International Symposium on the
Long-Term Variability of Pelagic
Fish Populations and their Environment

14-17 November 1989
Sendai, Japan

INTERRELATION BETWEEN ENVIRONMENTAL CHANGES AND FLUCTUATING FISH POPULATIONS IN THE BARENTS SEA

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Introduction

The two largest fish stocks in the North-Eastern Atlantic, the Norwegian spring spawning herring, Clupea harengus, and the Barents Sea capelin, Mallotus villosus, have been depleted in recent years. These are the main stocks of plankton feeders in the Barents Sea, and the dominant predator, the North-East Arctic cod, Gadus morhua, has nearly perished due to lack of food. Crowds of underfed seals have moreover invaded Norwegian coastal waters and thousands of dead seabirds have drifted ashore on the north Norwegian coast. The traditional coastal cod fisheries are struck by the most serious crisis on record, and these dramatic events demonstrate that the upper trophical levels of the ecosystem of the region are out of balance. The present paper aims at giving a comprehensive review of the exploitation history of the main fish stocks. The possible effects of the fisheries on the stocks are considered, and aspects of stock interrelationships under various environmental conditions are analyzed and discussed.

The Environmental Conditions

The Barents Sea is a high-latitude shallow continental shelf area, in which the physical conditions are governed by the inflow of Atlantic water through the Faroe-Shetland Channel (Fig. 1). Two main branches of the Atlantic current, one going north and one going south into the North Sea, create two separate ecosystems. The region associated with the northern branch contains two highly productive areas, one in the Norwegian Sea along the Polar front, and one in the marginal ice zone of the Barents Sea. The production processes in the latter area are linked to the movement of the ice edge (Gjøsæter et al. 1983).

The strength and properties of the inflowing Atlantic water vary periodically and determine the climate of the region.Increased inflow of Atlantic water increases the temperature in the upper water masses and favours recruitment of the main fish species. Mean temperature and salinity in the Barents Sea in the period 1964-1985 are shown in Fig.2.

The Ecosystem

The structure of the ecosystem above fish level is outlined in Fig. 3. The plankton production in the Norwegian Sea is harvested by the adult herring while the juvenile herring and the capelin harvest the production in the Barents Sea. Two large stocks of semipelagic fish

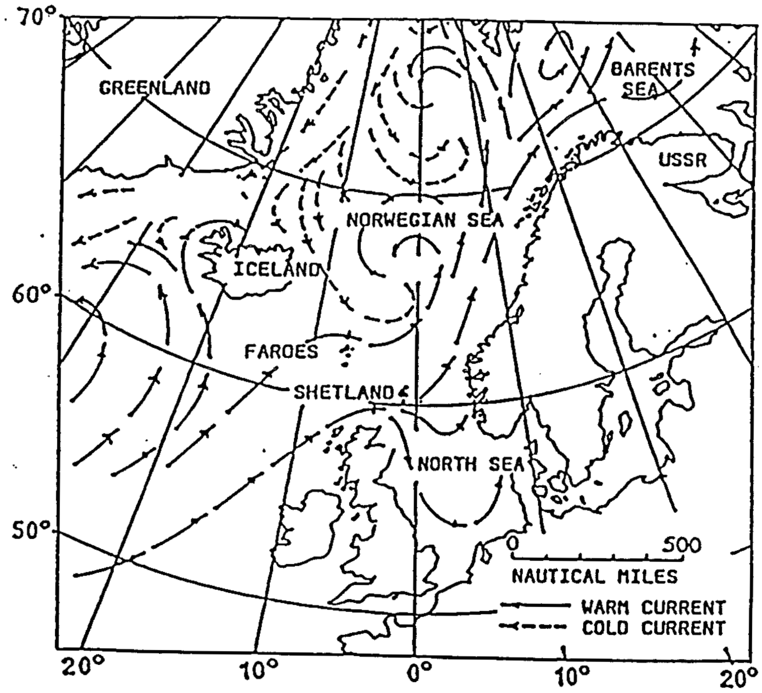

Fig. 1. The circulation of the Norwegian Sea.

Fig. 2. Mean temperature and salinity (broken line) 1964-1985 (Midttun *et al.*, 1986).

