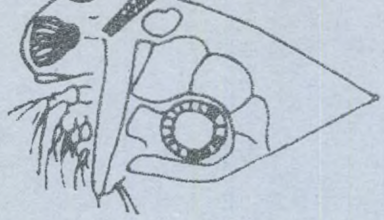

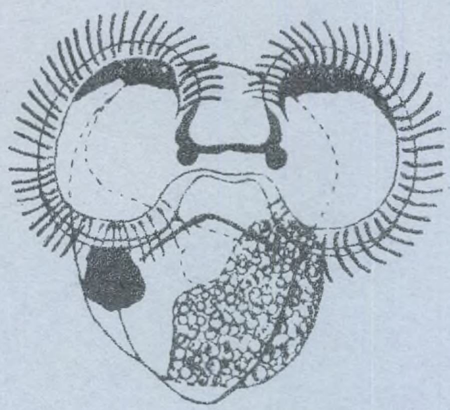

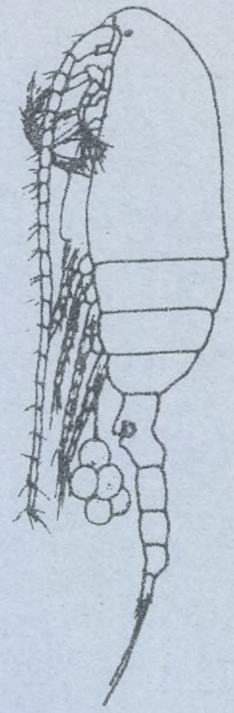

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Estimations of the amount of zooplankton and fish in the Baltic proper

by

Hans Ackefors and Lars Hernroth

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av Hans Ackefors och Lars Hernroth

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Estimations of the amount of zooplankton and fish in the Baltic proper.

by

Hans Ackefors and Lars Hernroth

ABSTRACT

The authors have calculated the biomass of zooplankton off the coast in 7 different subareas of the Baltic proper. The annual means of the zooplankton biomass of the different subareas fluctuated from 7.46 to 13.39 g wet weight m^{-2} or 0.39 to 0.70 g carbon m^{-2}. The mean values for all areas together calculated as two months interval fluctuated from 4.88 to 18.66 g wwt m^{-2} or 0.26 to 0.97 g C m^{-2} with minimum values in March-April and maximum values in September-October. The greatest amount of zooplankton, 41 g m^{-2}, was found in September in the Bornholm area. The yearly production of zooplankton was estimated to 5 g C m^{-2} (100 g wwt m^{-2}).

The fish catches in the Baltic consist mainly of herring, sprat and cod. Those three species made about 90 % of the total catch amounting to 617 000 tons in 1970. The fish catches in the Baltic proper have increased from 313 000 tons in 1961 to 548 000 tons in 1970. This corresponds to 1.57 g m^{-2} in 1961 and 2.74 g m^{-2} in 1970.

A crude estimate of the stock sizes in the exploited phase of the three most important species was made based on the various figures for fishing mortality and the yield; the calculated ranges of the stock sizes were for cod 128 000-229 000 tons, for herring 211 000-644 000 tons and for sprat 129 000-450 000 tons. It is likely that the true figures are close to the upper range. The total biomass of fish including other commercial and non-commercial species in the Baltic proper was estimated to 1.0-1.8 milj. tons. The annual production of fish was calculated to 0.8-1.2 milj. tons, corresponding to 4-6 g fish m^{-2} or about 0.4-0.6 g C m^{-2}.

The total amount of production for the whole Baltic proper in some parts of the ecosystem has been summarized. The primary production of phytoplankton was estimated to 20 milj. tons C, the benthic algae 1 milj. tons C, the secondary production of zooplankton 1 milj. tons C, the benthic evertebrates 0.8 milj.tons C, the pelagic fishes 0.06-0.09 milj. tons C and the demersal fishes 0.02-0.03 milj. tons C. The present fish yield for human consumption is 0.05 milj. tons C.

INTRODUCTION

The energy flow in the ecosystem of the Baltic proper is now in focus for the interest of many researches. In connection with the UN conference in Stockholm, June 1972, Jansson (1972) presented a paper dealing with the energy flow through different levels of the ecosystem in the Baltic proper. The paper is a general description of the present research from various parts of the ecosystem and the project "Energy Flow Through the Baltic Ecosystems", carried out at the Askö Laboratory, University of Stockholm. The authors were asked to report about the secondary production of zooplankton and the biomass of fish in the Baltic proper. Ackefors (1972) has reported about the methods to estimate the secondary production of zooplankton and express the data as gram wet weight (wwt) or gram carbon (gC) per m^2. This paper gives also the results of earlier studies in the Askö area (Ackefors 1965, 1969) recalculated into g m^{-2} (wwt and C).

This present paper deals with the biomass and secondary production of zooplankton off the coast and the biomass and production of fish in relation to fish catches 1961-1970 in the Baltic proper. The paper is a revised edition of a preliminary paper given to Jansson for his report of the current research in the ecosystem of the Baltic proper (Jansson 1972).

The authors want to express their sincere thanks to Dr. F. Thurow, Kiel, for his valuable help when this manuscript was prepared.

METHODS AND MATERIAL

Regular plankton researches in connection with hydrographical investigations in the Baltic proper have been carried out at least 3-5 times every year since 1967 by the Institute of Marine Research, Lysekil, Sweden. The results from 1968-1970 appear in Ackefors & Hernroth (1970 a, b and 1971). At least seven plankton stations are visited, each situated in 7 different subareas of the Baltic proper (see fig. 1) (cf. Ackefors 1969). The aim is to study the ecology and the biomass of zooplankton in relation to horizontal and vertical distribution in the Baltic proper.

The plankton samples were taken with Nansen nets with a mesh size of 0.16 mm at different intervals from bottom to surface (cf. Ackefors 1969; Ackefors & Hernroth 1970 a, b, 1971). Since 1971 the samples have been taken with a mesh size of 0.09 mm as the three first nauplius stages of the copepods (especially Arcartia spp.) were not caught by the coarser net.

The results from those investigations as well as from the investigations carried out in 1963 have been recalculated and expressed as a volume, g wet weight and g carbon per m^2, according to the methods reported by Ackefors (1972).

