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North Atlantic cod: the broad canvas

D. J. Garrod and A. Schumacher

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The catches of North Atlantic cod in the twentieth century are reviewed, with emphasis on the period since 1950 when landings statistics are considered to have been highly reliable. Time series of landings data are used to describe the historic development of the fisheries and the main events affecting catches. These are coupled with a comparison of trends among stocks to distinguish environmental and climatic effects from fishery-induced changes. An overview of North Atlantic cod landings indicated that, following a highly productive period 1950–1965, the cod fisheries have subsequently suffered a protracted decline. Concomitant environmental changes would not be expected to cause a consistent decline in all cod stocks throughout their north–south climatic range; if some might have improved, others might not. Comparison of landings trends between various stocks provide some evidence of climatic effects; however, the very widespread decline in landings in nearly all stocks speaks in favour of increased fishing mortality as the dominant factor in recent years. The potential benefits of a precautionary management approach to rebuilding cod stocks is discussed and recommended.

D. J. Garrod, Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research, Fisheries Laboratory, Pakefield Road, Lowestoft, NR33 OHT, Suffolk, England; A. Schumacher, Finkeneck 3, D-25421 Pinneberg, Germany.

Foreword

Fishery statistics were originally introduced in the context of national and regional economic issues as the main source of information on the catch and effect of fishing rather than for research purposes. When the scientific evaluation of fishery resources began it required a more complete reporting system of catches taken by all participants in a fishery and, owing to the international character of most fisheries, this, in turn, required international cooperation. It was the International Council for the Exploration of the Sea (ICES) which, at the beginning of this century, started to organize the collection and publication of the information required for stock evaluation purposes.

Obviously, such an undertaking could not immediately be successful. A certain period of learning and adaptation was required and improvements in the reliability of the fishery statistics have mainly been associated with the progress made by ICES and other international fisheries organizations (i.e., the International Commission for North Atlantic Fisheries (ICNAF); North Atlantic Fisheries Organization (NAFO); and the United Nations Food and Agriculture Organization (FAO)) to obtain appropriate and complete data from all countries. Nonetheless, there have been periods when the accuracy of this information has not been as precise as desired. Within the ICES area, the uncertainty of the statistics lasted into the 1920s, and for the ICNAF area (judging from the ICNAF *Statistical Bulletin*) not before 1959 from many stocks. From then until the mid-1970s the information could be regarded as being fairly complete and reliable. There were difficulties with catch allocation for some of the smaller stocks, but aggregate landings statistics for broad stock areas were generally satisfactory. However, with the beginning of the 1970s, when the discussion on management by catch limitation and the introduction of Exclusive Economic Zones (EEZs) started, misreporting began to introduce a new element of uncertainty.

Inaccuracy began to occur owing to: (i) over-reporting of catches to support claims in negotiations about fishing opportunities or shares of TACs (quotas), and (ii) concealing overfishing of quotas, mis-reporting catches of quota species from another fishing area, or as different species, or perhaps not at all. These deficiencies have to be kept in mind when drawing conclusions from fishery statistics alone. However, the present article considers the development of the cod fishery in the North Atlantic in a wider context, and therefore the less reliable data are not expected seriously to affect the conclusions.

Introduction

The historic development of individual Atlantic cod fisheries is dealt with in the area reviews presented later in this Symposium. Our purpose is to present the evolution of the fisheries in the Atlantic-wide context, drawing on the similarities and differences between stocks to illustrate common trends and key events in management. The factors which have contributed to this history inevitably lead back to the persistent issues of fisheries science, namely the relative importance of environmentally and fishery-induced changes in determining the productivity of fish stocks. We hope that the comparisons between stocks will add to conclusions that will emerge from consideration of individual stocks.

Our information is drawn from the reports of ICES and NAFO working groups, coupled with advice from the scientists concerned with each stock. **All such catch series involve a measure of interpretation by the scientists best placed to do so, and these have been accepted as of 1992, without detailed annotation of each data set in the knowledge that discrepancies are minor in relation to the broad features referred to in this review. The statistics have NOT been updated to conform exactly to the data in other papers presented at this Symposium and it is those which should be regarded as the authorized record. In the interests of brevity the various sequences are presented as figures rather than tabulations.**

North Atlantic cod catches – the twentieth century (Table 1) (Data sources listed in the References)

Total Atlantic

The major cod fisheries of the Northeast Atlantic were developed in earlier centuries. The early history of the Northwest Atlantic (Newfoundland) fisheries has recently been reconstructed from historical archives (Cushing, 1988). The present review begins with the earliest year of this century, but is primarily concerned with the period since 1930.

The development of cod landings from the Atlantic since 1930 is shown in Figure 1. The steady increase to about 3 million tonnes in 1956 was only interrupted during the war period 1939–1945. In 1968, maximum landings of about 3.9 million tonnes were reached, followed by a continuous decline to the lowest level of the past 60 years. Three main areas, i.e., the Northeast Atlantic, Northwest Atlantic, and the European Shelf region, contribute to the development of the total yield, but in different ways.

Northeast Atlantic (Fig. 2)

Total catch

A strong component of the total Atlantic cod fishery has always comprised the yields from the cod stocks in the boreal Northeast Atlantic (especially Northeast Arctic, Iceland, and Greenland). Fishery statistics for these stocks have been available since the turn of the century and are thought to be of sufficient accuracy to describe the historical development of the fisheries in broad terms.

Apart from the interruption of two war periods, there has been a steady increase in total landings from the Northeast Atlantic from a level of about 400 000 t at the beginning of this century to a maximum of more than 2.2 million tonnes in 1956. The following period, with a generally declining trend, showed some high peaks as a result of a few good year classes available for exploitation in the Northeast Arctic cod stock. Catches from this stock have dominated the total yield from the Northeast Atlantic since the mid-1930s.

Northeast Arctic and Iceland cod

The Northeast Arctic and Iceland stocks have amongst the longest recorded histories of any of the North Atlantic cod stocks and many ecological similarities within their own geographical and seasonal ranges. Both fisheries have the distinctive elements of a traditional fishery on spawning cod of great antiquity which, with the advent of powered trawlers, was then extended on to often less accessible feeding grounds. The fisheries were then further developed in the 1920s by trawler fleets of northwest Europe. The development of the fisheries through the 1930s was followed by the interruption of the war years, when the landings from the Northeast Arctic cod must be in some doubt, but renewed post-war expansion led to a peak in landings during the mid-1950s. This was followed by a protracted decline to the present day. Northeast Arctic cod stocks show a high level of short-term variability throughout the time series. This is less marked in the Icelandic fishery, where catches reached an all-time peak of over 500 000 t during 1930–1933. This may reflect the first benefit at Iceland of immigrant spawning cod from the expanding cod stocks at west Greenland.

The proportions of Icelandic and distant water fisheries at Iceland became almost equal from 1920. There was a decline from the 1933 peak due to economic reasons, and in the war years, but this was followed by redevelopment reaching a level of 300 000–400 000 t

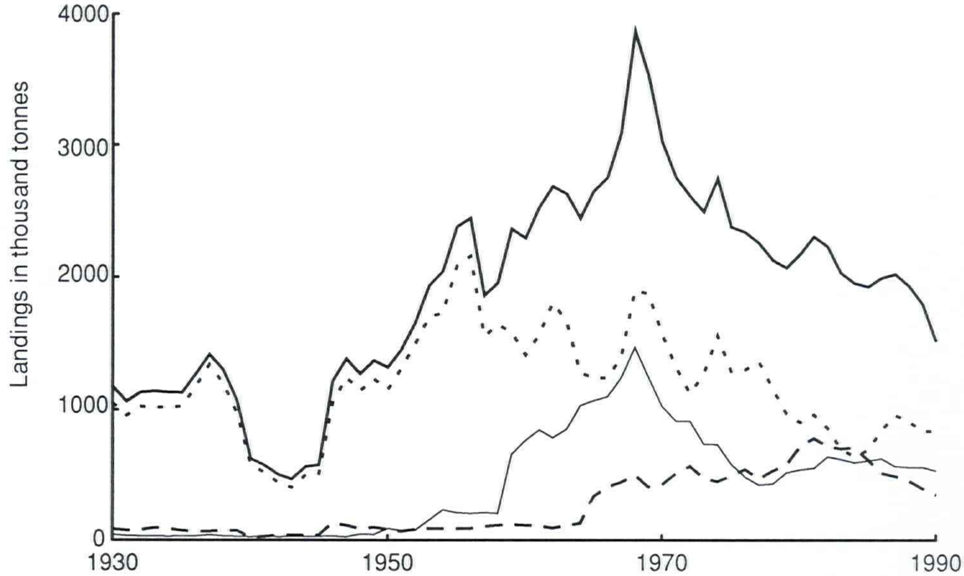

Figure 1. Total landings in the North Atlantic cod fisheries 1930–1990. —— Total; - - - European Shelf; - - - - NE Atlantic (excl. European Shelf, inc. Greenland); —— Northwest Atlantic.

which was maintained (with fluctuations) until around 1970 and then followed, despite the termination of the traditional distant water fisheries, by a more persistent, gradual decline, but with occasional better periods.

