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Fluctuation in Stock Properties of Arcto-Norwegian Cod Related to Long-term Environmental Changes

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Contents

Abstract

From a historic perspective the cod in the Barents Sea–Svalbard region has been the most productive gadoid stock in the Atlantic. Variation in catches has always been large, but during the last 10-15 years catches and stock abundance have reached the lowest level on record. Three major causes of variation have been discussed; stock reduction through exploitation, environmental influences on recruitment, and species interaction effects on maturation, growth and mortality. In addition, interactions between these three sources might be important. The influence of each specific factor is difficult to evaluate from incidental observations and short-term time series. In that respect, the time series on catches and on biological and environmental information of this stock, which partly goes back to the 19th century, assumes a unique position in comparison with data on most other stocks.

In this paper fluctuations in catches and stock abundance will be compared with changes in recruitment, size/age composition and growth. This information is discussed in view of historic variation in ecological and environmental parameters. The stock has been under particularly high exploitation pressure since the mid-seventies. Further, large changes in growth rates and poor recruitment to the commercially exploited stock have characteristic for the end of the 1980s and the 1990s. The analysis here shows that substantial long-term variation might underlie short-term variability, and, more importantly, that long-term changes roughly coincide with similar fluctuations in the environment. Consequently, it is suggested that inserting on a steady-state perspective on the population dynamics of this stock may lead to mismanagement and to a reduction of long-term yield.

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Fluctuation in Stock Properties of Arcto-Norwegian Cod Related to Long-term Environmental Changes

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Introduction

Variation in catches of major commercial species caused in former times substantial survival problems for the coastal human population. Therefore, extensive investigations on cod (*Gadus morhua*) biology and population dynamics were initiated at the turn of the century (Hjort 1914). Systematic environmental observations are also available from about the same period, because it was early hypothesised that variation in catch could be caused by a changing environment. The amount and quality of the data have gradually improved, particularly during the post World War II period, as quantitative data on the stock size and composition have become available (ICES 1999).

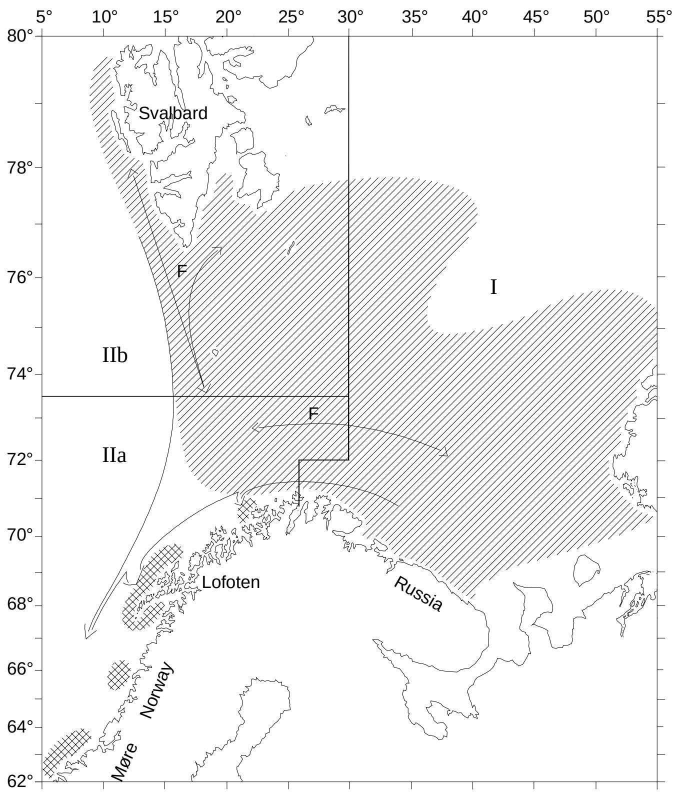

Figure 1. Main area of distribution and migration of Arcto-Norwegian cod. Arrows marked with F show seasonal migration of immatures in the feeding areas (hatched). Spawning areas are double hatched and main spawning migrations are shown by the double arrows. Straight lines delineate ICES Sub-areas/divisions (I, IIa, IIb).

The Arcto-Norwegian cod stock, is in a historic perspective the most productive gadoid stock in the Atlantic (Garrod 1987, Nakken 1994) stock is distributed in the Barents Sea – Svalbard region towards its extreme northern boarder, and is thus sensitive to changes in environment (Fig. 1). The long seasonal feeding and spawning migrations which are performed annually (Fig. 1, see also Bergstad *et al*. 1987), are considered to be adaptation to improve survival in a changing environment. The environment appears to affect stock abundance and production directly through influence on survival of recruits (Sætersdal and Loeng 1988) and may also influence growth and maturation (Jørgensen 1990, 1992). Further, production and availability of food organism (Mehl and Sunnanå 1991) may indirectly affect the same parameters. Also, cannibalism has been suggested as a major stock regulation mechanism (Bogstad *et al*. 1994; Hamre 1990, Mehl 1991). Plausible explanation for variation in stock abundance and recruitment is in many cases easily found for the past, while models for prediction based on environmental and ecological parameters has till now shown very little progress.

Long term fluctuation in stock abundance has long been considered a problem for commercial harvesting (Hjort 1914, Rollefsen 1948). In this paper historical variation in stock abundance and the accompanying exploitation are reviewed and compared to long term changes in stock composition and fluctuation in the physical and biological environment. This information is used in an attempt to distinguish between natural versus man made influence on stock variations. The main goal is to put stock dynamics in a longest possible historic perspective.

Material and Methods

The data used in this paper are mainly found in published sources.

Stock abundance and exploitation

From 1946 stock and spawning stock abundances, stock age composition, and exploitation levels are obtained from standard VPA (virtual population analysis) runs as described by the ICES Arctic Fisheries Working Group ICES (1999). Before 1946 variation in abundance and composition of the stock is evaluated on the basis of catch and effort data and average individual size measures from the Norwegian spawning cod fisheries.

