THE EFFECT OF OCEANOGRAPHIC CONDITIONS ON DISTRIBUTION AND POPULATION
DYNAMICS OF COMMERCIAL FISH STOCKS IN THE BARENTS SEA
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RECRUITMENT AND DISTRIBUTION OF NORTH-EAST ARCTIC SAITHE IN RELATION TO CHANGES IN THE ENVIRONMENT

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ABSTRACT

The stocks of North-East Arctic saithe and Arctic cod have responded in a similar way to the period of cold climate in the Barents Sea 1976 - 1982. Since a relationship with the climate has been established for Arctic cod, a relationship with the climate also for North-East Arctic saithe is indicated. Time series of recruitment, landings, and catch per unit of effort were compared with historic data on the climate. The results showed little evidence of relationships. A concurrence of poor recruitment in all North-East Atlantic saithe stocks 1974-1977 coincided with a period of extreme low salinities in the Faroe-Shetland Channel, indicating that the recruitment may suffer in years with reduced inflow of Atlantic water. Although little other evidence of a relationship with the climate is found, the lack of a close stock-recruitment relationship reveals that environmental factors affect the recruitment of the North-East Arctic saithe, but the nature of these factors are mostly unknown. The feeding area and therefore probably also the availability of food appears to be more stable for saithe than for cod. It is suggested that this may be the evolutionary basis for the relatively small variation in year class abundance for saithe compared to cod.

INTRODUCTION

The cold climatic regime in the Barents Sea from 1977 to 1982 coincided with a series of poor year classes of Arctic cod (ANON. 1986, SÆTERSDAL and LOENG 1984). Also for the North-East Arctic saithe recruitment was on the average poor, though the 1978 year class was abundant (ANON. 1985). In this period there was a westward shift in the distribution of cod (NAKKEN and RAKNES 1984). For saithe, there was a marked decline in the saithe fishery on the east coast of Finnmark, which may have been caused either by a westward migration or by reduced recruitment to that part of the coast. The recruitment was improved for cod from 1982 onwards, and there are strong indications that this has been the case also for saithe. The 1982 year class dominated the purse seine catches from Finnmark in 1985. In 1983 and 1984 substantial numbers of 0-group saithe were recorded in the Barents Sea and at Spitsbergen during the 0-group survey in August-September (ANON. 1983, 1984a). A similar distribution has previously been recorded only in 1967

(BENKO et al. 1967, HYLEN and JAKOBSEN 1971), and that year class of saithe was abundant also on the Norwegian coast. According to reports from fishermen living in northern Norway, the abundance of juvenile saithe has been increasing the last three years.

These observations indicate that the saithe has reacted to the changes in temperature during the last 10 years in a manner similar to cod and haddock. For the cod, SÆTERSDAL and LOENG (1984) showed that there is a relationship between the water temperature in the Barents Sea and the year class strength. It was decided to investigate if a similar relationship exists for saithe. Unfortunately, the historic data for North-East Arctic saithe are less extensive and probably also less reliable than for Arctic cod. Nevertheless, if temperature conditions significantly affect recruitment and distribution of saithe, this should in some way be reflected in recruitment estimates, landings, and catch rates.

MATERIAL AND METHODS

Hydrography

The saithe spawning takes place in Atlantic water which provides the environment during the early stages of life when the year class strength presumably is established.

The periodical changes in sea water temperature in the Barents Sea since 1900 have been described by SÆTERSDAL and LOENG (1984). The basis was observations along the Kola section where the temperature changes reflect fluctuations in the flow of warm Atlantic water into the Barents Sea. As far as fisheries are concerned, the flow of Atlantic water is undoubtedly the most influential environmental factor in this area as well as on a large part of the Norwegian coast. All references to temperature and climate in this paper, unless otherwise stated, are from SÆTERSDAL and LOENG (1984).

Recruitment Estimates

Estimates of year class strength for North-East Arctic saithe for the period 1959-1981 are available from Virtual Population Analysis (VPA). For the most recent year classes there are yet no reliable estimates. The full updated time series 1959-1981 is not published, but is available from the ICES data files. The most recent Saithe Working Group Report (ANON. 1985) gives the yearclass strength back to 1975.