The fish catches taken by the international fleet in the Baltic, 1961 - 1970, are given in Bulletin Statistique (1963 - 1972). The figures for 1970 are preliminary. The catches taken by GDR are not included in the figures of Bulletin Statistique. The whole Baltic area is dealt with as a unit. In order to get an approximate figure for the Baltic proper only, the authors have subtracted the catches landed by Swedish boats along the coast of the Gulf of Bothnia from the total catch in the Baltic. The catches taken by Finnish boats are considerd to be taken in the Gulf of Finland or in the Gulf of Bothnia and also subtracted from the total catch. The catches have been converted to g fish m^{-2}. The area of the Baltic proper is considered to be 200 000 km^2 or 2×10^{11} m^2. The carbon contents of fish have been put to 10 % of the fresh weight.

For zooplankton the dry weight is considered to be 13 % of the wet weight and the carbon content 40 % of the dry weight or 5.2 % of the wet weight (cf. Ackefors 1972).

RESULTS

a. The biomass and production of zooplankton in the Baltic proper.

The results of the zooplankton studies appear in tables 1 - 3. The first table shows the complete list of the results from the investigations carried out off the coast in 1963 and 1968 - 1970. From the table it is evident that the highest productivity appeared in the Bornholm Sea (S 24)(cf. fig 1). The greatest amount of zooplankton was found in September, 1968, when 41.01 g m^{-2} or 2.13 g C m^{-2} appeared at that station. Even in September 1970 the biomass was rather high, 20.09 g m^{-2} or 1.04 g C m^{-2}.

If we study the values from most of the stations in the Baltic proper we found that the highest biomass appeared in September except for station S 12 in the Arkona Sea where no such tendency was found.

The other stations east and north of Bornholm Sea are normally less productive. If we compare the stations two and two, e.g. S 24 - 8 A, S 24 - S 41 etc. from west to east and from south to north we can see that there was a decreasing amount of zooplankton from west to east and from south to north. The only exception was the Arkona Sea (S 12). Although there are exceptions the sea areas along the Swedish side of the Baltic proper seem to be more productive than those of the Polish and Soviet side of the Baltic when comparing areas at the same latitude.

In table 2 the mean values of zooplankton biomass have been arranged in two months interval. It is quite clear that the greatest biomass of zooplankton off the coast appeared in September - October. The highest mean value for those two months were found at station S 24 and the lowest at station S 12. We can easily see the tendency of decreasing amounts of zooplankton from west to east and from south to north when the stations are compared two and two as proposed above. The biomass was in the range of 30.5 - 13.7 g m^{-2} in September - October except at station S 12. The mean value for all stations was 18.7 g m^{-2}. In general the plankton biomass was much lower in November - December. The mean value was less than half of the previous mentioned period or 7.8 g m^{-2}. The lowest amount of plankton was found in the Bornholm area (S 24) which normally had greater amounts of zooplankton than the other areas. The greatest amount of zooplankton in November - December was instead found at station S 41 west of Gotland.

In January - February the biomass of zooplankton was only slightly lower than in November - December. The mean value was 6.9 g m^{-2} and the maximum biomass appeared at station S 24. The smallest biomass appeared during the next two months as compared to the other periods. The mean value for March - April was 4.9 g m^{-2} and the lowest biomass ever found or 1.6 g m^{-2} during the investigation appeared at station F 78 (the Landsort Deep) in the north-east Baltic proper.

In May - June the biomass was higher or about the same level as in November -December. The mean value was 7.6 g m^{-2}, the minimum value appeared at station F 78 and the maximum at station S 24. July - August was next to September - October the most productive month. The mean value was 10.0 g m^{-2}. The annual mean value for all areas was 9.3 g m^{-2}.

The values of carbon contents per m^2 in the zooplankton biomass have been calculated in a similar way and reported in table 3. The yearly mean values in the bottom of the table show that the range of the carbon contents per m^2 in different areas of the Baltic proper was 0.39 - 0.70 g C m^{-2}. It is obvious that the Bornholm Sea area (S 24) had a much higher standing crop of zooplankton than the other areas.

The mean values for the two months interval reported in the table to the right were in the range of 0.26 - 0.97 g C m^{-2}. The yearly mean value for all areas was 0.48 g C m^{-2}.

The production of zooplankton in the Baltic proper can be calculated if we can use the total instantaneous mortality rate estimated for the two most important copepod species in the Askö area (Ackefors 1972) as a standard value for all plankton populations.

Ackefors found that the average value expressed on a monthly basis (Z x 1/12) was 0.85. If the average values for standing crop in table 3 are multiplied by a factor about 10 (12 x 0.85) we will get the yearly production in the different areas. The result will be a mean value of production in the whole Baltic proper in the order of 5 g C m^{-2} $year^{-1}$. The total amount of zooplankton produced annually during the studied period would be 10^{12} g C or 10^{6} ton C. This corresponds to a wet weight of 2 x 10^{7} ton zooplankton. If we compare the annual production in the different subareas we find that the greatest difference to be between the Bornholm Sea (7 g C $year^{-1}$) and the northern area represented by station F 78 and F 72 (about 4 g C $year^{-1}$). The same difference was also found when the Arkona Sea (S 12) is compared with the Bornholm Sea.

b. The amount of fish caught in the Baltic proper.

The amount of fish caught in the Baltic 1961 - 1970 is reported in table 4 (Bulletin Statistique, 1964 - 1972). Cod, herring and sprat dominated the catches in the 1960's. The cod catches have slightly increased during the period while herring and sprat have increased very much. The most striking event in the fishery of the Baltic proper is the heavy exploitation of the sprat stock east of Gotland which started in 1950's mainly by the Soviet and Polish fleet (fig.2). The other commercial catches in the Baltic consist mainly of salmon, smelt, eel, flounder, plaice and various freshwater fishes. The catches of industrial fish are in the order 15 000 - 20 000 tons according to the official statistics. The catches of pelagic fish have increased from 201 000 tons in 1961 to 407 000 tons in 1970. The herring catches increased from 155 000 tons in 1961 to 287 000 tons in 1968. In 1969 and 1970 the catches decreased slightly to 250 000 tons. The sprat catches have increased continuously since 1961, from 37 000 tons to 142 000 tons in 1970. This indicates that the greatest amounts of sprat is now taken in the Baltic proper as compared to all areas in the north-east Atlantic area. Not less than 64 % were taken in the Baltic proper in 1970.

The catches of pelagic, demersal and industrial fish in the Baltic proper only have been calculated in table 5. Swedish catches landed along the coast of the Gulf of Bothnia and Finnish catches are considered to be caught in the Gulf of Bothnia or in the Gulf of Finland. Those catches are subtracted from the catches in the Baltic and the rest is considered to be caught in the Baltic proper.

