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Ref. Pelagic Fish (N) Committee

Multispecies Fish Stock Assessment for the North Sea 1960-1979

by

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Abstract

Yield and stock assessments allowing for species interaction through food competition and predation were made by means of a previously described model. The results are in fair accordance with observations of total North Sea yield and also in accordance with pooled data for groups of species with certain similarities. Deviations from data are more apparent when each species is considered separately.

Tentative predictions until 1979 based on 1976 effort levels suggest stable, high catches of most species, herring excepted. An outstanding mackerel yearclass was found able to reduce the catch of most other species in several years.

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Introduction

Species interaction was introduced into the Beverton and Holt (1957) assessment model as roughly indicated in the Appendix to the present paper and more fully described in earlier papers presented at previous ICES meetings (Andersen, Lassen and Ursin, 1973; Andersen and Ursin, 1974, 1975; Ursin and Andersen, 1975; Lassen, 1975). A full account of the model is in press (Andersen and Ursin, Medd. Danm. Fiskeri- og Havunders., N.S., vol. 7,p 319).

The Model

The method roughly involves (a) establishing a list (a state vector) of numbers and body weights, at one particular moment, of each agegroup of each species considered and (b) calculating growth and mortalities in a subsequent short time interval. These are added to or subtracted from the original data. From the resulting new state vector, growth and mortalities are calculated for the second time interval, and so on.

Spawning is fixed at species-specific dates, the eggs being inserted as the 0-group, moving older agegroups one step up in age. The last agegroup of each species is a cumulative one, i.e., if a species is represented by 5 agegroups then these are 0,1,2,3 and 4+. Ideally, each species should be represented by as many agegroups as used in e.g. Virtual Population Analyses. As computer time, however, is proportional to the square of the total number of agegroups, limited funds have necessitated the restricted number of agegroups involved in this exercise.

The Present Application of the Model

The species considered are shown below (number of agegroups in brackets):

Mackerel	(5)	Haddock	(5)
Herring	(5)	Cod	(7)
Sprat	(4)	Saithe	(5)
Sandeels	(5)	Plaice	(7)
Norway pout	(3)	Dab and long rough dab	(4)
Whiting	(6)		

Dab and long rough dab are treated as one species with intermediate parameter values. The model also comprises 7 groups of zooplankton, 9 of zoobenthos, 2 of unicellular algae and 7 of such detritus and dead animals which remain available as food for some time.

Adjusting the initial parameter values is a slow process because an extensive automatic simulation cannot be applied for economic reasons. As a first step a state vector was prepared for 1st January 196o and the computations carried through to the end of 197o, the output being size and landings by species, agegroup and year. These figures were compared with official catch statistics and other published information. In case of major discrepancies the parameter values were adjusted and the program rerun. This procedure was repeated until a fair agreement of calculated and observed values was obtained.

A state vector was then prepared for 1st Januar 1969 and the computations carried through to the end of 1979, the output for the three last years being prognoses. Except for yearclass strength and fishing mortality the parameter values were those estimated by means of data for 196o-197o.