Based on the numbers at age in the stock in 1960 and 1961 resulting from this VPA, estimates can also been obtained for the year classes 1946-1959 if assumptions are made about the fishing mortalities. The Norwegian saithe landings which were dominating in this period increased rapidly from 1946 to 1948, but thereafter the increase slowed down to an average annual rate of about 2% until 1960 (Fig. 1). The change in fishing mortality from 1948 to 1960 has therefore probably been relatively small, and the level generally low (about 0.2 in 1960). Ignoring possible changes in the fishing mortality, year class strength for 1946 to 1958 was estimated by comparing the stock numbers for the same age groups in 1960 and 1961 in the VPA.

While the errors introduced by the assumption of a stable fishing mortality are probably small, larger errors are likely to have been caused by the VPA. The size of the errors will generally increase backwards in time, both because

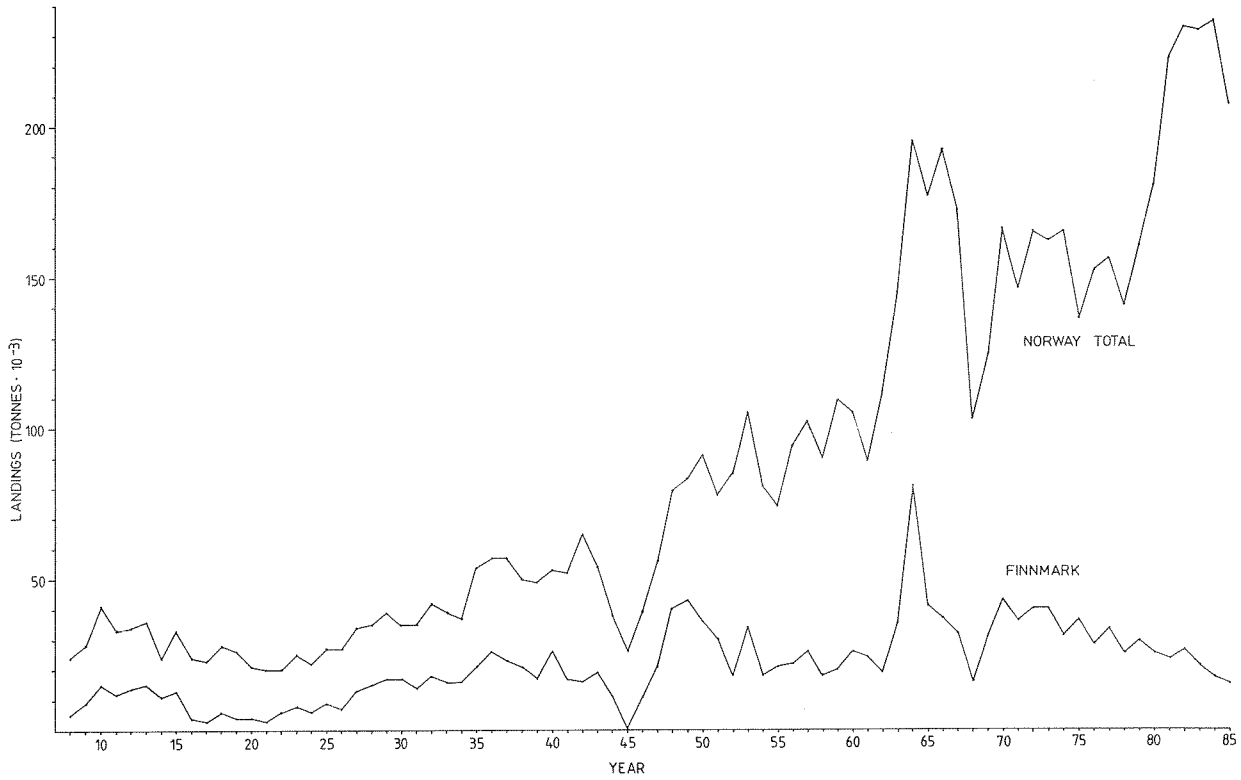

Fig. 1. Norwegian landings of saithe 1908-1985, total and in the county of Finnmark.

fewer years of sampling are included in the VPA for those age groups and because each year class is compared directly only with the previous one.

Prior to 1946, data on age and length distribution of saithe are very sparse, and reliable estimates of the recruitment could therefore not be obtained for earlier periods.