Data on mean fishing mortality are illustrated in Figure 3 and show, for Icelandic cod, a continuous increase from 0.3 in 1955 to about 0.8 in 1976. There was a reduction in 1977, when EEZs were introduced. How-

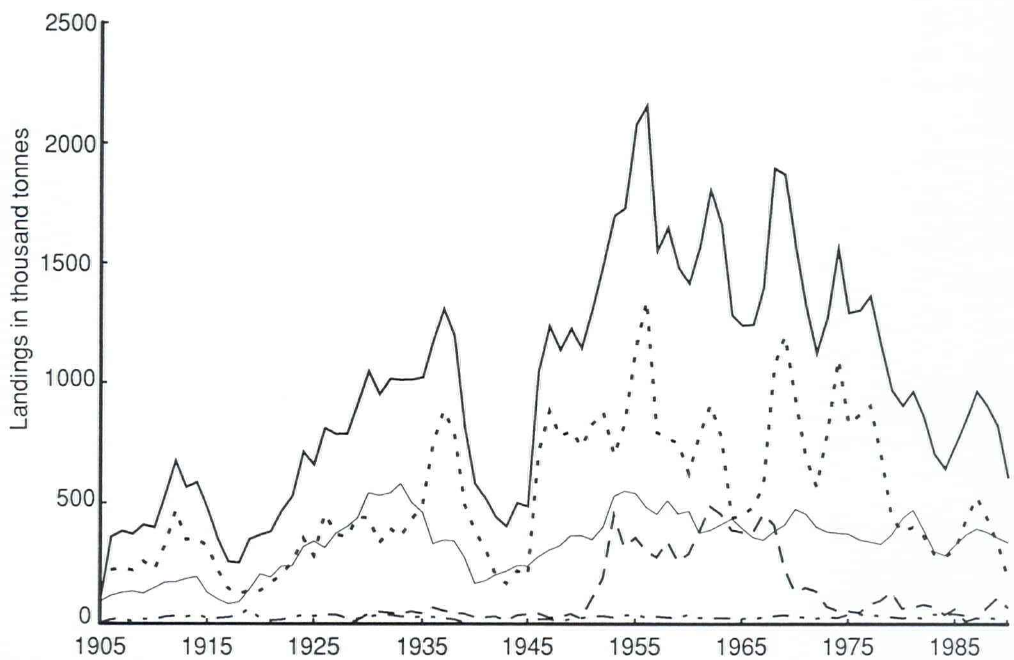

Figure 2. Total landings in the Northeast Atlantic cod fisheries 1905–1990. —— Total; - - - - - - NE Arctic; ——— Iceland; - - - - Faroe Is; — — — — — Greenland.

Table 1. Total cod catch (t) (rounded to the nearest thousand)

	Overall stock totals									Aggregated stocks			
			European Shelf										
	NE Arctic & Iceland	Faroes	North Sea Kattegat and Skagerrak	Other: incl. Baltic	E, W Greenland	2G–3NO	3M	Nova Scotia.Sth Newfoundland 3Ps-4X Newfoundland	S.A.5&6	Total of regional totals	NE Atlantic excl. European Shelf incl. Greenland	European Shelf	NW Atlantic excl. Greenland
1905	92	4	–	–	–	–	–	–	36	132	96	–	36
1906	341	19	89	–	–	–	–	–	62	510	360	89	62
1907	362	20	85	–	–	–	–	–	57	524	382	85	57
1908	358	12	94	–	–	–	–	–	40	504	370	94	40
1909	387	20	115	–	–	–	–	–	40	562	407	115	40
1910	376	19	115	–	–	–	–	–	35	545	395	115	35
1911	497	30	119	–	–	–	–	–	26	672	527	119	26
1912	641	32	130	–	–	–	–	–	28	830	673	130	28
1913	535	29	129	–	–	–	–	–	24	718	565	129	24
1914	546	38	161	–	–	–	–	–	33	778	584	161	33
1915	452	25	107	–	–	–	–	–	18	602	477	107	18
1916	326	26	82	–	–	–	–	–	19	452	351	82	19
1917	230	27	59	–	–	–	–	–	21	337	257	59	21
1918	216	36	65	–	–	–	–	–	30	347	252	65	30
1919	285	64	110	–	–	–	–	–	30	489	349	110	30
1920	344	23	156	–	–	–	–	–	27	550	367	156	27
1921	367	14	143	–	–	–	–	–	32	555	381	143	32
1922	445	19	131	–	–	–	–	–	31	626	464	131	31
1923	501	26	86	–	–	–	–	–	30	643	526	86	30
1924	672	45	82	–	–	–	–	–	33	832	717	82	33
1925	623	38	85	–	–	–	–	–	34	781	662	85	34
1926	767	44	99	–	3	–	–	–	40	953	814	99	40
1927	742	45	97	–	3	–	–	–	39	926	790	97	39
1928	757	30	79	–	2	–	–	–	35	903	790	79	35
1929	874	27	75	–	14	–	–	–	37	1026	915	75	37
1930	977	33	84	–	43	–	–	–	41	1179	1053	84	41
1931	862	45	74	–	51	–	–	–	33	1066	959	74	33
1932	932	45	78	–	47	–	–	–	31	1134	1024	78	31
1933	938	38	93	–	42	–	–	–	32	1143	1018	93	32
1934	930	35	87	–	53	–	–	–	28	1133	1019	87	28
1935	949	32	74	–	45	–	–	–	31	1131	1026	74	31
1936	1078	35	64	–	68	–	–	–	31	1275	1180	64	31
1937	1230	27	67	–	55	–	–	–	40	1418	1311	67	40
1938	1132	24	71	–	46	–	–	–	32	1304	1201	71	32
1939	924	6	70	–	43	–	–	–	28	1072	974	70	28
1940	551	–	23	–	27	–	–	–	24	626	579	23	24
1941	490	–	25	–	28	–	–	–	32	575	518	25	32
1942	408	–	38	–	31	–	–	–	25	502	439	38	25
1943	388	–	39	–	14	–	–	–	27	467	401	39	27
1944	462	–	35	–	36	–	–	–	28	561	498	35	28
1945	469	–	39	–	41	–	–	–	29	577	509	39	29
1946	983	30	131	–	44	–	–	–	30	1219	1057	131	30
1947	1188	31	112	–	29	–	–	–	23	1383	1247	112	23

Table 1. Continued

	Overall stock totals									Aggregated stocks			
			European Shelf										
	NE Arctic & Iceland	Faroes	North Sea Kattegat and Skagerrak	Other: incl. Baltic	E, W Greenland	2G–3NO	3M	Nova Scotia.Sth Newfoundland 3Ps-4X Newfoundland	S.A.5&6	Total of regional totals	NE Atlantic excl. European Shelf incl. Greenland	European Shelf	NW Atlantic excl. Greenland
1948	1098	21	85	–	27	–	–	20	25	1276	1146	85	45
1949	1164	28	97	–	43	–	–	16	25	1372	1235	97	41
1950	1096	36	81	–	24	–	–	65	20	1322	1156	81	85
1951	1174	35	65	–	107	–	–	53	18	1453	1316	65	71
1952	1277	30	82	–	190	–	–	60	14	1653	1497	82	74
1953	1221	27	87	–	449	66	–	73	11	1935	1698	87	151
1954	1374	36	86	–	319	135	–	81	12	2042	1728	86	228
1955	1686	38	87	–	355	114	–	80	12	2374	2080	87	207
1956	1824	28	86	–	303	65	–	121	13	2440	2155	86	199
1957	1246	31	100	–	276	90	–	104	13	1862	1554	100	207
1958	1273	28	111	–	341	48	–	137	16	1955	1642	111	202
1959	1297	26	116	–	259	427	7	211	16	2358	1582	116	661
1960	1087	39	110	–	290	547	1	203	14	2291	1416	110	765
1961	1158	27	108	–	381	581	20	229	18	2523	1566	108	849
1962	1296	24	91	–	485	543	16	200	27	2681	1805	91	785
1963	1186	24	110	–	452	583	33	208	30	2626	1662	110	854
1964	871	25	125	–	385	676	39	290	28	2440	1282	125	1033
1965	839	26	186	147	378	694	54	282	42	2648	1243	333	1072
1966	841	23	230	177	379	728	29	286	58	2751	1243	408	1100
1967	918	27	250	195	454	894	37	270	43	3088	1399	445	1244
1968	1456	34	283	216	409	1058	34	331	50	3870	1899	499	1472
1969	1604	38	196	212	232	917	22	266	46	3534	1875	408	1251
1970	1405	32	226	198	134	649	18	327	34	3023	1571	424	1027
1971	1143	28	346	165	153	578	25	279	36	2752	1323	511	917
1972	964	24	375	193	137	575	57	252	32	2609	1125	568	916
1973	1173	27	264	212	75	435	23	245	35	2490	1275	476	739
1974	1477	27	242	207	54	450	25	227	35	2744	1559	449	737
1975	1200	39	218	275	54	339	22	192	34	2373	1293	493	587
1976	1216	42	251	294	46	244	22	189	30	2335	1304	545	485
1977	1245	37	225	244	82	194	27	161	40	2255	1364	469	422
1978	1027	35	300	232	99	158	33	193	48	2125	1161	533	432
1979	809	29	267	315	133	197	30	241	50	2070	971	582	517
1980	815	24	292	431	66	198	10	270	62	2169	906	723	541
1981	868	27	342	442	69	199	14	287	55	2302	964	783	554
1982	752	25	310	413	83	275	13	286	71	2227	860	723	644
1983	590	41	280	425	71	264	10	287	63	2030	701	705	624
1984	562	39	230	484	41	261	13	274	49	1954	642	714	597
1985	633	44	220	400	17	269	14	281	48	1925	694	620	611
1986	799	36	189	327	11	303	15	276	36	1991	846	516	629
1987	915	28	200	291	19	277	11	241	38	2020	962	491	567
1988	813	28	167	288	72	312	2	202	47	1931	913	455	563
1989	689	24	140	255	126	287	40	192	43	1796	840	394	562
1990	522	14	130	214	101	248	32	196	58	1516	638	345	533

