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The Baltic cod

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Abstract
A description of the biology of the two Baltic cod stocks, their distribution, growth, reproduction and their food and feeding based on the available literature is presented. The development of the fishery and the size of the cod stocks is described and discussed in relation to fishing effort and the abiotic conditions in the Baltic. A short description of the methods used for assessment of the Baltic cod stocks together with the historical background is presented. Finally, the future aspects of the possible fate of the Baltic cod stocks are discussed.

Keywords: stocks, reproduction, exploitation, assessment, regulation.

Introduction
The highest abundance of cod (*Gadus morhua*) in the recent history of the fishery in the Baltic occurred during the late 1970s to mid-1980s when the spawning stock biomass reached an estimated 700 000-800 000 tonnes, followed by a drastic decline (Anon. 1993) to less than 100 000 tonnes. The yield has fluctuated due to varying fishing effort and to varying strengths of year classes (Thurow 1974, Anon. 1988, 1991, 1993). Egg and larval survival, and hence the year-class strength, are closely related to environmental conditions such as the salinity and the oxygen content in the depth strata, where cod eggs are able to float (Wieland & Zuzarte 1991). Anthropogenic factors such as exploitation and eutrophication also influence the stock size as well as the oceanographic conditions to which the stock is exposed.

This article considers the natural conditions of the Baltic cod, addresses the effect of man and the regulatory measures applied to this stock and provides the future outlook for this stock.

The distribution of cod and the stocks
Two distinct stocks of cod exist in the Baltic Sea. Genotypic and phenotypic characteristics indicate that the two stocks occur on either side of longitude 14°30'E, immediately west of Bornholm (Figure 2). The zone of overlap between the two stocks is rather narrow. On the eastern side, the area of distribution of the 'true' Baltic cod stock extends north to about 63°N latitude. On the western side, the cod stock extends to the southernmost part of the Kattegat. Phenotypic and genotypic

characteristics of this stock indicate that it is a transition between the North Sea stock and the eastern Baltic stock.

A number of methods have been applied to separate cod stocks in the Baltic including

a. Morphometric characters (including meristic characters).
b. Genetic variation.
c. Tagging experiments.

Morphometric characters

Meristic characters such as the number of vertebrae and the number of fin rays have been used to discriminate stocks by several authors. Schmidt (1930), Ziecik (1938), Poulsen (1931), Kändler (1944) and Birjukov (1969) showed significant differences between two distinct stocks with a border in the Bornholm region (14°E). The characters and their means are shown in Table 1. Significant differences between areas

Table 1. Mean numbers of vertebrae and of finrays in the 1st (D_1) and 2nd (D_2) dorsal fin of cod caught west and east, respectively, of longitude 14°E in the Baltic as published by various authors.

	West of longitude 14°E			East of longitude 14°E		
Author	D_1	D_2	No. of vertebrae	D_1	D_2	No. of vertebrae
Schmidt (1936)		18.20-18.80	52.10-52.40		17.20-17.90	53.40
Ziecik (1938)	13.13	17.95		13.76	16.93	
Poulsen (1931)		18.38-18.50	51.71		17.46-17.53	
Kändler (1949)		18.15	52.10	17.37	52.72	
Birjukov (1969)	14.40-14.53		51.09	13.97		51.53-51.98

were accepted if the difference between the paired means exceeded threefold the mean error of that difference (Ziecik 1938, Kändler 1944).

However, recent results of Berner & Vaske (1985) show the same differences but indicate the mixing of the two stocks to be more extensive than hitherto believed. They compared the mean number of dorsal rays (D_1, D_2, D_3) and anal finrays (A_1, A_2) in cod from subdivisions 22, 24 and 26 (Figure 1) using a two-way classification ANOVA. Significant differences between areas were found especially in D_1, D_2, but also in A_1, A_2. A one-way ANOVA was also applied to a further 18 morphometric and meristic characters related to total length and sex of cod in subdivisions 22, 24, 25 and 26. This indicated significant differences between all areas in several characters.

Bagge & Knudsen (1974) used monthly data on stage of maturity, sex, and amount of stomach content sampled in the period 1969-1971 as parameters for investigation of the length–girth relationship in cod from subdivisions 22 and 25. It was shown that the girth of cod from subdivision 25 is 6% smaller than the girth of cod from subdivision 22, regardless of time of year. Ziecik (1938) also found morphometric differences in six characters (the distance snout–D_1, the distance between the eyes, length of the lower jaw, length of tail, height of the abdominal fin and height of the anal fin). Bagge & Knudsen (1974) and Ziecik (1938) investigated two areas only, and this indicated two different stocks, while the results of Berner

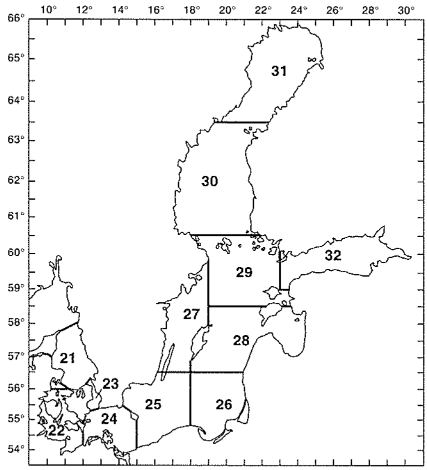

Figure 1. The ICES statistical subdivisions in the Baltic.

& Vaske 1985 give the same indications of a mixing between stocks as they found using meristic characters, indicating that the girth–length relationship may not be a good indicator of stocks.

Genetics

The genetic variation of cod stocks was investigated by Sick (1965). The haemoglobin type of cod was examined by agar electrophoresis of samples from 42 localities in subdivisions 22-26 and 28-30. Two distinct stocks with a border just west of Bornholm were found. Jamieson & Otterlind (1971) repeated this study but incorporated another polymorphic genetic system controlling serum-transferring variants. They were able to discriminate between two stocks but observed a diffuse border between their distribution areas. The results of Moth-Poulsen (1982), who used enzyme electrophoresis, support those of Berner & Vaske (1985).

Tagging

Tagging experiments in the Baltic started in the late 1950s and were intensified in the 1970s after the first ICES Working Group meeting on cod in Gdynia 1972 (Anon. 1972). Since then about 50-60 000 cod have been tagged by all countries bordering the Baltic Sea. Although records of recoveries have not been adequate, a clear picture of the movements of cod in the different parts of the Baltic was nevertheless obtained (Figure 2). Reviews of tagging results by Aro (1989) and Bagge & Steffensen (1989) confirm that there are two stocks in the Baltic and that the border between these varies in the area just to the east or to the west of Bornholm. The position of the border is possibly dictated by the relative abundance of the two stocks (Jamieson & Otterlind 1971) as well as advection of pelagic stages of cod from the western Baltic into the eastern part.

The DNA technique, which in recent years has been applied on North Atlantic cod stocks, has not yet been used in the Baltic. That method will possibly demonstrate a more extensive gene flow between these stocks.

Reproduction

Spawning

Spawning areas and time. Investigations on the spawning of cod in the Baltic were started by Strodtmann in 1904 and 1905. He found cod eggs in the western Baltic (Kiel Bay and Fehmern Belt) in February and May, but in the Bornholm Basin and the Gdańsk Deep only in May (Strodtmann 1906). In 1906 he found that the abundance of cod eggs in the western Baltic increased in March compared to February and that the main spawning in the Bornholm Basin and Gdańsk Deep started in May and that cod eggs still were found in late July and in August, respectively. In 1907 cod eggs were for the first time observed in the central Gotland Basin (Strodtmann 1918). Mielck (1926) confirmed the observations of Strodtmann and additionally found cod eggs up to 50 nautical miles north of Gotland in April 1925. The results of German surveys in the Baltic from 1925 to 1938 (Kändler 1944) described the main borders of the spawning areas, the spawning periods in these areas, the abundance of cod eggs per m^2 and their vertical distribution.

These studies have identified three main spawning areas for the eastern Baltic cod stock (the Bornholm Basin, the Gotland Basin and the Gdańsk Deep) and a secondary spawning site in the Slupsk Furrow. The most important spawning areas for the western Baltic cod stock were found to be in Kiel Bay and Fehmern Belt, with the spawning in the Arkona Basin just west of Bornholm being of minor importance (Figure 2).

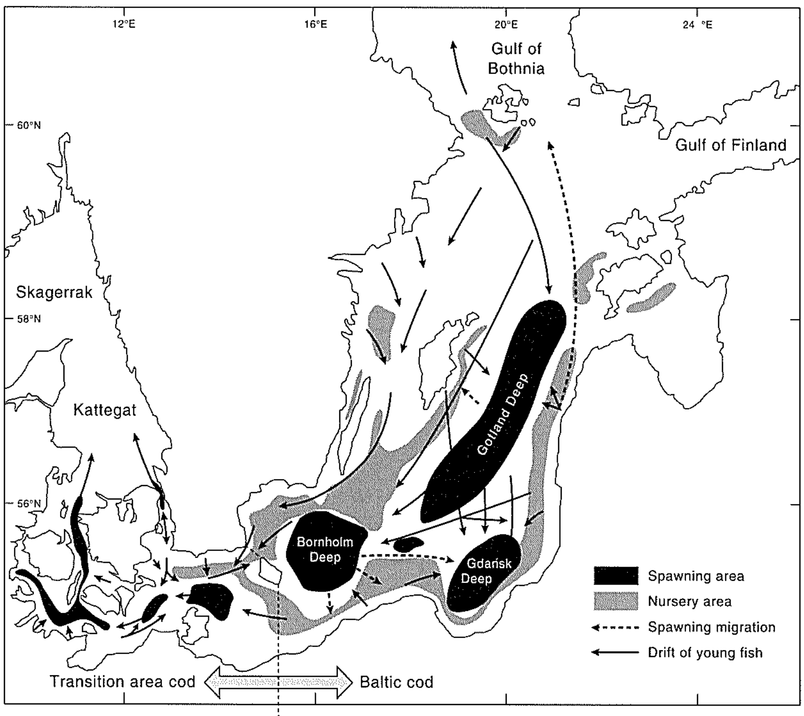

Figure 2. Spawning and feeding areas of cod. (after Bagge & Thurow 1993).

Table 2. Number of cod eggs in the water column per surface m^2 by month and subdivision. Numbers in brackets are number of observations.

