphipods to a larger degree in the second half of the year in the central and northwestern parts of the area, and euphausiids mainly in the southeastern Barents Sea in the second and third quarters of the year.

The cod stock's total annual food consumption has been used to study year-to-year variations in the cod's feeding patterns. Consumption is estimated by multiplying the mean stomach content weights by the rate of gastric evacuation

and the number of cod in each age group, area, season, and year (Mehl 1989). The stomach content weights have been obtained from the joint Soviet–Norwegian database, and gastric evacuation rates come from an experiment in Balsfjord, Tromsø (J. dos Santos pers. comm.; Bogstad & Mehl 1990). The number of cod in each age group is 1988-VPA-data from ICES (ICES CM 1989b), and the geographical distribution of the different age groups is based on acoustic survey data (Høyen et al. 1989; Jakobsen et al. 1989; unpubl. survey data).

Table 1. Prey-categories found in cod stomachs in the Barents Sea in 1984–1989. (Listed in taxonomic order)

Phacophyceae fucales	Mysidae	Sagitta elegans
Foraminiferida	Leuconidae	Asciacea
Porifera	Diastylis rathkei	Oikopleura
Hydrozoa	Anthuridae	Raja radiata
Scyphozoa	Flabellifera	Teleostei
Ceriantharia	Valvifera	Clupea harengus
Hormathia digitata	Epicaridea	Mallotus villosus
Metridium senile	Amphipoda	Argentina silus
Beroidae	Byblis gaimardi	Maurolicus muelleri
Rhynchozoela	Haploops tubicola	Benthoosema glaciale
Polychaeta	Rhachotropic macropus	Lophius piscatorius
Aphroditidae	Haustoriidae	Boreogadus saida
Anaitides maculat	Lysianassidae	Gadus morhua
Nereis	Hyperia galba	Pollachius virens
Nephtys caeca	Parathemisto libellula	Melanogrammus aeglefinus
Onuphis conchylega	Parathemisto abyssorum	Trisopterus minutus
Eunicidae	Caprellidea	Trisopterus esmarkii
Spinoidae	Euphausiacea	Merlangius merlangus
Chaetopteridae	Meganyctiphanes norvegica	Micromesistius poutassou
Flabelligeridae	Thysanoessa inermis	Lycodes vahlii
Opheliidae	Thysanoessa longicaudata	Lycodes esmarkii
Capitellidae	Thysanoessa raschii	Macrourus berglax
Maldane sarsi	Segestes arcticus	Gasterosteidae
Ampharetidae	Pasiphaeidae	Sebastes
Terebellidae	Spirontocaris spinus	Sebastes marinus
Sabellidae	Eualus gaimardi	Sebastes mentella
Trochidae	Pandalus borealis	Sebastes viviparus
Buccinidae	Crangon allmanni	Icelus bicornis
Turridae	Sclerocrangon ferox	Arteidiellus atlanticus
Limacina helicina	Pontophilus norvegicus	Arteidiellus europaeus
Clione limacina	Pagurus bernhardus	Cottus
Arca	Pagurus pubescens	Gymnocanthus tricuspis
Pectinidae	Munida sarsi	Myoxocephalus scorpius
Astarte	Hyas coarctatus	Triglops pingelii
Cardium	Hyas araneus	Agonus decagonus
Rossia	Geryon tridens	Careproctus reinhardti
Gonatus fabricii	Geryon affinis	Eumicrotremus spinosus
Ommastrephes sagittatus	Echiurus echiurus	Liparis liparis
Octopodida	Priapulius caudatus	Anarhichadidae
Pycnogonida	Alcyonidium gelatinosum	Lumpenus lampretaeformis
Copepoda	Ceramaster granularis	Leptoclinus maculatus
Calanus hyperboreus	Ophiura sarsi	Ammodytidae
Calanus finmarchicus	Ophiopholis aculeata	Glyptocephalus cynoglossus
Metridia	Echinozoa	Hippoglossoides platessoides
Cyclopoida	Psolidae	Reinhardtius hippoglossoides
Caligus	Cucumaridae	Indeterminatus
Balanidae	Synaptidae	

The Northeast Arctic cod stock's total consumption in 1000 tonnes of commercially important prey species during the period 1984–1988 is presented in Fig. 7. During the first years of this period, capelin was the main prey item. In 1984 it accounted for about 40% of the cod stock's consumption; in 1985, when a higher proportion of the cod stock had grown enough to consume large amounts of capelin, it contributed over 50%

to the cod's diet. There was also a better overlap between the two stocks during the winter survey in 1985.

