The Baltic cod stock: fluctuations and possible causes

Ole Bagge and Fritz Thurow

Introduction

The highest abundance of cod (*Gadus morhua*) in the recent history of the fishery was in the late-1970s to mid-1980s, followed by a dramatic decline (ICES, 1993). The yield has fluctuated owing to varying fishing effort and to varying strengths of year classes (ICES, 1988, 1991, 1993, and Thurow, 1974). The success of reproduction and hence the year-class strength is closely related to the salinity and the oxygen conditions in the depth strata where cod eggs are able to float (a salinity of 10-11). A peak in abundance and a maximum yield in historical time were registered in the mid-1980s, followed by a drastic decline. The fluctuations in abundance are discussed in the light of fishing effort, inflow of saline water from the North Sea, eutrophication, and predation.

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Salinity

The Kattegat, the Danish straits, and the westernmost part of the Baltic are meeting points for the high-salinity water masses from the North Sea (35), and the brackish water masses from the Baltic (8-10% at the surface). Because of the difference in the specific gravity of the two water masses, a stratification occurs with the brackish Baltic water on the surface. In the transition areas there are two sills, one in the southern Sound at Drogden (depth 6 m) and another at Dars (depth 18 m), (Fig. 1), over which 20% and 80%, respectively, of the inflows had to pass (Wyrtki, 1954). The inflow of January 1993 was found to have entered both entrances in almost equal proportions (Håkansson et al., 1993). The sills prevent the inflow of high saline water under average weather conditions and cause a mixing of bottom and surface water very much reducing the salinity of the inflowing water. Only under extreme...
weather conditions is high saline water forced over the silts. The effect on salinity is that three strata are found in the Baltic: a fairly saline bottom layer, an intermediate layer with lower salinity, and a brackish surface layer. Big inflows of high saline water occur very irregularly, and sometimes at several years' intervals. The average salinity in the bottom layer in the Bornholm Deep, in the Gdańsk Deep, and the Gotland Deep may be 18, 14 and 11%, respectively, but these will decrease in periods with no inflow. The surface layer, which is almost isohaline vertically, is separated from the deep water by the primary halocline. This transition layer is about 10-20 m thick. The depth of the halocline increased from 50-60 m in the Bornholm Deep to 80 m in the Gotland Deep. The salinity in the surface layer is about 7 in the Gotland Deep and 8% in the Bornholm Deep.

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. Owing to sedimentation of organic matter there is a persistent oxygen consumption and, if not made up for by inflow, results in an extended but varying oxygen deficiency in the deeps, depending on the frequencies of inflows. Since 1977, no major inflow has occurred (Fonselius et al., 1984; Fonselius, pers. comm.) and the situation has been that of a decreasing salinity, a decreasing oxygen concentration, and the development of hydrogen sulphide in the eastern deeps (Matthäus, 1992; Juhlin, 1990). An increasing eutrophication producing an increasing sedimentation of organic matter may further contribute (Rosenberg et al., 1990).

The fish fauna
The biomass of the fish has been dominated by a small number of species, the most important of which are herring, cod, sprat, and flounder, in that order. The total biomass of these in 1990 was about 7.4 million
tonnes. Other species are salmon and sea trout with a biomass of about 5000 t and turbot about 1000 t in 1990. The biomass of some other commercially caught species may be of the same order of magnitude, recent catches being: eel 2000–4000 t and smelt 4000 t. The yields of other species fluctuated widely: stickleback 100–19 000 t and eelpout 100–9000 t (ICES Fisheries Statistics; Thurow, 1993). Some species are not listed in the catch statistics although they are caught in considerable quantities, e.g., four-bearded rockling, lump sucker, and others. In the western part of the Baltic, there is an increased species diversity because of a higher salinity and a shorter distance to the Kattegat.

The Baltic Cod

The 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 extends to about 63°N latitude. On the western side, the transition area cod stock extends to the southernmost Kattegat. The separation of these two stocks has been shown by meristic characters (Schmidt, 1930), by electrophoresis (Sick, 1965; Jamieson and Otterlind, 1971), and by numerous tagging experiments (Aro, 1989). A review of stock identification in the Baltic has been given by Bagge and Steffensen (1989). The total stock size of the western and eastern stock in 1989 was estimated at 40 000 t and 350 000 t, respectively (ICES, 1991). In the following, only the cod stock east of longitude 14°30'E, i.e., in the Baltic Proper, is considered.