Area	Kiel Bay	Mecklenburg Bay	Arkona Basin	Bornholm Basin	Bornholm Basin	Gdańsk Deep	Gotland Basin	Gotland Basin
Subdivision	22W	22E	24	25	25	26	26/28	26/28
Period	1903-49	1903-38	1903-38	1903-38	1969-73	1903-47	1925-38	1969-73
January	3(18)	0(7)		0(1)				
February	41(60)	12(43)	3(7)	0(4)	1(?)	0(5)		
March	38(60)	13(12)	2(14)	14(32)	33(?)	8(5)	0(4)	1(?)
April	35(42)	24(19)	3(17)	49(9)	82(?)	56(4)	5(7)	1(?)
May	9(67)	6(18)	0(15)	22(6)	56(?)	58(9)	11(4)	10(?)
June	1(31)	0(10)	1(3)	47(3)	44(?)			11(?)
July	0(27)	0(1)	1(8)	109(18)	55(?)	57(24)	2(7)	14(?)
August	0(11)	0(11)	2(3)	109(14)	5(?)	116(6)	1(5)	9(?)
September			0(4)	41(16)		9(6)		1(?)
October			0(4)	3(17)		6(1)		
Reference	Kändler (1949)*	Kändler (1949)*	Kändler (1949)*	Kändler (1949)*	Grauman (1974)**	Kändler (1949)*	Kändler (1949)*	Grauman (1974)**

*Weighted mean of numbers over sampling periods; **average of numbers for 1969, 1971 and 1973.

In the western Baltic, cod begin spawning early in the year (January) with the peak spawning in March. In May the spawning is completed (Kändler 1949, Berner 1960, Thurow 1970). Table 2 shows the abundance of cod eggs per 1 m^2 by month and spawning area, as weighted means of observations in the period 1903-1949 (Kändler 1949) combined with the data of Graumann 1969, 1971 and 1973 (Graumann 1974). The highest abundance of eggs in the western Baltic is February-April. In the eastern Baltic the spawning period is more extended and the peak abundance of eggs occurred later in the year (1903-1949, June-August). Investigations by Graumann (1974) and by Bagge & Müller (1977) indicate a peak abundance in the Bornholm Basin in May. Investigations conducted in the period 1987-1992 (Wieland, in prep.) show that the peak abundance during the period has gradually changed from early May to mid-June (Figure 3). That may be due to a large-scale reduction of the spawning stock combined with a change of the age distribution towards very young fish (Anon. 1993). The mean abundance of cod eggs below 1 m^2 in the main spawning areas in the eastern Baltic for the period 1954-1970 is given by Graumann (1974). She found the highest mean abundance during this period in the Bornholm Basin followed by the Gotland Basin and the Gdańsk Deep.

Vertical distribution and mortality of cod eggs. The vertical distribution of cod eggs and other fish eggs is controlled by their specific gravity. The minimum salinity which allows cod eggs to float is 10.5-11.0 psu. Investigations of the vertical distribution of cod eggs in the Baltic have been made by Hensen (1884), Strodtmann (1906, 1918) Apstein (1911), Mielck & Künne (1935) Kändler (1944, 1949), Hansen (1978), Graumann (1974), Bagge (1981), Müller & Pommeranz (1984), Wieland (1989) and Wieland & Zuzarte (1991). In the western Baltic, cod eggs are

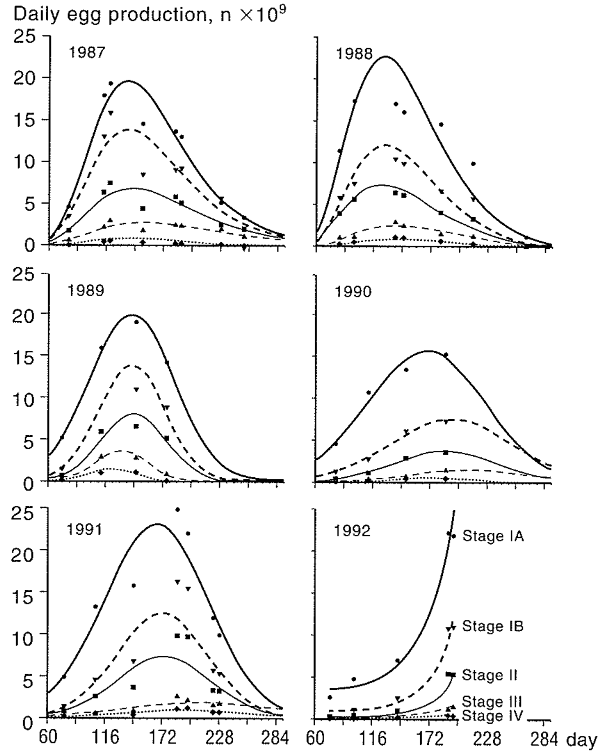

Figure 3. The daily egg production of cod during the spawning period in the Bornholm Basin and the development stages 1987-1992 (Wieland, in prep.). Stage IA: early stage; stage IV: just before hatching.

found at depths below 20 m. In the Bornholm Basin this was below 55 m with a maximum abundance at 60-70 m (Müller & Pommeranz 1984, Wieland & Zuzarte 1991). In the Gdańsk Bay, the eggs are found below 80 m with a varying maximum abundance between 80-110 m while in the southern Gotland Deep maximum densities are found between 90-130 m (Graumann 1970). The depth of the peak abundance varies between month and years due to variations in the pycnocline depth (Hansen 1978, Wieland 1989).

The mortality of cod eggs has been estimated by a number of techniques. Graumann (1974) simply counted the proportion of live and dead eggs in her samples. She found a mean survival for the period 1954-70 of 8.9% in the Bornholm Basin decreasing to 7.2% in the Gdańsk Deep and 6.5%, 4.8%, and 0.8% in the southern, central and northern Gotland Basin, respectively. Müller & Bagge (1977) and Bagge & Müller (1978) found an instantaneous mortality of 0.28-0.44 (per day) corresponding to 24.4%-35.6% (per day) or a total mortality (12 days) of 96.5%-99.5% estimated by repeated sampling from a batch of eggs. Wieland (1988) used a similar technique. He found an instantaneous daily mortality of 0.314 and 0.322 corresponding to 27.0 and 27.5% or total mortality (12 days) of 97.7 and 97.9%. He later estimated the number of eggs produced from February-October 1987-1991 and the fraction surviving (Table 3; Wieland, in prep.).

The mortality of cod eggs is caused by several factors. Salinity combined with the oxygen content, both of which are determined by the frequency of major inflows,

Table 3. Number of cod eggs produced and number surviving until hatching in the Bornholm Basin 1987-1991. Wieland (1994).

Year:	1987	1988	1989	1990	1991
No. of eggs produced (February-October) $\times 10^{12}$	4.44	3.65	3.30	2.96	3.70
No. of eggs survived until hatching $\times 10^{12}$	0.0588	0.0461	0.0626	0.0356	0.0874
Percentage of eggs surviving until hatching	1.32	1.26	1.90	1.20	2.36

have been considered the most important. The minimum oxygen content for successful egg development is 2.3 $ml \cdot l^{-1}$ (Wieland & Zuzarte 1991).

Cod larvae. Cod larvae are found in the same areas as the eggs, both above and below the pycnocline. Kändler (1944) found larvae of cod in 1937 and 1938 in the Bornholm Basin, the Gdańsk Deep and the Gotland Basin, but he also found larvae in more shallow water (30-40 m) in the southern Bornholm Basin. Waller (unpubl.) cited in Waller *et al.* (1993) observed an active upwards vertical migration of yolk sack larvae to the photic zone at an average speed of 4.0 $mm \cdot s^{-1}$ regardless of the ambient salinity. This vertical migration is assumed to be a feeding migration to the surface. Zuzarte (pers. comm.) found that small larvae caught below the pycnocline had not fed and thus are likely not to survive. The post-larvae may remain in the pelagic phase until May-June the following year and then as bottom stage in shallow water of less than 60 m depth until they are about two years old.

Maturity

Trawl survey data for the period 1926-38 were used by Kändler (1944) to describe the maturity stages, length and age distribution of the spawning cod in the Bornholm Basin, the Gdańsk Deep and the southern Gotland Basin. He found that maturity in the Bornholm Basin may start at a length of 17 cm for males and 22 cm for females. In the southern Gotland Basin very few small cod were caught (the lengths were not mentioned), all belonging to age group 2 and not mature. He also demonstrated that in the Bornholm Basin about 90% of males >30 cm and 80% of females >32 cm were going to spawn and further that the largest cod were spawning in March. That observation was also pointed out by Berner (1960) and indicated by Bagge & Steffensen (1991). They plotted the weight of gonads relative to body weight against months. This age-dependent spawning time may partly explain of the mechanisms of the extended spawning time of the Baltic cod. Maturity-at-age (1977-85) is given by Weber (1989) for subdivisions 25 and 26 together, based on German survey data submitted to the Working Group on Demersal Stocks in the Baltic. For the western stock, subdivisions 22 and 24, the maturity is given in Anon. (1986). Both data sets are shown in Table 4.

Table 4. Maturity-at-age of cod in the western and the eastern Baltic, respectively. (Weber 1989).

		Percentage cod mature at age, year							
Area	Subdivision	1	2	3	4	5	6	7	8
Western Baltic	22, 24	0	0	16	72	87	91	100	100
Eastern Baltic	25, 26	0	27	69	91	97	99	100	–

Fecundity

Publications dealing with fecundity of cod in the Baltic area are very scarce, Strzyzewska (1962), Botros (1959, 1962), Schopka (1971), and Kosior & Strzyzewska (1979).

Botros (1962) compared the fecundity of 71 cod in the length interval 40-90 cm from the Kiel Bay with the fecundity of 49 specimens 61-100 cm long from the Norwegian coast off Bergen. Regressions of number of eggs versus length and of number of eggs versus weight did not yield any statistically significant differences. He then compared the length groups 60-69.9 cm from the two localities as the mean length and the mean weight were almost identical. Egg number was 2093 $\times 10^3$ and 1975 $\times 10^3$ for cod from the Kiel Bay and off Bergen, respectively, also indicating a similar fecundity. Kosior & Strzyzewska (1979) compared the results of Botros with countings on cod from the Gdańsk Bay including the specimens dealt with by Strzyzewska (1962), in total 116 specimens (32-87 cm). They found a higher fecundity for cod from the Gdańsk Bay but only for specimens less than 60 cm, possibly due to a very small number of specimens larger than 60 cm. No statistical tests have been made and the authors do not refer to Schopka (1971), who compared the fecundity of cod from the Kiel Bay, the Arkona Basin, the Bornholm Basin, the Gdańsk Bay, the North Sea and Iceland. The number of specimens according to area was 9, 12, 35, 28, 23 and 53, respectively. Schopka (1971) found a significant difference between the fecundity in the Kiel Bay and the other three Baltic areas, but not within those. He pooled all the Baltic areas for comparisons with the North Sea and Iceland. As significant differences between regression coefficients were not found, a mean value of the regression coefficients (b) was calculated and used in the expression $F = q \cdot L^b$ yielding an almost 100 % higher fecundity in Baltic cod,

$F = 1.94 \cdot L^{3.1862}$ North Sea, Iceland,
$F = 3.87 \cdot L^{3.1862}$ The Baltic.