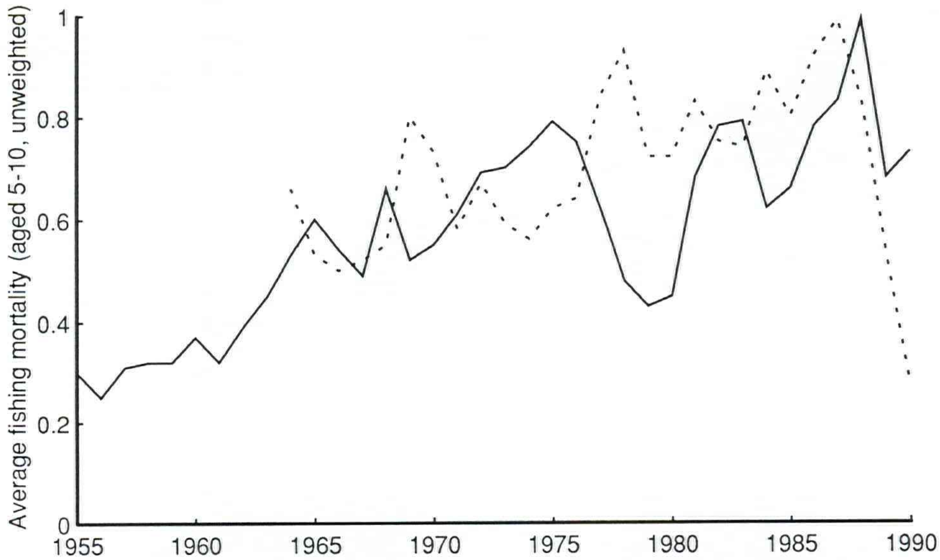

Figure 3. Fishing mortality in the Northeast Arctic and Iceland cod stocks 1955–1990. - - - - NE Arctic–Norwegian; —— Iceland.

ever, it appears that this lower level was only maintained over a short period, and by 1982 fishing mortality had returned to the previous relatively high level. The reduction in fishing effort following the exclusion of distant water fisheries was soon compensated for by the coastal state fishery.

An increasing trend in fishing mortality over the last 25 years is evident for the Northeast Arctic cod. There was, however, no significant drop in fishing mortality after introduction of the EEZs, since the two coastal states have always taken the largest proportion of the total yield.

Greenland

The time series for the Greenland fisheries are also shown in Figure 2 and are taken here to complete the overview of all the "Arctic" stocks (other than Labrador), which are subject to the low winter temperatures defining the northern limit of the range of the species in the Atlantic. The east Greenland fishery had always been relatively small in tonnage terms and somewhat intermittent, depending on ice conditions as much as on availability of cod. As noted above to emphasize the potential importance of the link with Iceland, the west Greenland fishery was redeveloped in the early 1930s. However, the main expansion took place after 1950. Landings peaked at 485 000 t in 1962 (from Table 1) but declined to less than 15 000 t during 1985–1987.

The high catch level in this period is almost exclusively the result of distant-water fishing activity, fishing on a much increased level of the cod stock (Dickson, 1994; Buch, 1994). The beginning of the "cod period" in the early 1950s cannot be explained by a sudden increase in fishing effort alone. Even before the start of this period there had been a continuous cod fishery at West Greenland by various distant-water fleets. The area was kept under continuous observation, and the first signs of increased fishing opportunities would have been detected and triggered a rapid expansion similar to the 1950s. The numbers of cod at West Greenland appear to have increased throughout the 1940s and attracted increasing fishing at the turn of the decade into the 1950s. This relatively sudden increase in yield at West Greenland is accepted as having been the result of an increase in biomass due to favourable environmental conditions.

Faroes

Although not subject to the Arctic extremes of winter temperatures, the cod in the Faroe area share many affinities with those at Iceland and in the Northeast Arctic. As can be seen in Figure 2, the stock is relatively small (catches ca. 30 000 t), but is of considerable interest because, having been one of the first to be developed in the early years of the century, catches have varied relatively little over the past 70 years compared to most other cod stocks (see also Fig. 11). It has, however, suffered a decline in the most recent five years, which must reflect a severe failure in recruitment.

Northwest Atlantic

Total catch

It has been possible to obtain some landings figures for the Northwest Atlantic as a whole, starting in 1930, but a more detailed area breakdown could only be presented from the beginning of the 1950s onwards (Fig. 4).

Yields from stocks in the Northwest Atlantic increased, with minor fluctuations, almost continuously to a maximum of 1.3 million tonnes in 1968, followed by a steady decline to a low of 344 000 t in 1977. They have since stabilized at about a level of 500 000 t.

Labrador to Newfoundland

The dominating component in the Northwest Atlantic has always been the cod stock from the Labrador and northern Grand Bank region (NAFO Areas 2J+3KL). Yields from this stock peaked at 810 000 t in 1968, but thereafter declined to 138 000 t in 1978. Landings ranged between 167 000 and 269 000 t during 1979–1990. Owing to marked declines in stock abundance, a fisheries moratorium was introduced in 1992.

The catches at Flemish Cap (NAFO Area 3M) are less certain than most because of the location and the different pattern of exploitation by various countries in recent years. The record since 1959 shows a peak catch of 60 000 t in 1965 followed by an almost uninterrupted decline (Table 1).

The development of yield from the Southern Grand Bank cod stock (NAFO area 3NO) and the St Pierre Bank cod stock (NAFO area 3PS) show trends similar to those of the Northern cod stock (Fig. 4).

Trends in exploitable biomass and fishing mortality for the Northern cod stock (NAFO 2J3KL) are shown in Figure 5 as percentages of the mean 1963 to 1984. The decreasing trend in exploitable biomass from the early 1960s to the mid-1970s is obvious as well as the increasing trend in fishing mortality during that period. As can be seen from Figure 6 this development was caused by the increase in distant water fishing activity since the late 1950s. The total cod yield from the distant water fisheries in all Northwest Atlantic regions reached a maximum of slightly below 1 million tonnes in 1968 and in every year over the period 1964–1974 the distant water fisheries took over 70% of the total landing, whilst the yield of the coastal state fisheries showed a somewhat declining trend. This pattern can also be found in the data for cod in NAFO 3NO and 3Ps. The mean fishing mortality for these three Northwest Atlantic stocks increased almost simultaneously – with the usual fluctuations – peaking suddenly at extremely high levels in 1974–1976 at a time when the catch of the distant water fisheries actually declined. Some of the lowest catches on record must therefore have been taken by a level of effort comparable to those preceding years.