Landings

Figure 2 compares the landings of cod, herring, and sprat since 1903. The cod fishery was the first to develop in open sea. The yields of cod from ICES division IIIid are given in Table 1 as means for 10-year periods. The statistics stem from ICES (1990), ICES Bulletin Statistique, its Advance Release, and Thurow (1974). This Division IIIid is almost identical to ICES Subdivisions 24–32. Thus, it should be noted 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 total landings were below 30 000 t. During the Second World War, landings increased to over 80 000 t. Following a drop just after the war, they increased to the range 112 000–197 000 t during the period 1948–1974. Since then landings increased substantially to a maximum of 413 000 t in 1984 before declining in 1992 to the level of the 1940s, i.e., 58 000 t. The reasons for the increasing yield may be attributed either to an increase in fishing effort or stock size or to a combination of both.
Abundance as indicated by catch and effort

Up to the second half of the 1930s the fishing effort on cod was low. The main fishery was on flounder and in the western part plantae as well (Jensen, 1954). It was not possible for the German fleet to work in the North Sea western part plaice as well (Jensen, 1954). It was not cod was low. The main fishery was on flounder and in the

Abundance estimated from VPA

The first VPA on the Baltic stocks based on age compositions of national landings was run in 1975 (ICES, 1975). An attempt based on Polish age data only was made in 1972 (ICES, 1973). Since 1975 the VPA has been updated yearly by the Working Group on the Assessment of Demersal Stocks in the Baltic. This relationship is depicted in Figure 3. An additional data series of Dementjeva (1959) for the period 1948–1956 is given together with the recent USSR series in Table 2. These presentations suggest that the stock in the period 1948–1956 was on a lower level than in the period 1974–1986. Since 1986 the stock has declined to the level of the former period. The maximum catch/day was observed in 1979 and 1980.

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Table 1. Landings of cod by countries from the Baltic (Division IIId; Subdivisions 24–32).

<table>
<thead>
<tr>
<th>Year</th>
<th>Denmark</th>
<th>Faroe Islands</th>
<th>Finland</th>
<th>Germany FRG</th>
<th>GDR</th>
<th>Poland</th>
<th>Sweden</th>
<th>USSR</th>
<th>Estonia</th>
<th>Latvia</th>
<th>Lithuania</th>
<th>Total (Bull. Stat.)</th>
<th>Grand total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1911-1920</td>
<td>0.8</td>
<td>0.0</td>
<td>0.9</td>
<td>1.2</td>
<td>0.1</td>
<td>2.2</td>
<td>1.2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>1921-1930</td>
<td>1.0</td>
<td>0.0</td>
<td>1.6</td>
<td>0.1</td>
<td>0.1</td>
<td>2.2</td>
<td>1.2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
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<tr>
<td>1931-1940</td>
<td>2.3</td>
<td>0.0</td>
<td>1.6</td>
<td>0.1</td>
<td>0.1</td>
<td>2.2</td>
<td>1.2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
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<tr>
<td>1941-1950</td>
<td>9.8</td>
<td>0.0</td>
<td>29.9</td>
<td>17.4</td>
<td>0.1</td>
<td>14.2</td>
<td>12.8</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
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<tr>
<td>1951-1960</td>
<td>14.6</td>
<td>0.0</td>
<td>6.0</td>
<td>13.7</td>
<td>0.1</td>
<td>22.1</td>
<td>45.9</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
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<tr>
<td>1961-1970</td>
<td>25.0</td>
<td>0.0</td>
<td>6.0</td>
<td>13.7</td>
<td>0.1</td>
<td>22.1</td>
<td>45.9</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>1971-1980</td>
<td>45.0</td>
<td>2.6</td>
<td>11.2</td>
<td>8.6</td>
<td>0.1</td>
<td>22.1</td>
<td>45.9</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>1981-1990</td>
<td>78.3</td>
<td>5.0</td>
<td>11.2</td>
<td>8.6</td>
<td>0.1</td>
<td>22.1</td>
<td>45.9</td>
<td>0.1</td>
<td>0.1</td>
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<td>0.1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Tiews (1974) compared the catch-per-hour of cod made by the German steam trawlers (1934–1944) with the catch-per-hour made by the research vessel "Anton Dorn" (1962–1970) in the Bornholm Deep, the Gdansk Bay, and the southern Gotland Deep. The catch rates in the Bornholm Deep in 1966, 1969, and 1970 were similar to those from 1939–1944, but in the Gdansk Deep and the Gotland Deep the catch rates in 1969 and 1970 were much higher. Because of varying oxygen conditions near the bottom in the Baltic, one would assume catch-per-unit-effort data from research vessels with bottom trawl not to be reliable. These vessels worked in short periods, and consequently the choice of period may have been the main influence on the catch. However, Tiews and Weber (1992) have shown that research vessel catches with bottom trawl in the Bornholm Deep (Subdivision 25) are highly significantly related to biomass 1975–1992 as estimated by the Working Group on the Assessment of Demersal Stocks in the Baltic (ICES, 1991, 1992). The same is true for data of commercial USSR vessels (1974–1988) which have been submitted to the ICES Working Group on Demersal Species in the Baltic. This relationship is depicted in Figure 3. An additional data series of Dementjeva (1959) for the period 1948–1956 is given together with the recent USSR series in Table 2. These presentations suggest that the stock in the period 1948–1956 was on a lower level than in the period 1974–1986. Since 1986 the stock has declined to the level of the former period. The maximum catch/day was observed in 1979 and 1980.
1988 it was reduced to 0.2. The effect of this measure was that biomass at the beginning of the year was reduced by about 30%. At the same time the maturity ogive was changed. Therefore, the 1988 and 1993 VPAs were used to cover the period 1966–1992. The recruitment, spawning-stock size, the fishing mortality, and the yield for the period 1966–1992 are shown in Figure 4 (ICES, 1988 and 1993).