### The second (bad) half of the 1980s

In 1986 capelin contributed only 25% to the cod's diet and by the end of the year the capelin stock

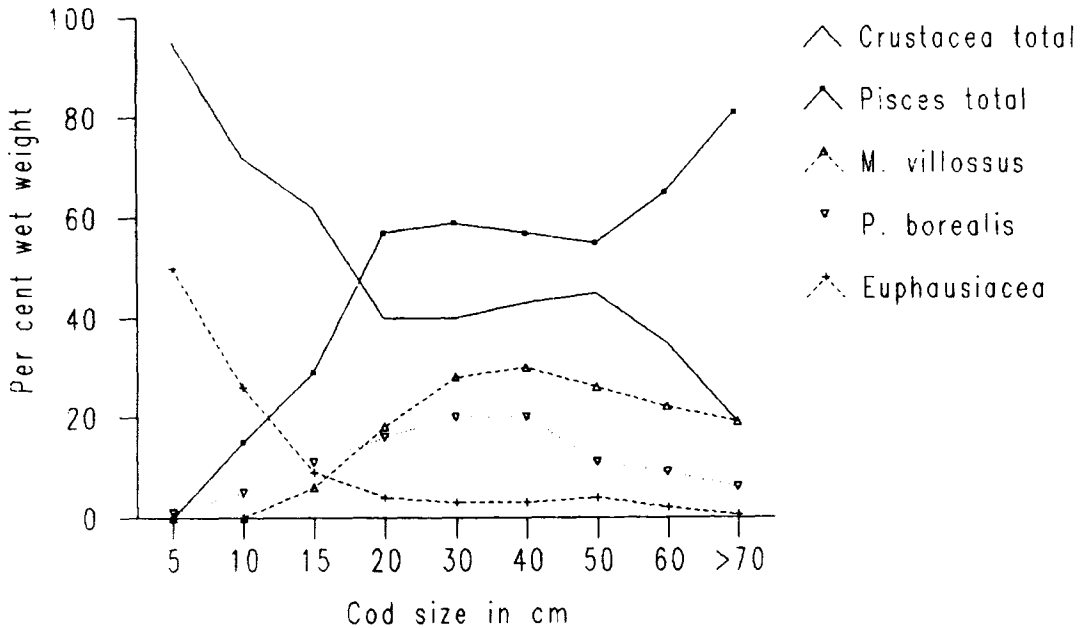


Fig. 6. Stomach content composition in percent wet weight by predator size for some of the main food items in the diet of Northeast Arctic cod during the period 1984–1989.

had been seriously depleted (ICES CM 1987), partly due to the increasing cod stock's predation pressure on the already declining capelin stock (Mehl 1989). Since 1983 there had been an annual increase in natural mortality in the capelin stock (ICES CM 1989c), and from 1985 the estimates of the cod stock's consumption exceeded the catch figures. In 1987 capelin made up less than 10% of the cod's consumption, and in 1988 there was an increase in this consumption, but it still was very low compared to earlier.

In 1984 the consumption of deep sea shrimp had been highest, contributing more than 20% to the cod's diet. In 1985, however, the consumption was reduced by more than 50% and has since made up 6–9% of the cod stock's annual consumption. From 1984 to 1986 the estimate of the shrimp stock in the Barents Sea was reduced by two-thirds (Hyllen & Øynes 1986); factors such as fishing, predation by cod, migration, and poor recruitment could be responsible for this decline (Tveranger & Øynes 1985).

Redfish was the second most important fish prey in the second half of the 1980s; on the average it made up almost 10% of the cod stock's consumption. Herring, haddock, and young cod contributed only a smaller part of the cod's diet

and, measured in biomass consumed, none of these contributed as much as 5% annually. However, measured in numbers consumed and compared with numbers at age in the prey-stocks, the predation pressure must have been considerable, and several year classes from 1984–1987 might have been largely reduced by this predation.