A sharp reduction in mean fishing mortality from the high 1976 level and a stabilization or reversal of the declining trend in exploitable biomass (as well as grow-

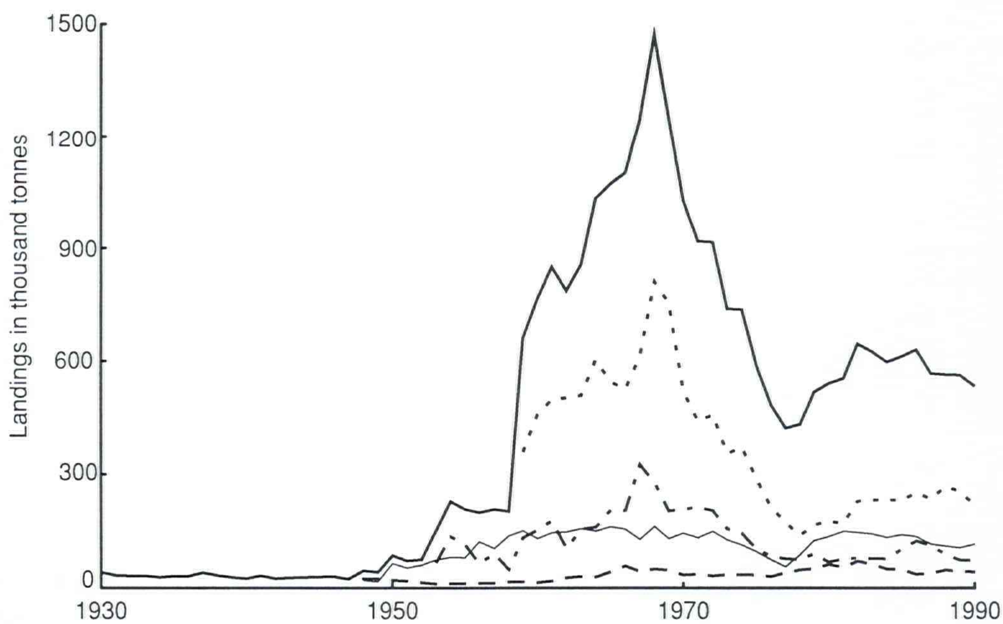

Figure 4. Total landings in the Northwest Atlantic cod fisheries 1930–1990. —— Total; - - - - 3M, 3NO & 3Ps; — — — — SA5 & 6; - - - - 2J 3KL; —— SA4.

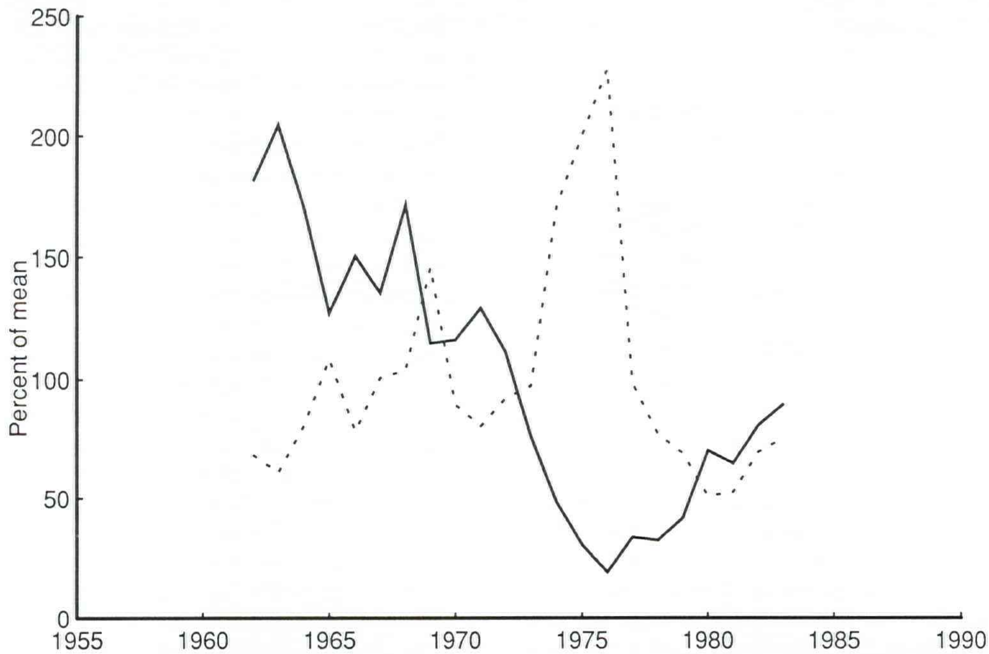

Figure 5. Exploitable biomass and fishing mortality; Northern cod (NAFO 2J + 3KL) 1963–1984. —— Exploitable biomass; - - - - - - Fishing mortality.

ing yield of the coastal states fishery) can be seen following the introduction of EEZs in 1977. A new increase in fishing mortality has been observed since the minimum in 1980, but it would be premature to comment on the most recent development, since it seems that some questions associated with environmental phenomena have to be clarified before final conclusions can be drawn.

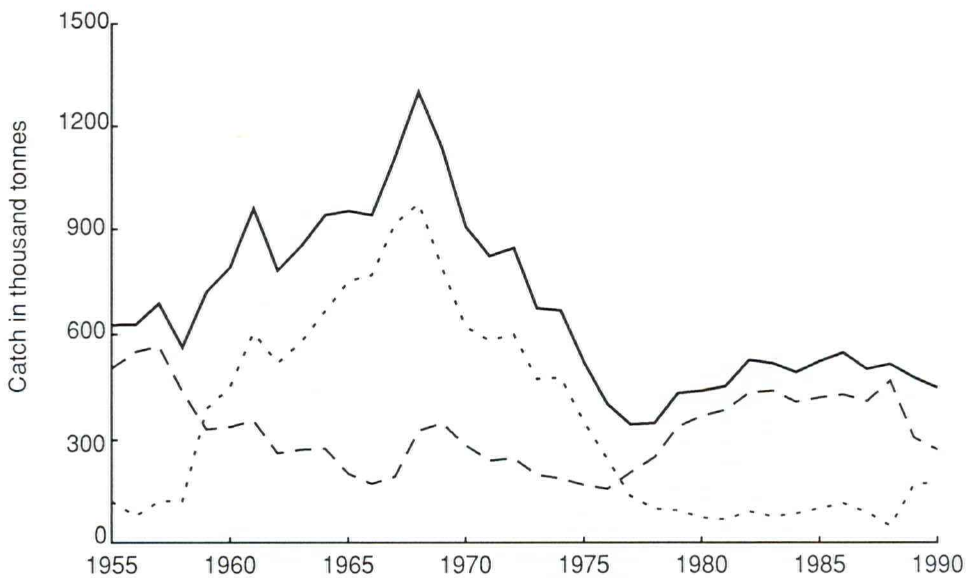

Figure 6. Comparison of landings in the distant water and coastal cod fisheries of the Northwest Atlantic 1955–1990. —— Total; - - - - - - Distant water fisheries; – – – Coastal states.

South from Newfoundland

Similar considerations and conclusions can be applied to the group of cod stocks lying off the eastern seaboard of North America south from Newfoundland. The time series of aggregate catches shows a maximum in the late 1960s followed by a secondary maximum in the 1980s. The secondary maximum is most evident in the New England series (SA 5&6), together with the cod fisheries off Nova Scotia (4x, 4VsW). Stocks more influenced by the Gulf of St Lawrence show complex intermediate variations. The purpose of summarizing the cod catches in this way has been to draw attention to significant correlations between some of the series of cod catches which are discussed later.

European shelf waters

The Northwest European shelf complex of stocks is as difficult to summarize as the stocks in the vicinity of the Scotian Shelf in the Northwest Atlantic, because the boundaries between some of them, and especially the fisheries, are not very distinct. Figure 7 gives catches from:

North Sea
  West of Scotland (ICES VIa)
  English Channel (ICES VIId–e)
Baltic (Areas 22–32)
  West of Scotland (ICES VIb)
  Bristol Channel (ICES VIIf, g)
Kattegat and Skagerrak
  Irish Sea (ICES VIIa)
  Celtic Sea (ICES VIIb–c, h–k)

The time series of catches which can be *reliably* ascribed to each particular stock area is relatively short for all except the Baltic and North Sea cod. The series for the Kattegat and Skaggerak begins in 1970 and these, taken together, show the same pattern of variation in catches as the North Sea fishery. For the present broad purposes they have therefore been combined into the larger, adjacent North Sea stock in Table 1. Together, the Baltic and North Sea catches represent a steady expansion in landings from a level recorded as less than 200 000 t in the first half of the century to a peak in the early 1980s.

The time series for the North Sea is long, and, in fact,

Figure 7. Total landings in European shelf cod stocks 1905–1990. —— European Shelf; —— Baltic; - - - - - Skagerrak and Kattegat; - - - - - - North Sea; – – – Channel and west of British Isles.

excluding war years, catches were surprisingly stable over the half century 1906–1963. There then followed what has come to be referred to as the "gadoid outburst" represented, in cod, by the very good year classes in 1969, 1970, 1976, and 1979. It is not really clear what is meant by an "outburst", nor whether the increase in catches in the late 1960s was associated with more favourable environmental circumstances. Although catch records are available, the detailed age composition of the North Sea cod stock is only very sparsely documented before 1963. Careful reconstructions confirm that even on alternative assumptions on the level of exploitation in the 1930s, the recruitment and stock size of North Sea cod increased to record higher levels in the 1960s and 1970s (Daan and Heessen, 1994, Fig. 8d). The improvements in catches in the late 1960s and 1970s reflect the more recent and well-documented increase in exploitation, coupled with the effect of an improved recruitment. Catches have since fallen back to the 1960s level in a decline which is still continuing.