Recruitment in the 1960s was about 300 million cod of age 2. Some ten years later a series of good and very rich year classes followed. Subsequently, a decreasing trend became obvious, and since 1986 recruitment has been the lowest on record, less than 100 million in 1989–1992. The yield increased to a maximum of about 400 000 t in 1984, before declining to about 58 000 t in 1992. Fishing mortality has had an increasing trend since 1979, reflecting a heavy increase in effort due to the transfer of fishing vessels from the North Sea, a transition to larger vessels, and the introduction of pelagic trawling for cod. The maximum fishing mortality on record (F=1.4) was found in 1991 (Fig. 4).

The development of pelagic single-boat trawling, which was introduced by German vessels, made it possible to fish continually day and night in contrast to bottom trawling. Bottom trawling is only practical in areas with sufficient oxygen near the bottom and only from sun-up to sun-down, because the cod leave the bottom when it gets dark. Consequently, effective effort increased by about threefold when they switched over to the pelagic method.

It can be seen from Figure 4 that fishing mortality in the 1960s was almost as high as in the late 1980s. This coefficient, as evaluated by the Working Group on the Assessment of Demersal Stocks in the Baltic (ICES, 1988 and 1993), is the weighted average F of age groups 4 to 7 and is thought to have a linear relationship with fishing effort.


<table>
<thead>
<tr>
<th>Year</th>
<th>Catch (t)</th>
<th>Year</th>
<th>Catch (t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1948</td>
<td>1.82</td>
<td>1976</td>
<td>3.06</td>
</tr>
<tr>
<td>1949</td>
<td>1.45</td>
<td>1977</td>
<td>2.10</td>
</tr>
<tr>
<td>1950</td>
<td>1.36</td>
<td>1978</td>
<td>3.18</td>
</tr>
<tr>
<td>1951</td>
<td>1.29</td>
<td>1979</td>
<td>4.29</td>
</tr>
<tr>
<td>1952</td>
<td>1.39</td>
<td>1980</td>
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</tr>
<tr>
<td>1953</td>
<td>1.14</td>
<td>1981</td>
<td>3.56</td>
</tr>
<tr>
<td>1954</td>
<td>1.24</td>
<td>1982</td>
<td>2.73</td>
</tr>
<tr>
<td>1955</td>
<td>1.27</td>
<td>1983</td>
<td>2.62</td>
</tr>
<tr>
<td>1956</td>
<td>1.66</td>
<td>1984</td>
<td>2.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1985</td>
<td>2.18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1986</td>
<td>1.98</td>
</tr>
<tr>
<td>1974</td>
<td>2.50</td>
<td>1987</td>
<td>1.75</td>
</tr>
<tr>
<td>1975</td>
<td>2.60</td>
<td>1988</td>
<td>1.24</td>
</tr>
</tbody>
</table>
Figure 4. Baltic cod. Subdivisions 25–32. Yield (1000 t). Average fishing mortality (ages 4–7), spawning-stock biomass (1000 t) at 1 January and recruitment at age 2 (no. in millions). (ICES, 1993).
The indication is therefore that effective effort decreased until the late 1970s and inclined thereafter. The proportion of ages >6 in the total biomass was relatively small, in the period 1970–1980 amounting to <15%. During the following years it increased to within the range 14–22% (except for 1986 when it was as high as 30%). This change indicates that more old fish survived because fishing mortality decreased. Because of the relatively low proportion of old fish we will now look at the course of F at ages 2–5.