From table 5 it is evident that the total catches have increased from 312 000 tons to 548 000 tons during the period 1961 - 1970. It is mainly the increase of pelagic catches which explains the increase of catches from the Baltic proper. The catches of pelagic fish have increased from 161 000 tons in 1961 to 347 000 tons in 1970. If the catches are converted to gram fish per m^2 in the Baltic proper we get an increase of about 1.2 gram fish per m^2 during the period 1961 - 1970 (table 6). The amount of fish caught per m^2 has increased from 1.57 g to 2.74 g from 1961 to 1970, mainly due to the increase of pelagic fish from 0.80 g in 1961 to 1.73 g per m^2 in 1970.

c. The stock size of different fish species in the Baltic proper.

A crude estimate of the stock size of herring, sprat and cod in the Baltic proper was made. The biomass in the exploited phase is possible to calculate if the values for fishing mortality (F) and natural mortality (M) are known. According to Gulland (1969) the yield is F times the average biomass of fish in the exploited phase. The following formula $B' = Y/F$ can then be used. (B'=average biomass, Y=yield and F=fishing mortality).

As the figures for fishing mortality and natural mortality vary in different investigations we have calculated with the highest and lowest values as regard to the range of M,F and Z when estimating the stock size (table 7). Thurow (1971) has estimated the natural mortality for cod in the Baltic to 0.40. He has also made a survey of the figures for total mortality from different authors. From 1951 and onwards the figures were very high or in the range 1.05 - 1.56. This indicates that the fishing mortality was 0.65 - 1.16. When using those values the stock size of cod in the Baltic proper can estimated to the range of 128 000 - 229 000 tons (median value 179 000) in the exploited phase (cf. table 7). The natural mortality for herring has been estimated by Ojaveer (1971). He investigated a population of herring in the north-eastern Baltic proper outside the coast of U.S.S.R. The population was not exploited until 1968. Before this year he found a natural mortality of 0.21 - 0.26 for herring. This value has been used in our calculations.

In two independent investigations the total instantaneous mortality rate for the strong 1964 yearclass of autumn spawners has been estimated. Popiel & Strzyzewska (1971 a) reported about an average of Z=0.65 and Rechlin (1971) estimated the Z-value to an average of 1.40 for the same period (1967 - 1969). Both investigations are based on samples from the Bornholm Basin.

Using those mortality figures the biomass of the stock of herring in the exploited phase is in the range of 211 000 tons to 644 000 tons, with a median value of 428 000 tons in 1970 (table 7).

Elwertowski (1960) has calculated the total instantaneous mortality rate for sprat in the period 1954 - 1958. Z-values were in the range of 0.93 - 1.13. For the North Sea sprat a natural mortality of 0.85 has been calculated by Johnson (1970) and he reported about a total mortality of 1.19 for Wash Sprats.

If the same natural mortality can be applied to the Baltic sprat the stock size can then be calculated to the range of 129 000 - 450 000 tons with a median value of 290 000 tons.

From table 7 it is evident that the total biomass of the three most important species - cod, sprat and herring - is in the range of 0.5 - 1.3 milj. tons, with a median value of 0.9 milj. tons.

The other commercial species mentioned in table 4 give rather small catches. In 1969 and in 1970 the catches of pelagic fish was about 15 000 tons. The catches of demersal fish increased from 32.000 to 41 000 tons. The catches of industrial fish was about 20 000 tons both years. If we consider that the stock size is 3 times the catch we must add about 0.20 milj. tons to the sum for cod, herring and sprat.

The catches of non-commersial fishes are not included in the statistics and thatś why we have at present very little knowledge about the stock size of those species. However, Anéer (1972) investigated for a period of one year the catches of a commercial bottom trawler in Landsort area (NE Baltic proper). He found that 21 % of the catches by numbers consisted of four-horned sculpins (Cottus quadricornis) and eel-pouts (Zoarces viviparus). We do not know the weight relation between the species but as nearly 70 % consisted of small herring, the weight of sculpins and eel-pouts was probably higher than 20 %. (The length measurements are reported in the paper). On the other hand this investigations can not be considered as representative for the conditions in the whole Baltic proper. But if we, at present stage, accept the catches of non-commercial fishes to be 20 % of about 200 000 tons (= the demersal catch in 1970)we get a yearly catch of about 40 000 tons annually. If we consider that the stock size of those species is at least three times the catch we get a contribute to the stock size with about 0.1 milj. tons. We must also take into consideration the stocks of small fishes as gobies, sticklebacks etc, which normally are not caught by trawlers or other gears. If we guess that the total amount of those fishes must be at least 0.1 milj. tons and the preexploited phase of the three most important commercial species - cod, herring and sprat - in the same order, we get another contribution of 0.2 milj. tons to the total biomass of fish in the Baltic proper.

In summary; we get a total biomass of fish in the range of 1.0 - 1.8 milj. tons with a median value of 1.4 milj.tons.

d. The production of fish in the Baltic proper.

At present it is only possible to make a very crude estimate of the production of fish in the Baltic proper. If we add the loss due to the natural mortality of the three important species - cod, herring and sprat - to the catches of 1970 we get an approximate figure of the annual production on the assumption that the stocks are fully exploited (table 8). When using M-values of 0.4 for cod, 0.2 for herring and 0.8 for sprat the annual natural loss of those three species together are in the range of 150 000 - 440 000 tons. If we add the catches from 1970, which were about 550 000 tons, we get an annual production in the range of 700 000 - 990 000 tons of cod, herring and sprat (table 8). Cod and herring are probably fully exploited in the Baltic proper but it is likely that the stock of sprat is not yet fully utilized. It is therefore reasonable to suppose that the production of sprat is higher than the calculated figures in table 8. If we suppose that the production of other fishes (commercial and noncommercial species) is similar we can add at least 150 000 tons, assuming that the mortality must be in the order of 0.4.

In summary; the total annual fish production in the Baltic proper is in the range of 0.8 - 1.2 milj. tons.

DISCUSSION

a. The standing crop of zooplankton

The standing crop of zooplankton fluctuated during the year with maximum in September and minimum in April (cf.table 1). The greatest amount of plankton ever found was 41 g m^{-2} (wwt) in the Bornholm Sea in the southern Baltic proper. The values are rather similar to those reported by Mankowski et al. (1959) from the southern Baltic proper. They found maximum values certain years in June and another maximum in August - September in the magnitude of 40 g m^{-2}. In January - February they reported values about 5 - 6 g m^{-2} as minimum values for the year.

