

Estimation of the total fish biomass in the Baltic Sea during the 20th century

Fritz Thurow



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Catch composition and yield data are used to estimate the evolution of fish biomass. These results are compared with the catch rates of Polish and Swedish fisheries. Both series, estimated biomasses and catch rates, suggest that biomass was low during the first half of this century. Subsequently, it increased to over 8 million tonnes in the 1970s. The yield shows essentially the same picture. Peak catches of almost 1 million tonnes were achieved at the end of the 1970s. Fishing mortality increased between 1900 and 1945. After this time, yield increased because of growing biomass (1940–1950, 1965–1970) or because of growing fishing effort (1950–1965, 1970–1975). There is evidence to indicate that eutrophication has caused the increase in biomass of Baltic fish stocks.

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F. Thurow: Langensæten 12, D-24 226 Heikendorf, Germany.

Introduction

Biomass is a key parameter for the evaluation of the state of a stock. It is indispensable for the estimation of recruitment and the effects of both fisheries and environmental factors on the ecosystem. These parameters do change in time, sometimes quite considerably so. Assessment Working Groups (AWGs) of the International Council for the Exploration of the Sea (ICES) have shown that the biomass of herring has varied by a factor of 1.4 in the last 20 years. For sprat and cod the corresponding factor is 4.4.

However, a period of some 20 years is very short when long-term variations are considered. Climatic trends extend over intervals of 10^0 to 10^4 years. Therefore, biomass estimates over a longer time span are required in order to obtain clues about the causes of fluctuations in fish stocks. This paper tries to ascertain the development of the biomass of the Baltic fish community during the 20th century.

For the purpose of this paper the relevant information has been brought together in a comprehensive data report (Thurow, 1997). Reference to information in the data report will be made by using the identification “DR”.

Data and methods

The recent history of the main fish stocks in the Baltic is well-known thanks to the sampling of commercial catch data, which allows for the estimation of fishing mortality, recruitment and stock biomass on the basis of Virtual Population Analysis (VPA). An attempt to extend time series data over longer periods, however, is limited by less complete information. In this report yield and age composition data are used to explore the overall trends in biomass.

In what follows the mortality coefficients used are identified and it is shown that an underestimate of biomass has to be approached first. An example of the method is then advanced. Attention is drawn to trends in catch rates as compared to those of biomass. Finally, consumption of fish by seals is introduced as an important factor governing biomass trends.

Mortality coefficients

Yield (Y), fishing mortality (F) and biomass averaged over the year (B) are related through $Y = F \times B$. For the years before 1970, only the coefficient of total mortality

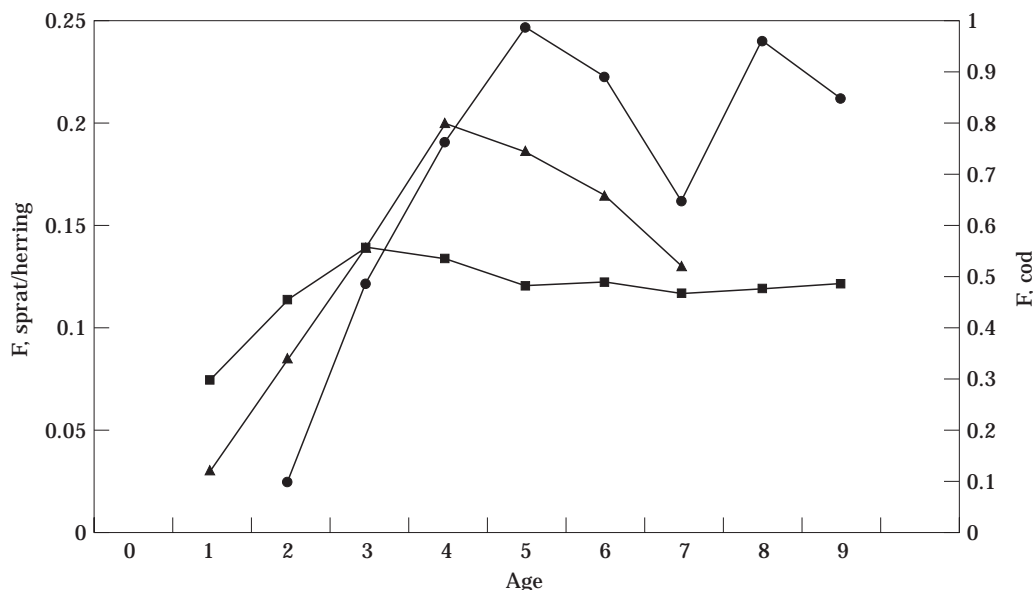


Figure 1. Mean F for 1974–1978 (Anon., 1992a, b). —■— Herring, —▲— sprat, —●— cod.

(Z) can be derived from numbers at age. This was done in the “Catch Curve” way by fitting straight lines to the log (numbers) at age, omitting those ages which were not fully recruited. Subtracting the natural mortality coefficient, M , from the estimated Z gives a value for the fishing mortality coefficient, F .

Natural mortality does not originate from a homogeneous source. The coefficient resulting from predation by cod, M_C , was evaluated by the Multispecies AWG, and the coefficient of residual natural mortality, M_R , has been assumed by the AWGs. This mimics the present state of affairs of clupeids and cod. However, during the earlier decades of this century, marine mammals probably played an important role in controlling fish biomass because they fed extensively on fish (Elmgren, 1989). A further coefficient, M_M , must therefore be introduced.

$$Z - M_C - M_R = F + M_M$$

Since M_M is not specifically known, the valuation of biomass will begin with $(F + M_M)$ instead of F alone. Cod is the dominant predator, driving $(M_C + M_R)$ of clupeids. Cod biomass peaked around 1980 with almost 1 million tonnes (Anon, 1992b). Such high biomasses of cod are unlikely to have existed ever before (Thurow, 1993). The lowest level of $(M_C + M_R)$ estimated on the basis of Multispecies VPA (Anon, 1992a) was therefore assumed to apply to the years before 1977 (DR, Table 1; DR, Figs 1, 2).

$(F + M_M)$ for partly exploited age groups was estimated as fractions of $(F + M_M)$ for older ages. Fish at age 0 are rarely caught and for this age group

$(F + M_M) = 0.01$ was assumed. The effect of fishing was postulated to decrease linearly from fully exploited ages to age 0. Example values of fishing mortality at age of herring, sprat and cod (Anon, 1992a,b), averaged over five years, suggest that this may be a useful approach (Fig. 1).

This method would provide reliable results only if the relative year-class strength had been fairly constant over a number of years. In order to reduce the effect of the actual fluctuations in recruitment, age compositions have been averaged over several years whenever the data source permitted (DR, Table 3).

The available annual yield data (DR, Tables 13–16) apply to the total stock summed over all ages, whereas $(F + M_M)$ is estimated for each age separately. The proper procedure to achieve a weighted mean $(F + M_M)$ is weighting of $(F + M_M)$ at age by the biomass of each age group. The weights used are shown in DR, Table 2 and DR, Figure 3. Since age-group 0 fish are rarely seen in the catches, $(F + M_M)$ is calculated for ages ≥ 1 .

The results of ICES VPAs will serve as the reference for the present analysis. These are the best assessments available and they date back to the early 1970s (Anon, 1975, 1982, 1987a,b, 1991a,b, 1992a,b) whereas catch curve information as presented here is available up to the late 1970s. The overlapping period (about 1970–1977) is used for standardization.

The calibration of $(F + M_M)$ against F_{VPA} should not be influenced by M_M , because this latter quantity has recently become negligible. ICES gives B for the beginning of the year, whereas this report estimates B averaged over the year. This difference is smoothed out

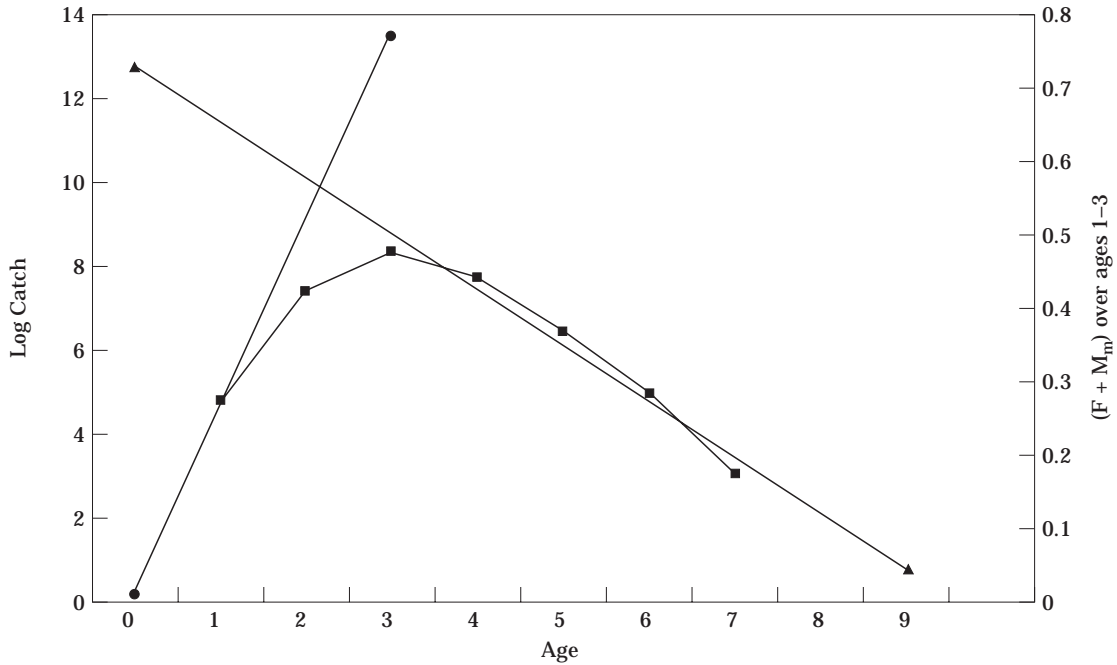


Figure 2. Estimation of Z and F+M_M for sprat 1923+1924, Z is from regression of LogCatch over ages 3-7, for F+M_M see text. —■— LogCatch, —▲— RegLine, —●— F+M_M.

by the use of values that are the means of 3-6 years. Any other distinction between (F+M_M) and F_{VPA} due to unknown causes are removed by a calibration factor, p, so that F_{VPA}=(F+M_M)/p.

