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The Fluctuations in Abundance of the Stock of Cod Compared to Environmental Changes and the Fishery

by

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1. Abstract:

The yield of cod in the Baltic has fluctuated due to varying fishing effort and to varying strength of year classes. The success of reproduction is closely related to the salinity and the oxygen conditions in the depth strata where the cod eggs are able to flow (a salinity of 10-11 permille). A peak in abundance and a maximum yield in historical time have been registrated in the middle of the eighties followed by a drastic decline. The fluctuations in abundance will be discussed in the light of fishing effort, inflow of saline water and eutrophication.

2. Introduction to the Area.

The Baltic Sea is the largest brackish waterbody in the world covering an area of 375.000 km^2 with a volume of 22.000 km^3. The mean depth is 34 m and the maximum depth 459 m (Landsort Deep). The drainage basin covers an area of 1.750.000 km^2 yielding about 470 km^3 freshwater per year.

The Danish Straits and the Kattegat form a transition area to the North Sea (Fig. 1). Precipitation and evaporation is of the same order of magnitude, which means that the net outflow from the Baltic Sea is equal to the run-off from the drainage basin. The water exchange through the Danish Straits is however 6-10 times larger and dependent on differences between the surface level in the Kattegat and the western and central parts of the Baltic caused by the barometric situation. This means that inflow of saline water mainly is caused by persistent westerly winds, but also by a deep water current generated by the horizontal salinity gradient between the North Sea and the Baltic Sea.

2.1. The Salinity.

The Kattegat, the Danish Straits and the westernmost part of the Baltic are meeting points for the high saline water masses from the North Sea (35 o/oo), and the brackish water masses from the Baltic (8-10 o/oo in the surface). Due to the difference in gravity a stratification will occur with the brackish Baltic water in the surface and the more saline North Sea water along the bottom.

In the transition areas there are two sills over which 20 % and 80 % of the inflows respectively have to pass, one in the southern Sound at Drogden (depth 6 m) and another at Dars (depth 18 m) (fig. 1), which prevent inflow of high saline water under average weather conditions and which cause a mixing of bottom and surface water reducing the salinity of the inflowing water very much. Only under extreme weather conditions high saline water is forced over the sills. The result is according to salinity that 3 strata are found in the Baltic, a more saline bottom layer, an intermediate layer with lower salinity and a brackish surface layer. Big inflows of high saline water occur very irregularly, several years may pass in between. The salinity in the bottom layer in the Bornholm Deep, in the Gdansk Deep and the Gothland Deep may be 18, 14 and 11 o/oo respectively - but decreasing in periods with no inflow. The surface layer which is almost isohaline vertically is separated from the deep water by the primary halocline. The transition layer is about 10-20 m thick. The depth of the halocline increases from 50-60 m in the Bornholm Deep to 80 m in the Gothland Deep. The salinity in the surface layer is about 7 o/oo in the Gothland Deep and 8 % in the Bornholm Deep.

2.2. The Oxygen.

The surface layer above the halocline is supplied with oxygen by thermal convection but the halocline forms an effective barrier to convection, which means that the main oxygen supply below the halocline is dependent on inflow through the Danish Straits. Due to sedimentation of organic matter, there is a persistent oxygen consumption, which if not made up for by inflow results in a permanent but varying oxygen deficiency in the deeps depending on the frequencies of inflows. Since 1977 no major inflow has occurred (Fonselius, 1984 and MS 1991) and the actual situation is a decreasing salinity, a decreasing oxygen content and development of hydrogen sulfide in the eastern deeps (Matthäus, 1991 and Juhlin, 1990).

2.3. The Fish Fauna.

The biomass of the fish fauna is dominated by a small number of species of which the most important according to biomass are herring, cod, sprat and flounder, mentioned in order of magnitude. The total biomass of these was in 1990 about 6.5 mill. tonnes. Other species are salmon, sea trout, 4. bearded rockling, 3-spined stickleback and turbot. In the western part of the Baltic the diversity is increasing due to a higher salinity and a smaller distance to the Kattegat.

3. The Baltic Cod.

3.1. Cod stocks.

There are two stocks of cod in the Baltic Sea which are quite well separated by a border along longitude 14°30'E immediately west of Bornholm (Fig. 1). On the eastern side the true Baltic cod stock is found up to about the latitude 63°N. On the western side the transition area cod stock is found up to the southernmost Kattegat. The separation of stocks is shown by meristic characters (Schmidt, 1938), by electrophoresis (Sick, 1965, Jamieson and Otterlind, 1971) and by numerous tagging experiments (Aro, 1989). A review of stock identification in the Baltic is given by Bagge and Steffensen (1989).

The total stock size of the western and eastern stock was in 1989 40.000 tonnes and 350.000 tonnes respectively (Anon.,1991).

In the following only the eastern stock shall be dealt with.