Under low and moderate exploitation rates, the main cause of variation in catch per unit effort, is presumably natural fluctuation in stock abundance. Up to about 1920 Norway was almost alone to exploit the Arcto-Norwegian cod stock, followed by a period before World War II when a trawl fishery was developed by several nations (Sætersdal and Hylen 1964). The Norwegian catches mainly came from two separated fisheries: The winter spawning fishery on the coastal banks from 62^0 – 71^0 N, and the spring cod fishery off the Finnmark coast on primarily large immature fish. With a three year displacement of the Finnmark fishery catch data, the total catch and the catch per unit effort from the two Norwegian fisheries before 1957 showed similar variation with time, indicating for that period that both fisheries vary with abundance of the stock (see Sætersdal and Hylen 1964). Before the full development of a trawl fishery, human effects on the cod stock were negligible before the exploitation in the Norwegian coastal fisheries. Therefore, for the pre-World War II period, the official Norwegian catch and effort statistics is considered the most appropriate available source of data for studying fluctuation in stock abundance. In this paper the catch per man of spawning cod in Lofoten from the period 1866-1952 is used as an index of variation in spawning stock biomass (SSB), and data are obtained from Sætersdal and Hylen (1964). Due to the insignificant exploitation by other countries, this will in most cases also reflect long term changes in total stock abundance. To limit the effect of year to year variations caused by e.g. changes in weather conditions, the five years moving average of spawning cod catches are used (see Sætersdal and Hylen 1964). Catches in numbers are used since catches in weight are not available until 1930. Average number of men in five years periods are used as effort for the period before 1937, and data are extracted from Sætersdal and Hylen (1964). From 1937 onwards, effort data by year have been taken from official Norwegian fisheries statistics.

Recruitment and spawning stock

Recruitment estimates at age 3 are produced by VPA (ICES 1999). Annual spawning stock biomass from the same VPA also exists. These are based on observed maturity ogives since 1982 while a knife edge maturation at age 8 is used before 1982. To avoid using the knife edge maturation, Tore Jakobsen (Institute of Marine Research) established maturity ogives for the whole VPA periods using the data from Jørgensen (1992). Based on these he has produced an alternative series of SSB, which he kindly have put to my disposition. Due to imprecise determination of SSB, Jakobsen (1996) proposed to use a moving average to the data when comparing SSB and recruitment which also have been tried for both time series. Thus, totally three series of SSB have been compared in the study of SSB – recruitment relationship of Arcto-Norwegian cod. Differences have been judged by comparing simple linear trends in the data.

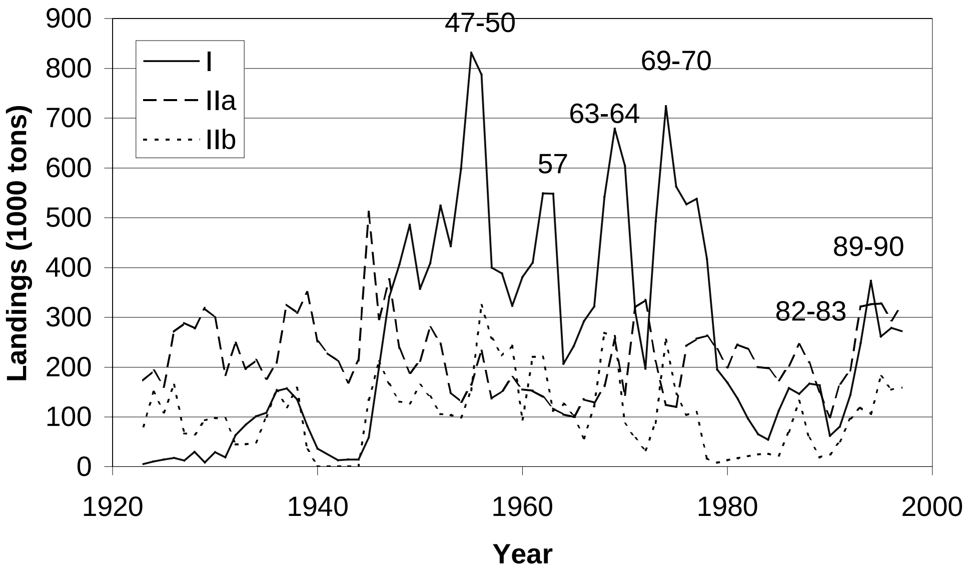

Figure 2. Landings (1000 tons) of cod by ICES Sub-areas (I and Divisions Iia and Iib see Figure 1). Numbers at peaks give years of birth of known dominant year classes.

Stock parameters and feeding

Information on growth, size composition and maturation are given by Rollefsen (1954), ICES (1999), Jørgensen (1990, 1992), and Godø (in prep.). By converting average length at maturity of first time spawners in the long-line fishery to weight, a continuous time series on individual average weight in the spawning population is available from 1884 to 1998. Length (L in cm) was converted to weight in kg (W) by

$$W = 0.6 \cdot 10^{-5} \cdot L^{3} ,$$

where 0.6 is the conversion of round weight to gutted weight and 10^{-5} is the condition factor when assuming isometric growth (length to the power of three).

Environmental data

Temperature data from the Kola hydrographic section in the central Barents Sea are given by Loeng *et al.* (1992) for the period 1900-1992 and are updated with more recent information. Long term changes in temperature in this section are used as an indicator of changes in the ocean climate.