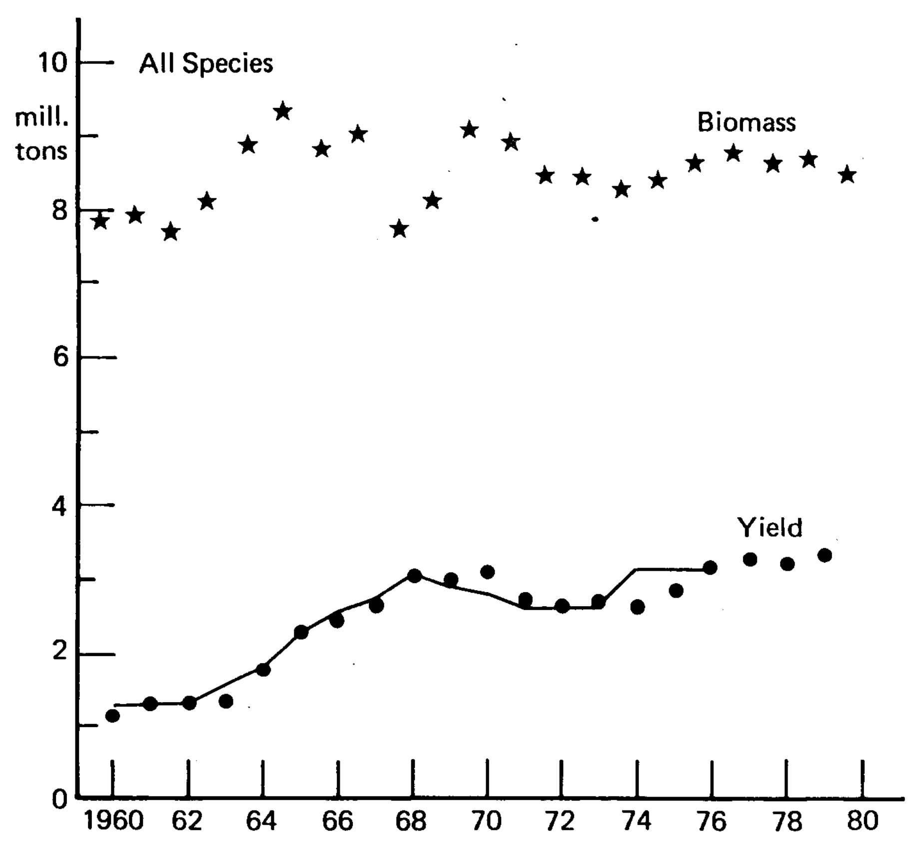
As the causes of yearclass strength variation are largely unknown, this component could not be included in the model. When yearclass strength is known it can be introduced with its appropriate value. For the most recent years and, of course, for future years mean values must be inserted. Particularly outstanding yearclassess which would influence the average year class strength considerably were excluded when calculating the mean. Assessing the possible effects of strong yearclasses upon the ecosystem is simply done by changing one or a few input-figures.

The model has scarcely reached its final form as yet. Discrepancies between the computer output and observed data still occur although at a decreasing rate. It is often difficult to distinguish discrepancies due to an unrealistic mathematical formulation from those due to incorrect data. Particularly the predation pattern, of paramount importance to a model of species interaction, is unsatisfactorily known. Some remaining problems are discussed below.

Results

Total Yield and Biomass

The total North Sea yield (ICES stat.div.IV) of the species considered is indicated by the solid line in the figure below. The data are taken from the Bulletins Statistiques with such amendments as are suggested in the reports of ICES working groups. The most conspicuous development is the rapid increase in yield in the middle sixties following the introduction of a purse seine fishery on the adult North Sea herring and mackerel. The yield has stabilized at a level about twice the previous one even though purse seine catches were reduced in the early seventies.



The calculated yield is indicated by dots. The calculations predict a stable and high total yield of the North Sea fisheries in 1977-1979, but it must be stressed that the reliability of the model prognoses is unknown, so far.

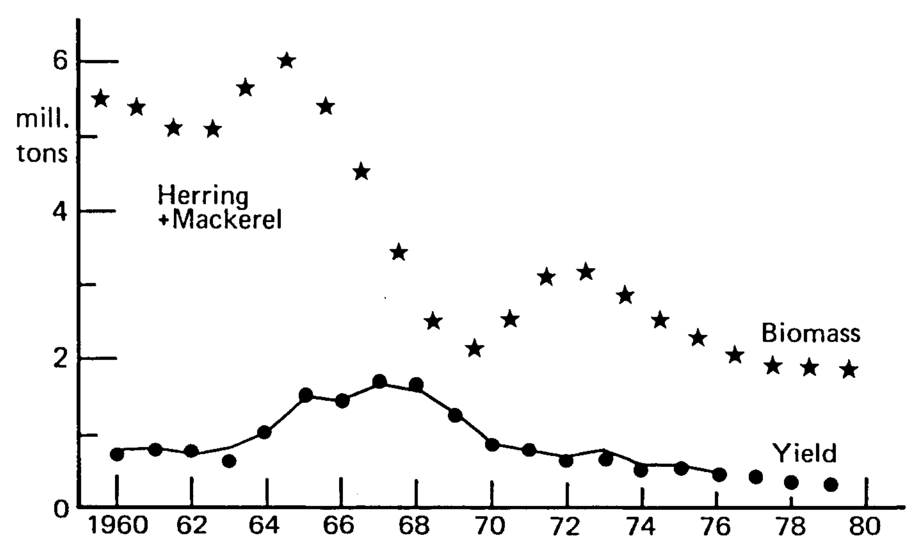
The calculated total biomass (1.Jan.) of the fish species considered is shown by asterisks. The first rise is mainly due to strong year-classes of herring and mackerel. The decrease after 1966 coincides with the removal of large quantities of herring and mackerel by the purse seine fisheries. A quick recovery (although not by herring and mackerel) brought total biomass to a stable and slightly higher level than in the early sixties.