The counting technique used by the authors mentioned was quite different, Kosior & Strzyzewska (1979) counted sub-samples from gonads kept in formalin, while Schopka (1971) treated the gonads with Gilson's fluid and used a counting machine. Despite this the two sets of results agree.

Growth

Thurow (1974) summarized all investigations on growth of Baltic cod published 1923-1971. He pointed out that only one report, Draganik & Netzel (1966) was published on the estimation of von Bertalanffy growth parameters. He further demonstrated that plotting L_{t+1} against L_t, using data from the published reports, yielded straight lines being nearly parallel to the bisector through the origin, indicating an almost constant growth. He suggested that most of the values were not realistic. The reason for that could be biased sampling methods especially with respect to the youngest age groups due to different sampling periods and gear.

Another source of bias, and possibly the more important which was not mentioned by Thurow, is errors in age readings.

In contrast to the western cod stock the reading of the majority of otoliths from cod more than three years old in subdivisions 25-32 is difficult. This may be due to a low degree of contrast between the seasonal growth zones, possibly because part of the cod are staying below the pycnocline most of the year where temperature is stable. Further, the opaque growth zone is developed late in the year (Kändler 1944), (Berner 1968), because the most intensive feeding in that area is October and November, (Baranova & Uzars 1986), (Baranova 1992). In addition, the spawning period is very extended (Steffensen 1980), which may hamper definition of the central growth zone.

After 1971 work on growth has been more comprehensive. Lablaika *et al.* (1975), Kosior (1976), Sjöblom *et al.* (1980), Berner & Borrmann (1985) and Steffensen & Bagge (1983) have estimated the von Bertalanffy parameter from mean length-at-age data and Sjöblom *et al.* (1980) from tagging data. Again the results are not convincing, possibly still due to age reading problems. The results are shown in Table 5, from which it is indicated that the value of L_∞ is much depending on the number of age groups included. The results from marked samplings seems also to differ, possibly because the younger age groups are not fully recruited. Published data on mean length-at-age (2-7) sampled from research ships in subdivisions 25 and 26, (Lablaika *et al.* 1975, Kosior 1976, Berner & Borrmann 1980, Steffensen

Table 5. Von Bertalanffy growth parameters of Baltic cod by subdivisions as published by various authors.

Subdivision:	22			23			24			25			26			29			Ref.	Age
	K	L_∞	t_0	K	L_∞	t_0	K	L_∞	t_0	K	L_∞	t_0	K	L_∞	t_0	K	L_∞	t_0		
1960-74													0.111	120.0	-0.020				A	
1960-74 fm.													0.142	98.0	-0.024				A	
1975										0.125	119.6	0.33							B	3-10
1975													0.153	107.9	0.550				B	3-10
1965-76										0.145	102.1	-0.36							C	
																0.192	103.0	-	D*	3-7
																0.192	103.0	-	D	3-7
							0.10	142.50	-0.58										E	1-13
1963-82	0.21	115.4	0.52																F	
1963-82	0.18	122.1	0.19																F	2-9
1972-82	0.22	112.6	0.49																F	3-9
1972-82	0.21	114.7	0.36																F	2-9
1968-82										0.11	120.6	-0.63							F*	1-7
1958-62				0.10	139.0	-0.47													F*	1-7
1968-81										0.14	108.5	-0.24							F*	1-7
1968-82																			F*	1-7
1968-82										0.07	134.9	-2.33							F**	3-9
1968-82										0.18	85.9	-0.42							F**	2-7

Key to references. A: Lablaika *et al.* 1975; B: Kosior 1976; C: Berner & Borrmann 1980; D: Sjöblom 1980, tagging; D*: Sjöblom 1980; E: Berner *et al.* 1985; F: Bagge & Steffensen 1983; F*: Bagge & Steffensen 1983 RV; F**: Bagge & Steffensen 1983 marked.

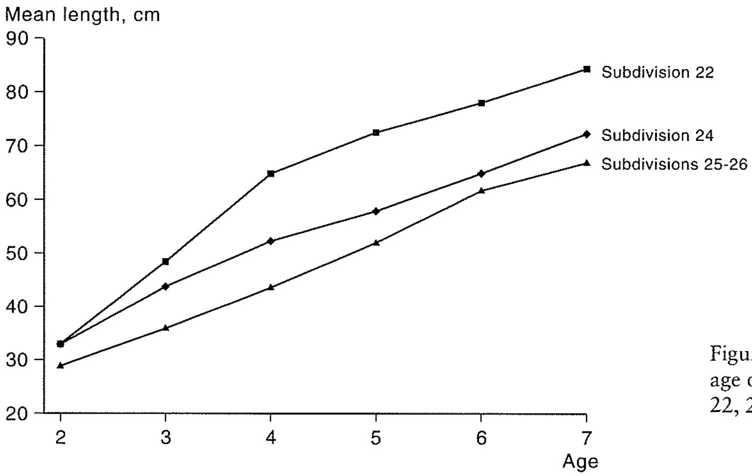

Figure 4. Mean length-at-age of cod in subdivisions 22, 24 and 25-26.

& Bagge 1983), are pooled as simple means and shown in Figure 4 together with similar plots from subdivision 24 (Arkona Basin) and subdivision 22 (Belt Sea), Berner & Sager (1985) and Steffensen & Bagge (1983). In contrast to subdivision 22, the differences between the mean length of successive age groups in the eastern subdivisions and in subdivision 24 are almost constant and thus do not fit the von Bertalanffy growth model. That is possibly caused by biased age readings also in subdivision 24 being a border area between stocks. There appears to be a difference in growth between the three areas.

The problems of age readings of cod have been considered by The International Council for the Exploration of the Sea (Anon. 1973, 1989, Lassen 1985). In 1973 differences of approximately 1.5 years was found, and in 1985 the differences averaged 0.5 year. In 1989 good agreement was found for young cod but not for older cod from the Åland Sea, but the results are not specified. A combination of mean weight-at-age data (age 2-7) from six Baltic countries, 1977-88 (Thurow 1994, unpubl.) indicated differences between the lowest and highest estimate per age group of some 80%. No lasting, methodological improvements have been achieved and this is unlikely to occur until the subjectivity in age readings is eliminated.

Berner *et al.* (1984) and Berner & Sager (1984 and 1985) have fitted published length- and weight-at-age data from different parts of the Baltic to other growth models which are forced through the origin (Richards (1959) (length-at-age data) and Janoschek (1957) (weight-at-age data). As the same data referred to in Figure 3 have been used more reliable results could not be expected.

Food and feeding

The species composition of food consumed by cod in the central Baltic has been studied by Uzars (1975, 1976, 1985 and 1993), subdivisions 25 and 28; Załachowski *et al.* (1976), Załachowski (1977 and 1985), subdivisions 25 and 26; Bagge (1981) and Bagge & Bay (1987), subdivision 25; and Axell (1982) subdivision 29. In the western Baltic the contributions in this field are given by Arntz (1974, 1977 and 1978), Arntz & Weber (1980), Bagge (1966), Schultz (1988) and Weber & Damm (1991).

The eastern Baltic

In subdivision 29, young cod (15-24 cm) feed mainly on invertebrates such as *Mysis* sp., *Pontoporeia* sp. and *Antinoella sarsi*. In the group 25-34 cm, *Mysis* is still most important together with *Saduria entomon* and small herring and sprat. Cod (>35 cm) prefer herring and sprat in almost identical amounts, but also *Saduria entomon* is important.

In subdivision 28, the same spectrum of food animals is preferred, but *Saduria entomon* is as important as herring and sprat together. The share of sprat is dependent of the size of the stock of sprat and of the hydrographical conditions as the spawning area of cod and sprat is extended further to the north when the oxygen conditions are favourable. In all the subdivisions it is common that if the bottom water is stagnated, cod has to feed in the water column or in shallow water which may influence the ratio between fish and invertebrates (*Saduria* and *Antinoella*) in its diet.

In subdivision 26, sprat is more important as food than herring, possibly because sprat remain in the food spectrum of cod during its whole life span while herring more than two years old are too large to eat. Since the late 1980s the importance of *Saduria entomon* has been reduced by a factor of 2 due to the lasting water stagnation. Instead the share of the polychaete *Antinoella sarsi* has increased, and a change to other benthic food invertebrates like *Crangon* sp., *Gammarus locusta* as well as fishes, *Pomatoschistus* sp., *Osmerus eperlanus, Ammodytes tobianus* and even *Zoarces viviparus* has occurred. Freshwater animals were also found in the stomachs (Uzars 1993).

In subdivision 25, in common with the other subdivisions, the crustaceans *Mysis* sp. and *Pontoporeia* sp., together with the polychaete *Antinoella sarsi*, dominate the food in cod <20 cm. The length group 21-30 cm cod take herring and sprat as the most important food items as also shown in the larger length groups. The proportion of herring and sprat taken depends on the stock size of the two species and of the dominating length group of herring. *Saduria entomon* is less important than in the other subdivisions. Cod is eaten in varying amounts and the predation on juvenile age groups seems to be important (Jensen & Sparholt 1992). Jensen & Sparholt estimated mortalities (*M2*) ranging from 0.2-1.0 for age 0 and 0.1-0.6 for age 1. As the cod used for stomach investigations in most cases are taken in small-meshed bottom trawl from research vessels, part of the cod may have been eaten in the trawl, and thus overestimated as prey.

The predation by cod on herring and sprat has a varying effect on the stocks of these species, depending on the stock size of cod. Several attempts to estimate the total annual amount eaten of herring, sprat and other food have been made in the past. A review is given by Bagge (1989). The food of cod was found to be a widely varying part of the biomasses of herring and sprat. This was due partly to different assumptions about daily rations and partly due to the inadequacy of the estimations of biomasses of the predator and prey stocks.

An ICES Baltic Multispecies Assessment Working Group met for the first time in 1986 (Anon. 1987a). Cod stomach data from 1977 and onwards were used to run a multispecies VPA model with cod as predator on herring, sprat and other food as prey. An important result was the estimate of the predation mortality *M*2 on herring and sprat which appeared to be much higher than assumed hitherto in single-species VPA. The annual predation mortalities-at-age on herring and sprat as a mean for the period 1978-1992 (Anon. 1994) are shown in Table 6.