The authors, however, found minimum values later in March - April. But in coastal waters, in the northern Baltic proper, Ackefors (1972) found also minimum values in January - February.

The maximum values of standing crop are also found later in the year off the coast in September - October according to the authors' investigations than in coastal waters where it occurs in July - August (cf. table 2 and Ackefors 1972). The greatest food supply for plankton feeding fish off the coast as sprat and herring occurs evidently in the beginning of autumn. This can be correlated with the yearly fluctuation of fat content in sprat. In late autumn (October - November) the highest fat content in the adult sprats of the Bay of Gdansk was found (Elwertowski & Maciejczyk 1964).

The Arkona Sea (S 12) has a lower productivity and the normal development of the plankton community seems to be disturbed by the unstable hydrographical conditions. This area is considered as a transition area in the Baltic. It is greatly influenced by salt bottom waters which flow into the Baltic and outflowing brackish waters in the surface. This seems to be the reason why the average value of standing crop of zooplankton is lower or 7.5 g C m^{-2} as compared to the Bornholm Sea. The results from the coastal waters of Askö with unstable hydrography indicate lower productivity (mean value=1.8 g m^{-2}) than off the coast at the same latitude (mean value=8 g m^{-2}).

The mean value for the whole Baltic proper was about 9 g m^{-2} (cf. table 2) with a range of 7.5 - 13.4 g m^{-2}. Laevastu (1961) has estimated the standing crop to be 150 - 300 mg m^{-3}. Assuming a mean depth of 60 m this value corresponds to 9 - 18 g m^{-2}.

b. The production of zooplankton

The production of zooplankton in wet weight was estimated to 93 g m^{-2} $year^{-1}$; as the mean value for the standing crop was 9.3 g m^{-2} (table 2) and the instantaneous mortality rate (estimated on monthly basis) was 0.85. This corresponds to a value of about 5 g C m^{-2} for the secondary production of zooplankton in the Baltic proper. Andrushaitis (1971) estimated the production to 123.5 mg m^{-3} corresponding to a value of 4.4 g C m^{-2}. It is therefore reasonable to suppose that average level of secondary production in the whole Baltic proper off the coast is in the magnitude of 5 g C m^{-2} or 90 - 100 g wet weight m^{-2} per year.

The secondary production off the coast seems to be much higher than in coastal waters with unstable hydrogrphical conditions. Ackefors (1972) found that the secondary production in the Askö area was only 1 g C m^{-2} per year, i.e. only 25 % of what is found off the coast at the same latitude, or 20 % of the mean value for the whole Baltic proper. The main reasons for lower productivity in the Askö area as compared to other areas off the coast in the Baltic proper were according to Ackefors (1972); a. lower depth, b. unstable hydrographical conditions, c. lower surface temperature than in other areas, d. the critical salinity of 6 - 7 o/oo for many fresh water and marine species.

c. The primary production.

The annual secondary production of about 5 g C m^{-2} can be compared with the primary production in the Landsort area (not far from F 78, cf. fig. 1). Hobro & Nyqvist (1972) reported about an annual primary production of 114 g C m^{-2}.

This is nearly twice as high as Schulz & Kaiser (1972) found in the Gotland Sea, Bagge & Niemi (1971) and Bagge & Lehmusluoto (1971) in the Gulf of Finland. The annual primary production in the unpolluted areas of Gulf of Finland was in the range of 15-60 g C m^{-2}. However, they have used 24 hours as incubation time in the ^{14}C-method and Hobro & Nyqvist only four hours. The latter method gives higher values. Experiments have shown that there is probably a leak of radio-active substance out of the cells when using a longer incubation time than four hours. Therefore it seems reasonable to suppose, when regarding the figures for secondary production that the primary production must be higher than 15-60 g C m^{-2} in the Baltic proper. Fonselius (1971) reported about an annual primary production of 78 g C m^{-2} based on measurements from a lightship in the northern part of the Baltic proper. (Measurements with 24 hours incubation time.)

A recent published paper by Renk (1972) indicated on annual mean of primary production in the southern Baltic in the range of 72.6-104.1 g C m^{-2}. The highest production was found in the Bay of Gdansk and the lowest in the Arkona Deep. The time of incubation was from sunrise to noon (Renk, pers. comm.). To get a crude estimate of the primary production in the whole Baltic proper the authors have used a mean value of 100 g C m^{-2} $year^{-1}$ for the calculation which is evident in table 9.

The annual primary production in the open sea of the ocean is in the magnitude of 50 g C m^{-2}, in shallow coastal waters 100 g C m^{-2} and in special productive areas with upwelling waters about 300 g C m^{-2} (Ryther 1970). From the North Sea Cushing (in Gulland 1970) has reported about a range of 44-200 g C m^{-2} $year^{-1}$.

d. The biomass and production of fish, benthos and macro algae.

The fish catches in the Baltic proper was in 1969-1970 in the magnitude of 0.5 milj. tons per year and the production was in the range of 0.8-1.2 milj. tons per year and the total biomass was in the range of 1.0-1.8 milj. tons. The catch of pelagic fishes is twice as high as the catch of demersal fishes (cf. table 5). The main catch of demersal fish cinsists of cod. 150 000 tons are caught per year. The stock size in the exploited phase has been calculated to 179 000 tons (the calculated range is 128 000 - 229 000 tons). Probably the true figure is in the upper part of the range. In any case the heavy exploitation of cod with annual catches of 150 000 tons seems to be too high. Otterlind (1971) showed that the percentage of large cod, 50 cm total length and longer, decreased in Swedish catches during 1960's. He proposed new measures to protect the cod population.

The calculated stock size of herring might be in the range of 428 000 - 644 000 tons, i.e. above the median value. The reason for this is that to the annual catch of 250 000 tons you have to add a great amount of natural loss due to predation. Wiktor (1969) said that only the Polish catch of cod has consumed 80 000 tons of herring (and 89 000 tons of sprat). As the annual Polish catch was about 50 000 tons (1965-1967) this corresponds to about 1/3 of the total catch of cod in the Baltic. From this fact it is evident that the cod in the Baltic may consume more than 200 000 tons of herring per year. This indicates that the natural mortality rate must be much higher than 0.21-0.26 which Ojaveer (1971) calculated for the herring population in the north-eastern Baltic proper. In the southern Baltic proper with a dense population of cod it is likely that the natural mortality is much higher. From this follows also that the production of herring is higher than reported in table 8. On the other hand the cod in other areas may eat more sprat (cf. Lishev & Uzars 1967). Otterlind (1970) reported that the average size of herring in Swedish catches has recently decreased. This indicates that the herring stock in the Baltic proper may be a little overexploited.