Yield and Biomass of Species Groups

Some species have important characteristics in common and are conveniently considered together: -

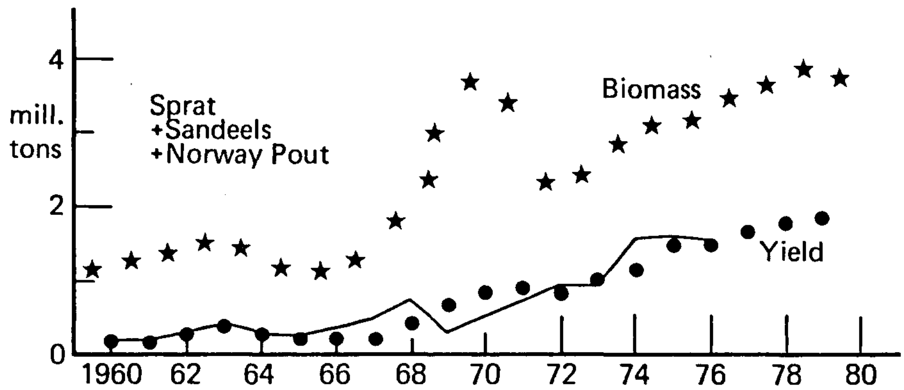
1. Herring and mackerel: pelagic stocks which declined concomitant with the increase in pelagic fishing effort.
2. Sprat, sandeels and Norway pout: small species recently caught in large quantities for processing.
3. Cod, saithe, haddock and whiting: the larger gadoids.

1. Herring and Mackerel



The yield increased in the middle sixties due to purse seining partly attracted by outstanding yearclasses. The prognosis of a continued decrease in 1977-79 is conjectural (see below, herring). Biomass, although influenced by outstanding yearclasses, is generally decreasing. Note that out of 7.8 mill. tons total biomass in the early sixties 5.2 mill. tons or two thirds were mackerel and herring. Now, the fraction is reduced to one fourth.

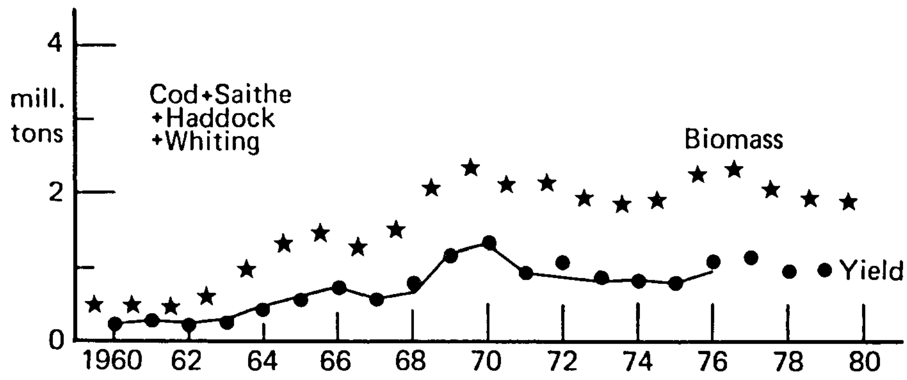
2. Sprat, Sandeels and Norway Pout



Unimportant in 196o these species contribute at the monent 1.6 mill. tons per year which is more than the total North Sea yield in 196o (by weight of course, not by monetary value). This is due to increases of both effort and biomass. The peak on the biomass curve about 197o is probably not realistic (see below, sandeels, Norway pout). Continued although small increases in yield and biomass are predicted for 1977-79, but since the calculations were obviously incorrect in 1969-7o they could be wrong again.