3.2. Landings.

The landings of cod from Subarea III d (Bull. Stat. and Anon. 1973-90) being identical with ICES Subdivisions 24-32 are shown from 1911-1990 in table 1. It should be mentioned that as Subdivision 24 is included, part of the western stock is included as well, but only amounting to 3-5 % of the total. It appears that until 1938 the total landings were below 30.000 tonnes. During the Second World War landings increased to about 80.000 tonnes. Following a drop just after the War the landings increased to a varying level of 112-197.000 tonnes in the period 1948-74. From 1979 the landings increased drastically to a maximum of 413.000 tonnes in 1984 and declined then in 1990 to the level of the sixties, 165.000 tonnes.

The reasons for the growing yield may be either an upward change in fishing effort or stock size or both.

3.3. Stock size.

3.3.1. Abundance as indicated from catch and effort.

Up to the second half of the thirties the fishing effort on cod was low, the main fishery was on flounder and in the western part also on plaice. (Jensen, 1954). Due to the outbreak of the Second World War, it was not possible for the German fleet to work in the North Sea, why 85 steam-trawlers were transferred to the Baltic. From table 1 it appears that the increase of landings 1939-44 were almost caused by this effort exclusively. Thurow (1971) gives an evaluation of the early development of effort and abundance based on data given by several authors (Alander, 1948 and 1949; Dementjeva, 1959; Jensen, 1954; Kändler, 1944 and Sahlin, 1959).

Growth in effort is suggested to be:

Germany between 1931-35 and 1937-38	2.6 times
Denmark between 1931-35 and 1936-39	2.5 times
Denmark between 1936-39 and 1950-53	2.7 times

Denmark between 1931-35 and 1950-53	7.0 times
USSR between 1948 and 1951	4.0 times
Sweden between 1933 and 1957	3.6 times

During the same period the catch per unit effort seems to have increased slightly but as data are scattered, partly obtained by research vessels in different areas and not comparable they are probably not reliable. An exception is the data given by Dementjeva (1959) based on commercial vessels as yearly mean catch/hour 1948-56, which show a decrease from 1948-53 followed by an increase to the same level as in 1948. Otterlind (1971) presents the catch of cod per fisherman in the trawl fishery 1932-70 of the Swedish South Coast which shows a small increase from 1932-40, a sharp increase from 1940-48, a decrease from 1948-53 followed by an increase onward to the beginning of the sixties. This coincides very well with the catch per unit effort in the period given by Dementjeva but it should be stressed that part of the transition area stock is included in the Swedish data.

Tiews (1971) compared the catch per hour of cod made by the German steam-trawlers (1934-44) with the catch per hour made by the research vessel "Anton Dohrn" 1962-70 in the Bornholm Deep the Gdansk Bay and the southern *Gothland* Deep. The catch rates in the Bornholm Deep in 1966, 1969 and 1970 were similar to those from 1939-44, but in the Gdansk Deep and the Gothland Deep the catch rate in 1969 and 1970 were much higher. Due to varying oxygen conditions near the bottom in the Baltic, catch per unit effort data from research vessels with bottom trawl are possibly not reliable, because these vessels are working in short periods, which means that the choice of period may have the main influence on the catch. Data obtained from commercial vessels working the whole year are better.

Data from commercial USSR 150 hp vessels (1974-88) have been submitted to the ICES Working Group on Demersal Species in the Baltic. The data are shown in table 2 together with the figures of Dementjeva (1959), which refer to the same area (Eastern Gothland Deep) and the same type of vessels (Latvian trawlers). The stock in the period 1948-56 was on a lower level than in the period 1974-86. After 1986 the stock has declined to the level of the former period. The maximum catch/day was observed in 1979 and 1980.

3.3.2. Abundance estimated from VPA.

The first VPA on the Baltic stocks based on national age readings of landings was run in 1975 (Anon., 1975). An attempt based on Polish age readings only was made in 1972 (Anon.,1973). Since 1975 the VPA has been updated yearly by the Working Group on Assessment of Demersal Stocks in the Baltic (Anon., 1975-91).
Until 1987 the natural mortality was estimated to be 0.3 but from 1988 and onwards it was reduced to 0.2. The effect of this measure was that the biomass at the beginning of the year was reduced by about 30%. At the same time the maturity ogive was changed. Therefore the 1991 VPA is used with a correction for the years before 1970. The recruitment, spawning, stock size, the fishing mortality and the yield 1966-1990 are shown in fig. 2, (Anon. 1991). The recruitment at age 2 increased from a level 300 mill. in the sixties to more than 450 mill. in 1972, 1975, 1976, 1977, 1979, 1980 and 1981 with the largest year-class ever in 1976 (770 mill.). Since 1981 the recruitment has continually decreased (except in 1985). The level of recruitment of the year classes 1989 and 1990 was below 1 mill.. The yield increased to a maximum of about 400.000 tonnes in 1984 and then declined to about 156.000 tonnes in 1990. The fishing mortality had an increasing trend since 1979 reflecting a heavy increase of effort due to transfer of fishing vessels from the North Sea, a change to larger vessels and the introduction of pelagic trawling for cod.