Results and Discussion

Exploitation

The area of distribution is normally divided in three: The eastern Barents Sea feeding and nursery grounds (ICES Sub-area I), the Bear Island – Spitsbergen feeding and nursery grounds (ICES Division IIb), and the Norwegian coast (ICES Division IIa). Division IIa includes all major spawning grounds and support the important spring feeding on mature capelin both by mature cod returning from spawning and large immatures on feeding migration. Before World War I the fishery was concentrated on spawning cod and large immatures in Division IIa and almost exclusively conducted with passive gears like gillnets, longlines and handline in coastal areas.

Around 1920, the trawl fisheries developed and more offshore locations were exploited, first in Division IIa and later in Division IIb and in Sub-area I (Figure 2, the peak in Division IIb around 1930 is probably an artifact of unreliable area allocation in the old catch statistics). Up to about 1930 the exploitation was mainly by Norway, whereas international trawler effort expanded in the last decade before World War II, starting with England and Germany in Sub-area I and IIb. The oceanic exploitation with trawl was almost absent during World War II, but was rapidly expanded after the war, particularly by USSR in Sub-area I. In the period 1950-1980 this area supported the largest fishery and catches peaked for each rich recruitment period when fish were 4-5 years old (Figure 2). Corresponding peaks also occurred for Division IIb. After 1980 the rich year classes have produced much lower catches than in the past, especially in Sub-area I.

The introduction of the trawl fisheries represented a tremendous expansion of fishing effort and average fishing mortality (age 5-10 years) levels of up to 1 was observed before strong regulations temporarily reduced fishing mortality below 0.4 (Figure 3).

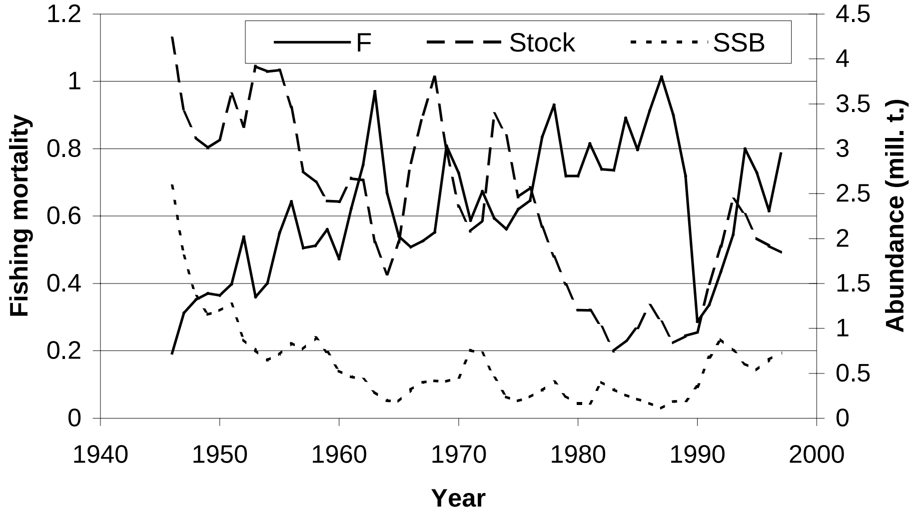

Figure 3. Fishing mortalities, given as average F for ages 5-10 fish (continuous line). Hatched and dotted lines represent stock and spawning stock respectively. Source ICES (1999).

Stock development

From the above presentation it is apparent that the stock was unable to sustain the high exploitation of the 1970's and 1980's. A decline is evident from the mid 1970's and the stock was drastically reduced during the 1980's. There are all reasons to believe that the dramatic drop in stock abundance and catches during the 1980's was provoked by overexploitation. Similar exhaustion of gadoid stocks after heavy exploitation is known, e.g. Northern cod stock (Newfoundland-Labrador Banks), which in 1999, after nearly a decade of catch prohibition or heavy restrictions is still in a very bad state (Lilly *et al* 1999). Unfavourable interaction between natural fluctuation in abundance and heavy exploitation is probable, but the actual causes are difficult to resolve (see e.g. Jacobsson *et al.*1994). From historic sources it is known that availability of cod along the Norwegian coast has varied substantially (Øiestad 1994). Can simple analysis of available historic records give any clues in this respect?

Total catches of the spawning cod generally increased up to end of the 1890s (Fig. 2). Distinct minima occurred in the first decade of the 20th century and around 1920, and the highest catch on record was around 1930. Since then there has been a general reduction in catches. It should, however, be mentioned that due to an accumulated stock with high average weight after World War II, catches in weight for 1946-47 were at the same level as in 1929-1930 (Sætersdal and Hylen 1964). Further, it is interesting to note that the peak around 1915 was due to contribution of catches from the southern spawning grounds, mainly from Møre. In this period catches from the southern spawning grounds increased to their highest level on record while landings from Lofoten remained relatively low. As there are no reasons to believe that these changes are due to changes in effort distribution (see Sætersdal and Hylen 1964), the phenomenon must be caused by a change in the distribution and migration pattern of the stock.