Problems in biomass estimation

In evaluating the biomass, the yield was estimated as a weighted average for the same period and in the same way as (F+M_M). For the earlier years, M_M has the effect that the biomass evaluated from yield, Y, and (F+M_M) is an underestimate (B_U):

The fishing yield is

$$Y = B \times F,$$

likewise the mammal fish consumption is

$$C = B \times M_M.$$

Adding the two

$$Y + C = B \times (F + M_M),$$

then making allowance for p

$$Y + C = B \times [(F + M_M)/p],$$

re-arranging (F+M_M)/p to

$$Y/[(F + M_M)/p] = B - C/[(F + M_M)/p] = B_U,$$

shows that the use of (F+M_M)/p underestimates B by the amount C/[(F+M_M)/p]. However, the expression (Y+C)/[(F+M_M)/p] is an estimator of B. The amount of fish consumed of mammals (C), the yield (Y) and

(F+M_M)/p have to be ascertained in order to determine B. We then have underestimated biomass (B_U) and estimated biomass (B) as compared to VPA-biomass (VPA-B) of ICES.

It is assumed here that the coefficient, (F+M_M)/p, of all "other species" caught in the Baltic is the same as the average of the main species, clupeids and cod. [Thurow \(1984\)](#) estimated that these "other species" made up 16% and 20% of the total fish biomass in 1970 and 1980, respectively. Since they are mainly caught as bycatches in the commercial fishery for the main species, hence with the same effort, it is valid to assume that Y/B_U for "other species" is the same as that for the main species.

An investigation into the reliability of the method used suggests that the method produces an adequate picture of trend development but not of short-term fluctuations (DR, Tables 25, 26).

Example of the method

The method used here is explained in [Figure 2](#) and [Table 1](#). Total mortality, Z, results from the regression of log Catch on age. F+M_M is from Z - (M_R+M_C). For ages 0-2 F+M_M is obtained from a linear adjustment between 0.01 and 0.77. The mean (F+M_M) for ages ≥ 1 is weighted by biomass, resulting in (F+M_M)=0.39.

Table 1. Catch curve method as shown for sprat (first sample DR, Table 4). For M and w see DR, Tables 1 and 2. Number in the stock (n) for ages 3–7 as in the catch, for ages 0–2, 8–9 from $N_i = N_{i+1} \times e^{1.33}$.

Age	Catch	Z _i	(M _C +M _R) _i	(F+M _M) _i	w _i	n
0			1.10	0.01*	1.0	337 730
1	119		0.91	0.26*	6.0	89 322
2	1650		0.72	0.51*	10.0	23 389
3	4176	1.33	0.56	0.77	12.0	4176
4	2272	1.33	0.43	0.90	13.0	2272
5	618	1.33	0.40	0.93	14.0	618
6	144	1.33	0.40	0.93	14.4	144
7	22	1.33	0.40	0.93	14.6	22
8		1.33	0.40	0.93	14.8	8
9		1.33	0.40	0.93	15.0	2
Mean (F+M _M) over ages 1 to 9 weighted by n × w				0.39		

*Not fully exploited ages. (F+M_M) linearly adjusted between 0.01 and 0.77 (see Fig. 2).

It is then possible to calculate an underestimated biomass for 1922–1925. For the 1920s we have three values of (F+M_M) for sprat (DR, Table 4), namely 0.39, 0.53, and 0.61, giving a mean of 0.51, 95%–confidence interval 0.23–0.79. With a weighted average yield of 3330 tonnes (DR, Section 2.3), $Y/(F+M_M) = 6500$ tonnes is calculated. Calibration of all $Y/(F+M_M)$ values against the VPA-biomass of ICES gives a factor of 2.14. Application of this number results in an underestimated biomass, B_u, of 14 000 t for the 1920s (Table 2). Division of the yield by the confidence limits (C.L.) of F+M_M multiplied by the factor, e.g. $(3330/0.233) \times 2.14$, gives the confidence range of estimated biomass. In

several cases the lower C.L. was below zero. These values were set to zero, resulting in asymmetry of the confidence range (Fig. 12).

Catch rates and stocks

A Swedish set of catch rates (Sahlin, 1959; National Central Bureau of Statistics, 1933–1980) and a Polish series (Łaszczynski *et al.*, 1964; Morski Instytut Rybacki, 1989) are shown in Table 3. Regressions of these catch rates on estimated biomass (DR, Figs 8, 9) are highly significant. Catch rates and estimated biomass closely follow the same trend.

For management purposes, AWGs consider a single stock of sprat for the entire Baltic and two stocks of cod, one in subdivisions 22+24, and the other in subdivisions ≥ 25 (Fig. 3). These units were also used for the present analysis. However, they can be used for the period beginning 1960 alone since statistics for earlier years are broken down into subdivision 22 and the remaining areas. Herring, however, is broken down into four stocks by the AWG. The populations in the Bothnian Sea and the Bothnian Bay are considered to be separate from the stocks in the Belt Sea and in the Baltic proper. The stocks there are relatively small (DR, Table 23). The same breakdown as for cod is assumed here for herring because of the statistical classification.

VPA-biomass of sprat and herring has been ascertained by the ICES AWG for the years since 1974. Age composition of catches is available from 1970 to 1973 (Anon, 1982, 1992a). These data have been used to run VPAs. The resulting biomasses are shown in Table 4, and DR, 21;22.

Table 2. Sprat, yield (Y) according to DR, Tables 14 and 15, VPA-biomass (VPA-B) according to ICES (Pers. Comm.) and $Y/(F+M_M)$, all in $t \times 10^{-3}$. Number of estimates of F+M_M of DR, Table 4 = n.

Period	Average F+M _M				Y/CF+M _M	VPA B	B _u = [Y/(F+M _M)] × 2.14	
	Y	n	F+M _M	95% C.L.			B _u	95% C.L.
1922–25	3.33	3	0.510	0.233–0.787	6.5		14	9–31
1931–39	12.89	7	0.689	0.515–0.863	18.7		40	32–54
1939–41	1.30	3	0.537	0.286–0.788	2.4		5	4–10
1951–59	18.27	8	0.360	0.144–0.576	50.8		109	68–272
1964–66	86.70	5	0.250	0.155–0.345	346.8		742	538–1197
1966–69	95.65	8	0.199	0.142–0.256	481.0		1029	800–1441
1964–69	94.10	13	0.219	0.175–0.263	429.7		920	766–1151
1969–73	178.81	8	0.309	0.235–0.383	578.7		1238	999–1628
1973–75	227.44	3	0.197	0.075–0.320	1154.5	1883	2471	1521–6490
1976–79	173.42	6	0.157	0.119–0.195	1104.6	2250	2364	1903–3119
1979–82	59.94	4	0.113	0.064–0.162	530.4	847	1135	792–2004
1982–85	48.13	4	0.108	0.000–0.234	445.6	1485	954	440–∞
1984–86	66.07	6	0.132	0.104–0.161	500.5	1175	1071	878–1360
1987–89	84.77	6	0.212	0.184–0.241	399.9	1204	856	753–986
1973–89					689.2	1474		

Table 3. Total catch per vessel per year (Y/f), t, and their corresponding biomasses (B), $t \times 10^{-3}$, as evaluated from the correlation with biomass in DR, Table 18 (Poland: Laszczynski *et al.*, 1964; Morski Inst. Ryb., 1989. Sweden: Sahlén, 1959; Nat. Ctrl Bureau Statistics, 1933–1980). Other biomass estimates for cod are added.

Year	From total catch				B of cod, subdiv. 25–32 DR, Tab. 21	B of cod, subdiv. 22+24 DR, Tab. 20
	Poland		Sweden			
	Y/f	B	Y/f	B		
1921	21.5	439				
1924	26.0	531				
1927	21.8	446				
1930	26.9	550				
1932	57.4	1173	32.3	1159		
33			27.3	1104		
34			32.9	1162		
35	78.5	1605	44.0	1283		
36			47.7	1326		
37			46.5	1313		
38	15.6	319	37.4	1210		
39			37.5	1211		
1940			16.8	1005		
41			24.9	1081		
42			41.0	1249		
43			43.8	1280		
44			46.3	1310		
45	56.7	1159	60.0	1482		
46	123.4	2304	70.7	1631		
47	119.5	2837	86.2	1874		
48	111.4	2277	103.7	2193		
49	118.2	2359	111.2	2345		
1950	151.6	3099	82.0	1804		
51	166.6	3450	90.9	1955		
52	187.1	3825	87.5	1895		
53	169.6	3463	86.4	1876		
54	181.4	3708	92.5	1982		
55	163.8	3348	103.7	2193		
56	183.9	3759	110.6	2333		
57	168.3	3440				
58	141.0	2882	146.1	3207		
59	132.5	2708	146.2	3210		
1960	158.0	3230	175.4	4171	283	
61	127.8	2612	176.3	4205	265	
62	141.4	2890			273	
63	167.4	3422	203.1	5340	276	145
64	152.4	3115	170.4	3988	271	122
65	158.7	3244	175.1	4159	282	103
66	195.6	3998	188.7	4699	333	139
67	191.3	3910	208.0	5586	398	94
68	230.4	4710	206.7	5525	390	89
69	229.4	4689			368	92
1970	269.1	5501				
71	275.2	5625				
72	297.4	6079				
73	298.9	6108				
74	348.2	7118				
75	429.0	8769				
76	403.8	8254				
77	340.1	6952				
78	348.3	7120				
79	408.8	8356				
1980	430.7	8804				
81	403.3	8244				
82	411.4	8409				
83	365.9	7479				
84	410.1	8383				
85	389.5	7962				