The changes in recruitment in recent years have to some degree been similar for Arctic cod and the North-East Arctic saithe, and it was decided to investigate if a relationship existed over a longer period. The cod data are available from the Arctic Fisheries Working Group Report 1985 (ANON. 1986) and the ICES data files.

There are apparently also common trends in recruitment of the different saithe stocks in the North-East Atlantic Ocean. The year class abundance of the North-East Arctic saithe 1960-1980 was compared with those of the North Sea, Faroe, and Icelandic saithe stocks (ANON. 1984b, 1985, ICES data files).

Catch Statistics

The official Norwegian fishery statistics give landings of saithe by county for each year from 1908. The catches are usually taken in the same area where they are landed, but trawl catches may be landed far from the catch locality. However, it is only after the rapid increase in trawling for saithe in the most recent years that this can give large discrepancies between landings and catches in the different coastal areas. If a westward shift in the distribution of saithe occurs, the effect would be expected to be greatest on the landings

in the northeasternmost county, Finnmark. Fig. 1 shows the total Norwegian saithe landings and the landings in Finnmark 1908-1985. The ratios between landings in Finnmark and the total Norwegian saithe landings have also been calculated.

Catch per Unit of Effort

For saithe, the longest continuous data series of catch per unit of effort in the Barents Sea region is for English conventional trawlers in ICES Sub-area I for the years 1946-1978. For 1946-1972 data are given in ANON. (1974). Values for 1973-1978 and revised figures for the period 1966-1972 were submitted by Mr. B.W. Jones, Fisheries Laboratory, Lowestoft, England.

RESULTS

Recruitment

Table 1 shows the estimates of year class strength of North-East Arctic saithe for 1946-1958, the year class strength 1959-1981 taken directly from the VPA, and indications of the climatic regime in each year. There is no evidence of a close correspondence between year class strength of saithe and the climate. Of the seven most abundant year classes in the period 1959-1981, three were

Table 1. Year class strength (age 1) of North-East Arctic saithe 1946-1981 from VPA (1946-1958 back-calculated), and indications of the climatic regime in each year.

Year	Number (millions)	Climatic regime	Year	Number (millions)	Climatic regime
1946	157	Medium	1959	278	Warm
1947	69	Medium	1960	413	Warm
1948	144	Medium	1961	144	Warm
1949	122	Medium	1962	439	Warm
1950	200	Warm	1963	246	Cold
1951	312	Warm	1964	327	Medium
1952	237	Warm	1965	234	Cold
1953	238	Warm	1966	454	Cold
1954	179	Warm	1967	426	Cold
1955	131	Warm	1968	464	Cold
1956	194	Cold	1969	272	Cold
1957	127	Cold	1970	344	Warm
1958	140	Cold	1971	147	Warm
			1972	255	Warm
			1973	460	Warm
			1974	377	Warm
			1975	223	Warm
			1976	352	Warm
			1977	205	Cold
			1978	447	Cold
			1979	172	Cold
			1980	147	Cold
			1981	144	Cold

produced in warm years, and four in cold years. Exactly the same distribution between warm and cold years was found for the seven poorest year classes.

In the earlier period the year class strength was apparently on a lower level. However, this may be an artificial effect of the VPA. If only the relative sizes of the year classes 1946-1958 are considered, there seems to be a relationship with the climate. The four strongest year classes (1950-1953) coincide with a warm period, and two of the three most recent and therefore most reliably estimated of the poor year classes were produced in a cold climatic period.

Fig. 2 shows the year class strength of Arctic cod versus the year class strength of North-East Arctic saithe in the period 1959-1980. There is no linear correlation, and the only observation which may be of some significance, is that the most abundant year classes of saithe have been produced only in years with poor or medium year classes of cod, and vice versa. In other words, strong year classes of cod and saithe have not been produced in the same year.