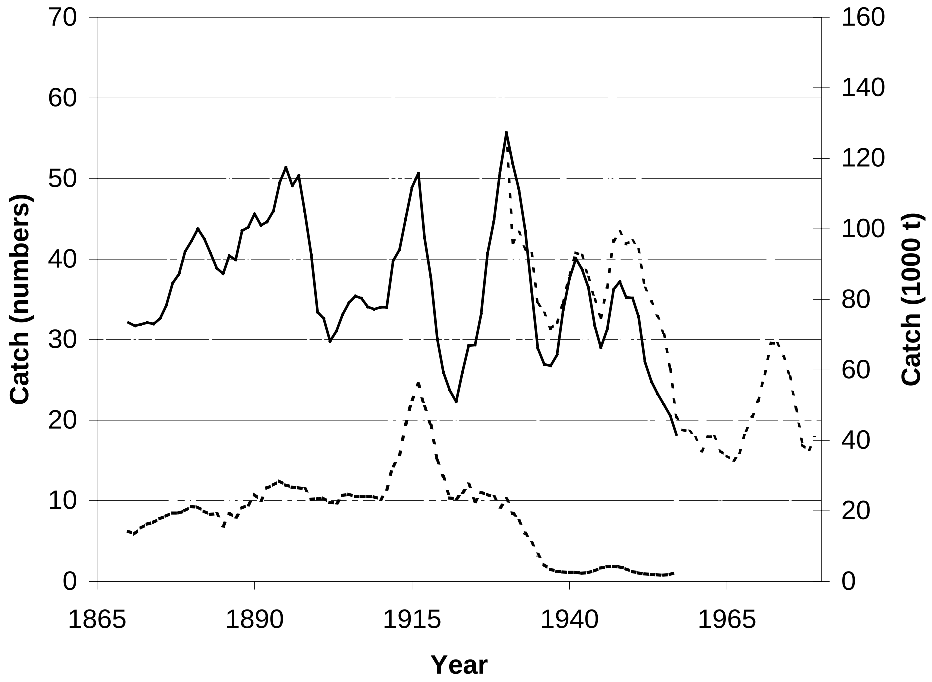

Figure 4. Historic catches of spawning cod from 1866 to 1956 recorded in numbers. The data are presented as 5 years moving averages. The continuous line represents total catches and the lower hatched line shows catches for the Møre spawning location. For comparison, total catches (in 1000 tons) from the Lofoten spawning fishery are included in an overlapping period (upper hatched line) and continued to present time.

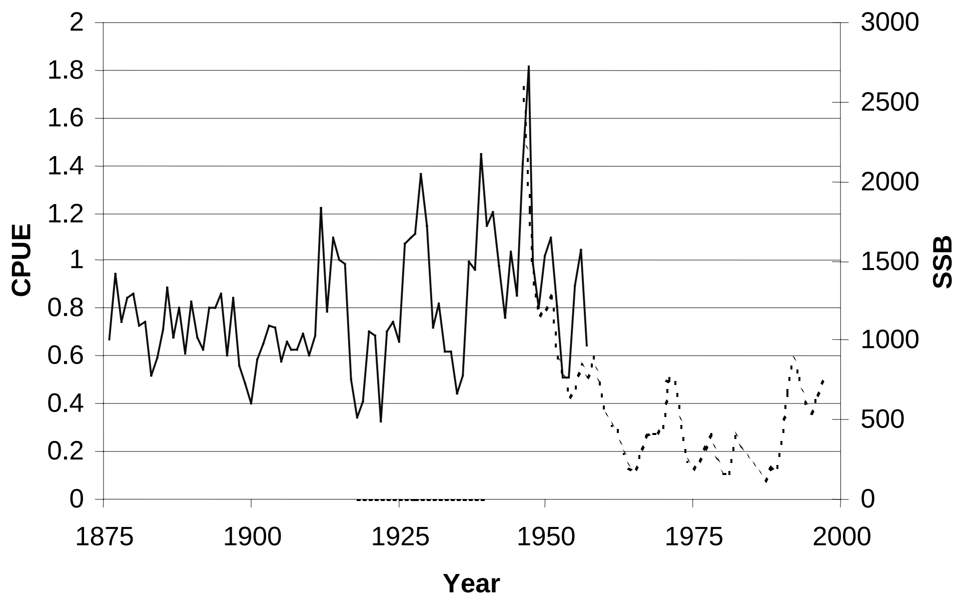

Figure 5. Variation in spawning stock abundance as measured by CPUE (continuous line) and from VPA (hatched line).

By using CPUE as an index of abundance, variation in spawning stock biomass (SSB) can be studied back to 1865 (Figure 5). The lower catches of mature cod in the post World War II period correspond with the strong decline of the spawning stock. According to the CPUE index from 1866, the spawning stock had a minimum during the two first decades of the 20th century, a maximum after World War II and has thereafter decreased. It should be noted that the peaks between 1920 and 1950 are more pronounced than the corresponding catch peaks. The spawning stock dropped dramatically during the 1950s and 1960s, and except for a short period during the early 1990s, it has constantly been below 1/3 of the spawning stock size around 1946.

The use of CPUE as an index of stock abundance is based on an assumption of constant efficiency of the applied unit of fishing effort. Sætersdal and Hylen (1964) document that a considerable development occurred during the studied period. In Figure 5 the variation in CPUE in relation to important changes in the fleet efficiency can be studied. The introduction of engines in the coastal fishing fleet occurred to a great extent in the period 1900-1920. These events represent a considerable increase in efficiency and thereby an increase in the total fishing effort on the mature part of the cod population (Rollefsen 1948). Hence, the drop in spawning stock as indicated by CPUE in Lofoten between 1900 and 1920 is in fact even larger than it appears in Figure 5. From 1920 until the 1960s a rapid development in the trawl fisheries, mainly by foreign countries, occurred off the Norwegian coast and in the Svalbard and Barents Sea regions (Figure 2). Although there is no connection between this development and the efficiency of the effort in the coastal fishery, it represents an additional exploitation with potential great negative effect on the spawning stock. Apparently, the trawl fisheries had no immediate effect on the CPUE of mature cod in Lofoten (Figure 5). Due to the continuous improvements in fishing gear it can be disputed if the apparent general increase in the period 1920 - 1950 really reflects an increase in SSB. It is, however, clear that the rapid technological development after the war (echo sounder, new net materials, mechanisation etc.(see Sætersdal and Hylen 1964), lead to increased exploitation and a negative development of the spawning stock (Figure 5). Since about 1960, actions to reduce effort, particularly on small fish, have been taken. A stepwise increase in minimum legal mesh size (90, 110, 120, 125, 135 mm) was introduced. Effort from third countries were to a great extent excluded in the period 1977-1988 due to the introduction of the 200 n.mile economic zone regime. Under this regime also areas with undersized fish have been protected (Hylen and Jacobsen 1987). In spite of these actions, there has been a decreasing trend in stock and spawning stock size as well as catches since the 1950-ies. Drastic regulations (quota reduction and area protections) at the end of the 1980s reduced fishing mortality and improved the situation temporarily in the beginning of the 1990s (Figure 3).