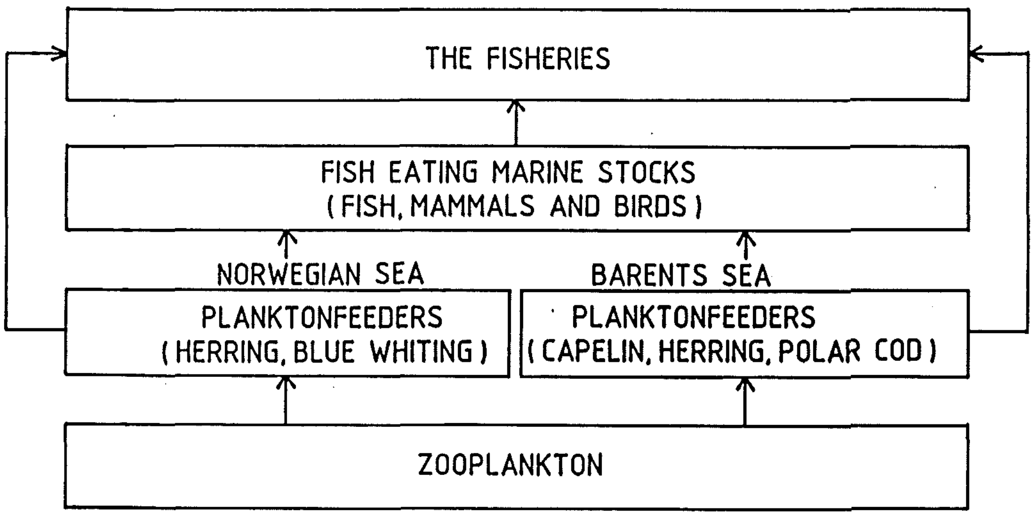

Fig. 3. The structure of Norwegian Sea-Barents Sea ecosystem.

feed in the same areas, the blue whiting, Micromesistius poutassou, in the Norwegian Sea and the polar cod, Boreogadus saida, in the Barents Sea. Herring and capelin are the main food sources for a large variety of fish stocks, mammals and birds. The North-East Arctic cod is the largest predator in the system and plays a decisive role in the balance of the predator-prey relationship. All the main stocks of fish and mammals are harvested by man.

Relevant features of the general biology of the fish stocks are illustrated in Fig. 4. The adult herring used to feed in the Polar front area of the Norwegian Sea during summer, but spawns on the Norwegian west coast in the early spring. The juvenile herring (age 0-4) is distributed in Norwegian coastal waters, and in the southern parts of the Barents Sea when the inflow of Atlantic water is high (abundant year-classes). The adult capelin feeds in the marginal ice zone of the Barents Sea from June to November and spawns on the Norwegian north coast and the coast of Murmansk in the early spring. Larvae and juvenile capelin are distributed in the southern and central parts of the Barents Sea and overlap the nursery area of juvenile herring in years with abundant herring year-classes. The capelin spawns at an age of 3 to 6 years, depending on the growth rate, and suffers mass mortality after spawning.

The growth potential of the semipelagic stocks which feed in the water column below the pelagics is probably affected by the size of the pelagic stocks. The semipelagic stocks are however of marginal importance for this ecosystem because they spawn in other areas.

The cod spawns on the central Norwegian coast between the spawning grounds of the pelagic stocks, and feeds in the southern and central part of the Barents Sea and in the Svalbard area. The cod matures at an age of 5 to 8 years. The juveniles have a more north-eastern distribution than the adults, but the distribution is limited to the area south and west of the marginal ice zone. The adult capelin is therefore mostly available as food for cod during the spawning migration of capelin in winter and spring, whereas the cod may feed on juvenile herring and capelin throughout the year.

Little is known about the magnitude of the predation caused by mammals, but the whales and seals are no doubt of importance for the ecobalance of the region.