The stocks of these small species seem to have been particularly small about 1965 when catches were generally low. In the model output, however, the minimum occurs in 1966 and is linked with heavy predation by the generally very large fish stocks about 1964. It seems that the choice of parameter values causes one or several predatory fish species to prey upon younger fish than they actually do. It is unfortunate that so little is known about the predator/ prey size ratio of common North Sea fish species, especially considering the effort that in the past has been invested in analysis of stomach contents.

3. Cod, Saithe, Haddock and Whiting



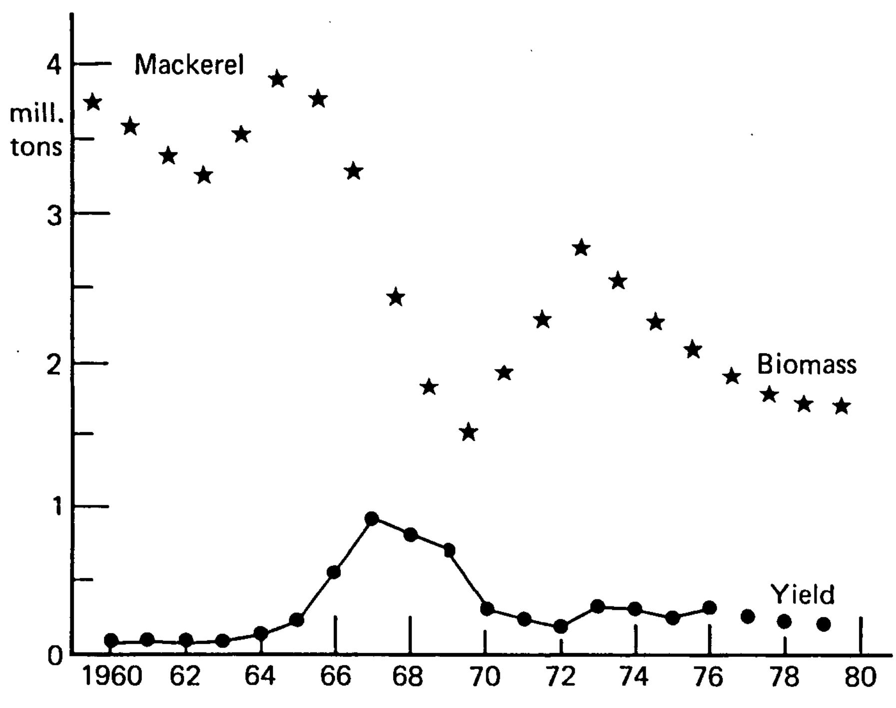
These species follow the same pattern as sprat, sandeels and Norway pout. The peak in 1969-7o is due to the outstanding 1967 haddock yearclass. The yield seems now to oscillate about 1 mill. tons per year with fairly good prospects for the near future.

Yields and Biomasses of Individual Species

Although the ordinate scale differs in the following diagrams there is in each diagram used the same scale for yield as for biomass, because this gives the correct impression of the magnitude of the overall fishing mortality (F = yield/biomass).

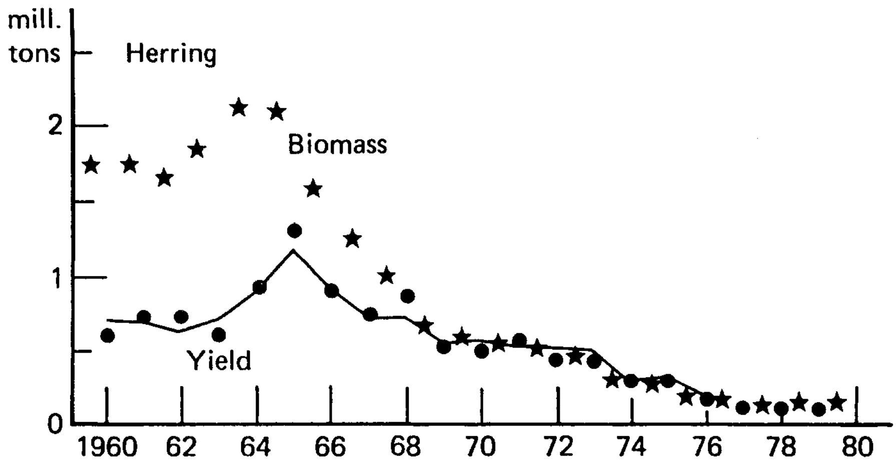
Mackerel

Quantitatively the dominating species in 196o its biomass decreased from about 5o pct of total fish biomass to only 25 pct in 1975. The large catches in 1965-69 were