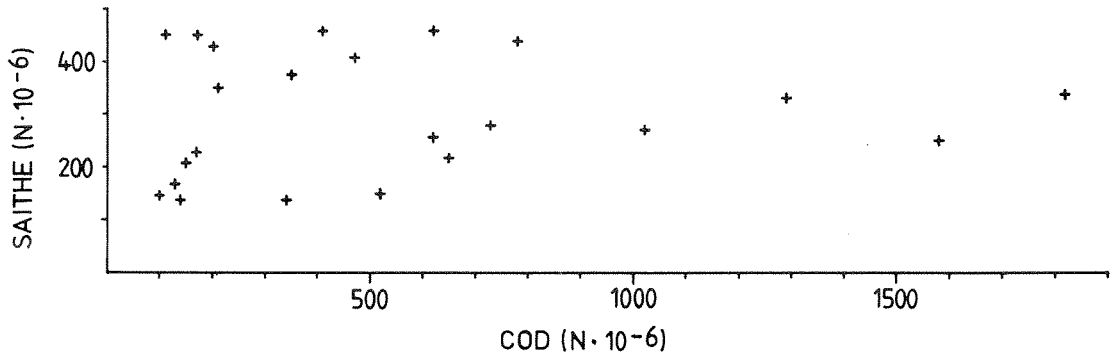

Fig. 2. Year class abundance of Arctic cod vs. year class abundance of North East Arctic saithe.

Table 2 shows the year class strength 1959-1981 for the North-East Arctic, North Sea, Faroe, and Icelandic saithe stocks. Although the linear correlation between any two of the series is poor, a common feature is that all stocks had a period of good recruitment in 1966-1968 and a period with poor recruitment in 1974-1977.

Fishing

The landings of saithe in Finnmark were generally increasing from 1908 to 1940, approximately at the same rate as the total Norwegian saithe landings (Fig. 1). After the war, the total landings have continued to increase, whereas in Finnmark the landings show large fluctuations, but no clear trend until 1970. After 1970, landings in Finnmark have been declining. The general increase in saithe landings probably reflects improved efficiency in the fisheries. It is likely that deviations from the general pattern to some extent is caused by changes in the saithe stock, but it is equally possible that market mechanisms, weather conditions, and the availability of other fish stocks have influenced the fishing effort and accordingly the catches. It would therefore be only guesswork to try to infer something about the size of the saithe stock from the landings.

Table 2. Year class strength of the North-East Arctic, North Sea, Faroe, and Icelandic stocks of saithe 1960-1980. (For each stock, XXX=the seven strongest, XX=the seven medium, X=the seven poorest year classes in the period).

Year class	Stock of saithe			
	NE Arctic	North Sea	Faroe	Iceland
1960	XXX	X	XX	XXX
1961	X	X	X	XX
1962	XXX	XX	XX	XXX
1963	XX	X	XX	XXX
1964	XX	XX	XXX	XXX
1965	X	X	XX	XXX
1966	XXX	XXX	XXX	XXX
1967	XXX	XXX	XXX	XXX
1968	XXX	XXX	XXX	XX
1969	XX	XX	XXX	XX
1970	XX	XX	XX	X
1971	X	XX	XX	X
1972	XX	XXX	X	X
1973	XXX	XXX	XX	XX
1974	XX	XX	X	X
1975	X	X	X	XX
1976	XX	X	X	XX
1977	X	X	X	X
1978	XXX	XXX	XXX	X
1979	X	XX	X	X
1980	X	XXX	XXX	XX

A low ratio between landings in Finnmark and total Norwegian landings may be an indication of a westward shift in the distribution of the saithe stock. It is not known to what degree factors that are not stock-related can affect this ratio, but there is a possibility that they to some extent cancel out. Table 3 gives the ratios for the whole period 1908-1985 together with indications of the climatic regime. The ratios for 1940-1945 can safely be assumed to have been affected by the war. In the years after 1976, the ratios have been declining. This is to a large extent a result of the rapid increase in Norwegian saithe catches from the North Sea following the introduction of national economical zones. In both periods 1908-1939 and 1946-1976, the ratios are on the average slightly higher in warm than in cold periods. However, this difference is clearly not significant because the average ratios for the years of medium climate are by far the highest in 1908-1939 and the lowest in 1946-1976.

The time series of English catch per unit of effort in Sub-area I is given in Table 4. The high level immediately after the war is in all likelihood due to the increased stock size which must have resulted from the low level of exploitation during the war. Apart from this, three periods are outstanding: 1961-1963 with low values, 1969-1972 with high values, and 1974-1978 with low values. All three periods include both cold and warm years, and the only indication of relationship with the climate is that the periods with low values start towards the end of warm periods, while the high values start towards the end of a cold period. Allowing for a time-lag of about five years the two

Table 3. Landings of saithe in Finnmark 1980-1985 in proportion to the total Norwegian saithe landings, and indications of the climatic regime in each year.