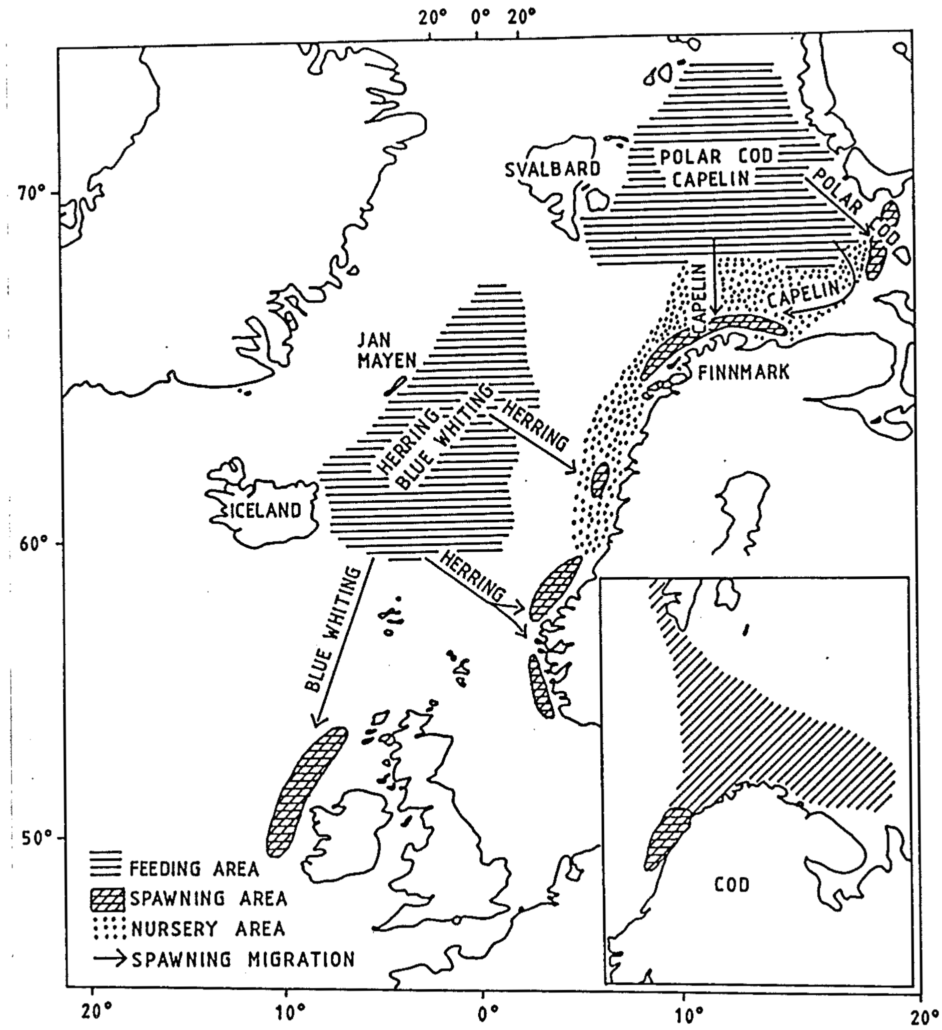

Fig. 4. Distribution of herring, capelin and cod.

Reproduction Mechanisms

Periods with high temperature and increased strength of the Atlantic current favour strong year-classes of herring and cod (Marty et al. 1963, Sætersdal et al. 1987). Extraordinarily strong year-classes have occurred in 1904, 1918, 1937, 1950, 1959-60 and 1963. In the warm period 1969-75 several strong year-classes of cod were recruited, but the recruitment of herring failed due to lack of spawners. This favoured the survival of capelin, and the capelin year-classes 1971-73 became extraordinarily abundant and overpopulated the Barents Sea in the period 1974-76 (Hamre 1985). The stock interrelationships in the early 1970's thus indicate that a warm climate also favours recruitment of capelin, and that abundant year-classes of cod have little effect on the survival of the juvenile capelin.

Plots of recruitment versus spawning stock for capelin, herring and cod are shown in Fig. 5. The capelin plots are closely related to a Beverton/Holt recruitment curve, except for the years 1984-85 when the recruitment of 1-year old capelin failed completely. The larvae production in these years was measured to be as high as in the previous years (Anon. 1987), and the apparent increase in the mortality of 0-group capelin in 1984-85 is assumed to be caused by abundant year-classes of juvenile herring.