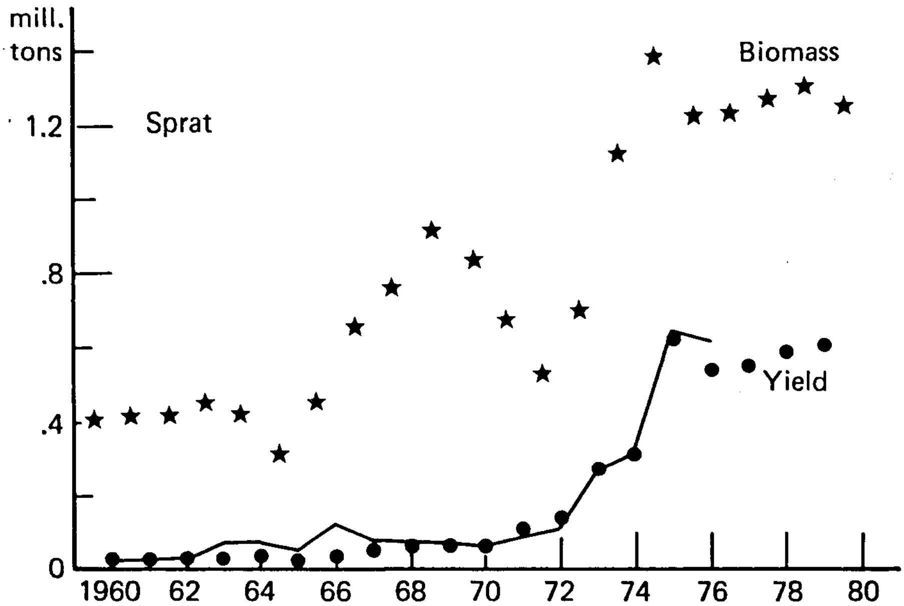
caused by the outstanding 1962 yearclass and by an effort 2o times as high as in 196o. The second peak on the biomass curve is due to another outstanding yearclass, that of 1969. The effect is now wearing off which causes a prediction of decreasing catches in the near future.

Herring



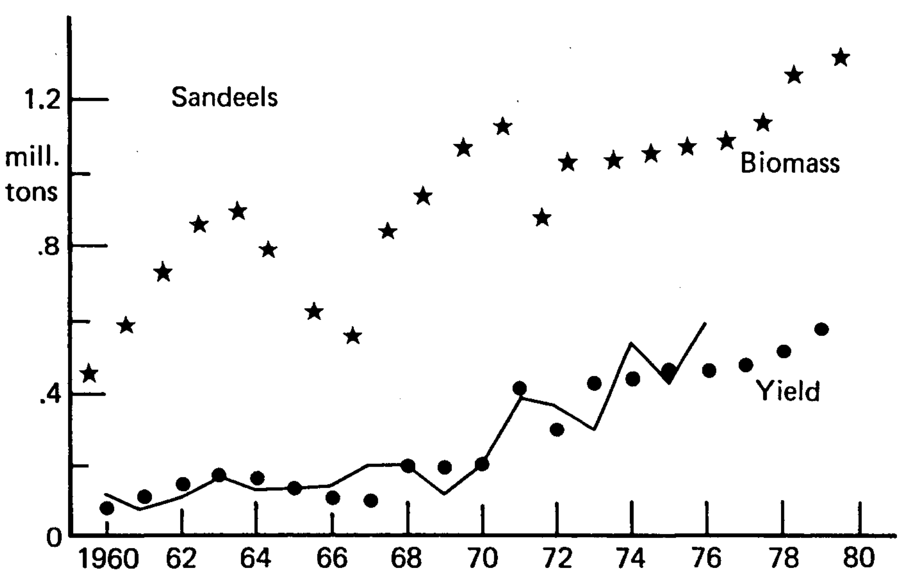
The biomass peak in 1963 - 1964 is caused by the 1956 and 196o yearclasses. The peak in the catches is due to the latter yearclass and to increased purse seining on adult North Sea herring. The yearclasses of 1972, 1974 and 1975 are so small that a state of recruitment overfishing is most likely. Since 197o recruitment shows a decreasing trend and is now about one tenth of the level prior to 1968. The model fails to predict this development. Obviously the stock-recruitment relationship introduced into the model (paper no. 45, ICES' Århus Symposium 1975) has an initial slope too steep to produce recruitment overfishing with the present egg production of North Sea herring. Pending a more realistic stock-recruitment relationship some adjustment has been made by reducing the recruitment parameter for 1976-79 to one tenth of its average value in 196o-7o. This is why the predicted catches of herring in 1977-79 were called conjectural in a previous paragraph.