Table 6. Predation mortality (*M*2) on herring and sprat in subdivisions 25-29. Anon. (1994).

	Sub-division	Age 0	1	2	3	4	5	6	7	8	9
Herring	25-27	0.20	0.57	0.15	0.09	0.07	0.07	0.05	0.05	0.04	0.03
Sprat	25-27	0.22	0.74	0.54	0.44	0.39	0.49	0.42	0.44		
Herring	28-29	0.20	0.56	0.21	0.25	0.20	0.20	0.17	0.18	0.16	0.12

The table illustrates that the highest mortalities are on the younger age groups. The corresponding amount of herring and sprat eaten by cod in the eastern Baltic is shown in Figure 5 (Thurow 1993). Since 1989, the sampling of cod stomachs have

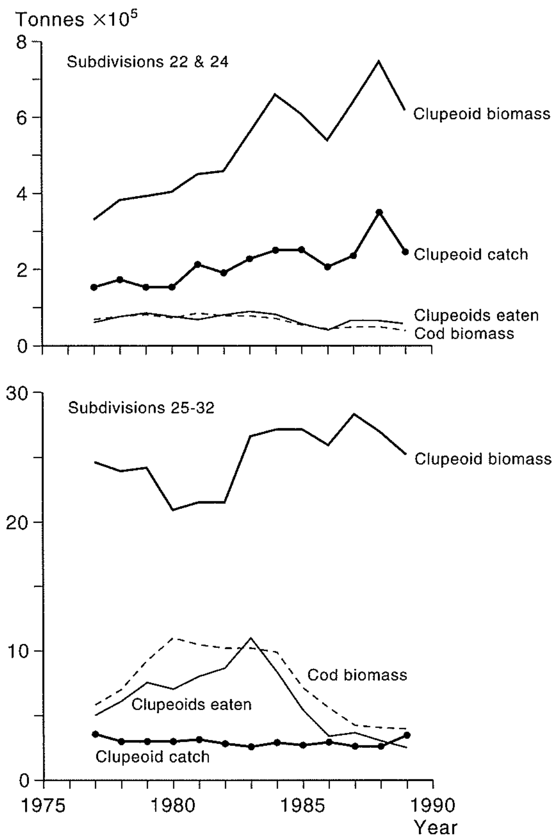

Figure 5. The amount of herring and sprat eaten by cod in subdivisions 22 and 24, and subdivisions 25-32. Clupeoid catch and biomass as well as cod biomass is also shown (Thurow 1993).

been standardized and an international data base has been established (Anon. 1989). At 1 January 1993, 43 544 cod stomachs from the Central Baltic have been included in the database.

A review on the compilation of cod stomach data for the Central Baltic MSVPA is given by Sparholt (1993).

The western Baltic

Compared to the eastern Baltic, the proportion of herring in the food of cod in subdivisions 22 and 24 is less than sprat, possibly because mature and maturing herring migrate to the Kattegat and Skagerrak for part of the year (Sparholt *et al.* 1992). In the 1960s clupeids accounted for as little as 6.7% (Arntz 1977, 1978) and the invertebrates, especially the bivalve *Arctica islandica*, were the main prey items of even large cod (Bagge 1960, Arntz & Weber 1980). Due to several events of stagnation in the 1980s (Weigelt & Rumohr 1986, Kils *et al.* 1989) the importance of *Arctica* has been largely reduced and the clupeids' contribution to the diet has increased to 24-40% (Weber & Damm 1991). From 1978 to 1989 about 13 000 cod stomachs have been sampled in order to run a multispecies VPA. The results of the last run in which the predation on invertebrates was kept constant, confirm the relatively low predation on herring, even though it is considered underestimated as a consequence of the migration (Anon. 1994). The mean estimated predation mortality-at-age (*M*2) 1978-1989 on herring and sprat is shown in Table 7. The corresponding amount of herring and sprat eaten in the western Baltic is shown in Figure 5 (Thurow 1993).

Table 7. Predation mortality (*M*2) on herring and sprat. Subdivisions 22 and 24 (Anon. 1994).

	Age								
	0	1	2	3	4	5	6	7	8
Herring	0.08	0.21	0.06	0.02	0.01	0.01	0.01	0.01	0.01
Sprat	0.13	0.30	0.23	0.13	0.10	0.22	0.12		

Methods of stock assessments

The essential information needed for this review is expected to be given in the reports of the Working Group on Assessment of Demersal Stocks in the Baltic (WG ADSB) (Anon. 1972-93). However, working group reports are not written for the public; reference to methods, in particular, uses key words only known within the expert circle and gives little information on original publications. Also, the WG ADSB in its early report does not give all results of calculations. These features make a review of the information difficult.

Historical background

Attempts to assess Baltic fish stocks and fisheries were not successful before the 1970s. In the early 1950s, the Baltic-Belt-Seas Committee of ICES continued to discuss the matter of stock evaluation and recommended a Special Meeting on Improvement of Demersal Stock in the Baltic which was held in 1957. This produced valuable results which could later be used to discuss the state of stocks and fisheries (ICES 1959). Little information was relevant. In essence, total mortality was evaluated from reduction of year-class strength from year to year (Dementjeva, Jensen, Rutkowicz, above report).

The ICES Baltic-Belt-Seas Committee existed until 1966. Thereafter, Baltic affairs were dealt with inside the Demersal Northern Committee. In 1968, this body established a Working Group for Assessment of Demersal Stocks in the Baltic (WG ADSB) which met in 1968, 1969, and 1970. It proposed and carried out tagging experiments on cod in order to define unit stocks and estimate mortality rates. It also discussed the possibilities for an analysis of the state of the cod stock. However, the knowledge on age composition, mortality rates, tagging techniques, and catch statistics was found to be insufficient. A special meeting on these subjects was therefore recommended and agreed upon by the Council to be held in 1971 (ICES 1974).

Among other things it was agreed that data suitable for assessment were still scarce. The main problem appeared to be the inadequacy in age data which would prevent the use of age-structured models. Under these conditions tactics were to follow two lines: firstly, to improve ageing techniques to enable year-class analysis, and secondly, to collect data for the application of yield function tables (Beverton & Holt 1966).

The Assessment Working Group, at its 1972 meeting in Gdynia, considered errors arising from age determinations. Large disagreements in the interpretation of age readings were found and causes for the differences have been suggested but not clearly identified. Further comparative readings were made in Rostock 1975 and in Gdynia 1993. The latter showed extremely large differences between experts.

Catch predictions based on year-class analysis (not published) were first made by the Assessment Working Group during its 1973 and 1975 meetings. Predictions at the 1976 meeting were based on observed length distributions and estimated growth functions. Results were shown to be very sensitive to assumptions of the input growth parameters (Anon. 1986). The first use of an age-based year-class analysis (VPA, see below) was applied and documented at the 1978 meeting in Lysekil.

Methods of assessment

A new impetus was given to the assessment work by the founding of the International Baltic Sea Fisheries Commission. It requested management advice from ICES.

By the time the WG ADSB had been established, the powerful technique of Virtual Population Analysis (VPA) had already been published (Gulland 1965). The technique pictures the past situation of considered year classes. Results of this backward-in-time analysis converge towards more precise mortality estimates of the younger ages. With this background, a reliable catch prediction for the coming year, i.e. at least two years ahead of the last data year or five years ahead of the last reliable year, is not possible.

The other possibility for assessing the state of the fishery was by use of yield function tables (Beverton & Holt 1966) as applied in 1974. This requires age interpretations as well. It is also based on past situations and can give information on a steady-state situation alone. Therefore it did not remove difficulties in performing short-term catch predictions. In addition to catches in numbers by age and year, a Virtual Population Analysis requires assumed or known values of natural mortality (M) for all ages and years considered. It further needs terminal fishing mortality (F) for the oldest ages in all years and for all ages in the last year. The actual situation is properly evaluated on the condition that the inputs are correct. Assessment methods considered here are therefore those which try to narrow down these inputs to actual values. Auxiliary data like effort or density are used for this calibration.

Natural mortality

The WG ADSB has dealt with the matter of natural mortality several times. The basis of its deliberations until 1988 had been the finding of Thurow (1974). Using total mortality (Z), and considering it as a function of total yield, he estimated $M = 0.4$. This value related to the period between 1920 and 1968. Cod was very lean then, and this was considered to be due to poor feeding conditions. Subsequently the quality of the fish appeared to have improved and the WG ADSB in 1974 decided to use $M = 0.3$.

After this time the situation changed markedly. By 1979-83 the biomass of the cod stock had tripled, and yet there were no signs of lack of food for cod. The WG ADSB used several data sets and methods to re-estimate natural mortality. They failed or gave unjustified results (Anon.1986).

Two years later the matter was reconsidered (Anon. 1988). Grzebielec & Kosior (1987) had advocated $M = 0.12$-0.18 as found from the relations between Z and Polish effort. These data were not substantiated, though. The WG ADSB also discussed predation mortality and decided to disregard it. No other estimations have been possible. Since the feeding conditions appeared to have been excellent, the procedure of the Baltic Multispecies Assessment Working Group was followed and $M = 0.2$ was used from 1988 and onwards.

Quality of assessment

As stated above, the reliability of the evaluation of the state of stocks and fisheries is dependent on the quality of the terminal F values which are used as an input to the VPA. In the early years of assessment the WG ADSB considered static stocks and fisheries. Later, auxiliary data in addition to catch-at-age were collected and used to adjust the inputs to the actual conditions. The methods outlined above were all used to improve this adaptation process. It appears that assessment would become more accurate with the application of these new techniques.

Weber (1989) has made a retrospective analysis on this problem for the period 1974-86. He compared the first assessment with those made for the same calendar year several years later (final). This is a quality analysis in a general sense only in that differences between the two series of estimations are shown. No evidence for the true situation is given. Since the estimates of the VPA converge after a few

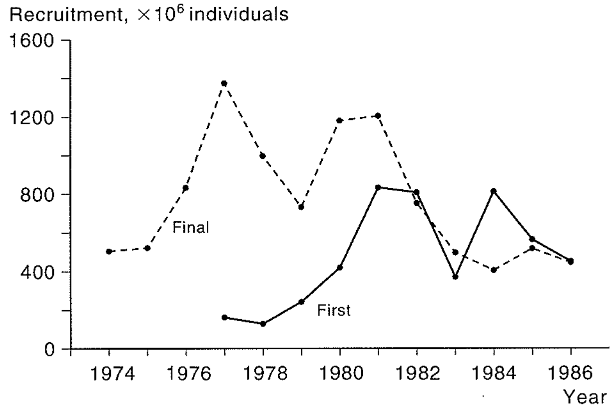

Figure 6. Recruitment, *R*, of cod at age 1 in subdivisions 25-32; comparison of the first year's assessment with the final in 1987 (WG 87); (Weber 1989).