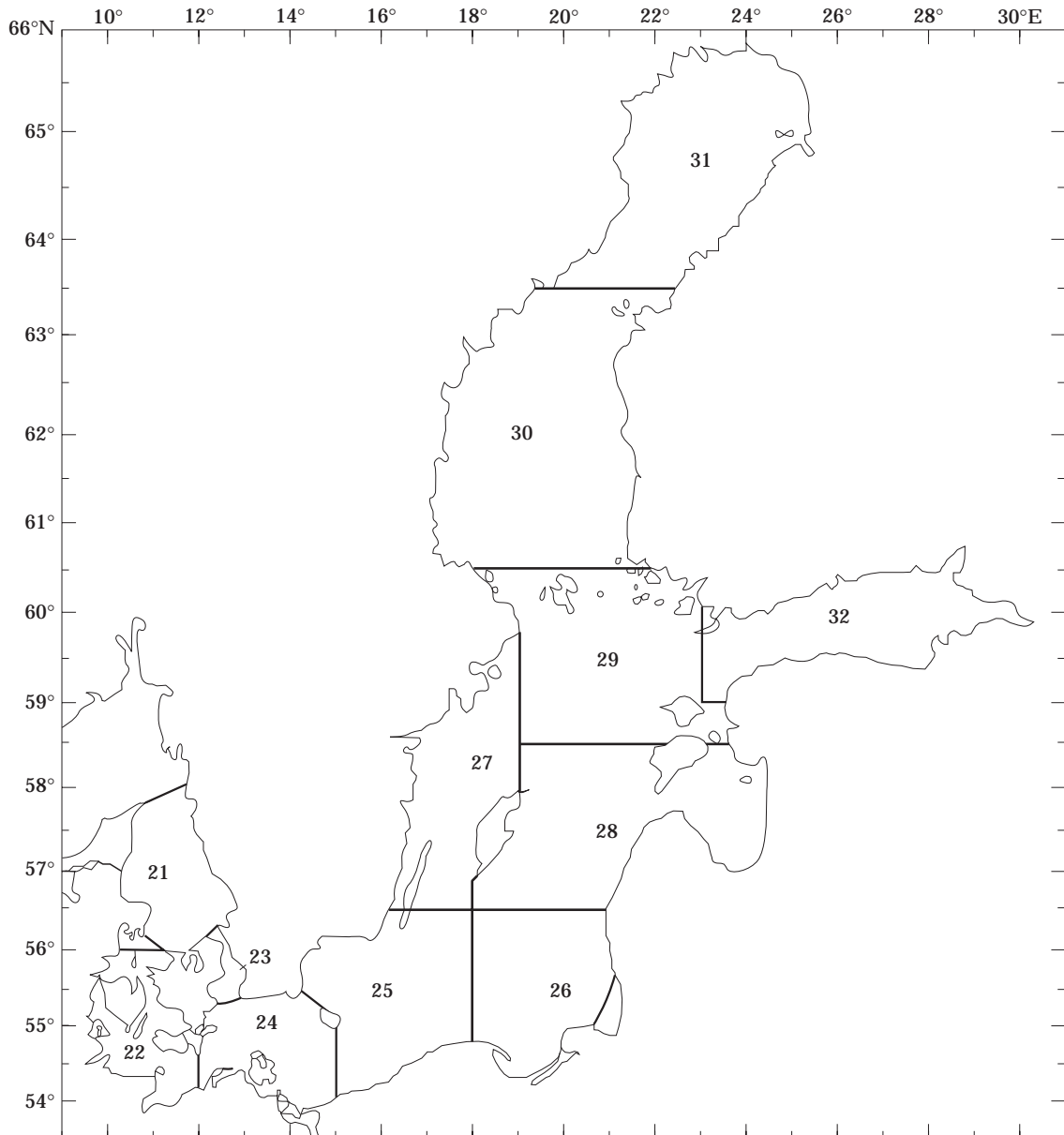


Figure 3. ICES statistical subdivisions in the Baltic.

Mammals

Seals have played an important role in regulating fish biomass during the earlier decades of this century, since they feed extensively on fish. [Elmgren \(1989\)](#), using an equation of [Innes *et al.* \(1987, cited by Elmgren, 1989\)](#), calculated an average fish consumption by seals and porpoises of 2.19 kg per mammal per day. He estimated the total fish consumption of these animals to be 320 000 t around 1900 and 6000 t in 1980. He also found that grey seal and ringed seal together

accounted for over 95% of the consumption by seals and porpoise.

[Durant and Harwood \(1986\)](#) modelled the decline of the ringed seals and arrived at 300 000 individuals in the year 1900. Since ringed seals contributed over 70% to the total population of mammals ([Elmgren, 1989](#)), [Figure 3b of Durant and Harwood \(1986\)](#) is used here to estimate the fish consumption of seals. It is assumed that the decline of the ringed seal population is representative for all marine mammals and that the total consumption

Table 4. Biomasses of Baltic fish stocks as estimated by VPA for clupeids (Anon, 1991a, 1992a; ICES, Pers. Comm.) and for cod (Anon, 1991b, 1992b), in $t \times 10^{-3}$. The 1991 value for herring in subdiv. 22+24, is from DR, Table 23, and DR, Figure 9. Data in brackets are from DR, Tables 21, 22.

Year	Sprat subdiv. 22-32	Herring		Cod	
		subdiv. 22+24	subdiv. 25-32	subdiv. 22+24	subdiv. 25-32
1970	(2852)	312	(3505)	89.5	343
1	(2423)	326	(4079)	97.7	313
2	(2143)	314	(4012)	96.7	347
3	(2609)	288	(4333)	96.0	385
4	1813	252	3288	89.1	480
5	1369	221	3293	85.2	551
6	2789	179	3876	87.6	517
7	2234	191	3931	69.4	508
8	1537	225	4254	74.2	675
9	1081	266	4061	78.4	926
1980	735	325	3916	77.1	991
1	775	345	3575	83.3	949
2	864	362	4083	75.9	996
3	1967	389	3264	78.0	968
4	1548	385	3616	71.3	888
5	1162	322	3480	63.4	712
6	816	238	3318	41.2	531
7	1223	277	3362	47.5	475
8	767	279	3697	43.8	455
9	1622	269	3942	37.1	359
1990	2207	212	4652	29.2	287
1	3207	200	4824	34.9	210

of mammals is linearly related to the number of ringed seals (Fig. 4; DR, Fig. 10).

Underestimated biomass, B_U

Underestimated biomasses for sprat, herring, and cod are ascertained and these results are used to evaluate a total underestimated biomass.

Sprat

Yield and mortality of sprat by periods are shown in Table 2. The relationship between $Y/(F+M_M)$ and the VPA biomass (ICES, Pers. Comm.) is not significant at the 5% level, when the data of the extended VPA back to 1970 were used (Table 4). They have, therefore, been excluded. The remaining six pairs of values are significantly correlated (Fig. 5). Since the intercept is not significantly different from zero ($p>0.4$), the regression was forced through the origin. This gives a multiplier of $1/p=2.14$ to convert $Y/(F+M_M)$ to B_U .

Herring

The herring data for subdivisions 22+24 are presented in Table 5. A split of $(F+M_M)$ for the last period, 1968-1979, into shorter intervals is given there. These

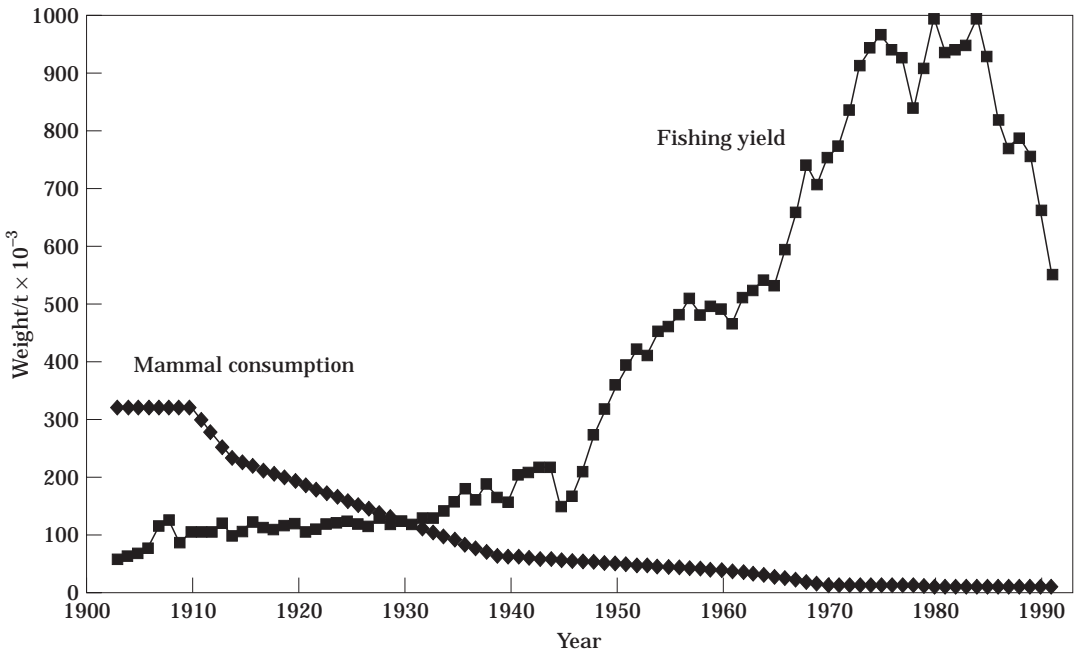


Figure 4. Take of mammals and fishery.