The development of pelagic single boat trawling which was introduced by FRG vessels made it possible to fish continually on a diurnal basis in contrast to bottom trawling, which can only be performed in areas with sufficient oxygen near the bottom and only from sun-up to sundown, because the cod leave the bottom when it gets dark. In that way the effort increased at least by a factor 3 for vessels switching over to that method.

From fig. 2 it appears that the fishing mortality in the sixties was almost as high as in

1990. This is very astonishing and is most likely an artefact caused by applying unrealistically high fishing mortalities in the early VPA's.

4. The reproduction of Baltic cod.

4.1. Spawning area.

There are 3 main spawning areas for Baltic cod, the Bornholm Deep, the Gdansk Deep and the Gothland Deep (Fig. 1). The spawning usually begins in March, reaches maximum in May-June and finishes in September.

4.2. Salinity and oxygen.

A salinity of not less than 10 o/oo is necessary to keep the eggs afloat (Grauman, 1973). At a lesser salinity the eggs are deposited on the bottom and do not develop, but even if the salinity allows the eggs to float, the oxygen content is a determining factor for the development.

Fertilization of the eggs is possible at lower salinities than 10 o/oo, but with a rapidly decreasing percentage of fertilization and with cease of further development (Westin and Nissling, 1991).

The cod eggs are found below the halocline in the Bornholm Deep between 60 and 75 m at a salinity of 11-13 o/oo, in the Gothland Deep at a depth of 80-100 m. The oxygen content in the strata where the eggs are concentrated may vary from 0.5-6.0 ml/l varying between months and years depending on inflow of saline and oxygenated water from the North Sea.

The lower limit for oxygen content at which development of cod eggs is possible is 1 ml/l at which level the egg mortality is very high (Grauman, 1973). Experimental investigations on cod eggs from the Bornholm Deep, (Wieland and Zuzarte, 1991) indicate that below 2.3 ml/l development of the eggs does not exceed stage III. Hence a combination of a salinity not less than 11 o/oo and an oxygen content not less than about 2.3 ml/l is very important for survival of the cod eggs. As salinity and oxygen content below the halocline is dependent of inflow from the North Sea stagnant periods, which reduce the salinity and the oxygen content, have a negative effect on the year-class strengths in the Baltic.

5. Inflows and stagnant periods.

Long-term trends of salinity below the halocline in the Gothland Deep are shown in Fig. 3 (Fonselius, 1984 and Matthäus, 1991). Periods with continuously decreasing salinity values were observed in 1922-1933 and 1952-62. Both periods began with very high salinities, possibly caused by heavy inflows. A big inflow into the Gothland Deep began in 1935 but due to the war, no further information exists between 1940 and 1947. After the 1952 inflow 4 smaller ones occurred with stagnant periods in between. The last major inflow occurred in 1979 (Mathäus, 1991). In Fig. 4 is shown the salinity and oxygen at station BY 9 in the south-eastern Gothland Deep from 1979 till 1990 (Olenin, 1991). An improvement of oxygen content in late 1983 and 1984, which is out of the spawning season for cod has happened. But in 1985 the improvement was within that season. It should be mentioned that the last average yearclass was produced that year. In Fig. 5 is shown the salinity, temperature and oxygen content in March 1991 on stations in the central Gothland Deep in a line from the central east coast of Gothland to off Libau at the Latvian coast. It appears that the oxygen content at a salinity of 11 o/oo is too low for successful development of cod eggs, further that hydrogen sulfide is found below 140 m.

Some authors have demonstrated a positive correlation between inflows and yearclass strengths of cod (Bay, 1981 and Kosior and Netzel, 1989).

6. Discussion.

Besides giving an effect of increasing salinity and oxygen content inflows also force nutrients from the bottom to the photic zone stimulating the primary production and this effect may be very important for a successful development of cod larvae.

Around 1920 the dominance of winds from WSW increased by about 25% (Jensen, 1953), which may have supported the inflows to the Baltic and the following increase of the stock size. In 1957 an increase of effort in combination with improved fishing methods resulted in a fishing yield of maximum 196.000 tonnes. The explosive development of the stock in the late seventies and the eighties cannot be explained by inflow and effort exclusively but possibly by an increased level of nutrient input from other sources (freshwater outlets and the atmosphere (nitrogen)), which together with a proper salinity and oxygen regime has produced the rich year classes (1972, 1975, 1976, 1977, 1979, 1980, 1981 and 1985). The stagnant period since 1979 during which the oxygen consumption has increased due to an increased sedimentation of organic matter has caused the production of a series of small year classes, especially in the Gothland and Gdansk Deep (Uzars et al., 1991). The reproduction of cod in the Baltic seems at present to be dependent on the spawning success in the Bornholm Deep exclusively.