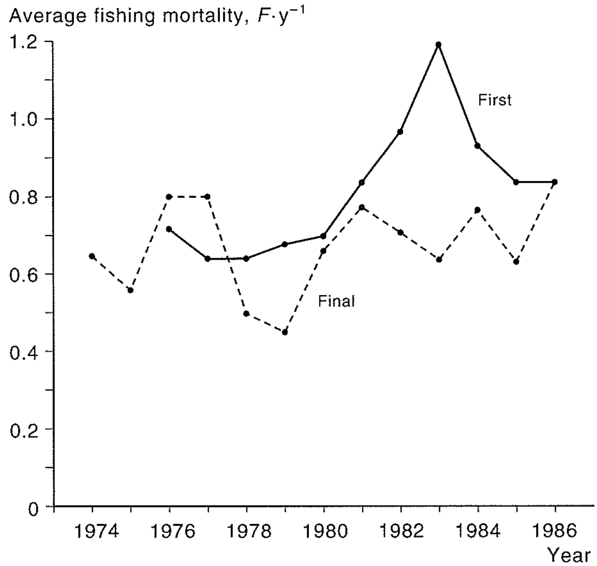

Figure 7. Average fishing mortality, *F*, of cod in subdivisions 25-32 for ages 4-7; comparison between the first and the final in 1987 (WG87); (Weber 1989).

years, it is very likely that the final assessment gives the best reflection of the true situation.

Figure 6 indicates that the estimates of recruits of age 1 in subdivisions 25-32 before 1981 were very inaccurate. The estimated average fishing mortalities of exploited ages for the same stock shown in Figure 7 also indicate large discrepancies between the initial and the final assessments (Weber 1989). With no data on effort and catch rates at hand, the inputs have simply been assumed. Among the values considered, the highest *F*s and the lowest *R*s were chosen so as to do no harm to the stocks.

At the time when Weber (1989) carried out his analyses, the methods outlined above have actually not been applied by the WG ADSB. The method of separable VPA has been used since 1984 to evaluate exploitations pattern. Full use of effort, and catch per unit of effort (CPUE), were made much later.

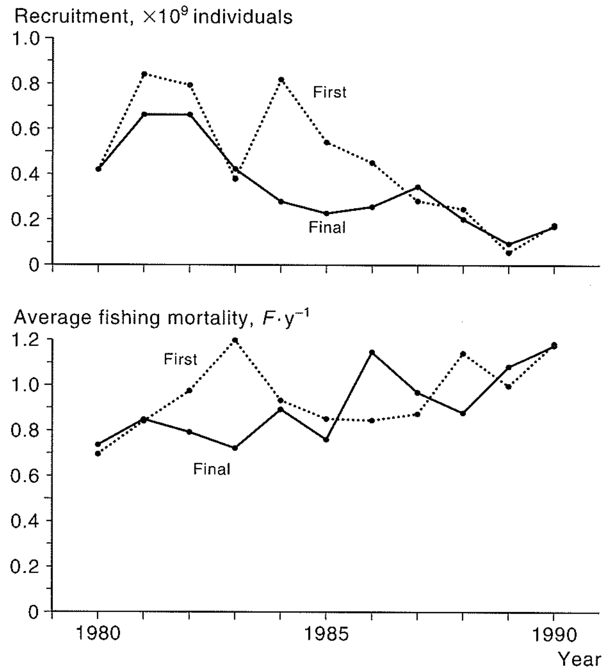

Figure 8. Number of cod recruits, *R*, of age 2, and cod fishing mortality, *F*, for ages 4-7, estimated in the year of the first assessment and in 1990 (Anon. 1981 through 1991).

Methods for tuning and parameter estimation were introduced since 1987. Figure 8 covers the period 1980-1990 for the same cod stock and is thus comparable to Figures 6 & 7. It shows a remarkable agreement between the two estimates of recruitment since 1987. The estimated average *F*s are also suggested to have improved since 1987 (Thurow 1993).

The Working Group on Methods for Fish Stock Assessments recommended a workshop to test the various methods for auxiliary data treatment (Anon. 1993c). This workshop, held in 1988, concluded that there is no indication, at present, that any of the methods which use auxiliary data clearly and consistently perform much better than any of the others (Anon. 1993c).

Development of the stock

Landing

At the beginning of this century, the exploitation of cod in the Baltic proper was on a very low level. By the end of the period 1921-1934 the total landings in subdivisions 22-32 were 4000-8000 tonnes and before that time less. The fishing gear used were mainly long lines, setnets and small seines in shallow waters. From 1935 onwards, the landings show a steady increase. The introduction of more efficient gear like ottertrawl, and in subdivision 25 also Danish seine, were responsible for this possibly because the stock was almost unexploited. From the 1950s until 1978, the landings varied between 120 000-180 000 tonnes, increasing in 1984 to about 400 000 tonnes followed by a reduction to about 60 000

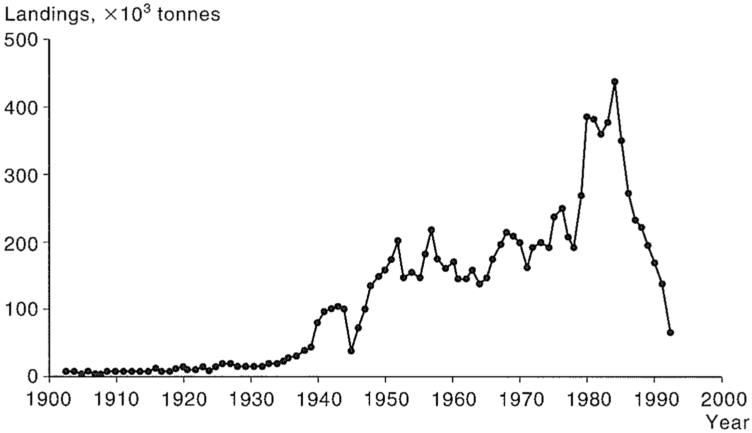

Figure 9.
The landings of cod in subdivisions 22-32, 1903-1992.

tonnes in 1992. The annual total landings of cod (1902-1992) in subdivisions 22-32 is shown in Figure 9. The landings in the western Baltic (subdivisions 22 and 24) are 5-8% of the total.

The variations are possibly due to changing environmental conditions caused by periods with major inflows, periods with stagnation and increasing eutrophication (Rosenberg *et al.* 1990) affecting the reproduction of cod and thus the strength of year classes but also changing fishing effort and exploitation patterns (Bagge & Thurow 1993).

The evaluation of the effects of fisheries on stocks in comparison to natural fluctuations in stock size was the main reason that led to the foundations of ICES. However, at the beginning of this century, fishing was confined to coastal areas and no idea existed as to natural units of fish stocks. Only in the 1920s, and more so in the 1930s, did the fishery increasingly exploit the open sea. This change was largely related to the introduction of engined vessels.

Even then, statistics on vessel numbers, catches or landings, and on areas fished, were incomplete or missing. Countries with extended coasts found it difficult to keep numerous small ports under surveillance.

Recruitment

In the 1960s (and possibly in the 1950s), the recruitment at age 2 is likely to have been at a relatively stable level of 300 millions (Figure 11). In the mid-1970s, a number of very good and extremely good year classes (up to 800 millions) appeared. They were most likely related to favourable hydrographic conditions. These high numbers of larvae would probably survive because of increased eutrophication since the 1960s. Plankton production as well as the biomass of benthos increased very much as an effect of eutrophication (Elmgren 1989), creating favourable feeding conditions for clupeids, the potential food of adult cod.

After this all-time maximum of recruitment the annual number decreased dramatically and was estimated to have reached 50 millions by 1990, the lowest number recorded (Anon. 1993) (Figure 11).

Positive correlations between the oxygen content during the spawning period and the recruitment one or two years later have been demonstrated by several authors.

Together with oxygen content as variable, Berner *et al.* (1989) also used salinity in March, May and August, zooplankton biomass in May and August and spawning stock biomass. They found that the oxygen content in March played the overwhelming predictive role for the recruitment of cod in the Baltic proper. The other variables were of minor importance.

Kosior & Netzel (1989) used simple regression analyses for the same period. They suggested that oxygen was important for all spawning areas (Bornholm, Gdańsk, Gotland). Salinity was also essential for the Gotland and Gdańsk Basins, but less so for the Bornholm Deep. The size of the parent stock and amount of zooplankton available had little effect on the magnitude of recruitment.

Lablaika *et al.* (1989) used salinity, oxygen, and water temperature in February and May in the Gotland Basin, as well as spawning stock size, to predict recruitment of two-year old cod for the period 1966-1985. They were not able to show that one of these factors alone had the sole responsibility for recruitment changes. All of them together, however, did significantly predict recruit numbers. The obvious difference compared to the foregoing results might be explained by these authors investigating only the Gotland Basin.

Beverton (1992) plotted the spawning volume (the volume of water with sufficient salinity and oxygen, which allows the eggs to float and to survive) against the recruitment of two-year old cod two years later. The relationship is significant but with a considerable variance indicating that other factors are involved.

Bagge (1993), using the unpublished data of Wieland (1993), related year-class strength to a factor combined of temperature, salinity, and oxygent content, expressed as the level (m) of water over which certain limits of these variables were reached. Significant regressions were obtained. However, the results showed that optimal levels of abiotic factors do not necessarily ensure good year classes. Additional unknown variables like predation on eggs and larvae, especially by sprat (Köster 1993) may have a significant effect on the egg mortality. A similar method was applied by Carlberg & Sjöberg (1992). They correlated the volume of water suitable for spawning and egg development with the corresponding number of recruits. A weak relationship was established, although they also found suitable conditions for a number of years which did not result in good recruitment.

In the studies mentioned above, the authors have either tried to estimate the mortality of cod eggs directly or to give an index of mortality by relating the abiotic conditions at the spawning places to the number of cod at ages 1 or 2 as estimated by VPA. That implies that the mortality in the period from yolk-sac larvae to age 1 or 2 is considered constant, which is unlikely to be true and contradicts the results of Jensen & Sparholt (1992) who found considerable cannibalism on age group 0 and 1. That is possibly another reason why correlations between the abiotic conditions and recruitment are generally not very convincing. In the western Baltic (subdivision 22) the salinity and the oxygen content has currently been favourable for development of cod eggs during the main spawning period (March-April) (NERI 1984-1991). Despite, the recruitment since 1982 has decreased drastically (Anon. 1990), which may indicate a mortality later than the egg stage. Berner *et al.* (1988) found significant negative correlations between salinity in May and recruitment. They also found a significant negative correlation between oxygen content and salinity in the same month. This indicate that low salinity and high oxygen content lead to a high recruitment. Since all eggs are spawned by May (Table 2) the mortality must occur in the larval stage or later.