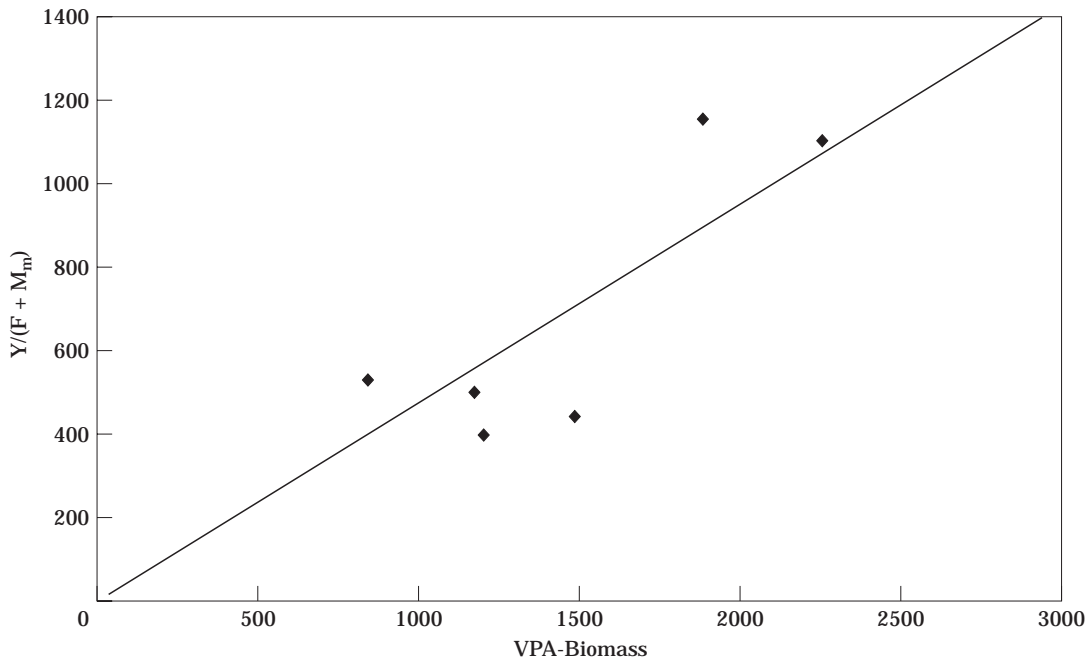


Figure 5. $Y/(F+M_M)$ of sprat vs. VPA-biomass according to Table 4.

Table 5. Herring in subdivision 22 (until 1959), and 22+24 (since 1960). Yield (Y) according to DR, Tables 14 and 15, VPA-biomass (VPA-B) according to Table 4, all in $t \times 10^{-3}$. Number of estimates of $F+M_M$ of DR, Table 5 = n.

Years	Average ($F+M_M$)				$Y/(F+M_M)$	VPA B	$B_u = (Y/(F+M_M)) \times 1.73$	
	Y	$F+M_M$	n	95% C.L.			B_u	95% C.L.
1920–27	7.5	0.835	2	0.000–2.550	9		16	15–∞
1935–41	5.8	0.692	5	0.153–1.231	8		15	8–66
1946–50	5.7	0.317	3	0.000–0.840	18		31	12–∞
1953–59	17.2	0.380	5	0.348–0.412	45		78	72–86
1963–67	53.8	0.255	6	0.117–0.393	211		365	237–796
1968–70	53.8	0.375	2	0.000–1.328	143		248	70–∞
1963–70	53.8	0.285	8	0.176–0.394	189		327	236–529
1968–72	55.9	0.355	2		157	312		
1969–73	64.6	0.335	2		193	326		
[1970–74	60.6	0.820	2		74	314]		
1970–74	60.6	0.350	2		173	314		
1971–75	62.5	0.370	2		169	288		
1972–76	63.2	0.455	2		139	252		
1973–77	73.8	0.480	2		154	221		
1974–78	64.1	0.455	2		141	179		
1975–79	74.0	0.437	3		169	191		
1968–77	64.2	0.391	12	0.328–0.454	164	278	284	245–339

data are to be used for a regression of $Y/(F+M_M)$ vs. VPA-biomass.

The first value of $(F+M_M)$ for the period 1970–1974, given in brackets, is very far outside the range of all others. It is likely to be an outlier and has therefore been rejected. No significant correlation can be shown for the remaining eight pairs of values. The high intercept is significantly different from zero. If, however, the period

1968–1977 with six mean values of $(F+M_M)$ is used, the intercept becomes small and is not significantly different from zero. If there is a meaningful relationship between both variables, it should pass through the origin as suggested by sprat and cod for subdivision 25–32. This concept is accepted here. The period 1968–1977 is used because the intercept is not significantly different from zero (Fig. 6). A multiplier of 1.73 results.

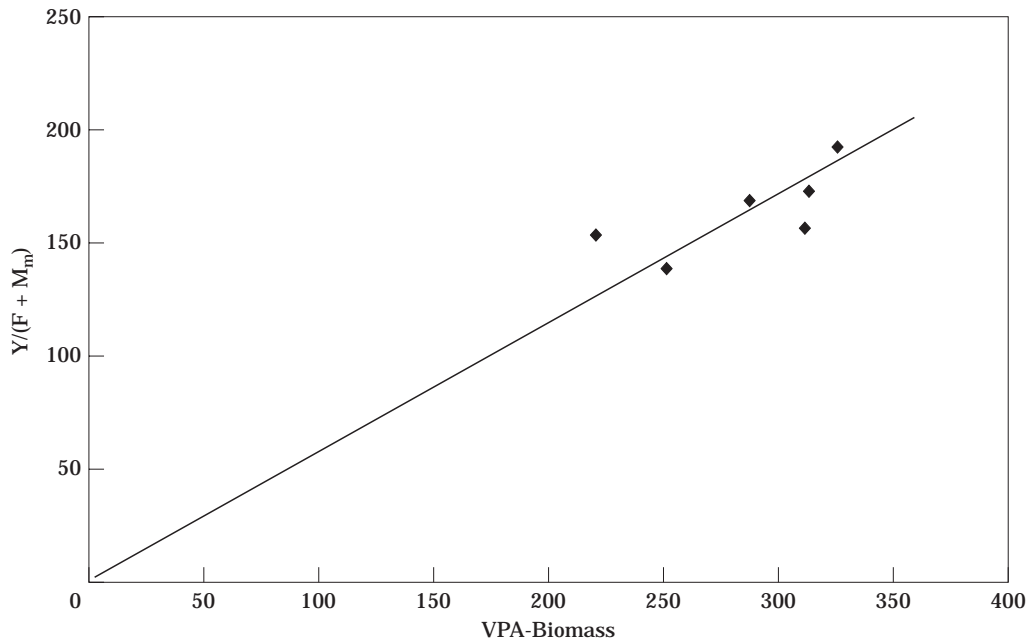


Figure 6. $Y/(F+M_M)$ of herring, in subdivisions 22+24, vs. VPA-biomass according to Table 5.

Table 6. Herring in subdivisions 24–32 (until 1959) and 25–32 (since 1960). Yield (Y) from DR, Tables 14 and 15, (VPA-B) from Table 4, all in $t \times 10^{-3}$. For asterisk see text. No. of estimates of $F+M_M$ of DR, Table 5 = n.

Years	Average ($F+M_M$)				$Y/F+M_M$	VPA B	$B_u = [Y/(F+M_M)] \times 2.33$	
	Y	$F+M_M$	n	95% C.L.			Mean	95% C.L.
1921–29	42.4	0.375	15	0.291–0.459	113		264	215–339
1935–40	59.9	0.382	6	0.163–0.601	157		366	232–856
1940–48	60.8	0.317	6	0.024–0.610	192		447	232–5903
1949–60*	166.1	0.090	10	0.000–0.224	1846		4303	1751–∞
	164.2	0.208	6	0.071–0.345	789		1840	1109–5389
1958–66	169.6	0.326	10	0.192–0.460	520		1213	859–2958
1963–69	231.9	0.288	9	0.170–0.406	805		1877	1331–3178
1958–69	199.4	0.308	19	0.227–0.389	647		1509	1194–2047
1969–72	267.7	0.150	6	0.033–0.267	1785	3741	4161	2336–18 901
1970–72	274.6	0.220	3	0.026–0.414	1248	3865	2910	1545–24 608
1971–73	300.6	0.217	3	0.000–0.490	1385	4141	3230	1429–∞
1972–74	326.3	0.285	6	0.160–0.410	1145	3851	2669	1854–4752
1973–75	336.0	0.200	6	0.077–0.324	1680	3638	3917	2439–10 167
1973–77	337.5	0.191	20	0.152–0.230	1767	3647	4120	3419–5174
1975–77	342.0	0.143	3	0.000–0.367	2392	3700	5576	2171–∞
1976–78	347.9	0.067	3	0.000–0.278	5193	4020		
1977–79	363.9	0.090	3	0.000–0.241	4043	4082		
1978–80	364.0	0.097	3	0.000–0.442	3753	4077		
1979–81	361.1	0.073	3	0.000–0.322	4947	3851		
1969–77	n=7				1629	3798		