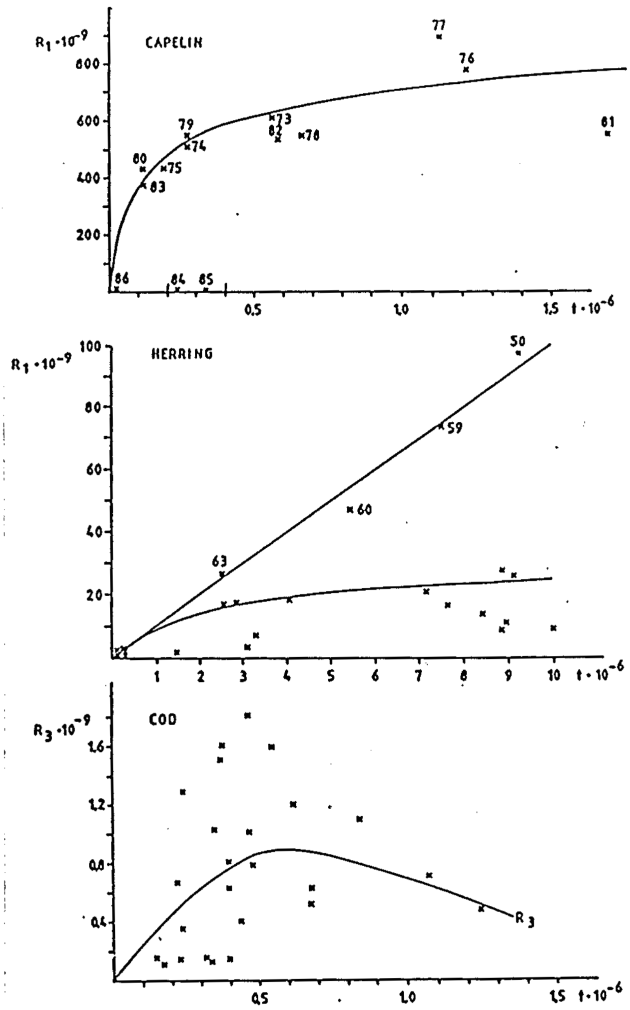

Fig. 5. Stock-recruitment plots of capelin, herring and cod.

For herring and cod the stock/recruitment plots in Fig. 5 are derived from catch-by-age statistics assuming constant natural mortality (VPA). The herring year-classes subsequent to the outstanding ones are assumed to be grossly underestimated because they have served as food resources for a growing stock of young cod. Fig. 5 indicates that under favourable recruitment conditions the strength of the herring year-classes is proportional to the parent stock, whereas the cod recruits strong year-classes on relatively low stock levels. This is crucial to an understanding of the dynamics behind the ecological crisis which developed in a period of favourable recruitment conditions for the main fish stocks.

Stock Abundance and Exploitation

Herring. The state of stock and exploitation from 1950 onwards is summarized in Fig. 6. The yearly catches are given in Table 1. The adult herring is estimated at 7 to 10 million tonnes in the 1950's, but declined to a level of some 3 million tonnes in the early 1960's. This was mainly due to poor recruitment in the period 1951-58. Two strong year-classes were recruited in 1959-60, but the stock was depleted in the late 1960's due to increased exploitation (Dragesund et al. 1980). A small component of juvenile herring survived in the early 1970's, and the stock increased slowly to some 500 000 tonnes in the cold period 1976-81. In the warm period 1983-85 three relatively strong year-classes were recruited, but the juvenile herring suffered mass mortality due to predation by an increasing stock of juvenile cod, especially the year-classes 1984-85 (Mehl 1987). The 1983 year-class matured in 1988, and the spawning stock increased to 1.5 million tonnes, (Anon. 1989). When the adult stock collapsed in 1970 the feeding migration to the Polar front area was disrupted and has not yet been resumed. The stock is now feeding off the Norwegian west coast during summer and autumn and aggregates during winter inside the Norwegian fjords, before spawning in the spring.