Fishing mortality

Reproduction during many of the years was confined to the Bornholm Basin. Only under optimal conditions (inflow) was reproduction on a large scale in more eastern and northern areas possible.

Spawning cod concentrate in the deeper areas where salinity is sufficiently high for the eggs to float. Therefore the fishing fleets concentrate on the spawning grounds between January and July.

With this in mind consider the fishing mortality, F (Figure 10). This was high in the end of the 1960s, decreased towards the end of the 1970s and then increased subsequently.

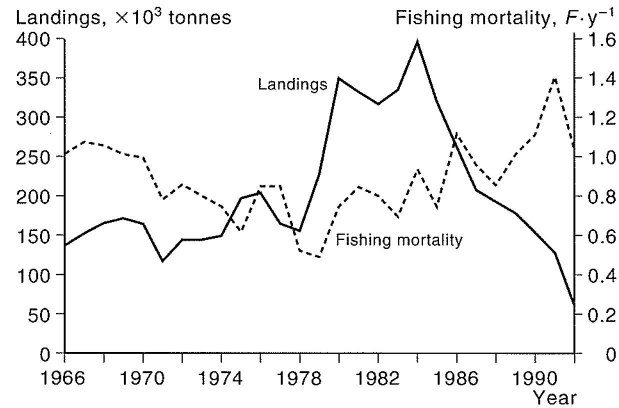

Figure 10. The landings and average fishing mortality, F (age 4-7). Subdivisions 25-32. (Anon. 1988, 1993).

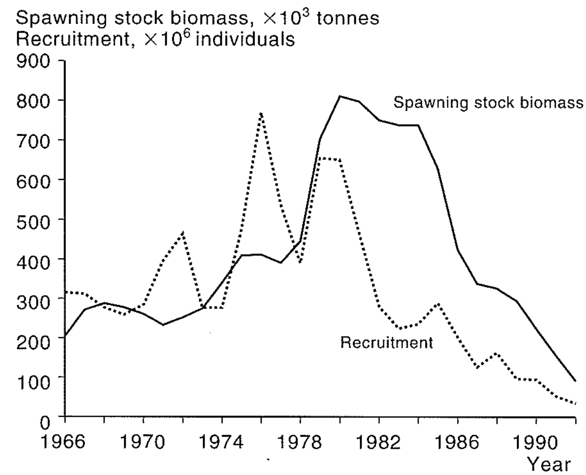

Figure 11. Cod spawning stock biomass at 1 January and recruitment at age 2. Subdivisions 25-32 (Anon. 1988, 1993).

This unexpected behaviour is thought to be connected to an extension of the spawning ground to the Gdańsk and Gotland Deep at the same time as the stock increased enormously. An essential contribution may have been a delay of the fishing fleet in the reaction to the increase and movement of the spawning shoals. At the increase in biomass, the fleets remained in the Bornholm Deep and left the new sites less exploited. A contributing factor to this phenomenon was the introduction of economic zones in 1978 which prevented a large part of the fleet to move east or north. In the 1980s F increased again, even when the stock was declining.

Biomass

Kosior (1975) and Berner & Borrmann (1980) assessed the cod biomass for the 1960s. If their results are calibrated against the VPA estimates of the Assessment Working Groups, the biomass appears to be at a level of approximately 400 000 to 500 000 tonnes between 1960 and 1973. Catch per unit of effort data of Dementjeva (1958) and the USSR (Anon. 1992) suggest that this level was also present in the 1950s. The conclusion is that the equilibrium biomass was 400 000-500 000 tonnes for approximately 25 years. Subsequently, the biomass more than doubled because of the favourable recruitment. Since 1985 spawning stock biomass very rapidly decreased to less than 100 000 tonnes in 1992, which is by far the lowest level recorded (Anon. 1993) (Figure 11).

Conclusions

The downward trend in the central Baltic cod stock since 1985 is obvious from the drop in biomass as well as from the decrease of recruitment. By 1989 the spawning stock biomass had fallen to some 300 000 tonnes reaching the long-term equilibrium level of the 1960s and 1970s. However, the decline continued to the present low level.

Between 1980 and 1985, the average fishing mortality for ages 4-7 was at a level of 0.8, i.e. three times the F_{max} of 0.25. Subsequently it showed an increasing trend until 1991 when it reached 1.37, more than five times F_{max}. Clearly, the stock was heavily overfished as was also the case for the smaller stock in the Belt Sea (Anon. 1993).

The high level in biomass of the central stock between 1979 and 1985 was preceded by high recruitment four years earlier. By 1985, the latter was at about the same level as in the stable situation of the 1960s and 1970s. Following this, recruitment declined steadily. Biomass showed a reduction as well, again with a time lag of about four years. This suggests an effect of recruitment failure on biomass.

The Belt Sea stock has shown a declining trend in recruitment since monitoring started in 1970. A clear indication of biomass decrease has been obvious since 1986. Since then biomass has followed the development of recruitment with a time lag of approximately 3-4 years.

Since 1986 fishing mortality for both stocks increased to the highest levels. This would have contributed to the decline in biomass. Recruitment overfishing cannot clearly be shown, but the extremely high fishing pressure on declining spawning stocks, which show the lowest size on record, may have led to the beginning of a tighter relationship between recruitment and spawning stock size.

This feature has to be looked at in the light of the development of other stocks. All demersal stocks in the Baltic, except turbot and sole, show severe reductions. The cod stock in the Kattegat decreased while recruitment decreased and fishing effort increased (Anon. 1993). A similar decline is recorded for North Sea cod (Anon. 1992). This indicates that a factor common to all these stocks caused or contributed to their decrease.

With respect to management, adverse effects of natural variables cannot be counteracted. However, a fishery can be adjusted to any level of stock size to give optimum returns. The present case requires reduction in effort in order to approach F_{max}. This is a process extremely harmful to the fishery at the present state. It would have been much easier at the time of high stock level around 1980, as recommended by ICES (Anon. 1985).

The two Baltic cod stocks form independent units which behave differently. This is obvious from a comparison of recruitment and spawning stock biomass. A very large increase in recruitment 1975-1981 and in biomass 1979-1985 was mentioned above for the central Baltic cod. This did not occur in the western stock. The declining phase common to them in recent years is suggested to have been the result of a factor that was acting on demersal stocks in the North Sea and the Baltic.

Although ICES recommended differential management of the two stocks, the Baltic Fisheries Commission has always applied a common management regime. This had the effect that the western stock was more heavily exploited than the central stock. It showed signs of collapse as early as 1986 whereas in the central Baltic this was indicated only in 1990.

Future aspects

The distribution of cod in the Baltic has been known for a long time and a sufficiently good identification of the stocks has been possible. Food, feeding and reproduction are well known as well, but recruitment cannot be adequately described.

Salinity, temperature, and oxygen in particular are important for new year classes, but they do not allow forecasts based on single major inflows. Additional factor(s) are involved (Carlberg & Sjöberg 1992, Bagge 1993). However, regressions with recruit numbers at ages 1 or 2 on variables consider that any mortality between hatching and these ages was always of roughly the same size. This is in contrast to new findings on cannibalism. A possible additional variable could therefore be predation by adult cod on juveniles. Jensen & Sparholt (1992) have shown that $M2$ ranges from 0.2 to 1.0 for age 0, and 0.1 to 0.6 for age 1.

The above-mentioned regressions showed that oxygen content in March is significantly related to recruitment, oxygen in May less so. Contrary to this, Wieland (1994), for the years 1987 to 1992, found the greatest numbers of eggs between April and July. All samples in March gave very low numbers. This discrepancy deserves more attention.

The basis of assessment applied to date is the age composition of catches. The quality of estimates does therefore depend greatly on the adequacy the age determinations. Several comparative age readings have revealed great discrepancies between readers. This would affect number-at-age as well as weight-at-age. For example weight-at-age as estimated by six different countries for 1985 gave maximum differences of approximately 80% for ages 2-7.

Age of central Baltic cod is difficult to interpret because no clear annuli can be identified. Homogeneous temperature has been suggested to cause this. The prolonged spawning season as compared to the western stock may play a role, but no criteria for ageing have yet been established. Clearly, this is a task of paramount importance.

At its maximum the western stock amounted to 5% the size of the central stock in terms of spawning stock biomass. The eye-catching high level of the larger stock requires consideration.

The role of oxygen and salinity for the recruitment have been discussed. It is likely that the very high numbers of cod larvae could not have been produced without strong inflows of saline and oxygenated water and the subsequent enlargement of the volume of water suitable for propagation.

The idea is put forward here that the larvae produced in the period 1975-1981 would not have grown to actual recruit numbers had this development not been proceeded by an increase in suitable food.

Elmgren (1989) has pointed out that the nutrients have greatly increased in the second half of the 1960s. This was followed by a corresponding increase in plankton and benthos production. As a consequence, the clupeid stocks increased to much higher levels than before (Thurow 1993). It is therefore suggested that the very high cod production which lead to a total biomass of over one million tonnes was a combined effect of eutrophication and water inflow from the North Sea.

There seems to be an agreement now that this eutrophication is largely a human effect. Associated with the nutrients is the input of a variety of harmful substances. Apart from the positive effect of an increase in valuable biomass, eutrophication produces adverse results. Directly of concern for the fishery is the increased bioproduction and the subsequent depletion of oxygen in bottom water layers, but also the accumulation of nutrients there.

Our future aim should therefore be to reduce eutrophication and its various adverse effects. This would imply a reduction in fish stocks and fish yields. Under quasi-natural conditions 1950-1975, the central cod stock was at a level of some 400 000 tonnes of total biomass corresponding to some 300 000 tonnes of spawning stock biomass. The comparable amounts for the western stock might have been 70 000 tonnes and 40 000 tonnes. At rational exploitation both stocks together would yield some 120 000 tonnes as compared to 56 000 tonnes in 1992 and 138 000 tonnes in 1991.

References

Anon., 1972: Report of the Working Group for Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1972/F: 5.

Anon., 1973: Report of the Working Group on Assessment of Demersal Stocks in the Baltic. Demersal Fish (Northern) Committee. – ICES. C.M.1973. F: 6.