Before the stock of Norwegian spring spawning herring collapsed at the end of the 1960s, young age groups of this stock were normally present in large numbers in the Barents Sea and made up an important part of the cod's diet (Zatsepin & Petrova 1939). In 1983 the recovering herring stock produced a relatively good year class, which to a large degree managed to avoid predation from the increasing cod stock before migrating out of the Barents Sea in 1986 (ICES CM 1987). The 1984, and especially the 1985, year classes of herring also appeared strong in the 0-group surveys, but later on these year classes almost disappeared (ICES CM 1986b, 1987). The cod stock's consumption of these year classes in 1984–86 was probably one of the main factors causing this depletion (Mehl 1989). Since 1986 there were almost no young age groups of herring in the Barents Sea.

In a situation with a depleted capelin stock, a

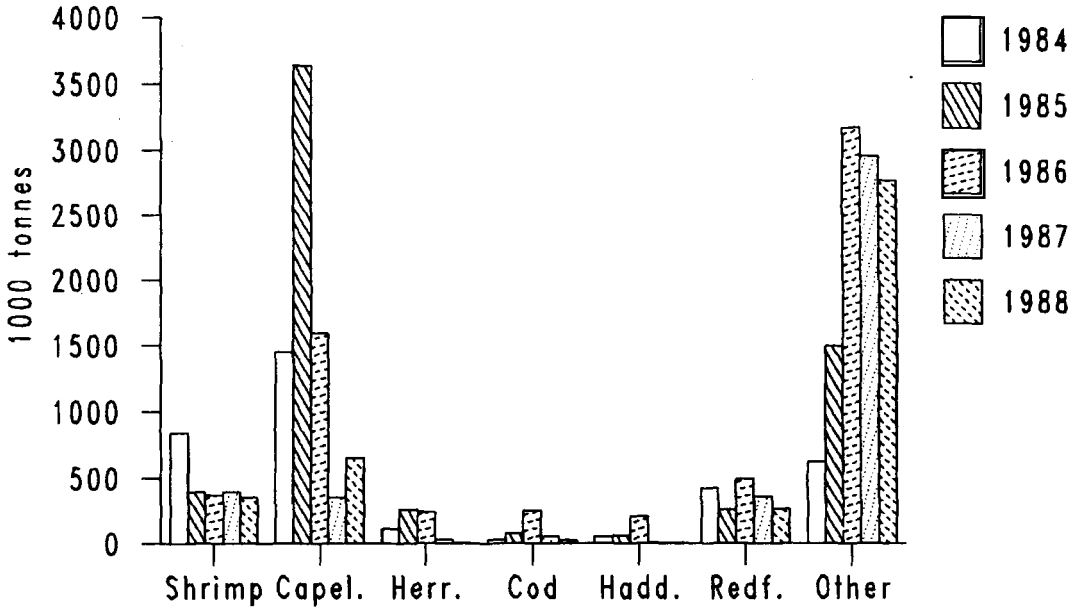


Fig. 7. The Northeast Arctic cod stock's consumption in 1000 tonnes of commercially important prey species during the period 1984–1988.

strongly reduced shrimp stock and relatively few young herring in the Barents Sea, an increase in cannibalism occurred, both absolute and relative. The older cod consumed an increasing proportion of the young cod (Fig. 8). The number of age group 3 in the stock is taken directly from the 1988–VPA (ICES CM 1989b), the number of age groups 1 and 2 are back calculations (for 1986 and 1987 of the prognosis), using natural mortality ( $M$ ) = 0.2 and the number of 0-group is estimated by the method described in Sundby et al. (1988). The number of cod consumed is probably an overestimate. The stomach content data used in the calculations are to a large degree based on data sampled by bottom trawling, and only to a lesser degree by pelagic trawling, since it is difficult to catch cod by the latter method. Small cod are only found in stomachs of cod taken by bottom trawling, while a major part of the cod stock was observed above the bottom (pelagic) during this period. Nevertheless, cannibalism and its effect were increasing, and during most of these years the cod stock consumed a higher number from its own stock (3+) in an average year (Korzhev & Tretyak 1989; Mehl 1989). This became obvious when the year classes which were good at the

0-group stage did not recruit to the fisheries as expected in the prognosis.