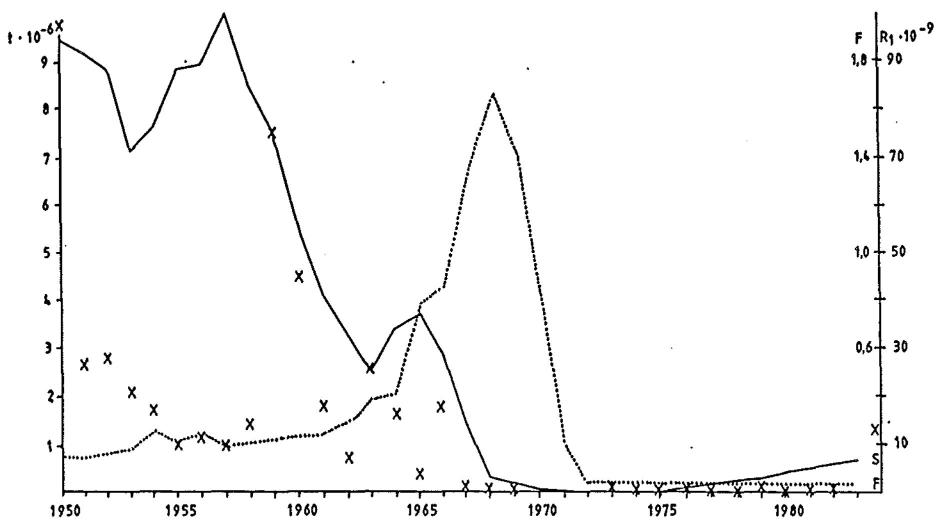

Fig. 6. Estimated spawning stock (S), fishing mortality (F) and recruitment (X) of herring as 1 year old.

Table 1. Catches of herring, capelin and cod.

Year	Herring	Capelin	Cod	Year	Herring	Capelin	Cod
1951	1278	9	827	1970	62	1314	933
52	1254	9	876	71	21	1392	689
53	1090	18	695	72	13	1593	565
54	1644	30	826	73	7	1336	792
55	1359	41	1147	74	7	1149	1102
56	1659	66	1343	75	3	1417	829
57	1319	70	792	76	-	2545	867
58	986	91	769	77	12	2940	905
59	1111	78	744	78	9	1894	698
1960	1101	92	622	79	2	1783	440
61	830	217	783	1980	8	1649	380
62	848	-	909	81	8	1987	399
63	984	28	776	82	11	1759	363
64	1281	19	437	83	18	2233	289
65	1547	217	444	84	48	1477	277
66	1955	379	483	85	71	868	307
67	1677	409	572	86	126	123	430
68	712	537	1074	87	112	-	523
69	67	680	1197	88	150	-	431

Capelin. The capelin has been fished as a prespawner off the USSR/Norwegian coast during winter since the early 1950's (Table 1). From 1968 onwards the capelin has also been fished in the feeding area during summer and autumn. After a temporary increase in the catch in 1959-61, a sudden collapse of the fishery occurred in 1962 (Table 1). From 1965 onwards the catch increased to a record catch of 2.9 million tonnes in 1977. Since 1978 the capelin fishery has been regulated by catch quotas, and from the autumn 1986 onwards the fishery has been banned.

Acoustic estimates of stock abundance are available since 1972 (Fig. 7). The estimates are obtained in September and cover the age groups 2 years old and older (Dommasnes et al. 1984). The capelin above 14 cm is expected to mature and spawn the subsequent winter, (broken line), and these estimates adjusted by the natural mortality and the catch in October-April are taken as the stock biomass of spawners in the subsequent year (dotted line). The corresponding year-class strength (X) is derived from the acoustic estimate of 2 years old and back-calculated to 1 year by VPA (Hamre et al. 1982).

The capelin stock increased in the first half of the 1970's and reached a maximum in 1975 of about 7 million tonnes. Three strong year-classes were recruited in 1971-1973, and due to high inflow of Atlantic water these year-classes were distributed far north and east in the Barents Sea, where the condition for growth is poor (Gjøsæter et al. 1987). The reduced growth rate delayed the maturation of the fish and increased the survival of the immature capelin. The extraordinarily high stock abundance in 1974-76 was thus a result of abundant year-classes and the accumulation of age groups in the immature stock. The 1971-73 year-classes matured and spawned in 1975-

1977, and the stock declined to a level of 4 million tonnes in the autumn 1977.In 1978-79 the stock remained at a stable state, but in 1980 the individual growth rate rose to the highest level ever recorded. The stock biomass increased accordingly, and a large portion of the stock matured and spawned in the winter 1981. Due to this, the stock declined to some 2.5 million tonnes in the years 1981-84. The abrupt decline in the stock size in 1976-77 and 1980-81 was thus caused by increased spawning mortality mainly, and was little affected by the fishery.