The very high natural mortality ($M = 0.85$) for sprat in the North Sea was calculated by Johnson (1970) using a formula proposed by Beverton & Holt (1959) and Beverton (1963); $M = 1.6 \times K$, K = growth coefficient, in this case $K = 0.53$. This was based on the fact that the faster a fish grows the higher its natural mortality rate is likely to be. It seems reasonable to suppose the same high mortality for the Baltic sprat due to the strong predation from other fishes in the Baltic proper. Only in the eastern

Gotland basin the cod eat 45 000 tons of sprat (Lishev & Uzars 1967), the Polish catches of cod (about 50 000 tons) consume annually 89 000 tons of sprat (Wiktor 1969) and the salmon eat 15 000 tons (Thurow 1966). Based on the figures by Wiktor (1969) only the cod which are caught annually in the Baltic eat more than 250 000 tons of sprat. This indicates that the stock size mentioned in table 7 may be in the upper range of the calculated 129 000 - 450 000 tons (cf. table 7) or probably higher than this figure.

The calculation of fishing mortality rate as well as the total instantaneous mortality rate for sprat and herring in the Baltic proper is difficult. The many small local populations of sprat e.g., which tend to mix in the open sea when the sprat becomes older (Lindquist 1971) may complicate the calculation. There is also a migration from spawning areas of many local herring populations along the coast to the fishing grounds in the Bornholm area (Popiel 1955, Otterlind 1961). The migration of herring to feeding grounds in the southern Baltic aftersevere winters is also important (Popiel & Strzyzewska 1971b). The reason is that after such winters the plankton is not so abundant in the other parts of the Baltic as in the southern Baltic. The fact that Popiel & Strzyzewska (1971a) and Rechlin (1971) reported about very different Z-values, 0.65 resp. 1.40, may indicate an influence of such migration. The limited fishery statistics in the Baltic area are probably the greatest nuisance for such calculations. At present stage it is therefore likely, that the unsufficient data will bias the calculation very much.

The biomass of 1.0-1.8 milj. tons of fish in the Baltic proper is equal to 5-9 g of fish per m^2 or about 0.5-0.9 g C m^{-2}, and the production of 0.8-1.2 milj. tons of fish corresponds to 0.4-0.6 g C m^{-2}. In order to get the relation to benthic food for demersal fish we can take into consideration the standing crop of benthos in the Baltic proper reported by Zenkevitch (1963). He found a density of 25 g/m^2 in the Gotland Basin and 60 g/m^2 in the southern Baltic. He estimated the total biomass to 8 100 000 tons. Assuming that the mean duration of life of benthos is one year these figures might be taken as equal to the annual production (Gulland 1970).

According to the above mentioned figures the annual production in different parts of the ecosystem can be summarized in table 9. The figures for benthic algae in the whole Baltic is about 1.7×10^6 tons (Jansson 1972). This means that the production of benthic algae in the Baltic proper is about 1.0×10^6 tons if the production is proportional to the area.

Finally, if we summarize the figures in table 9 we find that the primary production is 21 milj. tons C per year, the secondary production of zooplankton and benthic evertebrates is 1.8 milj. tons C per year and the production of fish 0.08-0.12 milj. tons C per year. The fish yield for human consumption is 0.05 milj. tons C.

We still lack a lot of figures for production of e.g. meiofauna, bacteria etc., in order to get the first crude estimate of the energy flow in the ecosystem of the Baltic proper. The present studies in the Baltic indicated by Jansson (1972) have given us at least some information about the standing crop from most parts of the ecosystem. The production figures for zooplankton and fish presented in this paper constitute the first attempt to evaluate the magnitude of the energy flow in relevant parts of the ecosystem.

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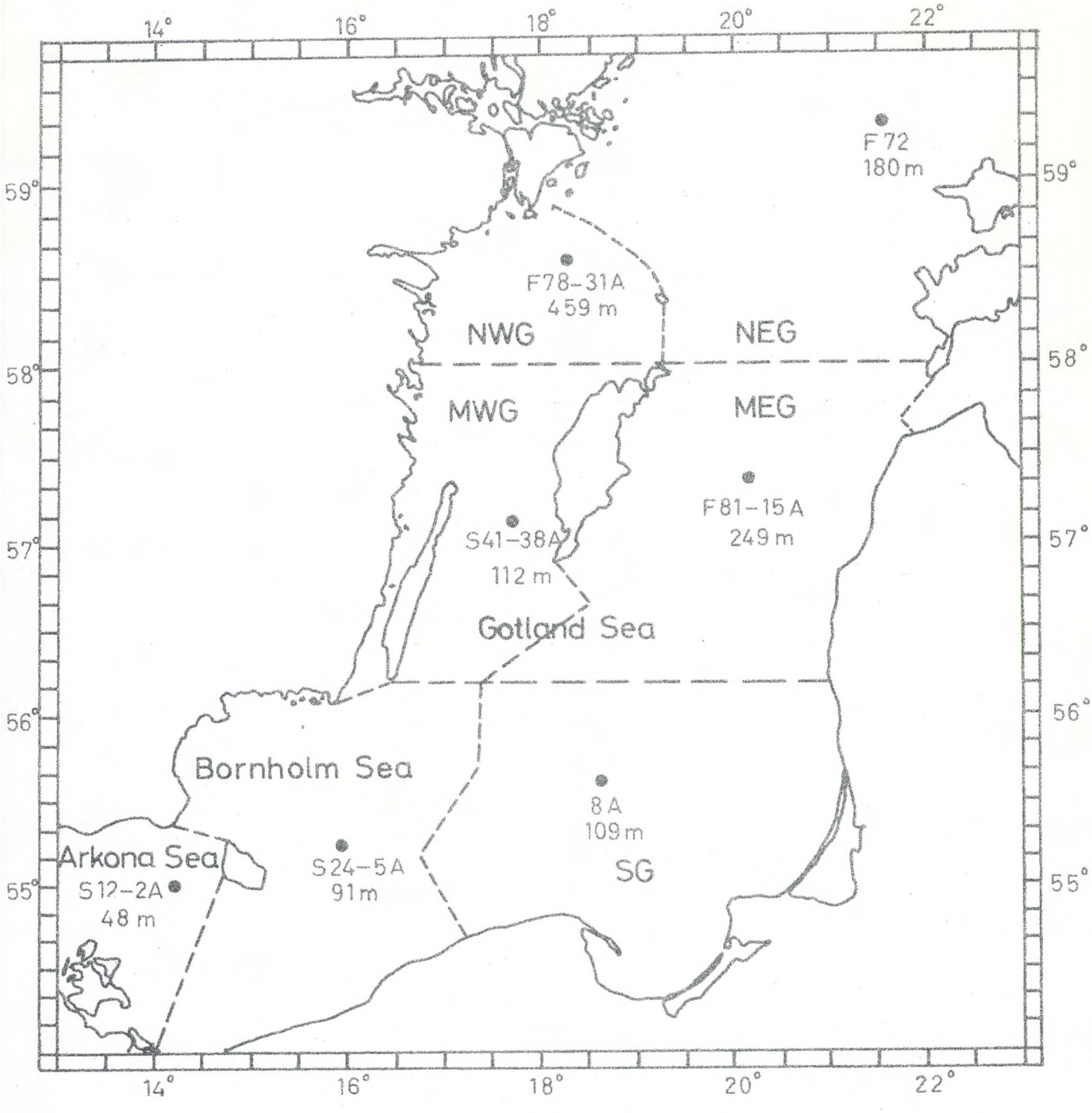