The consumption of young haddock was also considerable compared to the numbers in the

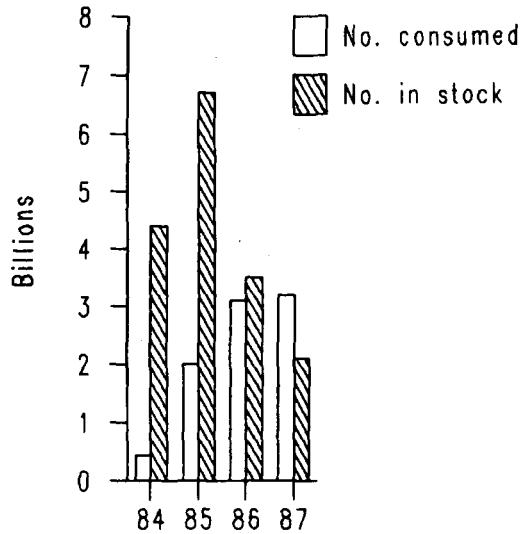


Fig. 8. The cod stock's annual consumption (during the period 1984–1987) in billions of cod, age group 0–3, compared with the estimated number of the same age groups in the stock.

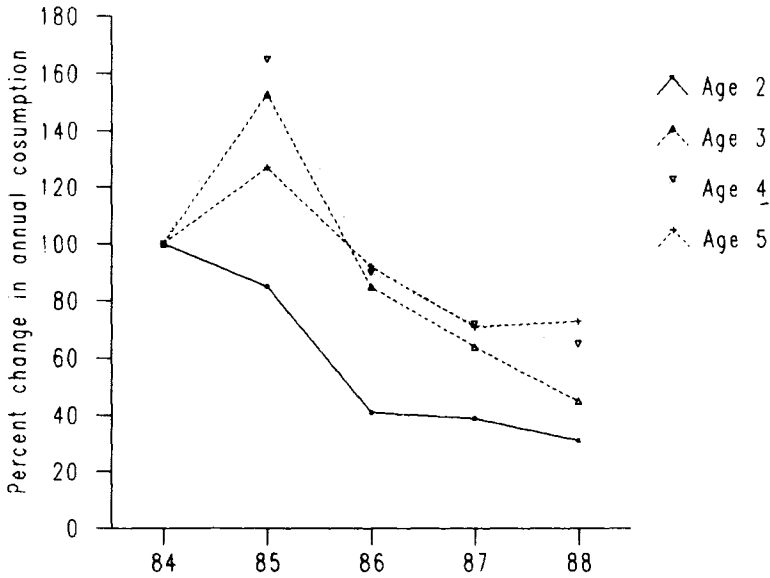


Fig. 9. Percent change in annual consumption relative to 1984 for cod age groups 2-5 during the period 1984-1988.

stock, and this probably influenced the recruitment just as much as in the cod stock.

After 1985 the consumption of other species increased considerably, and in 1987/88 these species accounted for almost 70% of the total consumption. The most important prey here were amphipods of the genus *Parathemisto*. There is

reason to believe that amphipods benefitted from the collapse of the capelin stock.

But the increased consumption of other species was not enough to replace the loss of capelin and deep sea shrimp in the absence of young age groups of herring. A reduction in the total annual consumption was found in all age groups, and this