Anon., 1974: Report of the Working Group for Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1974/F: 4.

Anon., 1975: Report of the Working Group for Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1975/P: 17.

Anon., 1976: Report of the Working Group for Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1976/P: 2.

Anon., 1977: Report of the Working Group for Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1977/P: 2.

Anon., 1978: report of the Working Group for Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1978/J: 3.

Anon., 1979: Report of the Working Group for Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1979/J: 4.

Anon., 1980: Report of the Working Group for Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1980/J: 3.

Anon., 1981: Report of the Working Group for Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1981/J: 2.

Anon., 1982: Report of the Working Group for Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1982/Assess: 17.

Anon., 1983: Report of the Working Group for Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1983/Assess: 15.

Anon., 1984: Report of the Working Group for Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1984/Assess: 13.

Anon., 1985: Report of the Working Group for Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1985/Assess: 15.

Anon., 1986: Report of the Working Group for Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1986/Assess:21.

Anon., 1987: Report of the Working Group on Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1987/Assess: 22.

Anon., 1987a: Report of the Baltic Multispecies Assessment Working Group. – ICES, C.M. 1987/Assess: 6.

Anon., 1988: Report of the Working Group on Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1988/Assess: 20.

Anon., 1989: Report of the Working Group on Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1989/Assess: 17.

Anon., 1990: Report of the Working Group on Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1990/Assess: 17.

Anon., 1989: Report of the Study Group on Cod Stomach Data for the Baltic. – ICES, CM. 1989/J:2.

Anon., 1991: Report of the Working Group on Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1991/Assess. 16.

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

Anon., 1992: Report of the Working Group on Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1992/Assess: 12.

Anon., 1993: Report of the Working Group on Assessment of Demersal Stocks in the Baltic. – ICES, C.M. 1993/Assess. 16.

Anon., 1994: Report of the Working Group on Multispecies Assessment of Baltic Fish. – ICES. C.M. 1994/Assess: 1.

Apstein, C., 1911: Die Verbeitung der pelagischen Fischeier und Larven in der Beltsee und den angrenzenden Meeresteilen 1908/1909. – Wiss. Meeresunters. *13*: 225-284.

Arntz, W.E., 1974: Die Nahrung Juveniler Dorsche (*Gadus morhua* L.) in der Kieler Bucht. – Ber. dt. wiss. Komm. Meeresforsch. *23*: 97-120.

Arntz, W.E., 1977/78: The food of adult cod (*Gadus morhua* L.) in the Western Baltic. – Meresforsch. *26*: 60-69.

Arntz, W.E. & W. Weber, 1980: *Cyprina islandica* L. (Mollusca, Bivalvia) als Nahrung von Dorsch und Kliesche in der Kieler Bucht. – Ber. dt. wiss. Komm. Meeresforsch. *21*: 193-209.

Aro, E., 1989: A review of fish migration patterns in the Baltic. – Rapp.P.-v. Réun. Cons. int. Explor. Mer. *190*: 72-96.

Axell, M.B., 1982: Feeding of cod in the Åland Sea and its influence on stocks of herring and sprat. – Fin. Fish. Res. *4*: 35-39.

Bagge, O., 1966: *Cyprina islandica* as food for cod in the Western Baltic. – ICES, CM. 1966/D: 15.
Bagge, O., 1981: Demersal fishes – *In* A. Volpio (ed.) The Baltic Sea, pp. 311-333. Elsevier Sci. Publ. Comp. Amsterdam.
Bagge, O., 1981: The yearly consumption of cod in the Baltic and the Kattegat as estimated from stomach content. – ICES, C.M. 1981/J: 27.
Bagge, O., 1989: A review of investigations of the predation of cod in the Baltic. – Rapp. P.-v. Réun. Cons. Explor. Mer *190*: 51-56.
Bagge, O., 1993: Possible effects on fish reproduction due to the changed oceanographic conditions in the Baltic proper. – ICES, C.M. 1993/J: 31.
Bagge, O. & J. Bay, 1987: Periodicity of feeding in Baltic cod. – ICES, C.M. 1987/J: 8.
Bagge, O. & H. Knudsen,1974: Length-girth relationship in cod. – Rapp. P.-v. Réun. Cons. int. Explor. Mer. *166*: 83-84.
Bagge, O. & A. Müller, 1977: The spawning of cod in the Bornholm Basin and the size of the spawning stock. – Meeresforsch. *25*(H. 3-4): 172-185.
Bagge, O., A. Müller & U.J. Hansen, 1978: Mortality of cod eggs in the Bornholm basin, 1978. – ICES, C.M. 1978/J: 16.
Bagge, O. & E. Steffensen, 1989: Stock identification of demersal fish in the Baltic. – Rapp. P.-v. Réun. Cons. int. Explor. Mer *190*: 3-16.
Bagge, O. & E. Steffensen, 1991: The condition factor in relation to maturity and filling of stomach in cod (Sub-division 25). – ICES, C.M. 1991/J: 13.
Bagge, O. & F. Thurow, 1993: The Baltic cod stock, fluctuations and the possible causes. – ICES, 1993/CC Symp. *14*. 20 pp.
Baranova, T., 1992: On the growth of eastern Baltic cod. – ICES, C.M. 1992/J: 29.
Baranova, T. & D. Uzars, 1986: Growth and maturation of cod (*Gadus morhua callarias* L.). in the eastern Baltic. – ICES, C.M. 1986/J: 7.
Berner, M., 1960: Untersuchungen über den Dorschbestand (*Gadus morhua* L.) der Bornholm- und Arkonasee in den Jahren 1953-1955. – Z. Fisch., Bd. IX. N.F., Heft 7-10: 481-602
Berner, M., 1968: Einige orientierende Untersuchungen an den Otolithen des Dorsches (*Gadus morhua* L.) aus verschiedenen Regionen der Ostsee. – Fisch.-Forsch. Rostock 6(1): 77-86.
Berner, M. & H. Borrmann, 1980: Die Entwicklung des Ostsee Dorschbestanden in den ICES-Untergebieten 25-32. (östlich Bornholm) in den Jahren 1965-1976. – Fisch.-Forsch. Rostock *18*(2): 11-23.
Berner, M., H. Müller & D. Nehring, 1988: Zum Einfluss von Umwelt- und Bestandsparametern auf die Rekrutierung des Dorschbestandes der Arkonasee (SD24). – Fisch.-Forsch. Rostock 26(2): 44-49.
Berner, M., H. Müller & D. Nehring, 1988: The influence of environmental and stock parameters on the recruitment of cod stocks to the east and west of Bornholm, described by regression equations. – Rapp. P.- v. Réun. Cons. int. Explor. Mer *190*: 142-146.
Berner, M. & G. Sager, 1984: Untersuchungen zu Längen- und Massewachstum, Zuwachs und Längen-/Masse-Relation des Ostseedorsches (*Gadus morhua callarias* L.). vor der Küste Finnlands nach Datenreihen von ARO. – Fisch.-Forsch., Rostock *22*(3): 49-58.
Berner, M. & G. Sager, 1985: Untersuchungen zu Längen- und Massewachstum, Zuwachs und Längen/ Masse-Relation des Dorsches der Arkonasee nach Datenreihen von Berner. – Fisch.-Forsch. Rostock *23*(1): 11-15.
Berner, M., G. Sager & R. Sammler, 1984: Untersuchungen zu Längen-/Masse-Relation der Geschlechter des Gotlandsee-Dorsches (*Gadus morhua callarias* L.) nach Datenreihen von Berner. – Fish.-Forsch. Rostock 22(3): 40-48.
Berner, M. & B. Vaske, 1985: Morphometric and meristic characters of cod stocks in the Baltic Sea. – ICES, CM 1985/J: 11.
Beverton, R.J.H., 1992: Fish resources; threats and protection. – Neth. J. Zool. *42*(2-3): 139-175.
Beverton, R. & S. Holt, 1966: Manual of methods for fish stock assessment, Part 2. – Tables of yield functions. – FAO Fish. tech. Pap. *38* (rev.I). 77 pp.
Birjukov, N.P., 1969: Spawning communities of Baltic cod and the extent of their mixing. – ICES, CM 1969/F: 7.
Botros, G.A., 1959: A comparative study on the fecundity of Norwegian and Baltic cod. – ICES, C.M. 1959, Gadoid Fish Comm. No. 99. 16 pp.

Botros, G.A., 1962: Die Fruchtbarkeit des Dorsches (*Gadus morhua* L.) in der westlichen Ostsee und den westnorwegischen Gewässern. – Kieler Meeresforsch. *18*: 67-80.

Carlberg, S. & B. Sjöberg, 1992: Is the reproduction of Baltic cod governed by oceanographic factors? – Abstract, ICES. Mar. Sci. Symp. *195*: 487.

Dementjeva, T.F., 1959: Some data on the life history and fishery of cod in the central Baltic. – Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer *147*: 68-73.

Draganik, B. & J. Netzel, 1966: An attempt to estimate the rate of growth of cod in the southern Baltic on the basis of tagging experiments. – ICES, C.M. 1966/D: 12.

Elmgren, R., 1989: Man's impact on the ecosystem of the Baltic Sea: Energy flows today and at the turn of the century. – Ambio *18*(6): 326-332.

Grauman, G., 1970: Peculiarities of cod spawning in the Baltic Sea in the spring-summer period of 1969. – Ann. Biol. *26*: 136.

Grauman, G., 1974: Investigations on the spawning of Baltic cod in 1968-1970. – Rapp. P.-v. Réun. Cons. int. Explor. Mer. *166*: 7-9.

Grauman, G., 1975: The spawning of Baltic cod in 1973. – Ann. Biol. *30*: 96.

Grzebielec, R. & M. Kosior, 1987: Mortality of cod in the southern Baltic in 1973-1986. – ICES, C.M. 1987/J: 5.

Gulland, J., 1965: Estimation of mortality rates. (Annex to Arctic Fisheries Working Group Report.) – ICES, C.M. 1965. 9 pp.

Hansen, U.J., 1978: Hyppighed and Forekomst af pelagiske Fiskeæg i Bornholmsdybet. – Thesis, Univ. Copenhagen.

Hensen, V., 1884: Über das Vorkommen und die Menge der Eier einiger Ostseefische, insbesondere derjenigen der Sholle (*Pleuronectes platessa*), der Flunder (*Platessa vulgaris*) und des Dorsches (*Gadus morhua*). 4. – Ber. dt. Komm. wissensch. Untersuch. dt. Meere, Kiel 1877-1881: 297-313.

ICES, Proc.-Verbal Reun., 1966 through 1972.