Fig. 1. Chart of the Baltic proper and the three subareas, the Arkona Sea, the Bornholm Sea and the Gotland Sea according to WATTENBERG (1949). The Gotland Sea is devided into an eastern and western part by WATTENBERG. According to ACKEFORS (1969) the Gotland Sea may be devided into five subareas; the southern (SG), the middle eastern and western (MEG and MWG) and the north-eastern and north-western (NEG and NWG). The seven plankton stations are evident from the chart, in some cases with both old and new symbols as well as the depths.

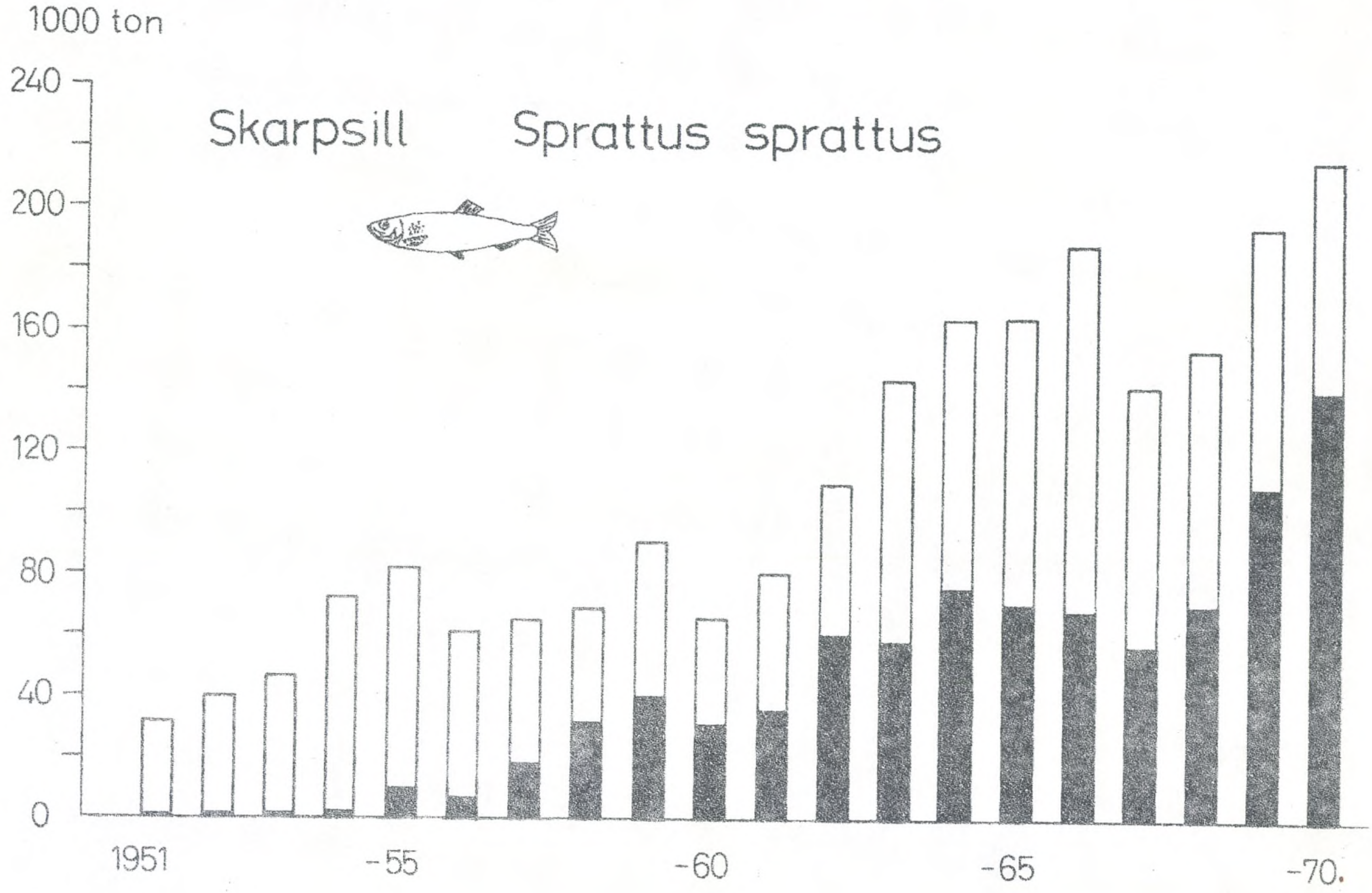

Fig. 2. The total catch of sprat in the whole north-eastern Atlantic area 1951 - 1970 according to Bulletin Statistique (1952 - 1972). The catches taken in the Baltic proper are indicated by the black part of the bars.

Table 1. The biomass of zooplankton expressed as volume, wet weight and carbon content per m^2. The values are corrected for a filtration coefficient of 0.7.