Figure 5 shows essentially the same picture as Figure 4 and suggests little clue about a change in fishing pattern. Figure 6 shows the average exploitation pattern for three periods. The early and late phases hardly differ with regard to ages 2–5. Some differences concerning their older ages are present, but not consistently so. A distinction can be made, however, between the middle stage and the other two, but this does not imply a change in exploitation pattern, it simply shows an overall decrease in fishing effort.

An increase in fishing mortality in the 1980s, as shown in Figures 4 and 5, was caused by a corresponding rise in effort (ICES, 1993). The declining effective effort and fishing mortality in the 1970s is not understandable at first sight. How can it be explained?

The overall analysis, so far, has determined that cod and the fishery are evenly distributed. If this were not so, the conclusions might be different. To investigate, we examine the distributions of catches by subdivisions. Unfortunately, Denmark and Finland did not split their catches accordingly, but the data of the remaining five countries can be used, their catches amounting to 63% to 83% of the total of all countries.

Figure 7 shows these catches in Subdivisions 25 + 26 and 27–32 as a percentage of the totals of the five countries. The development of the catches in the two areas is in opposite directions. A clearly declining trend is seen for Subdivisions 25 + 26 until about 1980, when the proportion of Subdivisions 27–32 increases. A highly significant correlation between the catch in Subdivisions 27–32 and total biomass is depicted in Figure 8. The essential point is that its intercept is also highly signifi-

Figure 7. Distribution of catches (%) on Subdivisions 25+26 and 27–32, 1970–1991.
Spawning of the Baltic Cod

Spawning area

There are three main spawning areas for Baltic cod: the Bornholm Deep, the Gdańsk Deep, and the Gotland Deep (Fig. 1). Spawning usually begins in March, reaches a maximum in May–June, and finishes in September–October.

Salinity and oxygen

In the spawning areas, a salinity of not less than 10 is necessary if the eggs are to remain afloat (Kändler, 1938, 1944; Grauman, 1973). At less salinity the eggs are deposited on the bottom and do not develop, but even if the salinity does allow the eggs to float, the oxygen content is a determining factor for development. Fertilization of the eggs is possible at salinities lower than 10, but with a reduced percentage of fertilization and a cessation 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 salinities of 11–13 (Müller and Pomerantz, 1984); in the Gotland Deep they are at depths of 80–100 m or where the salinity allows them to float. The oxygen content in the strata where the eggs are concentrated may vary from 0.5 to 6.0 ml/l, varying between months and years depending...
on the inflow of saline and oxygenated water from the North Sea. The lower limit of oxygen content at which development of cod eggs is possible is 1.0 ml, but at this level egg mortality is very high (Grauman, 1973). Experiments on cod eggs from the Bornholm Deep indicate that below 0.2 of 2.3 ml/l development of the eggs does not proceed beyond stage III (Wieland and Zuzarte, 1991). Hence a combination of salinity of not less than 11 and oxygen content of not less than about 2.3 ml/l is very important for the survival of cod eggs. As salinity and oxygen content below the halocline are dependent on inflow from the North Sea, stagnant periods which reduce the salinity and the oxygen content might be expected to have a negative effect on the year-class strengths in the Baltic.