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Table 1. Catch of cod from the Baltic (Subarea IIId). Subdivisions 24-32. (1000 tons).

Year	Denmark	Faroe Isles	Finland	Germany FRG	Germany DDR	Poland	Sweden	USSR	Total Bull.Stat.	Grand total
1911	0.4	-	-	0.4		-	0.7	-	1.6	-
1912	0.5	-	-	0.6		-	0.6	-	1.7	-
1913	0.5	-	-	0.8		-	0.7	-	1.9	-
1914	0.7	-	-	0.9		-	1.2	-	2.8	-
1915	1.4	-	-	1.2		-	1.8	-	4.3	-
1916	1.0	-	-	2.3		-	1.6	-	4.8	-
1917	0.5	-	-	0.7		-	0.9	-	2.2	-
1918	0.6	-	-	0.6		-	0.9	-	2.1	-
1919	0.9	-	-	0.5		-	1.4	-	2.8	-
1920	1.3	-	-	0.9		-	2.3	-	4.5	-
1921	1.1	-	-	1.0		-	2.2	(1)	4.3	5.3
1922	0.9	-	-	1.5		0.1	2.2	(1)	4.8	5.8
1923	0.9	-	-	1.9		0.2	1.9	(1)	4.9	5.9
1924	1.0	-	-	1.3		0.1	1.6	1.3	5.3	5.3
1925	1.1	-	-	1.7		0.1	2.4	2.5	7.7	7.7
1926	1.3	-	-	1.8		0.1	2.7	1.5	7.4	7.4
1927	1.2	-	-	1.8		0.1	2.7	1.1	6.9	6.9
1928	1.2	-	-	2.0		0.2	2.6	1.2	7.2	7.2
1929	0.8	-	-	1.5		0.2	1.6	0.7	4.8	4.8
1930	0.9	-	-	1.5		0.1	1.6	0.5	4.6	4.6
1931	0.8	-	-	1.1		0.2	1.5	0.6	4.1	4.1
1932	0.7	-	-	1.7		0.4	1.9	0.9	5.6	5.6
1933	1.0	-	-	2.0		0.3	1.9	1.6	6.8	6.8
1934	1.4	-	-	2.3		0.5	2.7	0.8	7.7	7.7
1935	1.7	-	-	3.0		0.5	5.0	1.0	11.2	11.2
1936	1.9	-	-	4.5		0.9	5.9	3.0	16.2	16.2
1937	1.9	-	-	7.7		1.7	6.2	3.3	20.9	20.9
1938	3.5	-	-	8.6		1.1	6.9	3.4	23.4	23.4
1939	3.7	-	-	14.0		2.7	7.6	3.4	31.5	31.5
1940	6.3	-	-	34.2		-	6.1	12.9	46.6	59.5
1941	14.3	-	-	52.9		-	8.1	(5)	75.3	80.3
1942	13.3	-	-	44.6		-	8.2	(5)	65.9	70.9
1943	9.9	-	-	53.1		-	11.9	6.1	74.8	80.9
1944	9.6	-	-	42.6		-	8.6	(5)	60.7	65.7
1945	2.8	-	-	5.0	-	1.5	11.6	(5)	14.4	25.9
1946	8.5	-	-	3.4	-	19.2	11.2	5.8	20.6	48.1
1947	8.1	-	-	18.8	(1)	29.4	14.8	10.9	22.9	83.0
1948	10.6	-	-	28.7	(2)	32.6	21.1	17.8	31.6	112.8
1949	14.4	-	-	24.4	(3)	37.7	25.8	25.6	64.6	125.9
1950	6.6	-	-	13.2	6.0	48.0	20.3	41.9	40.0	136.0
1951	11.7	-	-	3.2	8.0	51.2	20.5	46.9	35.6	141.5
1952	13.0	-	-	3.7	7.0	61.2	24.6	49.0	41.4	158.5
1953	12.4	-	0.1	3.6	12.0	46.6	19.5	28.2	35.5	122.4
1954	11.4	-	0.1	3.7	12.0	48.7	18.6	40.6	33.8	135.1
1955	12.9	-	0.1	4.2	12.0	39.0	20.6	37.6	114.3	126.4
1956	11.8	-	0.1	4.3	14.0	50.0	19.8	61.4	147.3	161.4
1957	16.0	-	-	10.7	23.0	56.2	26.4	64.6	173.8	196.9
1958	17.6	-	0.1	8.7	21.0	36.5	20.8	46.1	129.8	150.8
1959	19.0	-	-	7.4	18.0	35.0	22.6	40.5	124.5	142.5
1960	19.8	-	-	10.1	10.0	49.4	27.3	44.4	151.0	161.0
1961	25.3	-	-	8.2	7.0	37.9	28.4	(30)	99.7	136.7
1962	22.1	-	-	5.4	7.0	40.9	25.1	31.3	129.9	136.9
1963	23.6	-	-	3.2	7.0	47.5	22.8	30.6	127.7	134.7
1964 1)	23.3	-	-	4.3	5.0	39.7	16.2	24.5	105.1	110.1
1965	21.5	-	-	5.2	7.2	41.5	21.4	22.4	105.2	119.2
1966	22.7	-	-	3.3	6.7	56.0	22.5	38.3	135.7	149.5
1967	25.8	-	-	2.5	16.8	56.0	23.4	43.0	144.6	167.6
1968	28.3	-	0.1	4.8	19.4	63.2	24.0	43.6	157.3	183.4
1969	29.4	-	0.1	7.2	21.8	60.1	22.3	46.6	154.2	182.5
1970	28.0	-	0.1	7.0	13.6	68.4	17.8	32.3	-	167.2
1971	30.0	-	0.1	4.6	7.4	54.2	15.7	20.9	-	132.9
1972	42.0	-	0.1	5.0	9.2	57.1	16.5	30.7	-	160.6
1973	44.7	-	0.1	15.9	10.4	49.8	18.4	20.1	-	159.4
1974	39.5	-	0.2	12.2	7.9	48.7	16.4	38.1	-	163.0
1975	46.5	-	0.3	12.5	11.3	69.3	18.0	49.3	-	207.2
1976	57.1	-	0.3	14.3	7.3	70.5	20.1	49.0	-	218.6
1977	54.6	-	0.3	18.9	10.0	47.7	17.6	29.7	-	178.8
1978	36.8	-	1.4	5.2	7.7	64.1	16.2	37.1	-	168.6
1979	41.6	3.9	2.9	10.5	8.0	79.8	22.4	75.0	-	244.1
1980	57.1	1.3	6.0	12.4	6.5	123.5	31.9	124.4	-	363.1
1981	75.7	2.7	5.7	9.2	11.2	120.9	43.4	87.7	-	356.5
1982	78.6	4.3	8.1	14.5	9.5	92.5	46.4	86.9	-	341.8
1983	92.3	6.1	8.9	16.2	9.1	76.5	53.6	92.2	-	354.9
1984	98.1	6.4	9.4	30.7	8.0	93.4	65.7	100.8	-	412.5
1985	91.1	5.9	7.2	26.8	5.1	63.3	54.5	78.2	-	332.1
1986	88.8	4.6	5.6	20.2	2.4	43.2	49.3	52.1	-	266.2
1987	74.3	5.6	3.0	15.3	4.6	32.7	47.3	39.2	-	222.0
1988	67.9	6.9	2.9	14.6	4.3	33.4	54.8	28.9	-	212.9
1989	61.9	4.5	2.3	13.2	1.9	36.9	55.7	14.7	-	191.1
1990	54.1	2.9	1.7	5.7	1.5	32.0	53.2	13.5	-	164.6