For herring east of Bornholm 59 estimations of ($F+M_M$) were divided into 11 periods (Table 6). The regression of $Y/(F+M_M)$ on VPA-biomass gives no meaningful relationship (Fig. 7). Two groups of points are shown on the figure, one for the period before 1977,

the other for more recent years. During the latter, ($F+M_M$) is very low and sometimes negative (DR, Table 5). These values are from one country while the seven data points of the earlier period represent samples taken by four authors of three countries. This earlier set

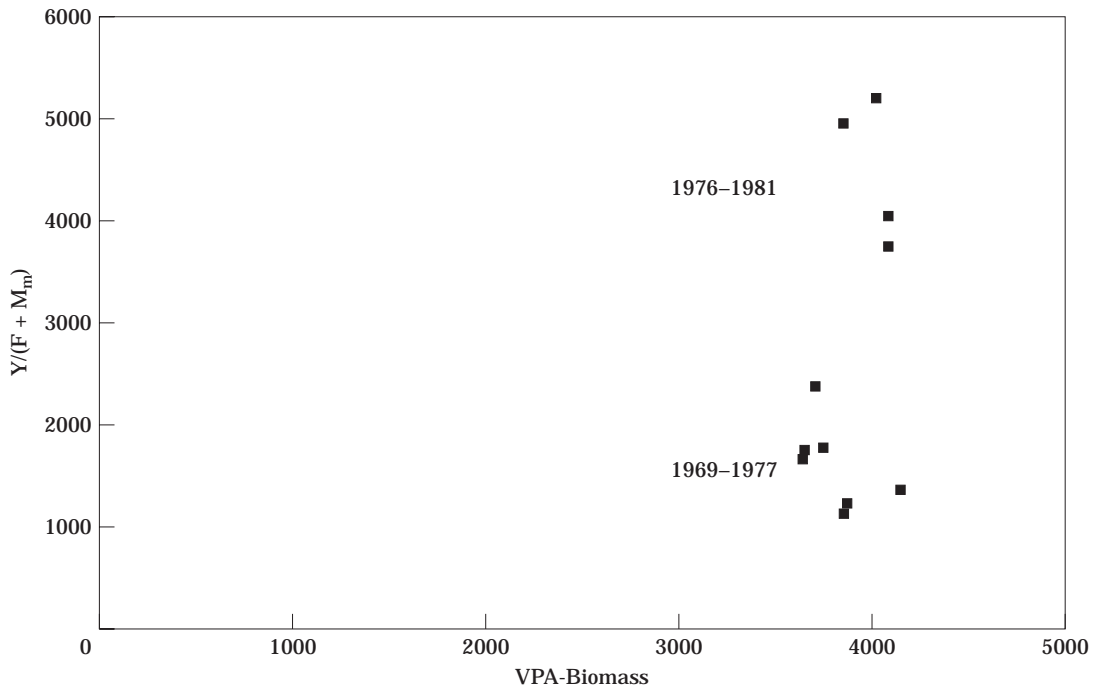


Figure 7. $Y/(F+M_M)$ of herring, in subdivisions 25–32, vs. VPA-biomass according to Table 6.

has been selected for calibration. The correlation is low because yield and VPA-biomass change very little throughout this period. The regression, when forced through the origin, results in the multiplier $1/p=2.33$. A similar shortcoming, as with the above group of most recent $(F+M_M)$ s, is indicated for 1949–1960 by an asterisk (Table 6). Among the 10 estimates of $(F+M_M)$, four exhibit negative values, three of which are from a single country. If these are omitted, the results in the next row are obtained and these are used in the following calculations.

Cod

Cod of subdivision 22+24 shows no significant regression between $Y/(F+M_M)$ and VPA-biomass for the period 1968–1977. The catch rates of Steffensen and Bagge (1990) are, however, highly significantly correlated with the VPA-biomass data (DR, Table 19). This relationship was used to estimate biomass values for the years prior to 1970, which were included in the calibration (Table 3, DR 24). However, no linear relationship can be shown. The biomass of the stock is very stable and varies little between 1963 and 1977. A calibration factor is therefore evaluated from VPA-biomass and $Y/(F+M_M)$ both averaged over 1963–1977. This gives a value of 2.15 (Table 7, Fig. 8).

Results for the cod stock in the central Baltic are shown in Table 8. The overlapping of $Y/(F+M_M)$ and VPA-biomass during 1970–1973 leaves little room for calibration. Table 3, however, gives a more extended biomass series. It can be used for the present purpose and gives five pairs of data. Biomass shows an increasing trend and therefore allows one to fit a regression between $Y/(F+M_M)$ and VPA-biomass. The slope was significantly different from zero at the 95% level, while the small intercept was not. The regression is therefore forced through the origin (Fig. 9) giving a multiplier of $1/p=1.83$.

Total underestimated biomass

The periods for which the biomasses of the different stocks have been evaluated differ slightly. Table 9 gives equal time spans for all stocks that comprise biomass of all years covered even when they do not exactly apply to all stocks. The deviations depend essentially on the different availability of age compositions in the original data sets. This could have the effect of placing the estimated mean biomasses a few years too early or too late on the time scale.

Yields and estimated biomasses allow calculation of a single average coefficient, Y/B_U , for the main species

Table 7. Cod in subdivision 22 (until 1959), and 22+24 (since 1960). Yield (Y) according to DR, Tables 14 and 15, VPA-biomass (VPA-B) from Table 4 and (in brackets) from Table 3, both in $t \times 10^{-3}$. Compare DR, Table 24. Number of estimates of $F+M_M$ of DR, Table 6=n.

Years	Average ($F+M_M$)				$Y/F+M_M$	VPA B	$B_u = (Y/(F+M_M)) \times 2.15$	
	Y	$F+M_M$	n	95% C.L.			Mean	95% C.L.
1906-09	2.7	0.365	4	0.015-0.715	7.4		16	8-38
1912-13	4.3	0.400	3	0.000-0.896	10.8		24	11-∞
1919-26	6.6	1.192	6	0.666-1.718	5.5		12	9-2
1923-29	9.5	0.834	5	0.615-1.053	11.4		25	20-34
1919-29	7.9	1.029	11	0.750-1.308	7.7		17	13-23
1925-38	9.7	0.323	7	0.127-0.519	30.0		65	40-164
1939-44	12.2	0.540	2	0.000-1.811	22.6		49	14-∞
1956-61	22.4	0.980	3	0.792-1.168	22.6		49	41-61
1958-67	36.6	0.984	7	0.785-1.183	37.2		80	67-100
1964-71	45.1	0.953	6	0.737-1.170	47.3		102	83-132
1958-71	40.4	0.970	13	0.848-1.093	41.6		89	79-102
1968-77	48.1	1.080	12	0.965-1.195	44.5	92.1	96	87-107
1963-77					45.3	97.2		
1963	31.2					(145)		
1964	35.8					(122)		
1965	44.9					(103)		
1966	42.5					(138)		
1967	44.1					(94)		
1968	51.9					(89)		
1969	42.3					(92)		

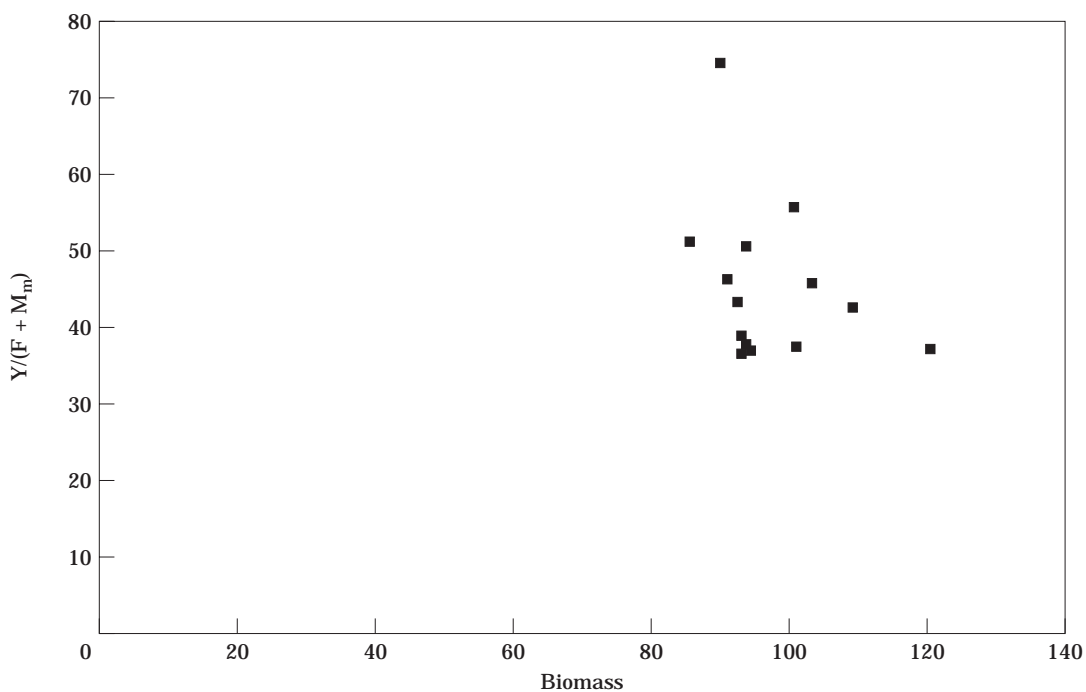


Figure 8. $Y/(F+M_M)$ of cod, in subdivision 22+24, vs. biomass according to Table 7.

sprat, herring and cod. It was previously suggested (see "Problems in biomass estimation") that Y/B_U of all other species caught in the Baltic Sea is the same as that

of the main species. This makes it possible to calculate the total underestimated fish biomass (Table 9). A steady increase of the stocks since the 1920s is suggested.