**Inflows and stagnant periods**

Long-term trends of salinity below the halocline in the Gotland Deep in 1895–1983 and 1977–1990 (Fonselius et al., 1984; Matthäus 1992) are shown in Figures 9 and 10. Long periods with continuously decreasing salinity values were observed from 1922 to 1933 and from 1952 to 1962. Both began with very high salinities caused by heavy inflows. A big inflow into the Gotland Deep also began in 1935 but, because of the war, there was no further information between 1940 and 1947. Four smaller inflows occurred after the 1952 inflow, interspersed with stagnant periods. The last major inflows occurred in 1970, 1974, 1976, and in 1979 (Matthäus, 1992; Matthäus and Franck, 1992). An inflow of medium size occurred in January 1993. Figure 11 shows the salinity, temperature, and oxygen content in March 1991 on stations in the central Gotland Deep in a line from the central east coast of Gotland to off Libau at the Latvian coast. It appears that a salinity of 11 is found at a depth of 120–130 m, at which the oxygen content is 0.5 ml/l or less, which means that cod eggs are unable to develop. Dahlin et al. (1993) present a similar but monthly set of data (1990–1993) from Station By 15, which is situated in the centre of transect 1 (shown in Figure 11). In 1990 the 11 contour is at a depth of 150 m and the corresponding oxygen content less than 0.5 ml/l. In 1991 the depth of the 11 contour and the oxygen content there in March corresponds to that shown in Figure 11, but in the last part of the year and in 1992 the 11 contour is situated at a depth of 180 m, where H2S is found. In 1993 the depth of the 11 salinity decreases rapidly to about 150 m, because of the inflow in January (Dahlin et al., 1993, Fig. 9).

Reproduction of cod in the Gdansk Bay has not been possible in 1990, 1991, and 1992 as these year classes have been almost absent in the area (Netzel, 1993; Uzars et al., 1991).

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**Figure 9.** Annual mean values of all salinity data (200 m depth) at the Gotland Deep station from 1890 to 1982 (Fonselius et al., 1984).
Discussion

Some authors have demonstrated a positive correlation between inflows and year-class strengths of cod (Berner and Borrmann, 1977; Bay, 1984; Kosior and Netzel, 1989; Bagge, 1993). In addition to increasing salinity and oxygen content, however, inflows also force nutrients from the bottom to the photic zone, stimulating primary production (Nehring, 1982), which may also be very important for the successful development of cod larvae. Around 1920 the dominance of winds from the west-southwest increased by about 25% (Jensen, 1954), and may have enhanced inflows to the Baltic. This may be a plausible reason for the subsequent increase of the stock size. In 1957 an increase in fishing effort, combined with more powerful fishing methods, brought about an increased yield of cod to nearly 200 000 t. The explosive development of the stock in the late 1970s and early-1980s, however, cannot be explained by inflow and effort alone, as inflows of the same magnitude have occurred earlier without this effect. One possibility is the increased level of nutrient input from other sources (freshwater outlets and the atmosphere, e.g., nitrogen) (Rosenberg et al., 1990). The high nutrient contents together with proper salinity and oxygen regimes is believed to have produced the rich year classes of 1972, 1975, 1976, 1977, 1979, 1980, 1981, and 1985. The stagnant period since 1979, during which oxygen con-

![Figure 10. Annual observation of salinity and oxygen in the Gotland Deep 1977-1990 (Matthäus, 1991).](image-url)
Figure 11. Measurements according to depth in a transect through (A) Station BY 15 in the Gotland Basin, of (B) temperature (°C); (and overleaf) (C) oxygen (ml/l); and (D) salinity.
Figure 11. Continued.
sumption increased as a result of increased sedimentation of organic matter, which reduced the thickness of the water layer where it is possible for cod eggs to develop (the spawning volume), contributed to the production of a series of small year classes, especially in the Gotland and Gdansk deeps (Uzars et al., 1991). The reproduction of cod in the Baltic seems at present to be largely dependent on spawning success in the Bornholm Deep, depending on small inflows to that area only. However, even plots of recruitment on spawning volume yield a significant positive correlation; variance is high (Beverton, 1992, Fig. 4; Bagge, 1993, Figs. 2 and 3), indicating that factors other than inflows are involved, e.g. interactions with other species such as sprat, which predate on cod eggs and larvae (Köster, 1992).

References

Juhlin, B. 1990. Oceanografiska observationer runt Svenska kusten i 1989 med fartyget attyge, nr. 35.

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