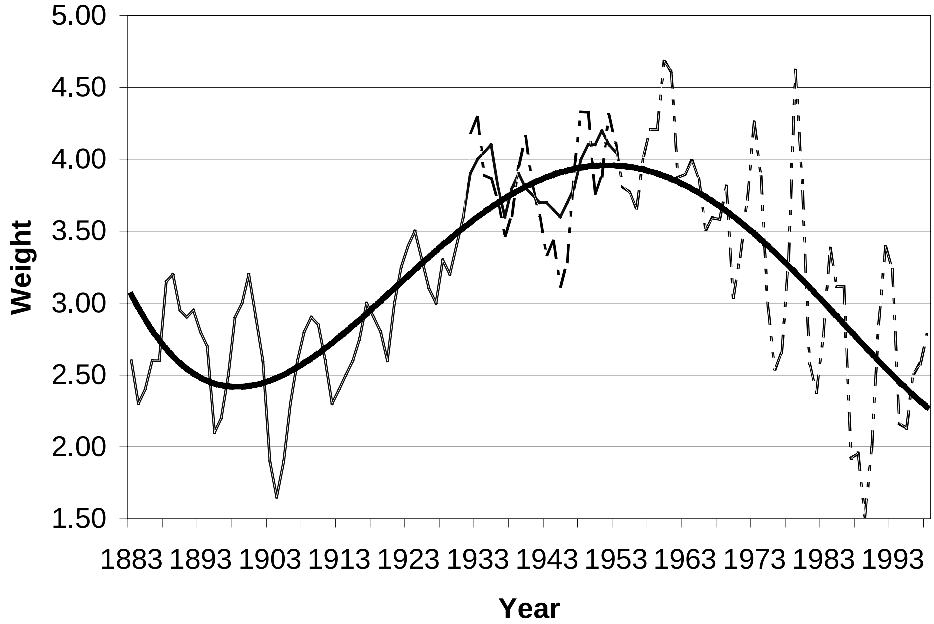

Figure 6. Variation in mean weight in the gill net catches of spawning cod 1883-1952 (continuous line) compared to estimated weight in long line fishery 1932-1998 (continuous zigzag line) in the post World War II period. The continuous smooth line indicates a polynomial regression fit for the whole period.

Stock composition, growth and maturation

All fishing effort will affect the composition of the stock through selection by size, maturation status etc.. For long living species like cod a mean total mortality of 0.7 reduces the chances of survival from age 3 to 10 to less than 1%. The introduction of a trawl fishery increased the exploitation of smaller fish, and hence the mean age in both catch and population is expected to decrease (ICES 1999). Further, no mesh regulation was introduced before in the 1960s and 1970s and 40% discard of small sized fish was reported from the early 1950s (Garrod 1967). Due to this development and stronger regulations of the fisheries during the last decades, CPUE in the post war period is not comparable with earlier periods. For this period however, more extensive studies of recruitment and stock parameters give improved opportunities to distinguish between natural and human induced variations in stock productivity. The major difficulty is to co-ordinate the old and new type of data to facilitate studies of long term fluctuations in the different parameters

By combining average weight measurements of spawning cod (1883-1952, Rollefsen 1954) and average estimated weight for first time spawners in the long-line fisheries, it is possible to study long term changes in size composition of the spawning stock (Figure 6). As the latter material only contains first time spawners, the weight will be underestimated for this period. The spawning populations were in this period composed of 60-80% first time spawners (Jørgensen 1990) and it is believed to roughly reflect the long term development in the stock. The consistency between two time-series is underlined by the good correspondence of information emerging from the overlapping period. The average weight of spawning cod from 1883 to 1952 showed a decreasing trend up to 1904 and thereafter increased. In the first part a reduction occurred in a period of low exploitation. In the second part, the average weight increased in spite of the increase in exploitation. Most important, this increase took place despite the shift in exploitation pattern towards smaller fish due to the development of the trawl fishery (Figure 2). After World War II the individual weights were reduced almost consistently from the mid-1950s till today. A third-degree polynomial regression fits well the continuous dataset. This strongly indicates that the composition of the spawning stock develops independently or in spite of substantial exploitation. It should be noted, that in spite of the substantial changes in size composition of the spawning population observed in this century, Jørgensen (1992) found no long-term trend in growth (length at age) of cod for the period 1933-1989 but changes in the order of 10-15 cm occurs over short periods.

Environment

According to Loeng *et al.* 1992 and as shown in Figure 7, average temperatures were mainly below long term average from around the turn of the century up to about 1920. The period 1920-1964 was a warm period when average temperatures only occasionally were below long term average. From then until today, periods of very low temperature have appeared, particularly the period 1977-1982. For later analysis and discussion the period 1930-1964 is considered the warm period of the 20th century with cool periods before and after. The warming indicated during the most recent years has not been considered a problem for this approach as the last years of the stock assessment are not used due to the inherent uncertainties connected to the non-converged part of the VPA (ICES 1999).