The other catches from the southwestern area, ICES Subarea VII, cod fisheries are much smaller. They are not illustrated because the landings from some of them, and the distinctions between them, are generally poorly determined, particularly in earlier years, and they are especially sensitive to the occasional stronger year class. Although crucial details of the 1950–1960 period remain uncertain because of the lack of detailed data on stock structure, the catches of all these stocks have declined since 1980s, with the onset of the decline in the Baltic being slightly later.

Fishing mortality for North Sea and Baltic cod is shown in Figure 8. Landings from both these stocks increased in the 1965–1990 period. This development in the stocks on the European shelf, and in particular the great extent of it, is hard to explain solely by the drastic changes in fishing effort during the same period. It seems more to have been a case where the influence of environmental factors may also have played a major role.

Overall trends

Since 1950, it has been clear that similar trends are apparent in each of the major sectors we have considered – the Northeast Atlantic "Arctic", Northwest Atlantic fisheries, and the European shelf fisheries. The fisheries and catches expanded through to the mid-1960s, driven largely by the expansion of the so-called distant-water trawl fisheries on both sides of the Atlantic. The peak was followed by a sharp decline as the declining catch was associated with high levels of exploitation. One might conclude that the peak catches could not be sustained. Certainly the change contributed to the extension of fishery limits which, in turn, led to the demise of the distant-water fisheries, some more rapidly than others! This reduction in effort, however, was quite rapidly offset by the expansion of coastal fisheries, and fishing mortality has reverted to its former levels almost

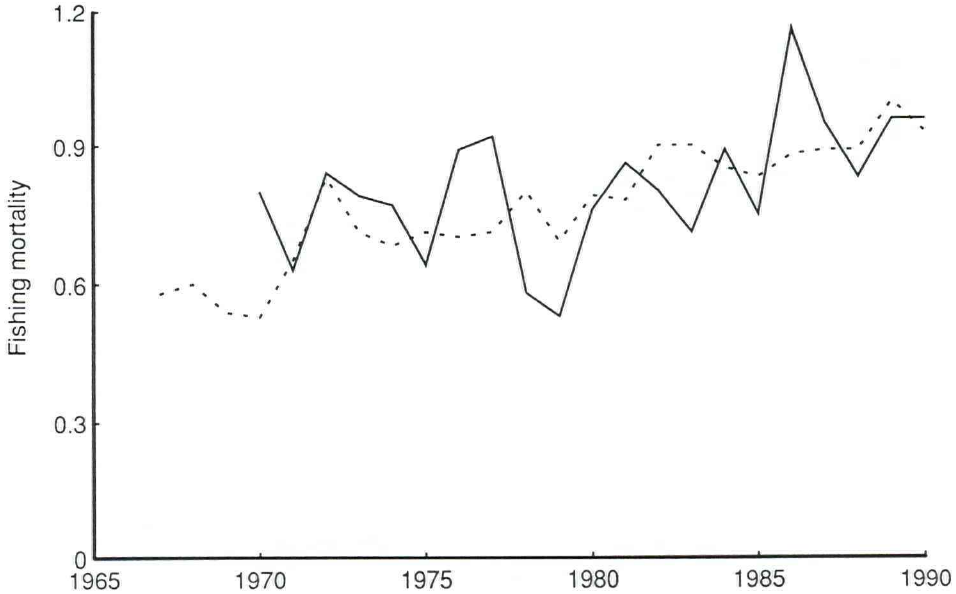

Figure 8. Fishing mortality in the North Sea and Eastern Baltic cod stocks 1965–1990. - - - - North Sea; —— Eastern Baltic (22–32).

everywhere (see below). More severe management measures were introduced in some areas, but these have not been effective in reducing fishing mortality or in promoting stock rebuilding. The one exception is the Northeast Arctic cod stock, where Fs have declined since the late 1980s and stock recovery is taking place.

Although the record for the early years is incomplete, there is no reason to doubt the gradual expansion to the peak of around 3.5 million tonnes in the late 1960s shown in Figure 1. This has been followed by a steady decline to the current level of around 1.5 million tonnes. This MUST be a matter for serious concern, and could be presented as a classic illustration of the consequences of overexploitation that corresponds very closely with theoretical expectations.

But is that the "whole story"?

The underlying trends in exploitation referred to earlier have been brought together in Figure 9 in "stock pairs", viz.

Northeast Arctic/Iceland
Labrador/Grand Bank (NAFO 3NO)
North Sea/Baltic
St Pierre Bank 3Ps/4x

For convenience, the annual F values for individual stocks have been calculated relative to their individual internal means 1970–1978 and then combined as the arithmetic mean of the named pairs. The pairings are based on geographical and ecological proximity in order to represent broad areas of the cod distribution. Statistical analysis indicates that there were no significant differences within the four pairs. More extended analysis showed a statistically significant linear trend in mortality with time in each pair. There was also a difference between the slopes, but all are positive. It is clear that although the rate has varied, there has been a gradual and systematic increase in exploitation throughout the North Atlantic stocks and the introduction of extended fishery limits failed to achieve more than a temporary hiatus before coastal states replaced the distant water fisheries and the anticipated fishery management benefits were lost. Transfers or exclusion of effort between one location and another did no more than temporarily delay a seemingly inevitable process. Indeed, even at Labrador and Grand Bank, where the sudden surge of exploitation was rapidly and dramatically restricted to the mid-1970s, the increase in F was almost immediately resumed.

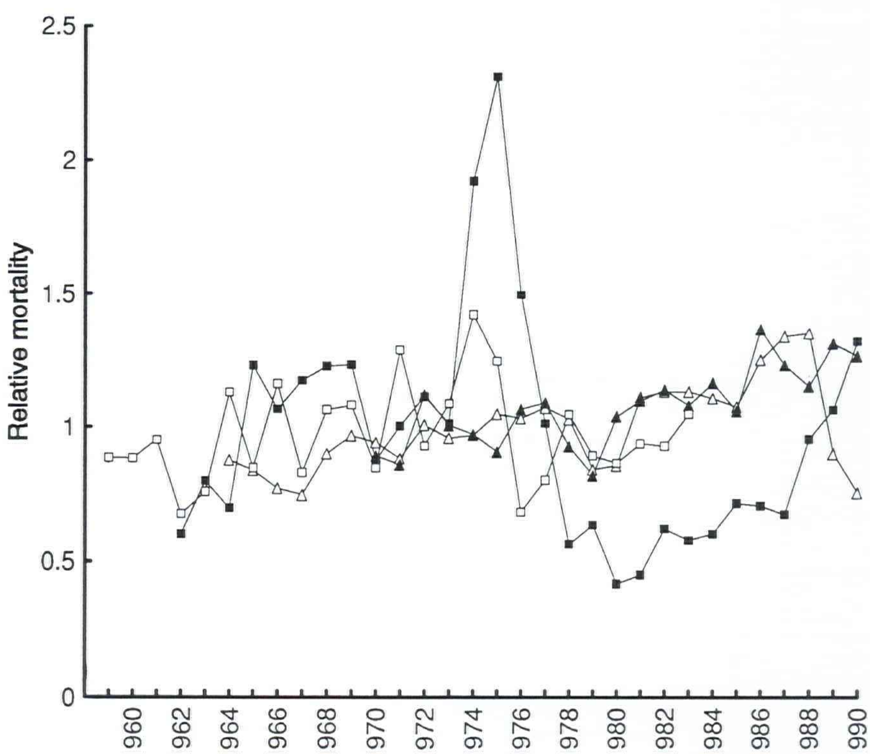

Figure 9. Trends in relative fishing mortality in selected cod stocks. △ Northeast Arctic and Iceland; ■ Labrador and Grand Banks; ▲ North Sea and Eastern Baltic; □ 3Ps and 4X.

It is perhaps a little difficult to reconcile the steady increase in exploitation at broadly similar levels in all these stocks with the difference in timing of the increase, peak and then the decline in yield in all major sea areas, as summarized in Figure 1. The differences are more what one might expect where yield is influenced by environmentally induced trends in recruitment occurring at different times in the different sectors.