	S 12				S 24			
	Volume mm^3/m^2	Wet weight g/m^2	Carbon content gC/m^2	Depth m	Volume mm^3/m^2	Wet weight g/m^2	Carbon content gC/m^2	Depth m
<u>1963</u>								
Aug.	9 156	9.16	0.48	45	13 326	13.33	0.69	90
<u>1968</u>								
Febr.	5 251	5.25	0.27	45	10 260	10.26	0.53	87
April	5 557	5.56	0.29	43	6 871	6.87	0.36	86
June	11 599	11.60	0.60	45	12 920	12.92	0.67	85
Sept.	7 622	7.62	0.39	45	41 008	41.01	2.13	85
Nov.	10 453	10.45	0.54	45	3 371	3.37	0.17	85
<u>1969</u>								
Jan.	2 770	2.77	0.14	45				
April	1 696	1.70	0.09	45	10 386	10.39	0.54	85
Nov.					6 123	6.12	0.32	85
<u>1970</u>								
Jan.	9 185	9.18	0.48	40	15 516	15.52	0.81	85
May	4 467	4.47	0.23	45	7 606	7.61	0.39	85
Sept.	8 571	8.57	0.45	45	20 090	20.09	1.04	80
Oct.	7 226	7.23	0.38	45	13 153	13.15	0.68	85

Table 1., continued

	F 81				F 78			
	Volume	Wet weight	Carbon content	Depth	Volume	Wet weight	Carbon content	Depth
	mm^3/m^2	g/m^2	gC/m^2	m	mm^3/m^2	g/m^2	gC/m^2	m
<u>1963</u>								
Aug.	6 010	6.01	0.31	247	13 850	13.85	0.72	500
<u>1968</u>								
Febr.	7 233	7.23	0.38	240	7 532	7.53	0.39	440
June	8 487	8.49	0.44	240	3 945	3.95	0.20	350
Sept.	21 750	21.75	1.13	200	27 957	27.96	1.45	400
<u>1969</u>								
Jan.	2 467	2.47	0.13	200	869	0.87	0.04	100
April	3 871	3.87	0.20	240	1 553	1.55	0.08	450
Nov.	5 538	5.54	0.29	200				
<u>1970</u>								
Jan.	11 596	11.60	0.60	240	1 652	1.65	0.09	200
June	18 873	18.87	0.98	230	2 142	2.14	0.11	200
Sept.	18 734	18.73	0.97	200	14 600	14.60	0.76	200
Oct.	10 685	10.69	0.55	235	13 891	13.89	0.72	100

Table 1., continued

	8 A				S 41			
	Volume	Wet weight	Carbon content	Depth	Volume	Wet weight	Carbon content	Depth
	mm^3/m^2	g/m^2	gC/m^2	m	mm^3/m^2	g/m^2	gC/m^2	m
1963								
Aug.	10 039	10.04	0.52	100	7 632	7.63	0.40	115
1968								
April	4 513	4.51	0.23	115	7 174	7.17	0.37	100
June	9 570	9.57	0.50		11 191	11.19	0.58	105
Sept.	27 287	27.29	1.42		27 822	27.82	1.45	105
Nov.					12 384	12.38	0.65	100
1969								
Jan.					8 094	8.09	0.42	100
April	4 044	4.04	0.21	90	9 980	9.98	0.52	100
Nov.	6 022	6.02	0.31	100				
1970								
Jan.	3 759	3.76	0.19	95	6 439	6.44	0.33	100
May	3 090	3.09	0.16	90	1 941	1.94	0.10	100
Sept.	23 093	23.09	1.20		14 128	14.13	0.74	100
Oct.	10 732	10.73	0.56		10 479	10.48	0.55	105

Table 1., continued

F 72

	Volume mm^3/m^2	Wet weight g/m^2	Carbon content gC/m^2	Depth m.
<u>1968</u>				
Febr.	12 488	12.49	0.65	100
Sept.	11 890	11.89	0.62	110
<u>1969</u>				
Jan.	4 176	4.18	0.22	50
April	3 598	3.60	0.19	150
<u>1970</u>				
June	6 079	6.08	0.32	170
Sept.	22 952	22.95	1.19	150
Oct.	6 329	6.33	0.33	100

Table 2. The zooplankton biomass expressed as g m^{-2} at different stations in the Baltic proper (cf. fig. 1). Mean values for wet weight, 1963, 1968 - 1970. The values are corrected for a filtration coefficient of 0.7. Original values are taken from Ackefors 1969 a, Ackefors & Hernroth 1970 a,b, 1971.

Months	Station S 12	S 24	8 A	S 41	F 81	F 78	F 72	Mean value
Jan.-Febr.	5.73	12.88	3.76	7.26	7.09	3.35	8.34	6.92
March-April	3.63	8.62	4.28	8.58	3.88	1.57	3.60	4.88
May-June	8.04	10.27	6.33	6.56	13.69	2.15	6.08	7.59
July-Aug.	9.15	13.33	10.04	7.64	6.01	13.86	-	10.01
Sept.-Oct.	7.81	30.54	25.20	17.47	17.06	18.82	13.73	18.66
Nov.-Dec.	10.45	4.75	6.02	12.38	5.53	-	-	7.83
Mean value	7.46	13.39	9.27	9.98	8.88	7.95	7.94	9.32

Table 3. The zooplankton biomass expressed as gram carbon per m^2 at different stations in the Baltic proper (cf. fig. 1). Mean values from 1963 and 1968 - 1970. The values are corrected for a filtration coefficient of 0.7. Original values are taken from Ackefors 1969 a, Ackefors & Hernroth 1970 a,b, 1971. e = estimated value.

Months	Station S 12	S 24	8 A	S 41	F 81	F 78	F 72	Mean value
Jan.-Febr.	0.29	0.67	0.19	0.38	0.37	0.17	0.43	0.36
March-April	0.19	0.45	0.22	0.45	0.20	0.08	0.19	0.26
May-June	0.42	0.54	0.33	0.34	0.71	0.11	0.32	0.39
July-Aug.	0.48	0.69	0.52	0.40	0.31	0.72	e 0.43	0.51
Sept.-Oct.	0.42	1.58	1.31	0.91	0.88	0.98	0.71	0.97
Nov.-Dec.	0.55	0.25	0.32	0.64	0.29	e 0.30	e 0.30	0.38
Mean value	0.39	0.70	0.48	0.52	0.46	0.39	0.40	0.48

Table 4. Catches of pelagic fish, demersal fish and industrial fish in ton in the Baltic, 1961 - 1970, according to Bulletin Statistique (1964 - 1972).