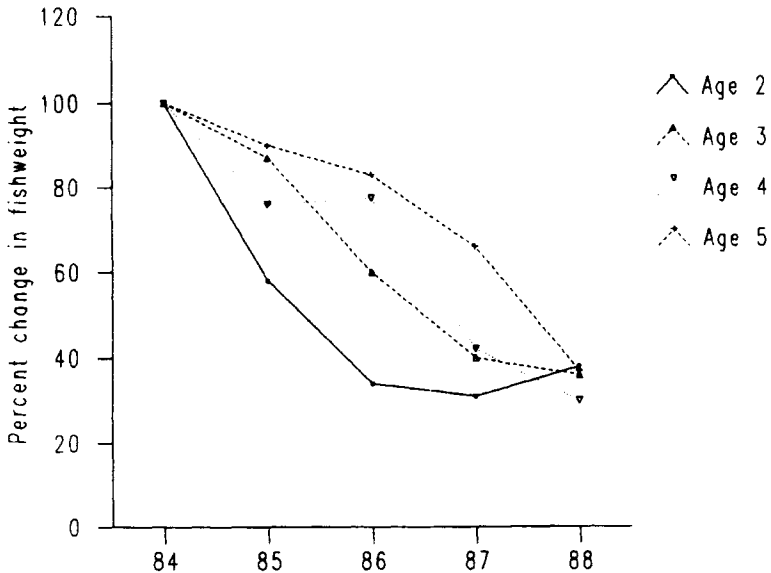


Fig. 10. Percent change in fish weight relative to 1984 for cod age-groups 2-5 in the period 1984-1988.



was most pronounced in age groups 2–5 (Fig. 9). During the first period of the stomach analysis program, cod in these age groups were found to be most dependent on capelin and partly dependent on shrimp, while younger cod consumed smaller crustaceans and older cod consumed larger fish prey. Therefore medium aged cod had the largest problem replacing capelin and shrimp as main prey items. From 1984 to 1988 the annual individual consumption was reduced by up to 50% in these age groups. Consumption is calculated by a method which renders it directly proportional to the weight of the stomach content. So far meal size effects have not been included in the calculations. dos Santos (1990) found slower evacuation rates at large-sized meals. During the winter survey of 1985, a very high content of capelin was found in most age groups. This may have been caused by higher overlap between cod and capelin during the survey in 1985 compared to 1984. There might also have been a better overlap during the survey in 1985 than in the rest of the season when cod preys upon capelin (unpubl. survey data). Therefore, consumption is probably overestimated for 1985, at least in relation to 1984.

The reduction in total annual consumption is probably the main reason for the severe reduction in individual growth in the cod stock in the same period (Mehl & Sunnanå 1990). Fig. 10 presents the percent change in fish weight for cod age groups 2–5 in 1984–1988. In all these age groups the mean weight was reduced by more than 50% from 1984 to 1988. Younger and older cod had a somewhat smaller reduction in growth because they were not so dependent on capelin and therefore to a larger extent able to maintain the total annual consumption.

## Concluding remarks

In the first half of the 1980s the relatively small cod stock produced some strong year classes. The individual growth was good and the cod stock increased by 50%. But at the same time the stock size of the main prey species, capelin and deep sea shrimp, were severely reduced (Fig. 11). The cod did not manage to find enough other suitable prey species, and a reduction in mean weight at most ages in the cod stock was observed. This caused severe management problems. Because of lower individual weights, more fish

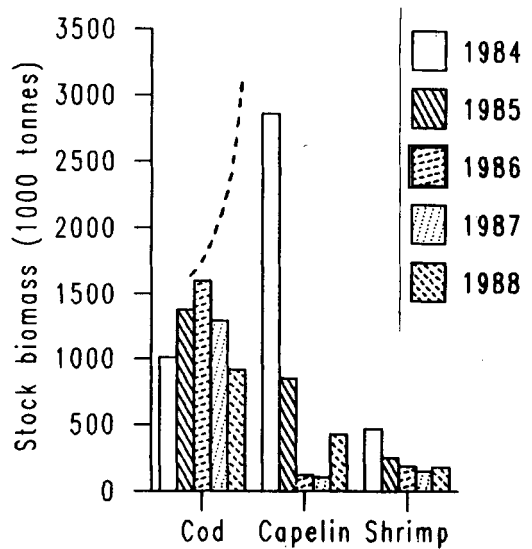


Fig. 11. Stock biomass of cod, capelin and deep sea shrimp in the Barents Sea during the period 1984–1988. (---) = prognosis on cod stock biomass from 1985, using the highest prognosis of fishing mortality (ICES 1986a).

than expected were caught and the discard increased. Also natural mortality probably increased during the period because cannibalism was raised by a factor of 3 (Mehl 1989). All these factors have led to a new reduction in the stock size of cod, far below the optimistic prognosis from the mid-1980s (Fig. 11), and the quotas have been reduced correspondingly. This calls for multispecies considerations in the management of the main predator and prey-stocks in the Barents Sea.

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