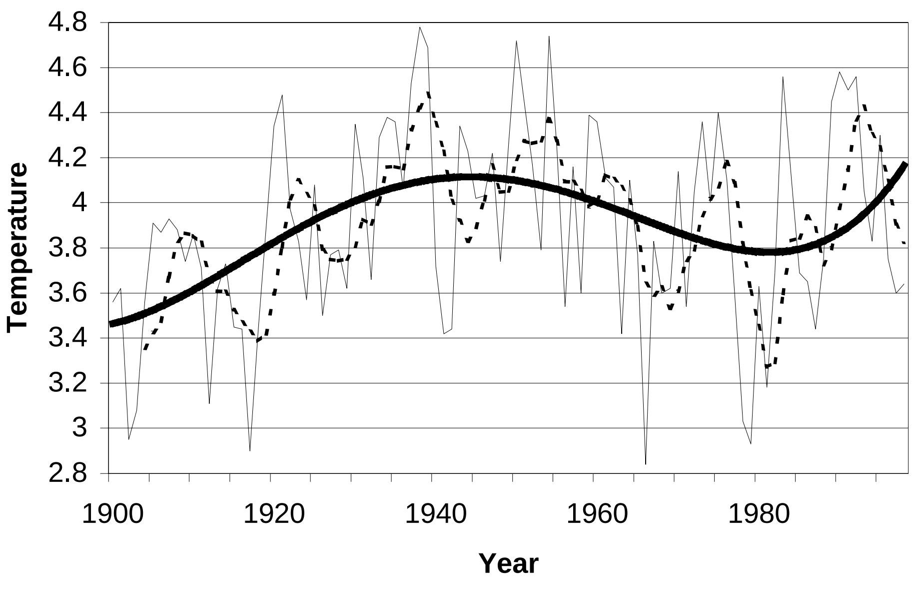

Figure 7. Long-term changes in annual temperature (thin line) smoothed with a 5 years moving average (dashed line) as observed in the Kola section (Loeng *et al.* 1992). A polynomial regression of the same type as in Figure 6 is indicated (thick continuous line).

Recruitment and spawning stock

The fishery at the turn of the century was directed towards the mature fish. The total effort was limited compared with that found later in the 20th century. Could the low catch rates (Figure 5) and the minimum in mean individual weight in the beginning of the 1900 (Figure 6) be caused by natural drop in the recruitment to the commercial stock? Low recruitment over an extended period will affect the spawning population in two ways. Firstly, low recruitment will over time give a lower stock level and hence reduction in CPUE. Further, reduction in average weight in the catches will be experienced when the old and large multiple spawners are gradually reduced in numbers by fishing and only partly replaced by smaller first time spawners. The answer to the question above could consequently be recruitment failure over a prolonged period. Similarly, the increasing trend in weight of spawning cod up to 1950 may indicate that in general recruitment during this period more than compensated for the increased exploitation (particularly by the trawl fishery on immature fish), leaving enough fish to survive to a high age.

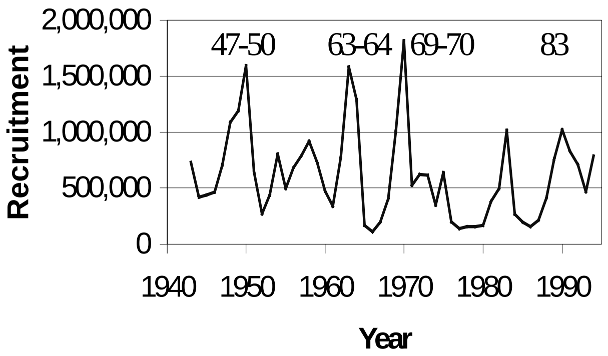

Figure 8. Recruitment at age 3 (from VPA). Years with strong recruitment are indicated.

Recruitment at age 3 from VPA shows that strong year classes (>1 bill. individuals) were produced in 1947-1950, 1963-1964 and 1969-1970 (Figure 8). After that only the 1983 and 1990 year classes has been close to that level at this age.

The high fishing mortality seen in later decades might link the unfavourable stock condition to human over-exploitation (Figure 3). Shifts between periods of high and low productivity caused by climatic changes should neither be ruled out. In periods with unfavourable environment and an increasing exploitation, as might be the case for the cod in the Barents Sea during recent decades, the stock might be particularly susceptible to exploitation. These complex issues have been widely discussed (see e.g. Jacobsson *et al.* 1994).

When studying SSB – recruitment relationships normally all available data are included in the analysis. If 'high' and 'low' productive periods exist, such analysis might be misleading. When treating the available data assuming that high and low productivity follows warm and cool periods respectively, the following effects emerge (see Figures 9 and 10):

1. Poor year classes (R=1) occurred three times more frequently at 'low' production level (freq=18) than at 'high' production level (freq=6) while such differences do not exist for the other recruitment level (R=2 and 3) (Figure 10).
2. Average recruitment for poor year classes (R=1) is significant (t-test) lower in 'low' productive periods.
3. A positive SSB-recruitment relationship exists for 'low' production level but not for 'high' production level (Figure 9).