Table 8. Cod in subdivisions 24–32 (until 1959) and 25–32 (since 1960). Yield (Y) from DR, Tables 14 and 15 and VPA-biomass (VPA-B) from Table 3 and 4, both in $t \times 10^{-3}$. Number of estimates of $F+M_M$ of DR, Table 6=n.

Years	Average ($F+M_M$)				$Y/(F+M_M)$	VPA B	$B_u = (Y/(F+M_M)) \times 1.83$	
	Y	n	($F+M_M$)	95% C.L.			B_u	95% C.L.
1919–28	6.2	6	0.545	0.384–0.706	11		20	16–30
1931–40	15.6	7	0.536	0.216–0.856	29		53	33–132
1940–51	87.0	6	0.658	0.445–0.861	132		242	185–350
1950–60	150.1	7	0.794	0.664–0.925	189		346	297–414
1960–66	118.4	3	0.783	0.661–0.906	151	278	276	239–328
1962–66	115.8	3	0.723	0.522–0.924	160	289	293	229–406
1965–70	149.0	3	0.857	0.828–0.886	174	357	318	308–329
1968–70	164.0	3	0.767	0.477–1.057	214	370	392	284–629
1960–70	135.2	12	0.783	0.731–0.835	173		316	296–338
1968–73	143.9	3	0.730	0.461–0.999	195	349	361	264–571
1960–73 (Average)					179.2	328.6		

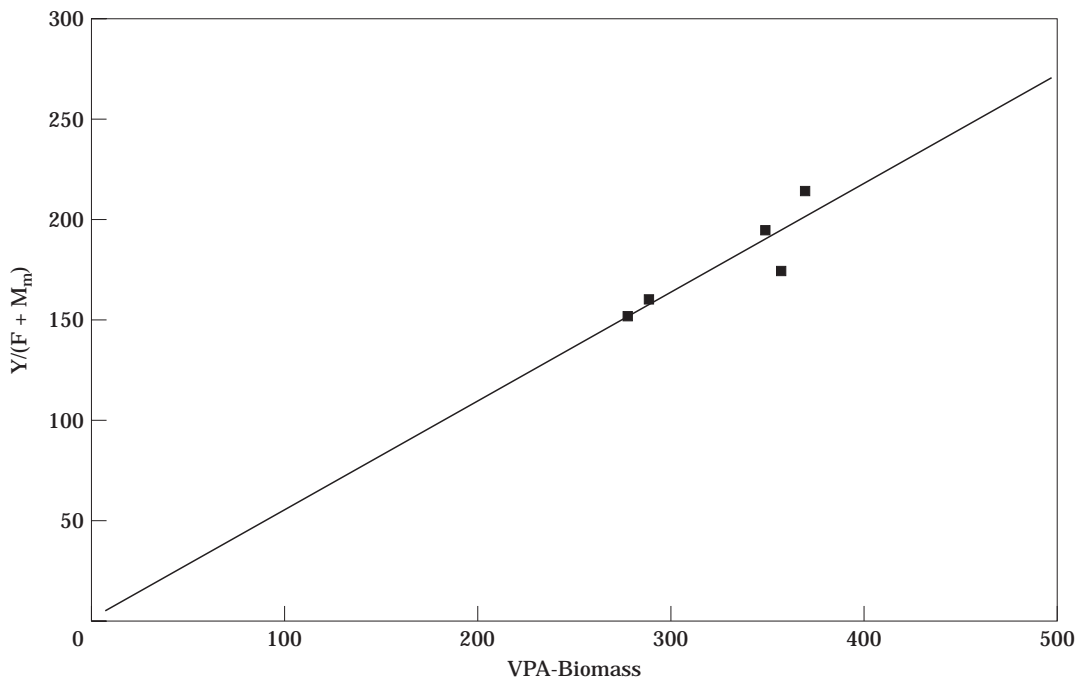


Figure 9. $Y/(F+M_M)$ of cod, in subdivisions 25–32, vs. VPA-biomass according to Table 8.

The effect of mammals

The amount of fish eaten by mammals was ascertained earlier in this paper (Fig. 4). Together with the yield, this enables the total estimated biomass for the years after 1920 to be calculated.

A regression of Y/B_U on the mean removal of fish (by man and seals) for seven periods from 1920 to 1977 is significantly different from zero (Fig. 10). The regression suggests that Y/B_U decreases with increasing removal. This is surprising. Table 9 indicates, however, that fish

biomass increased greatly, faster than removal. If this mechanism had been in effect at the beginning of this century, it would permit Y/B_U to be extrapolated for the years before 1920. The expectation is that underestimated biomass were high during the first years of the century and have decreased since the 1910s. Let us see whether or not there are indications for such a development.

Lundbeck (unpublished data) states that the East Prussian fishery (subdiv. 26) peaked in the first decade of this century. Later the catches declined by 75% to 90%.

Table 9. Total yield (Y), total estimated biomass (B), and confidence limits (C.L.) based on the variances of (F+M_M), all in t × 10⁻³. Three infinite C.L.s, for the small herring stock in subdivision 22 were found (Table 5). For these periods, the species total was computed from the larger stock in subdivisions 24–32 alone. Σ(S+H+C)=Sum of sprat, herring, cod.

Period	Underestimated biomass, from Tables 4–8						Estimated biomass, from DR, Table 18				
	Σ(S+H+C)			All species			All species				
	Y	B _u	Y/B _u	Y	B _u	95% C.L.	Period	Y	Y+C	B	95% C.L.
1903–09	48		0.180	67			1903–09	82	402	2233	
1910–19	60		0.191	98			1910–19	107	351	1838	
1919–29	67	331	0.204	111	543	435–728	1920–29	115	276	1339	1073–1795
1931–41	104	539	0.192	151	785	502–1853	1930–39	148	241	1267	810–2991
1939–51	167	774	0.215	225	1045	640–9108	1940–49	211	268	1273	780–11 095
1949–61	372	2422	0.154	461	2995	1962–7694	1950–59	447	493	3162	2071–8120
1958–67	465	2676	0.175	533	3046	2208–6123	1960–64	508	544	3107	2252–6246
1963–71	575	3574	0.160	648	4053	3060–6237	1965–69	648	672	5389	4069–8293
1968–77	703	6140	0.114	852	7475	4786–26 231	1968–77	852	866	7566	4844–26 550

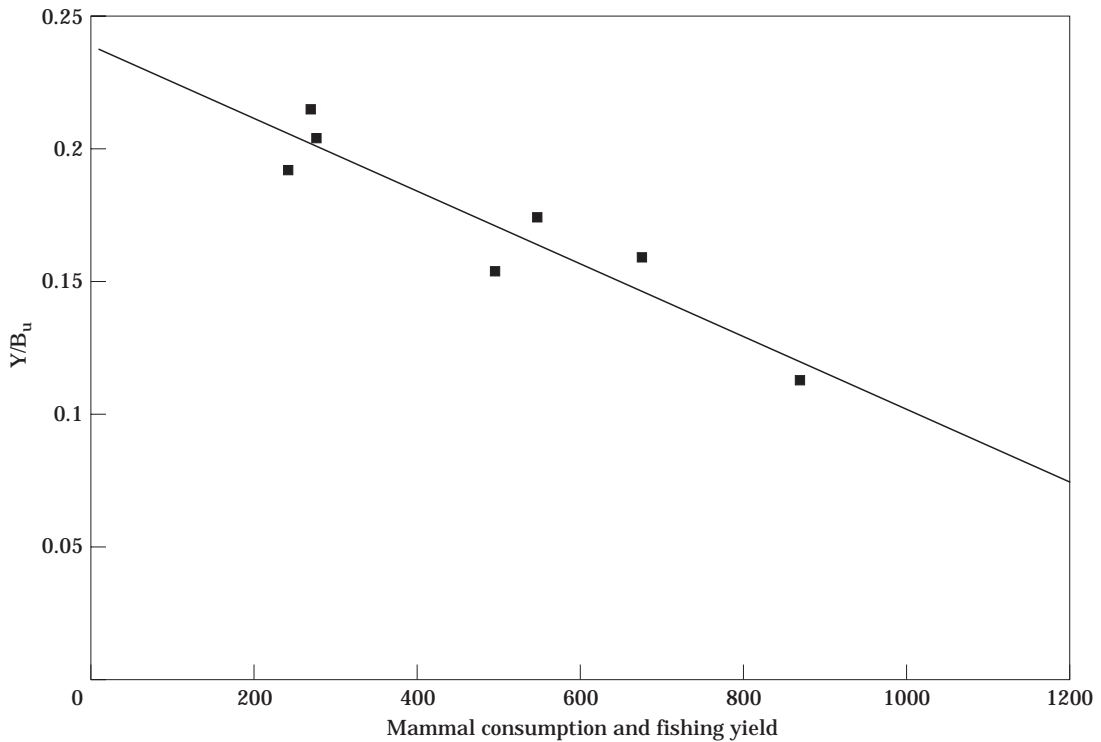


Figure 10. Y/B_u vs. take of fish by mammals and fishery, according to Table 9.

Hessle (1927) suggests that the sprat fishery in Sweden might have been formerly of greater importance than at the time of his report.

Jensen (1927) published graphs which permit the herring catch/vessel/year in tonnes at Bornholm (subdiv. 25), (DR, Table 27; DR, Fig. 13). It appears that herring density declined from an average of 20 tonnes per vessel per year 1910–1919 to an average of 13 tonnes in

1920–1924. Herring biomass is therefore suggested to have been lower in the 1920s than it had been before.