These second thoughts on the influences determining overall yield are reinforced by the scale of the changes. Figure 10 shows the relative yield from a stock with constant recruitment fished at progressively higher levels of exploitation (similar to the levels that have been recorded) showing the transitional yield as it is "fished up" by increasing levels of exploitation. The increase in exploitation has been distributed throughout the period in one case (Fig. 10a) and compressed into the early years of the series in the other case (Fig. 10b). The net benefit in yield from the fishing up of the "surplus" biomass by a progressive increase in exploitation is only in the order of 15%. This is far less than the scale of increase recorded in the fisheries themselves, and the larger transitional yield achieved by a rapid increase in exploitation would be restricted to only a very short period. The sustained improvement in catches from many of the Atlantic cod stocks is what could be expected from an increase in biomass and yield over and above what could be achieved from a stock where the recruitment was fluctuating without trend. It also suggests that the increase could not be achieved by an increase in catchability of the stocks as a result of some

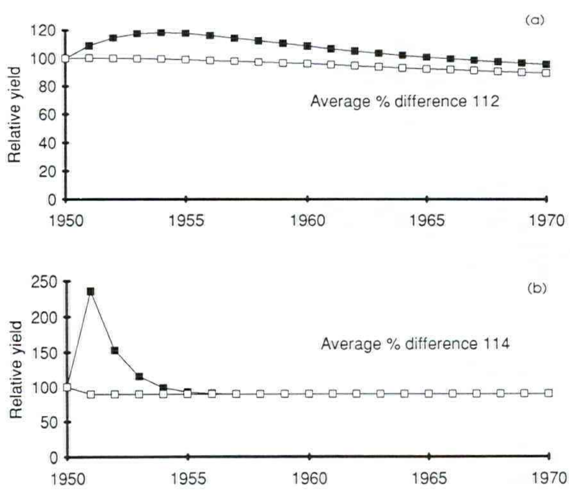

Figure 10. Comparison of transitional yield (as defined) and equilibrium yield at F = transitional F, (a) transitional fishing mortality increased from 0.3 to 0.9 over 20 years, i.e. 0.03 per year; (b) transitional fishing mortality increased 0.3 to 0.9 in 1951. ■ Total transitional; □ Total equilibrium.

environmentally induced distribution change, because that is already reflected in the recorded increases in the fishing mortality.

The environmental evidence

The search for correlation between environmental variables and fish catches and, more specifically, variation in year-class strength, has a long and distinguished history but, except in the context of the El Niño and its effect on Peruvian anchoveta, the proposed relationships have had very little predictive capability. The difficulty should not surprise us. There are problems with the biological estimates, and the choice of environmental variable is invariably limited by the time series of data available. The environmental variables used most have been sea-surface temperature and atmospheric pressure, at spatial scales which are not necessarily closely related to the mechanisms determining year-class strength in a particular locality.

The recent development of testable hypotheses concerning the mechanisms determining survival in the early life history testify both to progress in thought and technique, and recognition of the complexity of the systems involved. It is almost too much to expect that the totality of the environmental components could be characterized by a single annual value covering all the time and space scales involved for any one stock.

The significance of environmental effects is nevertheless accepted even if they cannot be specified. For North Atlantic cod, the most convincing evidence is to be seen in the 1940–1950 recovery of the stock at West Greenland (Dickson *et al.*, 1994). The Greenland stocks, and the northern components of the Labrador cod, are at the lower temperature boundary of the habitable range for cod. One could expect these stocks to re-expand in periods of climatic amelioration.

Environmental effects on fish stocks are, of course, best examined in the time series of recruitment in the individual area reviews and would therefore be out of place here. However, one would expect to see major short-term environmentally induced variations in recruitment reflected in variation in landings over and above the effect of changes in fishing in response to changing stock conditions.

Figure 11 illustrates the compilation of the landings data from Table 1 and provides a clear indication of a fundamental Atlantic-wide structure which can now be interpreted against the background of the underlying and uniform upward trend in exploitation.

The evidence of environmental effect on the Greenland cod stock has already been referred to. The Iceland and Northeast Arctic time series, both separately and together, show visual evidence of single multidecadal-

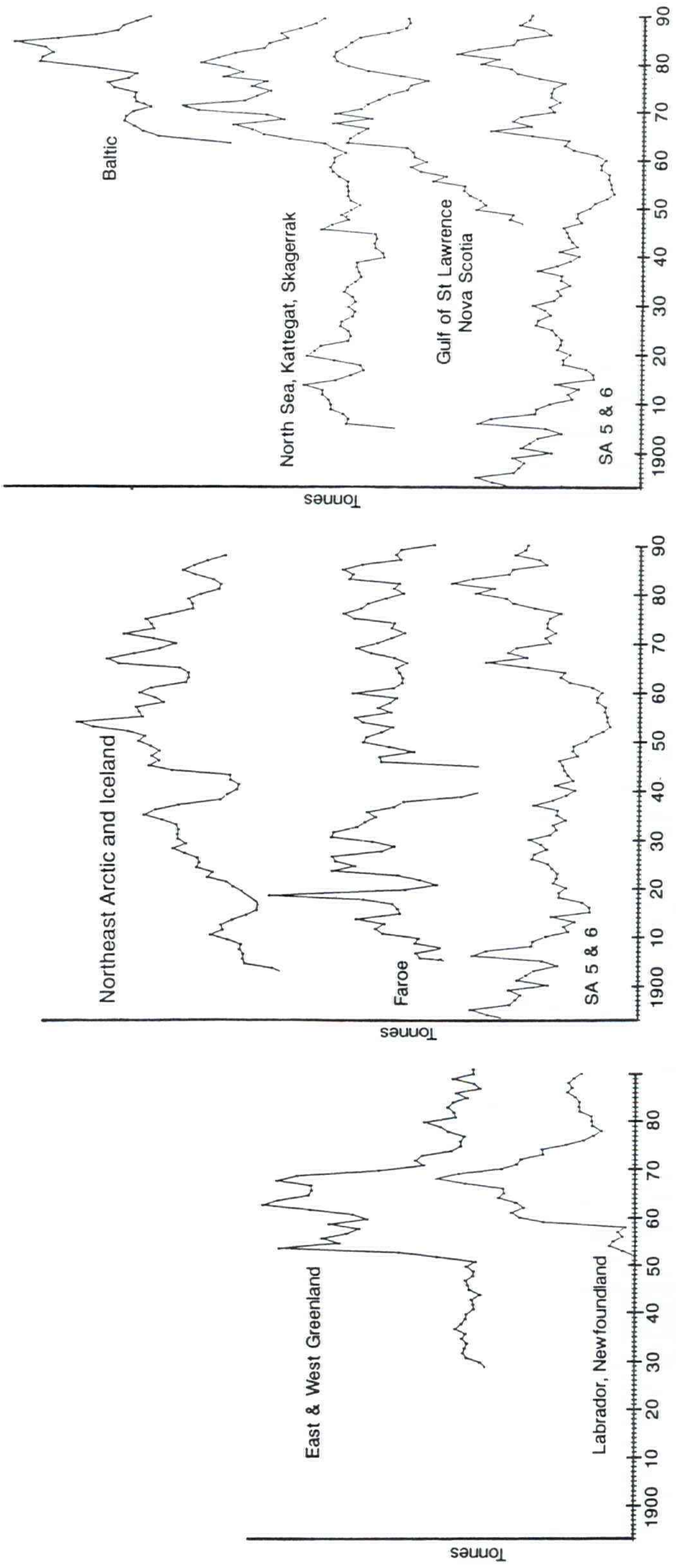

Figure 11. Compilation of cod landings from grouped cod stocks (Table 1).

induced rise to peak catches in the 1960s followed by a sustained decline. What are fairly obviously environmental periodicity and interannual variability are superimposed on this broader trend. The scale of the increase suggests that it involves more than increased exploitation over time and the key questions are how much of the long-term change is climatic, and whether the post-1950 downward trend in these stocks is evidence of a stock and recruitment decline. The patterns in the Arctic stocks are, however, quite different from the pattern of variation in the Faroe cod fishery. Following the initial development of the fishery, the variation there has been almost entirely of the shorter-term environmental type, with something like a five-year periodicity. Indeed, if one considered this array of stocks as a quasi-experimental situation, then the landings in the Faroe fishery could be interpreted as representing a "control" situation showing the profile of catches to be expected under gradually increasing exploitation in a situation where there was no environmental *trend* (as opposed to periodicity).

The North American, New England series from SA5 & 6 could be interpreted as showing a long-term climatic change which in visual terms appears to be a mirror image of the Arctic stocks. This is supported by the correlation shown in Figure 12. The result for 1906–1929 is indeterminate, but for 1930–1990 there is a negative correlation with $r^2 = 0.150$ over $n = 62$. This is only significant at the $p = 0.01$ level but would in fact be significant at $p = 0.001$ if the group of (ringed) outliers at low (and from the conditions prevailing at the time, surely suspect) 1940–1945 wartime catches in some of the Arctic stocks are excluded.

The correlation between the New England stocks and the North Sea cod 1906–1990 (Figure 13) is, however, positive, $r^2 = 0.318$, $n = 85$, $F = 38.66$, and $p<0.001$. This also looks convincing, though we note in Figure 11 that the effect on landings of the strong recruitment to the North Sea fishery in 1971/1972 has no such clear counterpart in the landings from stocks in SA5 and 6. Given the trends in exploitation described above, this relationship does therefore suggest a common effect, but with opposite sign in the two stock areas. Similar features can also be seen in the Nova Scotia time series in Figure 11. A third correlation of the Arctic Stock and the North Sea is "good in parts", but not significant.

Given the nature of the data and the scope for confounding factors we find the correlations somewhat surprising. The trend of increasing exploitation has been shown to be quite general. The opposing sign of the correlations is what one might expect of a climatic effect on a long time scale which affects stocks on both sides of the Atlantic at the *same* "ecological latitude" in the same way, but in a way which is reversed in the Arctic stocks. On the evidence, Faroe is at an ecological "point of balance".