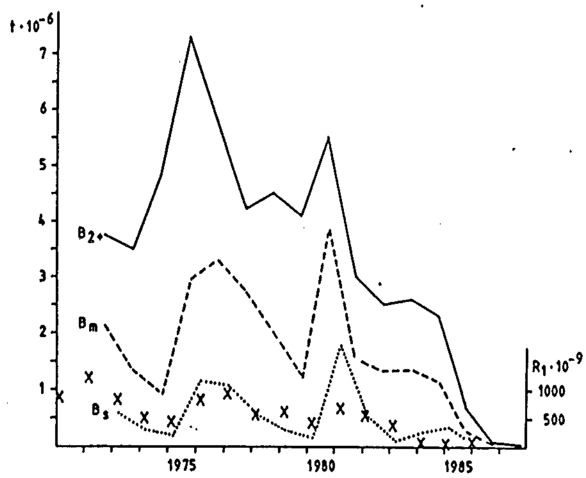

Fig. 7. Stock and recruitment estimates of capelin.

The natural mortality (M) has been estimated to 0.61 in 1974-78, 0.86 in the 1979-83 and 1.68 in 1984-85 (Anon 1987). The dramatic increase in M in latter years is caused by predation associated to an increase in the stock of young cod from 1983 onwards (Mehl 1987). In 1984 and 1985 the recruitment also failed, probably due to the presence of herring, and the stock collapsed in 1986. It is thus concluded that the capelin fishery contributed to some extent to the stock decline in the 1980's, but was of minor importance for the stock collapse in 1986. The year-classes after 1984 are all weak, except the 1969 year-class.

Cod. The state of the stock and fishery from 1950 onwards is illustrated in Fig. 8. In the middle of the 1950's a very strong 1950-year-class was recruited and the stock increased to about 5 million tonnes. In the subsequent years the stock declined to 2 million tonnes by 1964. This reduction was mainly due to increased exploitation. In later years the variation in stock size reflects to a large extent the variation in year-class strength. In the cold period 1976-81 the recruitment was poor and the stock declined to 1 million tonnes in 1983. From 1982 onwards several abundant year-classes were recruited, but the stock biomass did not develop as expected. Shortage of suitable food since 1985 caused a dramatic fall in the individual growth rate (Fig. 9), and stomach data of cod in the subsequent years indicate high mortality due to cannibalism (Mehl 1987, Anon. 1988). A serious crisis has struck the coastal fisheries and the present state of the stock is considered with concern.