ICES, 1959, 1974, 1989. Rapp. P.-v. Reun. Cons. int. Explor. Mer. 147, 166 &190.

Jamieson, A. & G. Otterlind, 1971: The use of cod blood protein polymorphisms. – Rapp. P.-v. Réun. Cons. int. Explor. Mer *161*: 55-59.

Jensen, H. & H. Sparholt, 1992: Estimation of predation mortality of cod in the Central Baltic using the MSVPA. – ICES, C.M.1992/J: 23.

Janoschek, A., 1957: Das reaktionskinetische Grundgesetz und seine Beziehungen zum Wachstum- und Ertragsgesetz. – Statist. Vjschr., Wien *10*: 25-37.

Kändler, R., 1944: Untersuchungen über den Ostseedorsch während der Forschungsfarten mit dem R.F.D. 'Poseidon' in den Jahren 1925-1938. – Ber. dt. wiss. Komm. Meeresforsch., N.F., *11*. H.2: 137-245.

Kändler, R., 1949: Die Häufigikeit pelagischer Fischeier in der Ostsee als Massstab für die Zu-und Abnahme der Fischbestände. – Kieler Meeresforsch. Bd VI: 73-89.

Kils, U., U. Waller & P. Fischer, 1989: The fish-kill of the autumn 1988 in Kiel Bay. – ICES, C.M. 1989/L: 14.

Kosior, M., 1975: Biomass and fishing mortality coefficients of Baltic cod evaluated by use of Virtual Population Analysis. – ICES, C.M. 1975/P: 14.

Kosior, M., 1976: The south Baltic cod growth parameters and length/weight relationships. – ICES, C.M. 1976/P: 20.

Kosior, M. & J. Netzel, 1989: Eastern Baltic cod stocks and environmental conditions. – ICES, Rapp. Proc.-Verb. *190*: 159-162.

Kosior, M. & K. Strzyzewska, 1979: Fecundity of Baltic cod. – ICES, C.M. 1979/J: 10.

Köster, F.W., 1992: Predation by herring and sprat on cod eggs and larvae in the Bornholm Basin. – Preliminary results. – ICES, CM/J: 41. Baltic Fish Comm.

Lablaika, I.A., S.A. Hoziosky & M. Kalejs, 1989: Abundance dynamics of Eastern Baltic cod stocks and related factors. – Rapp. P.-v. Réun. Cons. int. Explor. Mer *190*: 163-165.

Lablaika, I.A., M.N. Lishev, D.V. Uzars & S.A. Chozioskij, 1975: Struktur, Zustand und Nutzung der Vorkommen des Ostseedorshes und seine Bedeutung in der Nahrungekette. – Fish.-Forsch., Rostock *13*(1):31-38.

Lassen, H., 1985: Results from comparative age-readings of Baltic cod and flounder otoliths. – ICES, C.M. 1985/J: 12.

Mielck, W., 1926: Untersuchungen über die pelagische Fischbrut (Eier und Larven) in der Ostsee im april 1925. – Ber. dt. wiss. Komm. Meeresforsch., N.F., 2(4): 99-116

Mielck, W. & C.L. Künne, 1935: Fischbrut- und Planktonuntersuchungen auf dem R.F.D. 'Poseidon' in der Ostsee, Mai/Juni 1931. – Wiss. Meeresunters. Abt. Helgoland, Bd. XIX(7): 1-119.

Moth-Poulsen, T., 1982: Genetic variation of cod from the Danish Sound: Interrelations of stocks from adjacent waters. – ICES, C.M. 1982/G: 46.

Müller, A. & O. Bagge, 1977: The mortality of cod eggs, the spawning of cod and the biomass of the spawning stock in the Bornholm Basin. – ICES, C.M. 1977/P: 14. Baltic Fish Committee.

Müller, A. & I. Pommeranz, 1984: Vertical distribution of fish eggs in the Bornholm Basin. – *In* Int. Symp. Early Life History of Fishes and 8th Annual Larval Conference, Vancouver 1984, 21 pp. (mimeo).

NERI, 1984-1991: National Environmental Research Institute, Roskilde, Denmark. Internal reports.

Poulsen, E.M., 1931: Biological investigations upon the cod in Danish waters. – Medd. Komm. DFH, Ser. Fiskeri, *9*(1). 150 pp.

Richards, F.J., 1959: A flexible growth curve for empirical use. – J. exp. Bot. *10*: 290-300.

Rosenberg, R., R. Elmgren, S. Fleischer, P. Jonsson, G. Persson & H. Dahlin, 1990: Marine eutrophication case studies in Sweden. – Ambio *19*(3): 102-108.

Schmidt, J., 1930: Raceundersøgelser. X. Den atlantiske torsk (*Gadus callarias* L.), and dens lokale racer. – Medd. Carlsb. Lab. *18*(6): 1-88.

Schopka, S., 1971: Vergleichende Untersuchungen zur Fortpflanzungsrate bei Herings- und Kabeljaupopulationen (*Clupea harengus* L. und *Gadus morhua* L.). – Ber. dt. wiss. Komm. Meeresforsch. N.F. *22*(1): 31-79.

Schultz, N., 1988: Erste Ergebnisse der Nahrungsuntersuchungen zum Dorsch der westlichen Ostsee unter besonderer Berücksichtigung seines Einflusses auft die Herings- und Sprottbestände in diesem Seegebiet. – Fisch.-Forsch. Rostock *26*(2): 29-36.

Sick, K., 1965: Haemoglobin polymorphism of cod in the Baltic and the Danish Belt Sea. – Hereditas *54*(2): 19-48.

Sjöblom, V., E. Aro & P. Suuronen, 1980: Migrations, mortality and growth of cod in the northern Baltic Sea. – ICES, CM. 1980/J: 8.

Sparholt, H., 1993: Compilation of cod stomach data for the central Baltic MSVPA. – ICES, C.M. 1993/J: 11.

Sparholt, H., J. Bay, H. Jensen, B. Gloerfeldt-Tarp & W. Weber, 1992: The 1992 multispecies assessment of the fish stocks in the western Baltic. – ICES, C.M. 1992/J: 35.

Steffensen, E., 1980: Daily growth increments observed in otoliths from juvenile East Baltic cod. – Dana *1*: 29-37.

Steffensen, E. & O. Bagge, 1983: Growth of cod in different parts of the Baltic and the Kattegat. – ICES, C.M. 1983/J: 12.

Strodtmann, S., 1906: Laichen und Wandern der Ostseefische 2. Bereicht. – Wiss. Meeresunters., Abt. Helgoland. N.F. 7(2): 137-216.

Strodtmann, S., 1918: Weitere Untersuchungen über Ostseefische. III. – Ber. wiss. Meeresunters., Abt. Helgoland N.F. *24*: 33-94.

Strzyzewska, K., 1962: The changes in fecundity of cod from the Gdańsk Bay in the years 1959-1961. – ICES, C.M. 1962, Gadoid Fish Comm. *119*. 6 pp.

Thurow, F., 1970: Über die Fortpflanzung des Dorsches *Gadus morhua* (L.) in der Kieler Bucht. – Ber. dt. wiss. Komm. Meeresforsch. *21*: 170-192.

Thurow, F., 1974: Changes in the population parameters of cod in the Baltic. – Rapp. P.-v. Réun. Cons. int. Explor. Mer *166*: 85-93.

Thurow, F., 1993: Fish and Fisheries in the Baltic Sea. – ICES, Coop. Res. Rapp. *186*: 20-36.

Uzars, D., 1975: Peculiarities of feeding and quantitative food consumption of eastern Baltic cod. – ICES, C.M. 1975/P: 4.

Uzars, D., 1976: Feeding of young cod in the eastern Baltic. – ICES. C.M. 1976/P: 7.

Uzars, D., 1985: Food composition in the eastern Baltic cod for the 1963-1984 period. – ICES, C.M. 1985/J: 3.

Uzars, D., 1993: Feeding of cod (*Gadus morhua callarias* L.) in central Baltic. – ICES, Symp. Cod Climate Change *45*.

Waller, U., K. Wieland & D. Schnack, 1993: The survival of eggs and the hatching of larvae of cod (*Gadus morhua*) at different oxygen levels. – ICES, C.M. 1993/J: 21.

Weber, W., 1989: A review of stock assessment of cod in the Baltic. – Rapp. P.-v. Reún. Cons. int. Explor. Mer *190*: 224-234.

Weber, W. & U. Damm, 1991: Investigations on cod stomachs in the Western Baltic 1981-1989. – ICES, C.M. 1991/J: 23.

Wieland, K., 1988: Distribution and mortality of cod eggs in the Bornholm Basin (Baltic Sea) in May and June 1986. – Kieler Meeresforsch., Sonderh:. 6: 331-340.

Wieland, K., 1989: Small-scale vertical distribution on mortality of cod and sprat eggs in the Bornholm Basin (Baltic Sea) during two patch studies in 1988. – ICES, C.M. 1989/J: 19.

Wieland, K., 1989: Vertical distribution of cod and sprat eggs in the central Bornholm Basin (Baltic Sea) related to different hydrographic conditions in 1986 and in 1988. – ICES, C.M. 1989/J: 20.

Wieland, K. & F. Zuzarte, 1991: Vertical distribution of cod and sprat eggs and larvae in the Bornholm Basin (Baltic Sea) 1987-1990. – ICES, C.M. 1991/J: 37.

Wieland, K., (in prep.): Einfluss der Hydrographie auf die Vertikalverteilung und Sterblichkeit der Eier des Ostseedorsches (*Gadus morhua callarias*) im Bornholm Beeken, südliche, zentrale Ostsee. – Thesis, Univ. Kiel. 114 pp.

Weigelt, M. & H. Rumohr, 1986: Effects of wide-range oxygen depletion on benthic fauna and demersal fish in Kiel Bay 1981-1983. – Meeresforsch. *31*: 124-136.

Załachowski, W., 1977: Quantitative and ecological analysis of food consumed by southern Baltic cod populations in the years 1972-74. – Akad. Rolniza w. SzcZecinie, Rozprawy *53*. 109 pp.

Załachowski, W., 1985: An attempt to apply Bajkov's formula to estimation of food uptake of cod in the southern Baltic. – Acta Ichthyol. Piacatria *15*(1): 19.

Załachowski, W., J. Szyputa, S. Krzykowski & J. Kryzowska, 1976: Composition and amount of food consumed by sprat, herring and cod in the southern Baltic in the years 1971-74. – ICES, C.M. 1976/P: 23.

Ziecik, M., 1938: The biometrical features of the cod caught in the Polish and the Danish Baltic. – Arch. Hydrobiol. Rybact. *11*(1/2).