The signs of the trend change from south to north. Further evidence of an environmental effect can be seen in Figure 11 by comparing recent catches from the North Sea and Baltic. They have suffered a comparable de-

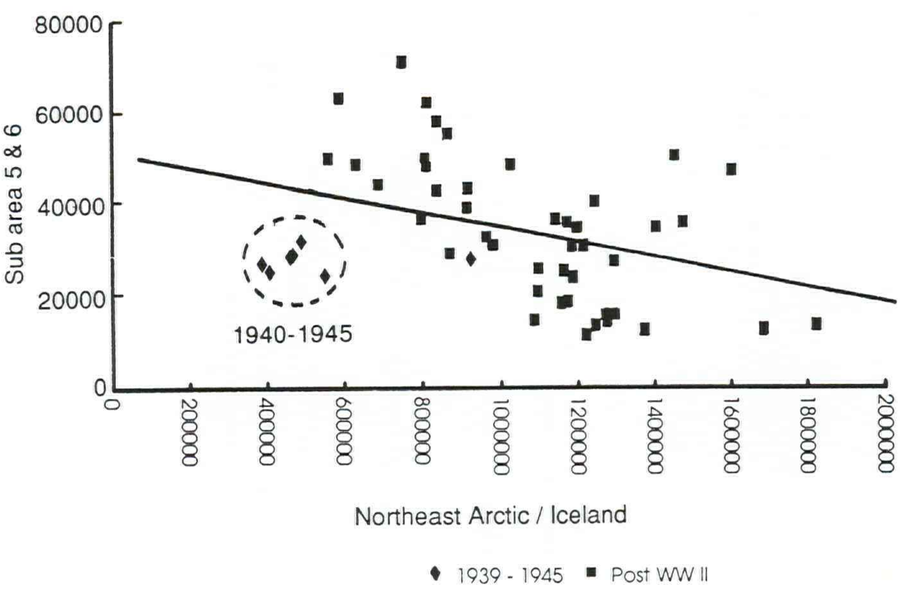

Figure 12. Regression of landings in Arctic (Northeast Arctic and Iceland) and NAFO S.A.5&6 cod stocks 1929–1990. ◆ 1939–1945; ■ post-World War II.

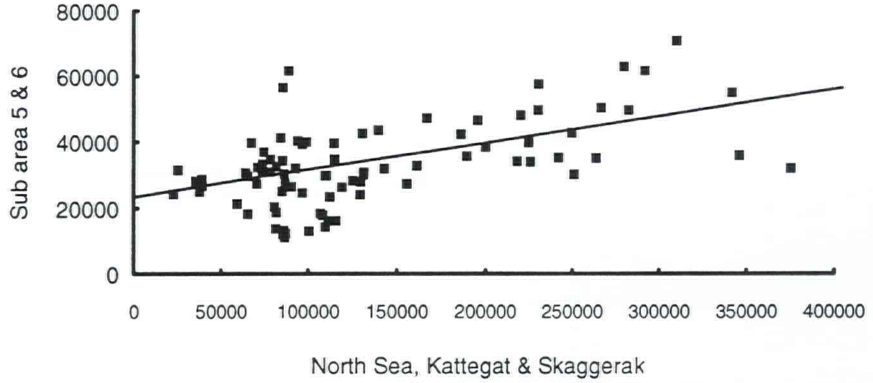

Figure 13. Regression of landings from North Sea and NAFO S.A.5&6 cod stocks 1906–1990.

cline, with a two-year lag into the Baltic. A similar feature can also be seen in the way the decline in the Labrador and Newfoundland catches lags behind the records for the Greenland fishery. Other analyses of individual stocks will consider likely environmental mechanisms responsible for these and similar effects. The present, admittedly simplistic approach does nevertheless argue in support of a widespread environmental trend affecting cod stocks through at least half the century, but with local effects superimposed in individual stocks, and in addition to the effect of fishing.

There are others better placed than us to identify the factors responsible. Dickson (1994) reminds us of classic papers that have established that "warming and salinification have been accompanied by radical northward shifts in the boundaries for a wide range of marine species". Ellet and Blindheim (1991) quote Ghil and Vautard's (1991) reconstruction of the principal component of the temperatures, the only example we know which purports to represent the northern hemisphere as a whole and thereby aggregates all the factors into a single annual figure. Ghil and Vautard's Figure 10 is reproduced with the Arctic cod catches in Figure 14 and the regression with Arctic cod catches (Arcto-Norwegian plus Iceland) in Figure 15, where $r^2 = 0.46$. It is actually difficult to find an environmental characteristic which, untuned, will correlate with fisheries data. This one just appeared without the usual diligent search and it is really quite difficult to escape the conclusion that this fits the broad trend of catches in the Arctic stocks quite well – up to the mid-1970s at least!

The entire time series might then be interpreted as showing the northward increasing relative abundance of cod comparable to the shift in boundaries referred to by Dickson and reflected here in the increased recruitment of cod to Arctic stocks. It might then be thought that the northward shift should be echoed by similar warming at the southern boundary of the distribution, which might be less then beneficial to recruitment there. From the negative sign of the North American/Arctic stock corre-

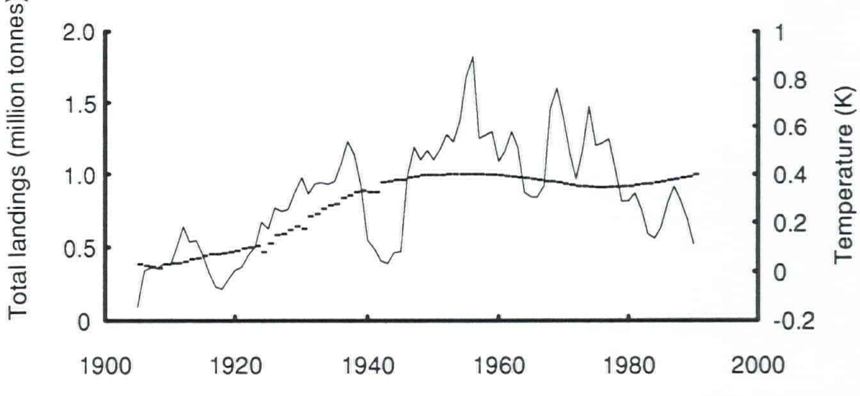

Figure 14. Comparison of combined Northeast Arctic and Iceland cod landings with the principal components of averaged surface air temperatures in the northern hemisphere (Ghil and Vautard, 1991). —— Total landings (million tonnes); - - - - - - Temperature (K).

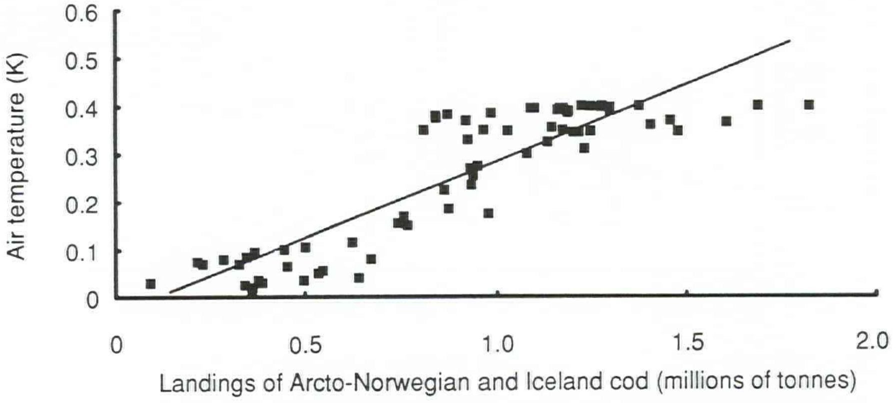

Figure 15. Regression of combined Northeast Arctic and Iceland cod landings on principal component of air temperature (as above).

lation and the positive North American/North Sea regression, that does indeed appear to be so. North Sea cod, for example, may not always benefit from colder climes, as Holden has proposed (1993) – but they may well be at a *disadvantage* on the southern boundary in the warm years. The two are not quite the same.

Figure 16 is a schematic interpretation, showing a hypothetical sinoidal band of increasing temperature covering the physiological range, which represents the potential for successful recruitment and therefore the potential geographical distribution of the stocks. As the physiological range moves northward with a warming trend there will be an increasing probability of good recruitment in warm years on the "cold" boundary, and a decreasing probability on the warm side. Hence the apparent inverse correlation between the Arctic stocks and those on the southern side, with the Faroe generally well within the range and showing relatively little response.