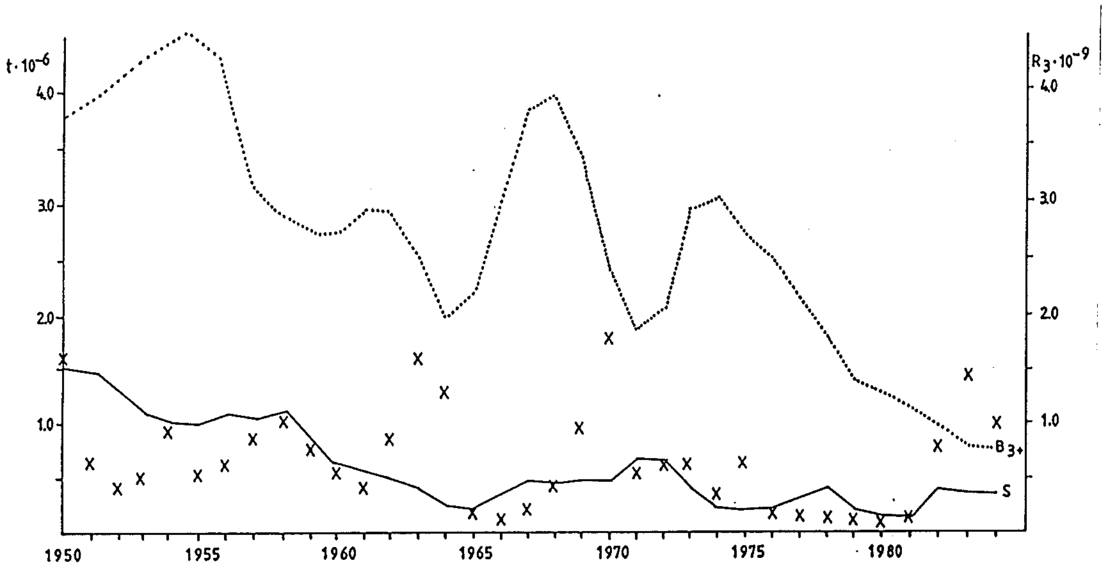

Fig. 8. Estimated stock of 3 years old and older cod (B_{3+}), the spawning stock (S) and recruitment as 3 years old (X).

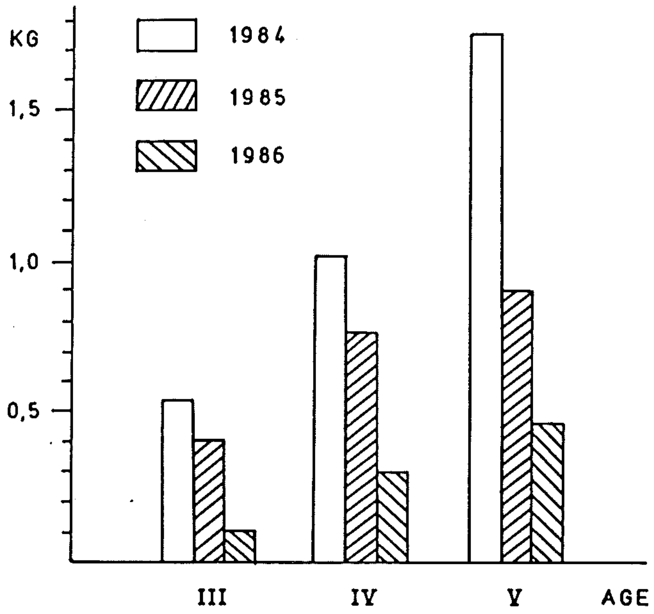

Fig. 9. Yearly increment of cod by age in 1984-1986.

<u>Mammals.</u> Mammals are important predators on both plankton and fish-feeding fishes in the Barents Sea, but data on stock sizes and feeding behaviour are inadequate to assess their effects on the plankton feeders of the region. The commercially most important stock of whale, <u>Balaenoptera acutorostrata</u>, has probably decreased in the period 1970-83 and there is no evidence for any abrupt increase in the stocks of seals in recent years (Anon. 1989). The effect of the mammals on the abrupt decline in the prey species is therefore considered to be small.

<u>Discussion and Results</u>

In the search for trends and general rules for stock interrelationships the following working hypothesis is adopted: (1) The herring is the key prey species at fish level of the food chain in the Norwegian Sea-Barents Sea ecosystem and the cod is the dominant predator. (2) The capelin is an opportunist in the system whose prospects of survival are governed by the state of the stocks of young herring and cod. The abundance of immature herring determines the survival of O-group capelin, whereas the abundance of cod determines the mortality of the older age groups.

The role of the cod and herring as the main predator-prey species is obvious as no other stocks in this area are comparable in size except for the stock of capelin in the 1970's. The assumption that herring and cod are key species of the system is also supported by their common reproduction cycles, which means that they are adapted to a similar environment and linked together through evolutionary processes. The role of the capelin needs, however, some further consideration.

Prior to the 1970's the capelin was regarded as an important stock as food for cod, but not as a large potential resource for exploitation. In a study of the cod's food demands, Ponomarenko <u>et. al.</u> (1975) did conclude that in the case of abundant year-classes of cod and haddock there would be no room for a capelin fishery at all. The conclusion is supported by the fact that the capelin has disappeared in previous periods, when the capelin fishery was insignificant, as in 1938-42 and in 1962-64 (Møller <u>et al.</u> 1962, Olsen 1965). These periods are characterized by the occurrence of abundant herring year-classes (1938, 1959-60). The impact of the juvenile herring on the recruitment of capelin is demonstrated in detail during the 1980's (Fig. 5). The data show that the O-group capelin has suffered mass mortality in the years 1984 and 1985 when 1- and 2-group herring was abundant in the Barents Sea. The extraordinarily strong capelin yearclasses in the early 1970's show that the juvenile capelin is little affected by a large stock of juvenile cod. In conclusion the evidence thus indicates that all the main fish species have high recruitment success at an early stage, when the inflow of Atlantic water is increasing, but the capelin does not survive the O-group stage when juvenile herring above 1 year old is abundant. The basic conditions for capelin being an opportunist of the system are therefore present.