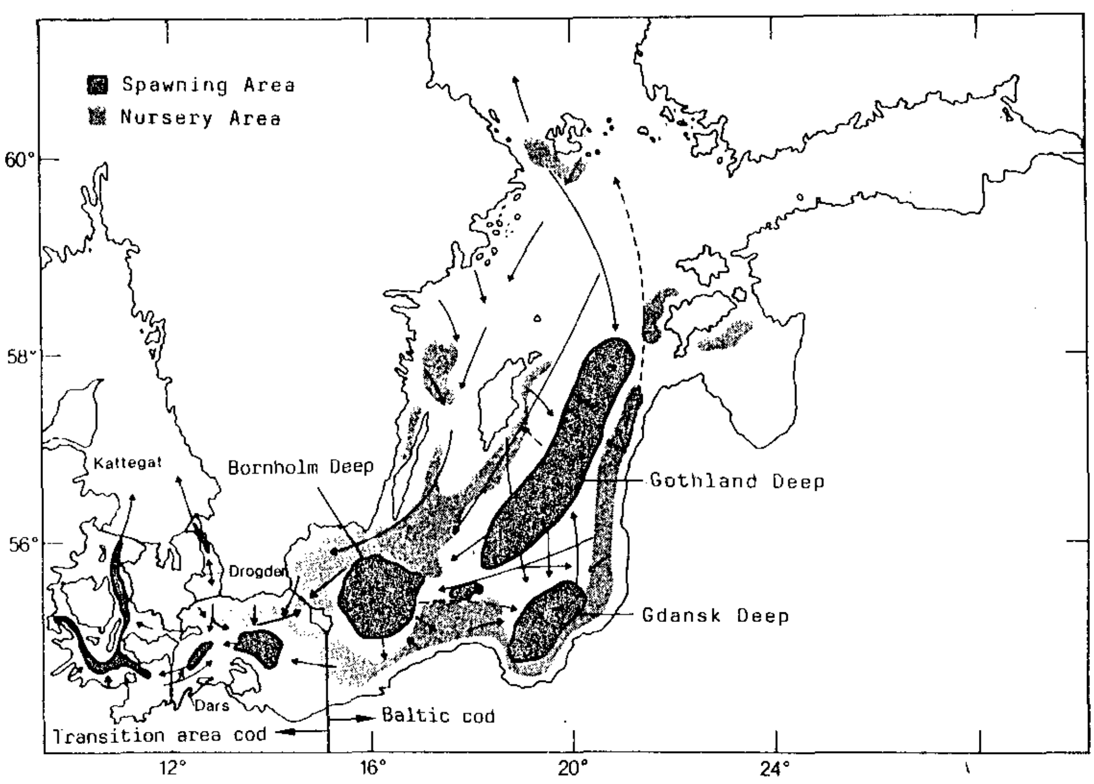
1) 1911-1964 after Thurow (1971) but without footnotes.