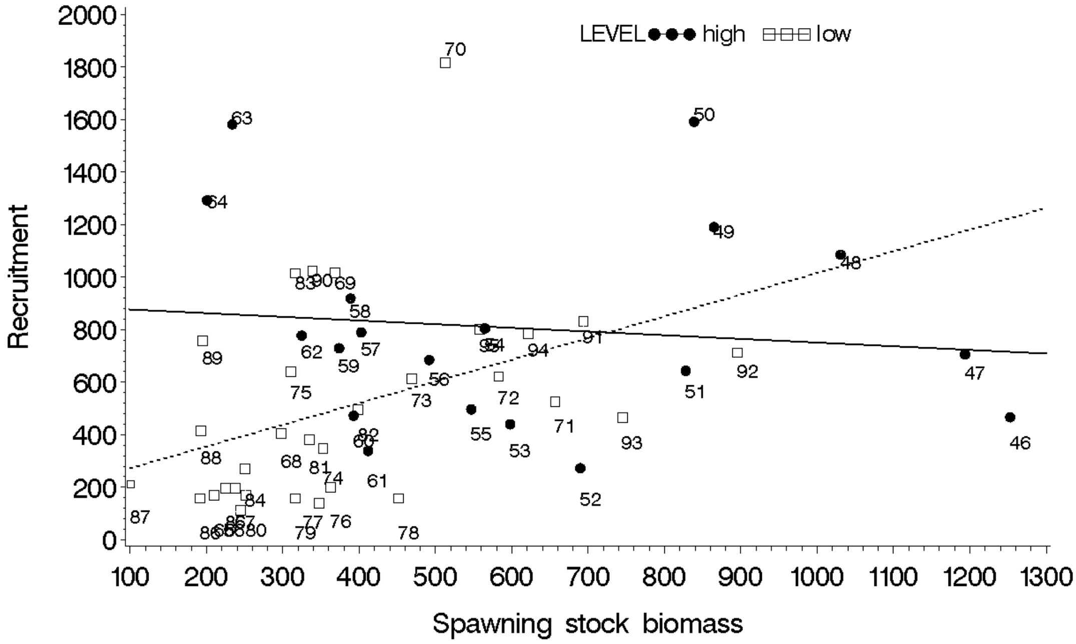

Figure 9. Spawning stock - recruitment relationship for high (dots) and low (squares) production levels. Spawning stock biomass based on calculations by T. Jakobsen for years before 1982.

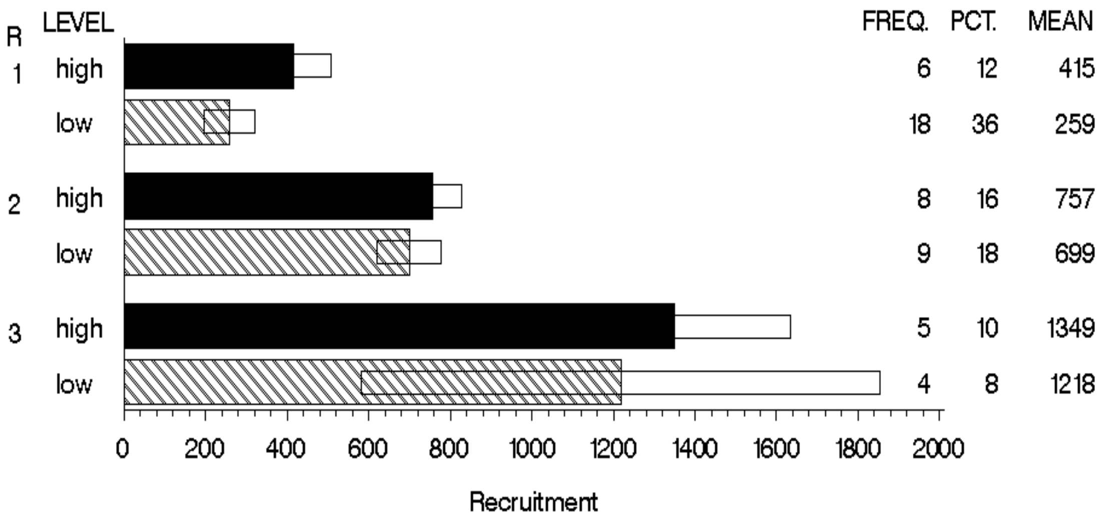

Figure 10. Average recruitment under 'high' and 'low' production (LEVEL) for different recruitment levels (R). Spawning stock biomass based on calculations by T. Jakobsen for years before 1982.

The analyses were done for the two spawning stock series (ICES 1999, and T. Jakobsen based) and in addition for moving averages of the two SSB series and all series showed the same tendencies as described above.

Perspectives

In the lack of comparable and reliable quantitative long-term biological and environmental data, any evaluation of the relationships between stock abundance and environment has to be subjective based on available information. When changes are distinct, a discussion of long-term variation could be a valuable supplement to more proper statistical analysis of short time-series. Such information may not only improve our knowledge of environmental influence on biological processes, but also be innovative in new development of improved recruitment and production models.

Sætersdal and Loeng (1987) have shown that short term variation in temperatures influence year class strength of cod in the Barents Sea. They found that changes in temperature more than the actual temperature level is decisive for the variation in recruitment. This fits with the promising analysis of Svendsen *et al*. (1991), who link recruitment of several stocks in the North Sea to two dimensional parameters like area of water with certain properties instead of a one dimensional parameter like temperature. Sætersdal and Loeng (1987) make no long-term comparison of levels of recruitment. Thus, a rich year class in the early years of the 20th century (relative to its surrounding year classes) is not necessarily comparable in abundance to a rich year class in another period. The coming discussion is structured under four time periods according to climatic changes. By interpreting the available biological data (catch, distribution/migration, growth/size, stock), for the same periods the aim is to track long term changes which can be linked to fluctuation in environment.

1864-1895: Very little information is available about the oceanic environment from this period. No historic documentation suggests specific features for this period, in contrast to the numerous historic and anecdotal description of the cold climate for the next decade. Available information indicates that the period around the turn of the century was particularly could with negative effects on the marine resources (see e.g. Hjort 1904, Helland-Hansen and Nansen 1909, Øiestad 1994). There are thus reasons to believe that this preceding period was warmer but that an ocean cooling took place. CPUE data from the Lofoten fishery in this period indicates a relatively stable or reduced spawning stock size (Figure 5).