Year	Ratio Finnmark/ Total	Climatic regime	Year	Ratio Finnmark/ Total	Climatic regime
1908	.22	Medium	1946	.28	Medium
1909	.33	Cold	1947	.37	Medium
1910	.38	Cold	1948	.51	Medium
1911	.37	Cold	1949	.51	Medium
1912	.42	Cold	1950	.40	Warm
1913	.41	Cold	1951	.39	Warm
1914	.47	Cold	1952	.21	Warm
1915	.40	Cold	1953	.32	Warm
1916	.18	Cold	1954	.23	Warm
1917	.12	Cold	1955	.28	Warm
1918	.21	Medium	1956	.24	Cold
1919	.14	Medium	1957	.26	Cold
1920	.21	Medium	1958	.20	Cold
1921	.17	Medium	1959	.18	Warm
1922	.33	Medium	1960	.25	Warm
1923	.32	Cold	1961	.27	Warm
1924	.29	Cold	1962	.17	Warm
1925	.32	Cold	1963	.24	Cold
1926	.25	Cold	1964	.41	Medium
1927	.39	Cold	1965	.23	Cold
1928	.43	Cold	1966	.19	Cold
1929	.44	Cold	1967	.19	Cold
1930	.48	Warm	1968	.16	Cold
1931	.39	Warm	1969	.25	Cold
1932	.42	Warm	1970	.26	Warm
1933	.41	Warm	1971	.25	Warm
1934	.43	Warm	1972	.24	Warm
1935	.39	Warm	1973	.25	Warm
1936	.45	Warm	1974	.19	Warm
1937	.40	Extra warm	1975	.27	Warm
1938	.42	Extra warm	1976	.18	Warm
1939	.34	Extra warm	1977	.21	Cold
1940	.49	?	1978	.18	Cold
1941	.33	?	1979	.18	Cold
1942	.24	?	1980	.14	Cold
1943	.36	?	1981	.11	Cold
1944	.30	?	1982	.11	Cold
1945	.01	Medium	1983	.09	Warm
			1984	.07	Warm
			1985	.07	Warm

first periods correspond to periods of respectively low and high recruitment. Also the low values in the most recent period correspond to a period where the year class strength was reduced, but not to the extent indicated by the catch rates.

Table 4. Catch of saithe per unit of effort by English conventional trawlers in Sub-area I, 1946-1978.

Year	Catch per unit of effort (tons per million ton-hours)	Climatic regime
1946	29	Medium
1947	74	Medium
1948	93	Medium
1949	75	Medium
1950	62	Warm
1951	47	Warm
1952	39	Warm
1953	49	Warm
1954	30	Warm
1955	27	Warm
1956	35	Cold
1957	39	Cold
1958	36	Cold
1959	36	Warm
1960	35	Warm
1961	16	Warm
1962	14	Warm
1963	12	Cold
1964	45	Medium
1965	38	Cold
1966	46	Cold
1967	25	Cold
1968	36	Cold
1969	56	Cold
1970	100	Warm
1971	58	Warm
1972	55	Warm
1973	32	Warm
1974	8	Warm
1975	10	Warm
1976	10	Warm
1977	10	Cold
1978	7	Cold

DISCUSSION

Although there are undoubtedly some errors in the recruitment estimates, the time series of year class strength is still the one most likely to reveal a relationship with the climate. The fact that no correlation was found therefore strongly indicates that there is no relationship or, at the most, a weak one. Since such a relationship has been demonstrated for Arctic cod (SÆTERSDAL and LOENG 1984), the poor correlation between year classes of North-East Arctic saithe and Arctic cod was to be expected.

The Norwegian data on landings are reliable, and except for the most recent years they correspond closely to the catches in the different coastal areas. The problem is that they do not necessarily reflect changes in the stock size

and the geographical distribution, because the fishing effort, in addition to being generally increasing, obviously also has fluctuated somewhat from year to year. However, if the climate strongly affects the catches in Finnmark, it would be a rare coincidence if variations in the effort had masked this effect over such a long period. The landings therefore also indicate a lack of relationship between North-East Arctic saithe and the climate.

The catch per unit of effort seems to have been more influenced by the stock size than by the climate. However, the English trawlers were fishing mainly for cod, and the catch rates for saithe may not be a very reliable index of the abundance.