Table 2.

Year	Catch (tons)	Year	Catch (tons)
1948	1.82	1976	3.06
49	1.45	77	2.10
50	1.36	78	3.18
51	1.29	79	4.29
52	1.39	80	5.00
53	1.14	81	3.56
54	1.24	82	2.73
55	1.27	83	2.62
56	1.66	84	2.66
		85	2.18
		86	1.98
1974	2.50	87	1.75
75	2.60	88	1.24

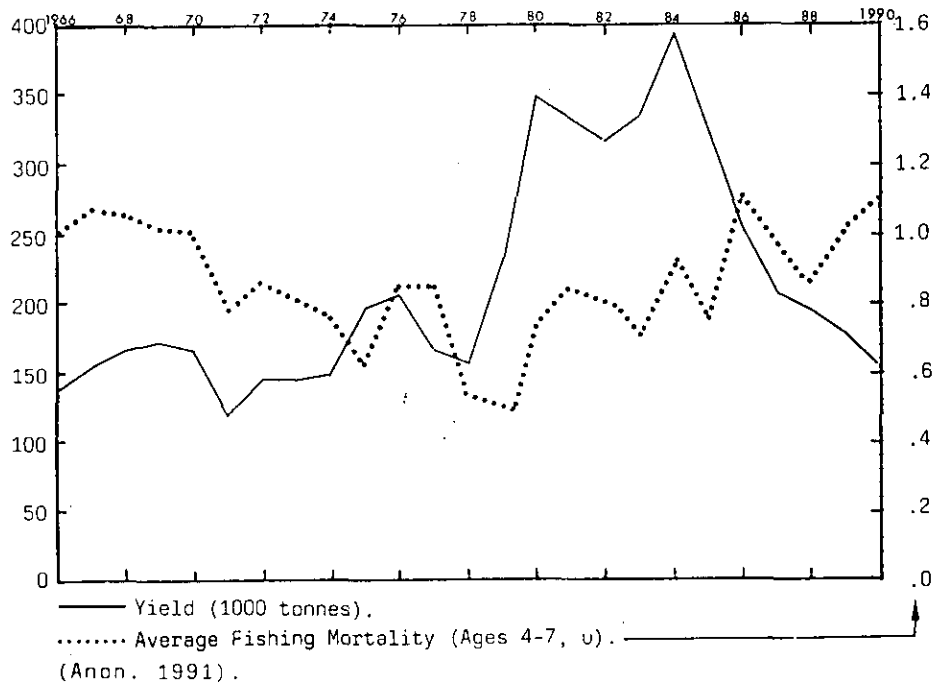
Mean daily catch by USSR trawlers in the Eastern Gothland Deep.
(1948-56 Dementjeva 1959. 120 hp trawlers)
(1974-88 Unpublished working paper (USSR). 150 hp trawlers).

Fig. 1. Spawning and Nursery Areas in the Baltic.



Full drawn arrows indicate spawning migrations, dotted arrows drift of young fish. (Anon. 1978, appendix. With some additions).

Baltic Cod. Subdivisions 25-32.