Data of Kändler (1944, 1949) from the main basin suggest that the density of cod in 1925, 1926 and 1929 may have been higher than at the beginning of this century. Poulsen (1931) found also higher cod numbers in the late 1920s (1923, 1926–1928).

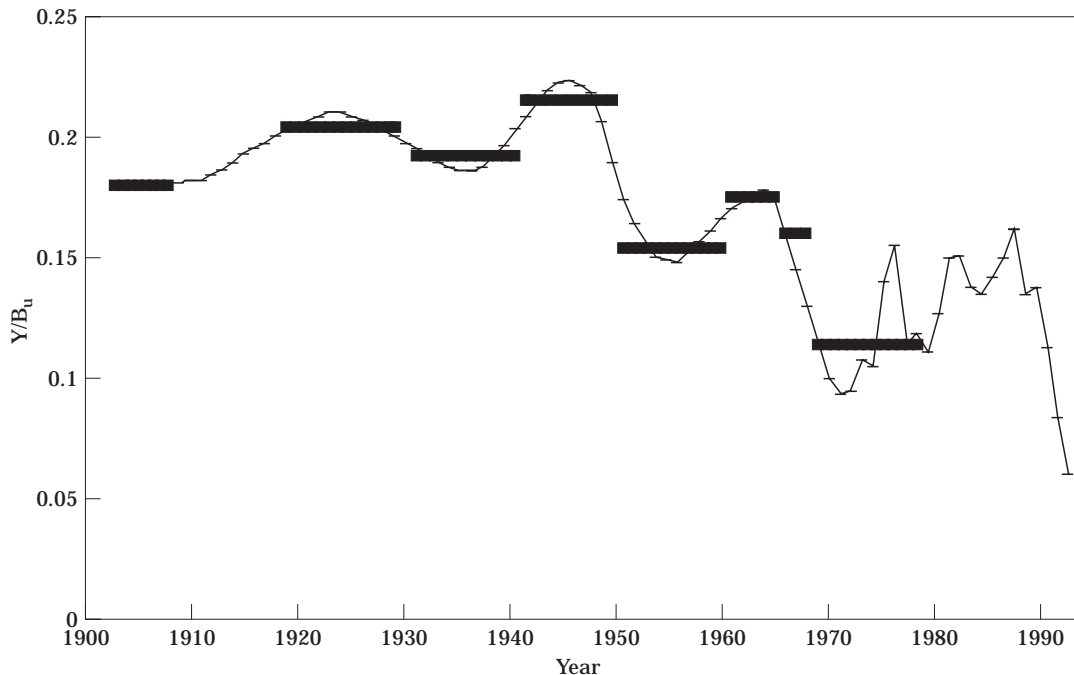


Figure 11. Y/B_U vs. time, estimated (●) (Table 9) and interpolated (—) (Table 10).

Hessle (1923) lists long-line catches of cod. In the Aland Sea they decreased from 19 kg/1000 hooks (13–24 kg) in 1910+1911 to less than 10 kg 1921 and 1922. In Gävle Bay (subdiv. 30) they decreased from 36 kg (28–52 kg) in 1910+1914 to 13 kg (9–19 kg) in 1922.

This information suggests that total biomass was higher before 1920 than afterwards. The information on cod is controversial but cod only represents a small share of the total biomass. Figure 10 is therefore used to predict Y/B_U for the years before 1920. Interpolation between the mean values of Y/B_U by use of Figure 11 gives the annual values.

Estimated total biomass (B) is computed from these annual values and the take by seals and the fishery (Fig. 12; DR, Table 18). A computation of the weighted coefficient of fishing mortality of all species, $F=Y/B$, is then possible.

Estimated biomass, B

The estimated total biomass, B, is shown in Figure 12; DR, Table 18. Up to almost 2.5 million tonnes are suggested for the beginning of this century with a decline to less than half of this amount by the 1930s. Beginning in 1945 there was an increase to more than 3 million tonnes by the 1950s. This level was maintained until the mid-1960s, then an enormous rise to over 8 million tonnes in 1970 took place.

The trend of the estimated biomass is also obvious from the catch rates of Poland and Sweden and from the confidence limits. The high variances of $(F+M_M)$ of the herring stocks east of Bornholm in the 1940s and 1970s produce rather high upper confidence limits for these periods.

At the beginning of the century total landings might have been at a level of some 100 000 tonnes (Fig. 13). About 200 000 tonnes were reached by 1941. A sudden increase occurred after the war and the all-time record of nearly 1 million tonnes was caught by 1975.

Y/B increased steadily from very low values at the beginning of this century to a peak in the 1940s. Wide fluctuations followed and the level of the early years was reached in 1991. By 1930 the coefficient of fishing mortality equalled that of mammal predation, $Y/B=C/B$. The high values of Y/B in the 1940s should not be given too much attention. The greatest catches at the time came from the cod fishery (some 50% of total yield, DR, Table 17). It rose fourfold whereas the clupeids' remained at the old level. This increased the combined Y/B .

Figures 12 and 13 suggest that the fishing pressure on the stocks increased between 1900 and 1945. Subsequently, there were periods when yields augmented because of growing biomass (1945–1950, 1965–1970) or because of growing fishing effort (1950–1965, 1970–1975).

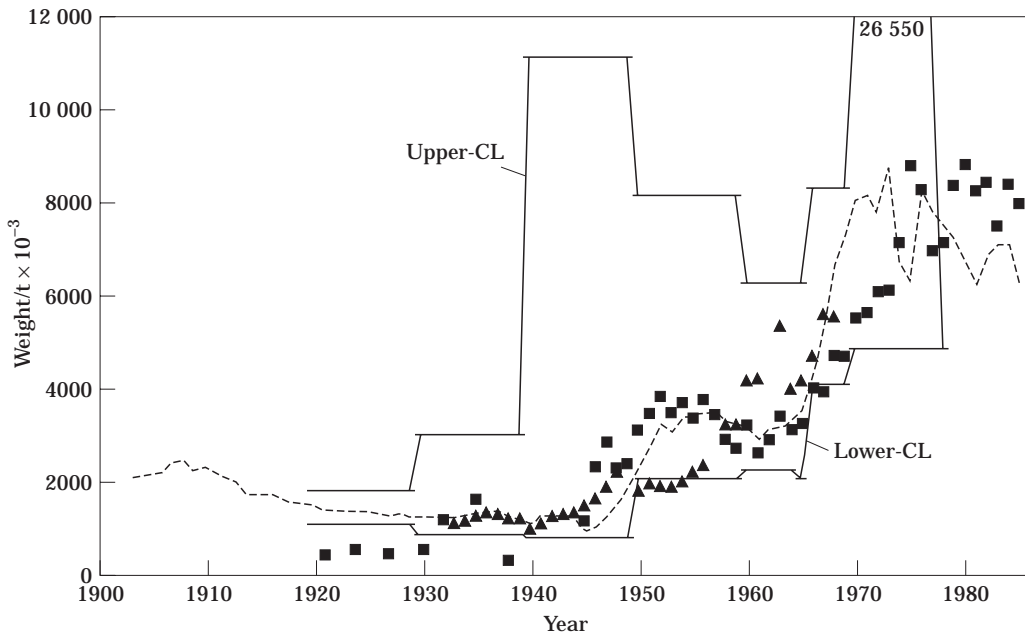


Figure 12. Total biomass (---, B) with 95% confidence limits. Catch rates of Poland and Sweden are adjusted to the level of biomass. ▲ Swed-B, ■ Pol-B.

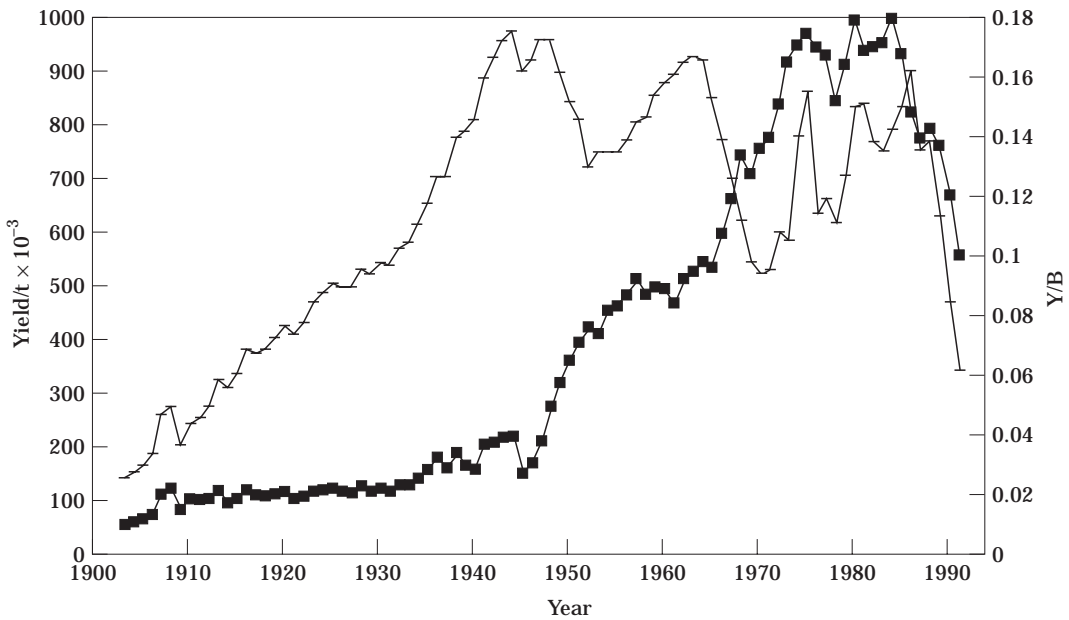


Figure 13. Fishing yield, Y (—■—), and coefficient of fishing mortality, Y/B (---).