1896-1919: The temperature recordings show that this was a very cold period ending with a rapid heating during the last two years. Due to the very low temperatures measured during the first years of observation (Figure 7), this period is set to start 5 years before. At the turn of the century catches of spawning cod were reduced with about 50% in 5 years. Reports of cod in bad condition and with low liver content, and an exceptional southern distribution of Arctic sea mammals manifested the extraordinary situation (Hjort 1904, Helland-Hansen and Nansen 1909). In Lofoten, catches and CPUE stayed low for more than 20 years in spite of a rapid increase in efficiency due to the introduction of motorized vessels. It is believed that catches dropped due to recruitment failure to the spawning stock, i.e. that the recruitment level in this period was low. In the same period the southern spawning areas had the highest catches on record, i.e. the recruitment to this ground improved and partly compensated for the loss in Lofoten. This shift is not considered a simple biomass displacement from one spawning ground to another due to two reasons. Firstly, the increase off Møre appeared one generation (8-10 years) after the drop in Lofoten, and was therefore composed of other year classes than those that previously failed to appear in Lofoten. Secondly, tagging experiments have shown that cod from the two grounds very seldom change spawning area during repeated spawning (Godø 1984). The same tagging experiments indicate that the Møre cod has a more westerly and southerly distribution on the feeding grounds than the spawning cod from Lofoten. Therefore, the biomass displacement on the spawning grounds towards south might be due to reduced survival conditions for the recruits in eastern and northern Barents Sea caused by the colder climate

1920-1964: This was a warm period with only occasional temperature observations below average. CPUE of spawning cod in Lofoten increased rapidly, mainly due to the strong 1918-1919 year-classes (Sætersdal and Loeng 1987) and initiated the period of highest total catches on record. In spite of increased exploitation level, mean individual weights in the spawning stock increased. CPUE peaked at the end of World War II (as a result of low fishing pressure during the war), co-occurring with the peak level of estimated spawning stock size from VPA. In the post war period the increased exploitation of immature fish by the trawler fleet, reduced the spawning stock to a small fraction of its accumulated size after World War II. Fishing mortality gradually increased and mean age and size in the catch and the spawning population decreased in the later part of the period. Percentages of first time spawners gradually increased (Jørgensen 1992). In spite of this, total catches remained high.

1965-1990: During this period cooling again took place and temperatures below average prevailed. Exploitation continued to increase up to 1987. Spawning stock size remained low, while stock size during the 1980s continued to decrease to its lowest level on record. Recruitment at age 3 was generally lower than during the previous period, i.e. only two year-classes exceeded 1 billion individuals during the last period, while five year classes were above this size between 1943 and 1964. Average year class abundance for the two periods (respectively 767 ± 167 and 421 ± 150 million individuals) are significantly different (95% level). The 0-group index gave good indication of year class strength for the years up to 1983. The year classes 1984-1986 appeared to be much lower than expected from the 0-group index. This event co-occurred with a period of low capelin stock biomass and low capelin growth.

In the 1980s an ecosystem 'crisis', as described by Hamre (1988; 1990) occurred. Cod recruitment and growth failed compared to expectations, and the following strong catch regulations caused a drop in catches to its record low level in 1990. This concurred with low capelin, shrimp and plankton abundance as well as capelin growth. It is generally accepted that these events are linked (Palsson 1994, Mehl 1991). However, the crisis in cod fishing industry is also often attributed to mis-management of the cod stock, e.g. by discarding of small fish and over-fishing of recommended TAC. Further, low recruitment and growth of cod is often attributed to the lack of multi-species and ecosystem consideration in the management. For example, the over exploitation and depletion of the capelin stock occurring simultaneously with the high 0-group abundance, undermined the possibility of survival and growth of cod and stimulated cannibalism (Hamre 1990, Mehl 1991). Disentangling the conglomerate of potential influential factors is impossible, but the appearance of an environmental unfavorable condition co-occurring with an overexploitation deflected through the whole ecosystem.

The use of terms like 'crisis' for the situation in the Barents Sea in the mid and late 1980-ies is partly based on the expectation that a well managed ecosystem will produce catches according to long term production models. A basic requirement for such models is stability over time. However, from the present study there appear to be periods of high and low productivity of the cod stock. The rich periods are linked to warm periods as occurring 1920-1964 and all year classes, rich as well as poor, appear to yield higher catches.

The similarities between the ‘crisis’ of the 1980-ies and the situation described for the beginning of the 20th century are striking and underline the influence of environment on stock abundance and production. In both periods a cold climate dominated. Capelin stock was low, a seal invasion hit the Norwegian coast and caused damage to fishing gears (Hjort 1904) and small, slender cod appeared on the spawning grounds. The basic difference between the periods is the higher capacity and efficiency of today’s fishing fleet and the shift in fishing pattern from old mature fish towards mainly immature cod today. Independently of this change, both periods experienced ‘crises’ due to stock reduction.

Based on the dramatic events as observed during the 1980-ies and as similarly described around 1900, it appears that two additional considerations need to be taken under cold climatic periods: Firstly, the level of recruitment may be reduced. Secondly, the risk for unexpected recruitment failure due to ecological effects, e.g. disappearance of capelin, will increase.

For the management of stocks, which live close to their extreme environmental limits, such changes in productivity may be of great importance and should be incorporated in the management strategies of the stocks. Normally, predictions of recruitment are based on correlation analysis between long time series of some kind of recruitment index and the later verified abundance of the year class at recruitment to the fishery. When environmental cooling occurs and productivity decreases, too optimistic stock predictions will emerge from a simple long-term regression model. Similar problems, and perhaps more important, will occur when the spawning stock – recruitment relationship is used for management decisions. It is suggested here that the generally lower recruitment given for the year-classes after 1965 might be strongly influenced by the environmental situation. Such mechanism is proposed for marine species by Gilbert (1997), and seems to be supported by the data for Arcto-Norwegian Cod stock. As the spawning stock is the major management measure for the stock, effects of such long term changes in productivity level of the stock should be taken into consideration in assessment and management models.

I am reluctant to give an evaluation of the most recent decade in the same way as above. There are uncertainties in the cod stock assessment in the most recent years due to the technicalities of the assessment methodology (ICES 1999), and it might also be difficult to evaluate the climatic situation at the end of a time series. The indicated inconsistency between the biological (Figure 6) and the climatic (Figure 7) trends should therefore be treated with caution, but nevertheless pursued in new studies with the aim of elucidating the potential consequence for sustainable management.

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