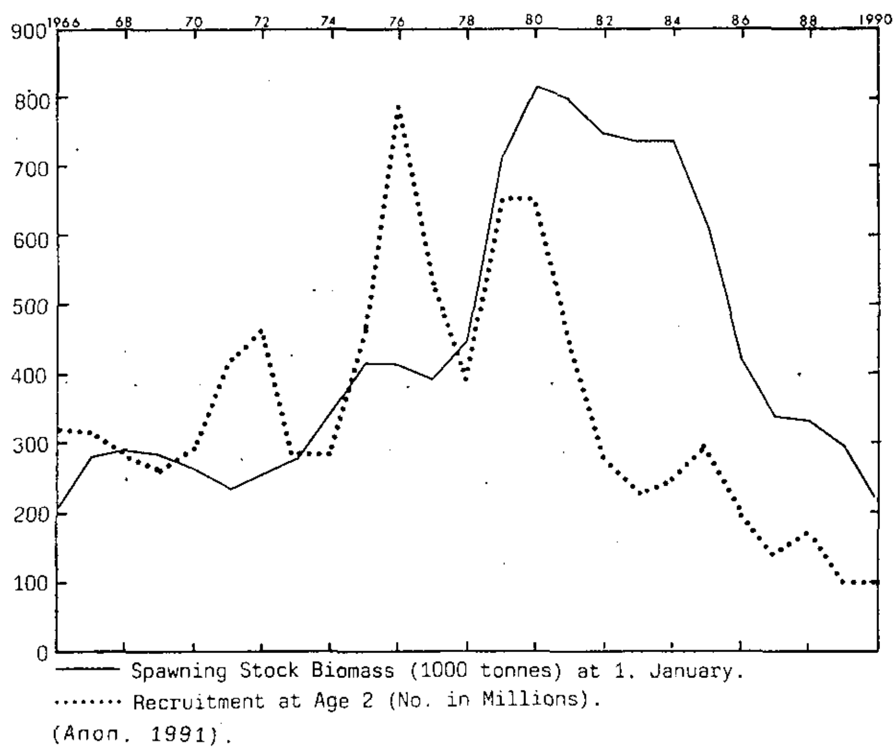


Fig. 2. Recruitment, spawning stock size, fishing mortality and yield during 1966-90.

Fig. 3.
Annual mean values of all available salinity data at the Gothland Deep station during the period 1890-1982. Sampling was carried out at 200 m depth. (Fonselius 1984).

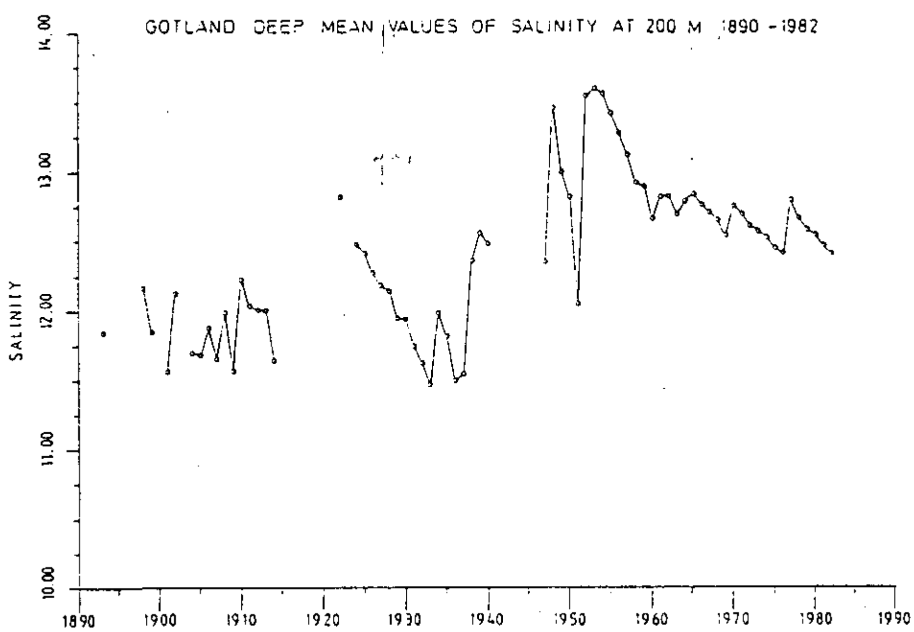
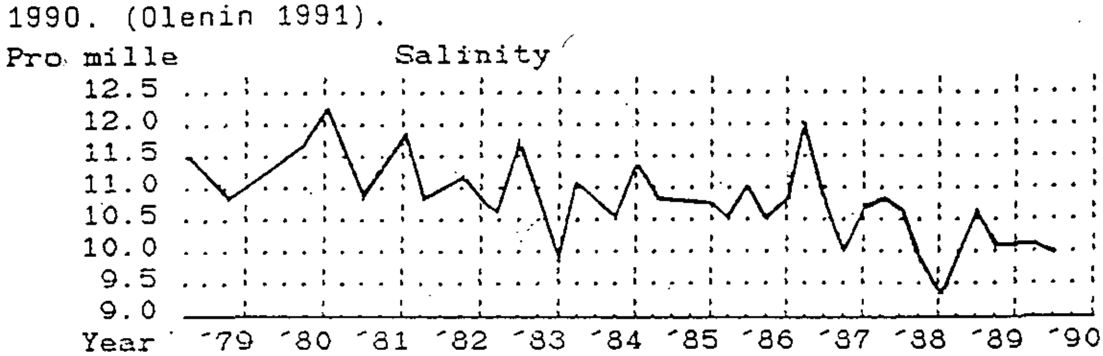
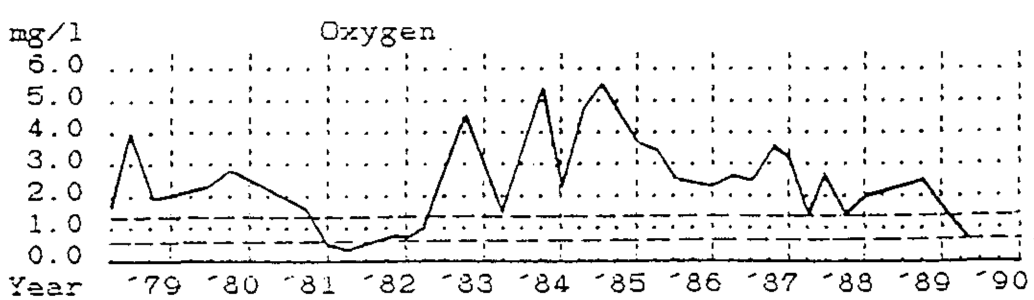