The capelin matures at about 14 cm in length and the growth rate is variable. The capelin reacts to increasing temperature by increased growth rate which increases the spawning stock biomass as in 1981. The shift from a cold to a warm climate will thus increase the recruitment of capelin prior to a period of increasing stocks of herring and cod. The increased inflow of Atlantic water will, moreover, distribute the juvenile capelin more to the north and east in the Barents Sea, where the condition for growth is unfavourable and the maturing of the fish delayed. The pronounced linkage of growth rate and maturing of the fish is thus an excellent adaptation to the environment to ensure optimal use of favourable recruitment conditions and survival in unfavourable periods, when young herring and cod are struggling for life in the southern and central parts of the Barents Sea.

The stock/recruitment functions of herring (Fig. 5) show that in periods with favourable recruitment conditions the supply of juvenile herring as food for cod is proportional to the abundance of the adult herring stock. The cod recruits however strong year-classes on relatively low stock levels. This means that in a state of reduced stock sizes, for instance after a long period of cold climate and/or heavy exploitation, the balance of the predator-prey relationship may change dramatically after a shift from a cold to a warm climate. Such a latent imbalance of the system did occur in the early 1980's. After a long period of cold climate and heavy exploitation, the stocks of herring and cod were much reduced when the climate changed in 1982. The cod stock however was large enough to recruit strong year-classes, whereas the herring, which needs large parent stocks to produce abundant year-classes, could not take full advantage of the improved recruitment conditions. Given the lack of juvenile herring the rapidly growing cod stock grazed down all the other available food fishes in the area, including its own progeny (Mehl 1987). These recruitment mechanisms thus explain the paradox that the ecological crisis developed in a period of favourable recruitment conditions for the main fish stocks concerned.

In the warm period of the early 1970's the stock of young cod was abundant and the herring was missing. The absence of the juvenile herring favoured however the survival of the 0-group capelin and no abrupt shortage of prey species developed. These observations indicate that the most serious shortage of food supply may occur when the herring stock is grossly reduced, but not fully depleted. This was the situation in the 1980's. The stock was sufficiently abundant to reduce the survival of the capelin larvae significantly, but too small to meet the predators' food demand. Taking into account the stock relationships in the 1970's, these findings support the hypothesis that this ecosystem is less stable with a reduced herring stock present than with the herring absent.

The latter hypothesis is of historic interest because a similar crisis in stocks and fisheries seems to have occurred in the beginning of this century. According to Johan Hjort (1903) the cod arrived late at the spawning grounds and the fish was meagre and had underdeveloped gonads. Large flocks of seals had invaded the coast and mass mortality of sea birds was reported. Hjort's description of the situation in northern Norway in 1903 could as well has been a description of the stocks and fisheries in 1987. It is in this respect interesting to note that prior to 1903 the herring stock had been depleted for 30 years and was in a state of rebuilding. No abnormality in the cod stock is reported from the previous period when this herring stock was extremely scarce (1875-1895). This indicates that the capelin had replaced the herring as the main food resource in the Barents Sea at the end of the previous century, and that the crisis in the stocks and fishery may have developed under stock conditions similar to those observed in the 1980's.

Although evidence indicates that the production potential of the capelin stock is sufficiently large to prevent starvation of the predators in the Barents Sea without the herring, the depletion of the herring stock constitutes undoubtedly a significant loss in the total production potential at fish level of this ecosystem. Overexploitation was the main reason for the collapse of the herring stock in the 1960's, and in a fishery management context, aiming at a high sustainable yield and a more balanced state of the predator-prey relationship in the region, the highest priority should be given to the rebuilding of the herring stock.

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