Discussion

Validity of findings

The confidence intervals of biomass shown in Table 9 and Figure 12 give an indication of the validity of the results. Some of the intervals are rather wide, essentially

due to the high variance of herring data in two periods. There is, however, hardly any doubt that a real increase in biomass had taken place by the middle of the century.

If the catch rates (Table 3) had been calibrated against VPA biomass instead of estimated biomass, they would have been biased, because the change in catchability is

not known. The procedure used here describes the trend but not the level.

Another indication for the validity of the assessment is the quality of the calibration factor. Its mean inverse, $1/p$, for the five stocks was 2.04 ± 0.25 (Table 2–8), suggesting stable estimates.

The density (B/m^2) in the Baltic increased from some $5 g/m^2$ in 1903 to $17\text{--}23 g/m^2$ in 1970–1990. The North Sea had the same range ($15\text{--}23 g/m^2$) in 1983–1985 (Sparholt, 1990). The annual catch in the Baltic increased from $0.3 g/m^2$ at the beginning of the century to $2.5 g/m^2$ in 1980, while it was $4.7 g/m^2$ in the North Sea in 1983. The higher exploitation in the North Sea may be due to the greater proportion of demersal fish there, which can withstand a higher exploitation rate.

Threshold stock sizes

The main species showed some fluctuations in VPA-biomass since ICES assessments started in the 1970s. Herring biomass varied by a factor of 1.4, sprat and cod by a factor of 4.4. These variations in stock sizes of species are partly smoothed out in the total VPA-biomass of all species which varied by a factor of 1.8 (DR, Table 18).

In 1991 the stocks had increased by a factor of 8.4 compared with 1940, double the change for single species in recent years (Fig. 12; DR, Table 18). Even higher increases were seen in other areas. The SSB of North Sea herring in 1991 was 33 times that in 1977 (Anon, 1992c). In 1946 the SSB of Arctic cod was 25 times the amount in 1988 (Anon, 1990).

Reasons for changes in biomass

Many conditions in the Baltic have exhibited significant changes in the course of this century. Salinity and temperature of Baltic waters below the halocline appear to have increased since the 1950s (Fonselius, 1962). Wulf *et al.* (1990) suggest that nutrient levels have been above the earlier levels since 1950. Seal predation has diminished since about 1910 (Durant and Harwood, 1986).

Cushing (1982) attributes the growth in Baltic cod (and clupeid) yield to the augmentation in salinity and to the rise of the halocline. However, cod catches have increased remarkably since around 1940, while salinities below the halocline of the Bornholm and Gotland Deep have only increased since 1951 (Matthäus, 1990).

It is also tempting to relate the events in question to the global warming that started around 1910. However, the temperature curves in the Baltic do not resemble that of global warming (Matthäus, 1990; Koltermann, 1991), because temperature trends are strongly influenced by inflows of North Sea bottom water.

The trends in Figure 4 suggest that the consumption of fish by mammals declined rapidly until about 1940. Total estimated fish biomass was at its lowest then. This was followed by a rise of stocks until the beginning of the 1950s and a rather constant level for almost 15 years thereafter. I conclude that this development was essentially due to the decrease in numbers of mammals. However, this does not explain why the growth of the fish stocks was delayed until the seal population declined to about 20% its original size.

The largest increase in estimated biomass occurred in the late 1960s when the Baltic had already changed from an oligotrophic to an eutrophic sea. It would make sense to attribute this final rise in biomass to the increase in nutrients, followed by a corresponding growth in primary production. Since surplus eggs and larvae are always produced, good year-classes would, *inter alia*, depend on the availability of their food to let them survive to the adult stage.

In an extensive literature study Hansson (1985) pursued this matter. In spite of the large increase in nutrients during this century, he came to the conclusion that an effect of eutrophication on fish stocks has not been clearly shown. The matter is, indeed, complicated. For the analysis of eutrophication effects the data series would have to cover the period from the oligotrophic to the eutrophic states and not only the latter.

Larsson *et al.* (1985) suggested that the nutrient input to the Baltic around 1900 may have been 300 000 t of nitrogen (N) and 10 000 t of phosphorus (P) per year. Rosenberg *et al.* (1990) list 1 million t N, and 50 000 t of P for the 1980s. Wulf *et al.* (1990) concluded that N and P had both increased since 1950. Augmentation of phosphorus levels in the Bornholm and Gotland basins were also shown by Fonselius (1968); Milewska and Andrulowicz (1982); Elmgren (1989) and Nehring *et al.* (1989). However, there are no nitrogen data, and few phosphorus data from before 1955. Possible effects of a higher input of nitrogen on primary production and, subsequently, on fish biomass before 1970 have not been demonstrated so far as fish stock estimates are only available since 1970. However, Cederwall and Elmgren (1980) have shown an increase in benthic biomass at depths above the halocline. They compared their results for 1976–1977 with those of Hessle (1923) for 1920 and 1923. This indicates an effect of eutrophication, although it is not known when this increase started. This makes it difficult to relate nutrient content to fish biomass (Hansson and Rudstam, 1990).

Additional information indicates that eutrophication began around 1950. Extensive data on the benthic macrofauna were published by Shurin (1960). He reported high densities in 1946–1952 at depths down to 200 m. After 1955 he observed the following detrimental effects. In 1958 the community of the mollusc *Macoma baltica* in the Gotland basin below the halocline was

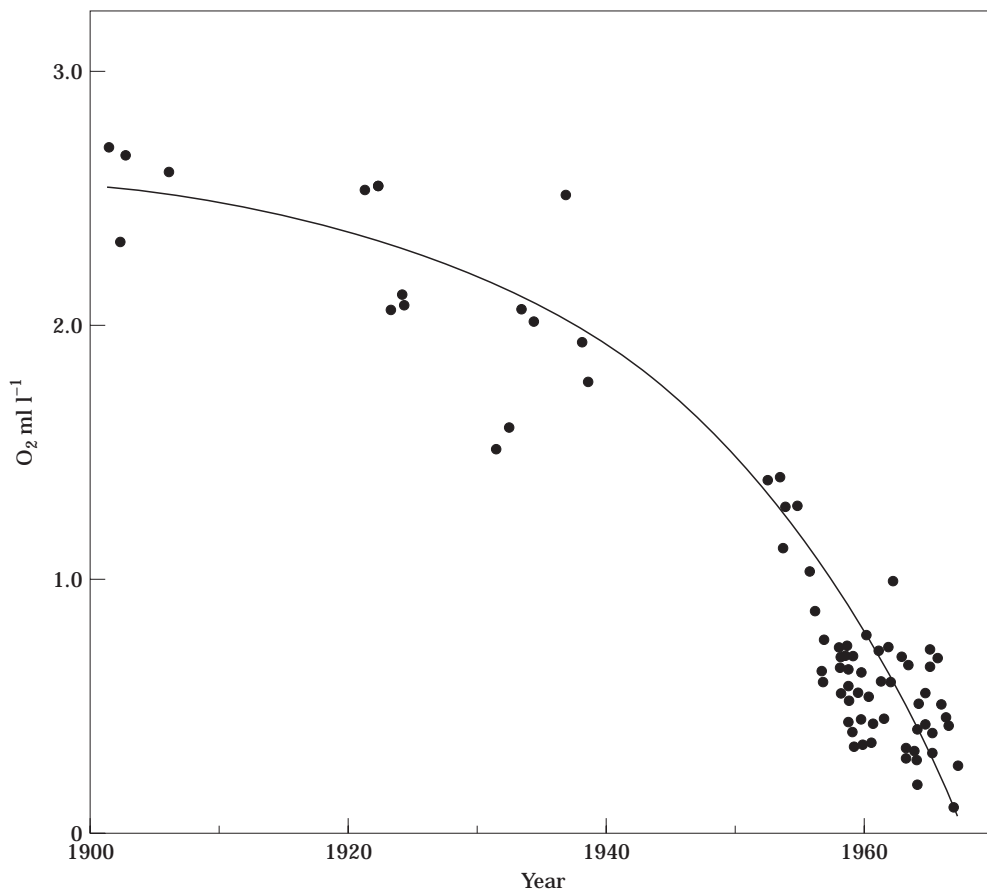


Figure 14. Oxygen content below the halocline, Landsort Deep (SD 27), acc. to Fonselius (1968).

wiped out because of lack of oxygen. In 1958–1959 the entire bottom fauna was destroyed. In 1967 Zmudzinski (1969) still found biomass values of less than 1 g/m^2 in the deep basins.

Fonselius (1968) has shown that the oxygen content in the Landsort deep (SD 27) in 1900–1952 has always been $\geq 1.5 \text{ ml/l}$, below the halocline. It subsequently dropped to less than 1 ml/l (Fig. 14).

The decline of oxygen in bottom water layers since 1952, and the breakdown of the bottom fauna below the halocline since about 1958 can be taken as indication for an increase in nutrients since 1950. A gain in nutrients since 1950 would have led to steadily increasing phytoplankton production, and in due time to higher fish production. Figure 12 and DR, Table 18 show that the estimated total biomass was lowest in the 1940s and highest in the 1950s. This agrees with the hypothesized development in nutrient levels and bottom fauna.

We may therefore assume that eutrophication has caused the increase in the Baltic fish stocks since about 1950. On the other hand, it has had clear adverse effects,

such as the decline in oxygen concentration (Fig. 14). Also, the additional nutrients are accompanied by a number of toxic compounds (Voipio, 1981), prompting proposals for a reduction of the input of N and P. This would inevitably lead to a lower fish biomass.

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