Fig. 4.
The salinity and oxygen content at station BY 9 in 1979-1990. (Olenin 1991).





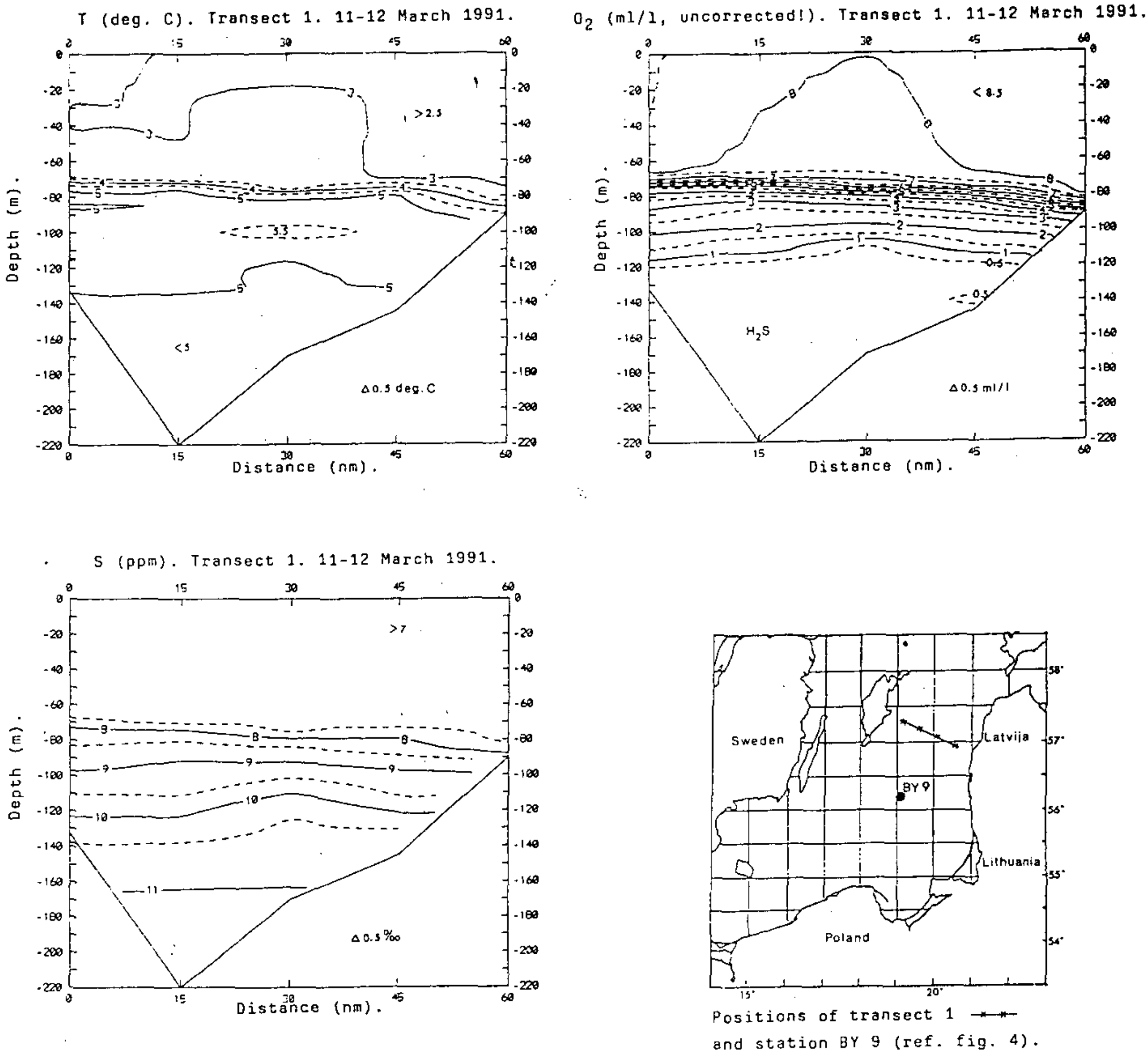


Fig. 5. Salinity, temperature and oxygen content in March 1991 on stations in the central Gothland Deep.