Whilst it is not yet possible to read the recent temperature changes in the context of a longer series, the continuing recent declines in cod stocks in some areas, e.g. Iceland/Faroe, do not appear to correspond to the Ghil and Vautard (1991) environmental principal component as convincingly as in the earlier years. A reduction in catches associated with reduced recruitment

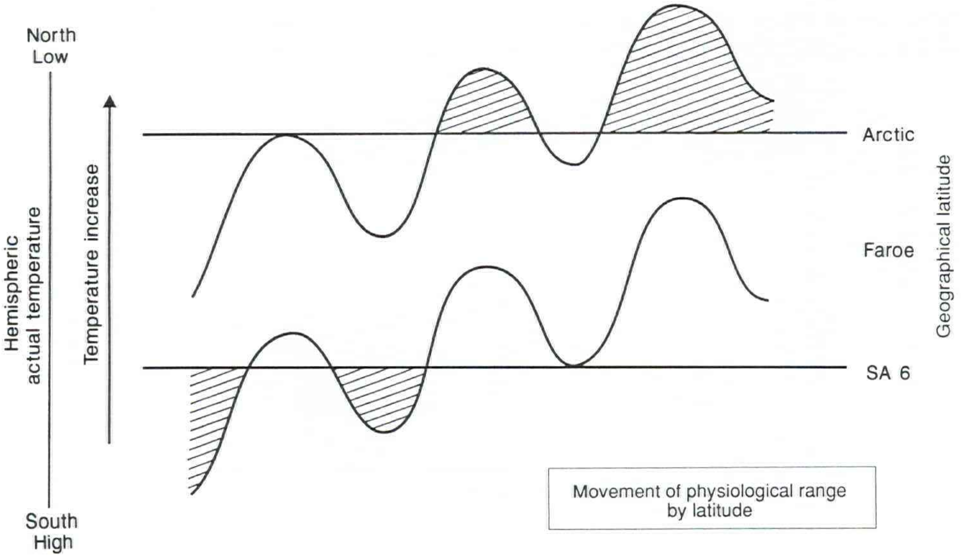

Figure 16. Schematic representation of trends in reproductive success with temperature as an index of favourable environmental conditions.

against the run of environmental expectation could occur as a result of a stock and recruitment relationship. The long-lived, late-maturing Arctic cod stocks on both sides of the Atlantic would be the most vulnerable to such an effect under sustained high levels of exploitation.

So what does the evidence of the time series amount to? First, a generally upward trend in catches into the mid-1960s was to be expected as fisheries were expanded and existing stocks were fished to a "lower" equilibrium level of standing stock. But whilst almost all stocks taken individually (and SA5 & 6 and North Sea series correlated together) conform to this pattern, the inverse relation between SA5 & 6 and the Arctic, even within the increasing trend, suggests that the effect of increasing exploitation has been superimposed on some wider pan-Atlantic scale environmental change most evident in the middle years of the century. By the statistical definition the correlation between some sets of catches and the Ghil and Vautard principal component parameter can hardly be fortuitous even though one may find it too facile, and as colleagues will hasten to point out it gives no indication of the mechanisms involved. But we think it is useful to have this wider evidence of changes in stocks and catches over such a geographical scale and which can be associated with a single environmental index, albeit a proxy for the real events, in a rational way. That the index is a derivative of temperature will confirm long-held presumptions and perhaps strengthen existing convictions, helping to focus forthcoming investigations.

Conclusion

We conclude from this analysis that the magnitude of variation in the POTENTIAL – the potential – for North Atlantic cod production has been strongly influenced by environmental circumstances, though the Ghil and Vautard "index" is not necessarily the most appropriate or only index. Other ecosystem constraints determine the actual stock production and therefore yield potentials, and this is in turn modulated by exploitation and by management to the extent it has, or could, control exploitation.

Recognition that environmental factors exert an important influence is not new. However, while the stronger evidence is useful because it confirms common sense, it should NOT be taken to mean that an environmental influence affecting stock decline provides justification for discounting future stocks and allowing unrestrained increases in fishing in order to maximize yield now. The North Atlantic cod stocks seem now to be environmentally weakened relative to, say, the 1950s. They are then especially vulnerable and there is even greater necessity to avoid double exposure to the additional risk of recruitment overfishing. In these circumstances, the level of exploitation needs to be even more carefully controlled to provide the basis for a future recovery. It is not an excuse for a "free for all" bonanza! It represents, in a sense, an application of the precautionary principle in fisheries, and should only be rejected if there is incontrovertible evidence that the stock will be totally lost regardless of the level of exploitation. We find it difficult to conceive of circumstances where this could apply and, indeed, remain concerned that if exploitation maintains the apparently inexorable trend of the last forty years the truly great North Atlantic cod will disappear.

Acknowledgments

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References

Anon. 1959–1988. Northwest Atlantic and NAFO Statistical Bulletins.

Baird, J. W., Bishop, C. A., and Murphy, E. F. 1991a. An assessment of the cod stock in NAFO Divisions 2J + 3KL. CAFSAC Res. Doc., 91/53, 84 pp. (mimeo).

Baird, J. W., Bishop, C. A., and Murphy, E. F. 1991b. An assessment of the cod stock in NAFO Division 3NO. NAFO SCR Doc., 91/83, 33 pp. (mimeo).

Buch, E., Horsted, S. A., and Hovgård, H. 1994. Fluctuations in the occurrence of cod in Greenland waters and their possible causes. ICES mar. Sci. Symp., 198: 158–174.

Campana, A. S., and Hamel, J. 1991. Status of the 1990 cod fishery in 4X. CAFSAC Res. Doc., 91/48, 48 pp. (mimeo).

Cushing, D. H. 1988. The provident sea. Cambridge University Press, 329 pp.

Daan, N., and Heessen, H. 1994. Cod and climate in the North Sea. Paper No. 13 presented at the Symposium on Cod and Climate Change. Reykjavik, Iceland, 23–27 August 1993. See also Daan *et al.*, 1994; and Heessen and Daan, 1994. ICES mar. Sci. Symp., 198: 229–243, 244–253.

Dickson, R. R., Briffa, K., and Osborn, B. T. 1994. Cod and climate; the spatial and temporal context. ICES mar. Sci. Symp., 198: 280–286.

Ellett, D. J., and Blindheim, J. 1992. Climate and hydrographic variability in the ICES area during the 1980s. ICES mar. Sci. Symp., 195: 11–31.

Fanning, L. P., and MacEarchern, W. J. 1991. Assessment of 4Vs, W cod. CAFSAC Res. Doc., 91/44, 42 pp. (mimeo).

Frechet, A., Schwab, P., and Gagnon, P. 1991. Evaluation du stock de morue du nord du Golfe de Saint Laurent (Divisions de l'Opano 3Pn, 4R et 4S) en 1990. CAFSAC Res. Doc., 91/43, 54 pp. (mimeo).

Ghil, M., and Vautard, R. 1991. Interdecadal oscillations and the warming trend in global temperature time series. Nature (Lond.), 350: 324–327.

Hanson, J. M., Ghouinard, G. A., Nielsel, G. A., and Currie, L. G. 1991. Stock status of the Southern Gulf of St Lawrence cod stock. CAFSAC Res. Doc., 91/49, 69 pp. (mimeo).

Holden, M. J. 1993. The common fisheries policy: origin, evaluation and future. Fishing News Books, Oxford. 274 pp.

ICES, 1966. Report of the North-Western Working Group, ICES CM 1966/G: 1.

ICES, 1969. Report of the Working Group on Assessment of Demersal Species in the North Sea. Coop. Res. Rep., Ser. A., No. 9, 74 pp.

ICES, 1986. Report of the Saithe (Coalfish) Working Group. ICES CM 1986/Assess: 18.

ICES, 1991. Report of the Arctic Fisheries Working Group. ICES CM 1991/Assess: 3.

ICES, 1991. Report of the Division IIIa Working Group. ICES CM 1991/Assess: 9.

ICES, 1991. Report of the Working Group on the Assessment of Demersal Stocks in the Baltic. ICES CM 1991/Assess: 16.

ICES, 1991. Report of the North-Western Working Group. ICES CM 1991/Assess: 21.

ICES, 1992. Report of the Irish Sea and Bristol Channel Working Group. ICES CM 1992/Assess: 1.

ICES, 1992. Report of the Roundfish Working Group. ICES CM 1992/Assess: 4.

Kristiansen, A. 1992. Landings of Faroe cod. Pers. comm. 3 March 1992 ref. Bull. Stat., 1903–1939. Hoydal 1952–1984. ICES WG 1985–1991.

Mann, K. H. 1993. Physical oceanography, food chains, and fish stocks: a review. ICES J. mar. Sci., 50(2): 103–119.

Moguedet, P. 1991. Variation in cod stock abundance in NAFO Subdivision 3Ps in the period 1978–1990. CAFSAC Res. Doc., 91/114, 5 pp. (mimeo).

Vasquez, A. 1991. Flemish Cap stock analysis. CAFSAC Res. Doc., 91/95, 18 pp. (mimeo).

Wooster, W. 1992. Advances in fisheries/oceanography in relation to climate change and fish populations. ICES CM 1992. Special Lecture.