Pelagic fish		1961	1962	1963	1964	1965
Salmon	*Salmo salar*	3 081	2 789	2 587	3 700	3 412
Smelt	*Osmerus eperlanus*	3 959	9 451	4 382	5 181	5 953
Various salmonids		1 163	3 859	1 858	1 803	3 365
Herring	*Clupea harengus*	154 848	151 332	191 975	177 933	185 429
Sprat	*Sprattus sprattus*	37 353	61 153	59 050	76 955	71 626
Mackerel	*Scomber scombrus*	209	160	99	104	158
Garfish	*Belone belone*	616	924	542	982	466
Total		201 229	229 668	260 493	266 658	270 409
Demersal fish						
Freshwater fishes		4 425	17 057	18 010	17 080	16 035
Eel	*Anquilla anquilla*	3 077	3 417	3 132	3 126	2 832
Dab	*Limanda limanda*	41	26	23	25	45
Flounder	*Platichthys flesus*	6 014	5 860	5 508	1 335	1 313
Plaice	*Pleuronectes platessa*	768	1 043	1 106	1 775	1 795
Turbot	*Scopthalmus maximus*	26	21	18	28	26
Various flatfishes		4	15	13	6 011	7 896
Cod	*Gadus morhua*	99 720	129 944	127 643	105 083	105 222
Whiting	*Merlangius merlangus*	15	11	-	1	3
Various codfishes		25 149	5	7	-	-
Various demersal percomorphs		-	5 129	1 092	3 012	3 382
Total		139 239	162 528	156 552	137 476	138 549
Industrial fish (Unidentified fish)		23 901	10 598	8 482	13 105	13 139

Table 4 ., continued

Pelagic fish	1966	1967	1968	1969	1970
Salmon	2 907	3 235	3 548	2 880	2 583
Smelt	5 855	8 914	12 250	7 501	6 879
Various salmonids	3 951	3 140	3 770	4 061	3 120
Herring	201 007	232 094	286 943	250 309	250 601
Sprat	68 699	57 852	71 076	110 015	143 741
Mackerel	64	60	32	30	31
Garfish	314	602	570	459	508
Total	282 797	305 897	378 189	375 255	407 463
Demersal fish					
Freshwater fishes	15 362	15 817	17 155	18 485	16 794
Eel	3 255	3 011	3 279	2 835	2 180
Dab	37	23	28	18	21
Flounder	1 708	2 170	1 330	4 619	4 765
Plaice	985	1 009	1 235	756	682
Turbot	23	22	20	15	16
Various flatfishes	9 151	6 941	8 709	4 173	3 731
Cod	135 746	144 626	157 339	154 216	149 412
Whiting	12	2	17	24	12
Various codfishes	-	-	1	3	-
Various demersal percomorphs	3 009	4 250	1 274	1 264	13 212
Total	169 288	177 871	190 387	186 408	190 825
Industrial fish (Unidentified fish)	14 778	14 322	16 109	20 503	18 769

Table 5. Catches of pelagic and demersal fish and industrial fish in tons in the Baltic proper, 1961 - 1970. Finnish catches as well as Swedish catches landed along the coast of Gulf of Bothnia are considered to be caught in the Gulf of Bothnia or in the Gulf of Finland and not included in the catches of the Baltic proper.

	1961	1962	1963	1964	1965
Pelagic fish	160 582	190 451	205 141	222 255	214 364
Demersal fish	139 016	154 191	147 935	129 938	131 724
Industrial fish	13 401	10 598	7 345	12 301	12 124
Total sum	312 999	355 240	360 421	364 494	358 212
	1966	1967	1968	1969	1970
Pelagic fish	230 874	251 274	309 828	308 492	346 396
Demersal fish	163 688	171 733	183 874	179 458	184 552
Industrial fish	13 537	13 188	15 176	19 219	17 354
Total sum	408 099	436 195	508 878	507 169	548 302

Table 6. Calculated catch per m^2 in gram wet weight per m^2 in the Baltic proper. The sea area is considered to be 200 000 km^2.

	1961	1962	1963	1964	1965
Pelagic fish	0.80	0.95	1.03	1.11	1.07
Demersal fish	0.70	0.77	0.74	0.65	0.66
Industrial fish	0.07	0.05	0.04	0.06	0.06
Total sum	1.57	1.77	1.81	1.82	1.79
	1966	1967	1968	1969	1970
Pelagic fish	1.15	1.26	1.55	1.54	1.73
Demersal fish	0.82	0.86	0.92	0.90	0.92
Industrial fish	0.07	0.07	0.08	0.10	0.09
Total sum	2.04	2.19	2.55	2.54	2.74

Table 7. The estimated stock size of cod, herring and sprat in the Baltic proper based on figures for fishing mortality (F), natural mortality (M), total instantaneous mortality (Z), and yield (Y), for cod (Thurow 1971), for herring (Ojaveer 1971, Popiel & Strzyzewska 1971, Rechlin 1971), for sprat (Elwertowski 1960, Johnson 1970). The catch in 1970 has been used when calculating the stock size for cod and herring and the catch in 1958 for sprat.

	stock size in 1 000 tons				
	range	median value	M	F	Y in 1000 tons
cod	128–229	179	0.40	0.65–1.16	149 (1970)
herring	211–644	428	0.21–0.26	0.39–1.19	251 (1970)
sprat	129–450	290	0.85	0.08–0.28	36 (1958)
Total	468–1 323	897			

Table 8. The estimated production of herring, sprat and cod in the Baltic based on catch figures for 1970 under the assumption that the natural mortality is 0.4 for cod, 0.2 for herring and 0.8 for sprat.
All figures in 1 000 tons.

	Catch	Natural mortality	Total
herring	251	38–116	289–367
sprat	144	71–248	214–392
Total	395	109–364	503–759
cod	149	42–76	191–225
Grand total	544	151–440	694–984

Table 9. The annual production of phytoplankton, zooplankton, benthic algae, benthic evertebrates, pelagic fishes, demersal fishes and fish yield for human consumption. In order to get the total production of pelagic fishes 100 000 tons has been added to the figures for herring and sprat and 50 000 tons to the figure for cod (cf. table 8).

Trophic level nr	Produced biological substance	Produced amount in milj. tons C
1	Nanoplankton and other phytoplankton	20.00
1	Benthic algae	1.00
2-3	Zooplankton	1.00
2-3	Benthic evertebrates	0.80
3-4	Pelagic fishes	0.06-0.09
3-5	Demersal fishes	0.02-0.03
4-6	Fish yield for human consumption	0.05