The lack of a close stock-recruitment relationship for North-East Arctic saithe (Fig. 3) is evidence of a dependence on environmental factors for the recruitment. Since the different time series have failed to reveal a relationship with the climatic regime in the Barents Sea, it seems likely that other environmental factors are more important. The similarities in relative year class strength between the stocks of saithe may be an indication of a common environmental influence for the North-East Atlantic Ocean. GARROD and COLEBROOK (1978) suggested that there was a common climatic effect on fish stocks in the area, but SHEPHERD, POPE and COUSENS (1984) found little evidence for this. For saithe they implied that the frequent long-range migrations of the species could mask differences in recruitment between the stocks. However, migration can hardly explain the concurrence of a period of low recruitment in all stocks from 1974 to 1977. It may therefore be significant that this occurred during a period when the salinities in the Faroe-Shetland Channel were reduced to a level not observed since before 1920 (DOOLEY, MARTIN and ELLETT 1984). The event started after 1972 and the minimum was reached in 1976. The Faroe-Shetland Channel is the principal route for the passage of Atlantic water into the Norwegian Sea, and the reduced salinities reflect, among other things, a reduced inflow. During the period of consistently high recruitment to the saithe stocks 1966-1968, the salinities were normal. This could mean that recruitment of the saithe stocks

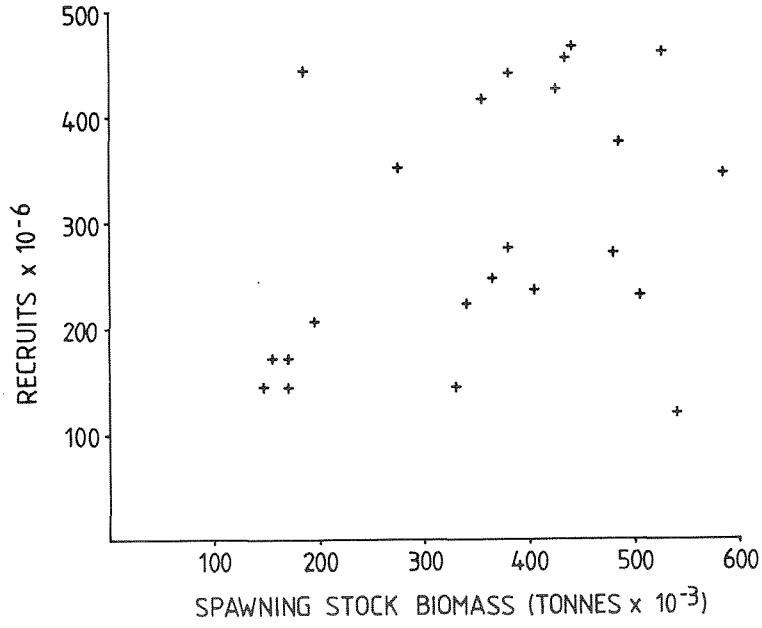

Fig. 3. North-East Arctic saithe. Spawning stock biomass vs. recruitment.

is reduced in years of extremely low inflow of Atlantic water, but that variations in inflow within the normal range is of minor importance. That fish stocks in many cases will react only to extreme changes of environmental conditions was suggested by SHEPHERD et al. (1984). Thus, the remaining variation in recruitment must be caused by other environmental factors. So far their nature is mostly unknown. However, there is evidence of one factor which seems to have a regulatory effect on the year class strength of saithe. EGIDIUS and ANDERSEN (1975) describe an epizootic of vibriosis on juvenile saithe along the Norwegian coast in 1974. Although the epizootics have not been regularly investigated, the disease which is caused by the bacterium Vibrio anquillarum seems to be especially lethal in years of high density of juvenile fish. This would tend to reduce the strong year classes and accordingly the variation in year class strength.

SÆTERSDAL and LOENG (1984) presented the hypothesis that the reproduction of cod through evolutionary processes is adjusted to the variations in the feeding area caused by climatic fluctuations. The feeding area of the North-East Arctic saithe is normally restricted to the coastal banks, and its extension appears to be clearly more stable than for cod. It is therefore possible that the saithe stock has a more stable supply of food. In this context it may also be significant that the saithe is feeding mostly on plankton. A stable supply of food from year to year is most efficiently utilized by a stable stock. This may be the evolutionary basis for the fact that the year class abundance for saithe is generally less variable than for cod.

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