Sprat



Catch-at-age data are not available for the first years. Constant F = .075 was assumed up to 1970. In 1960-64 the recruitment parameter was given the same value as used for predictions 1977-79.
There has been a marked increase in fishing effort in recent years. So far, the stock seems to tolerate this increase so that the prospects for the near future are good. The biomass boom about 1970 is scarcely realistic and probably due to inaccurate assumptions on predation patterns of species consuming sprat. This makes predictions extremely hazardous.

Sandeels

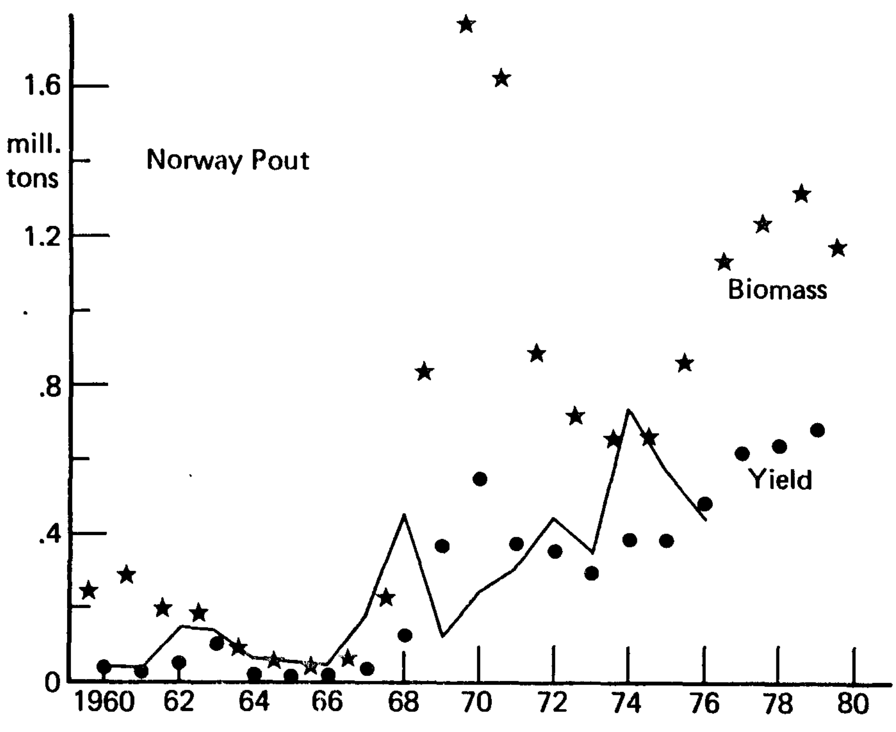


Strengths of individual yearclasses are not known. The recruitment parameter was therefore given the same value throughout. Fishing mortality was assumed constant (F = .24) up to 1971.

Yield and biomass had originally an unrealistic peak about 197o. It was demonstrated, however, by Jones and Richards (CM 1976/F:35) that haddock, although a demersal feeder in general, consumes sandeels in great quantities. The 197o maxima of biomass and yield almost disappeared when this was permitted in the program because the big haddock population at that time kept the sandeels in check.

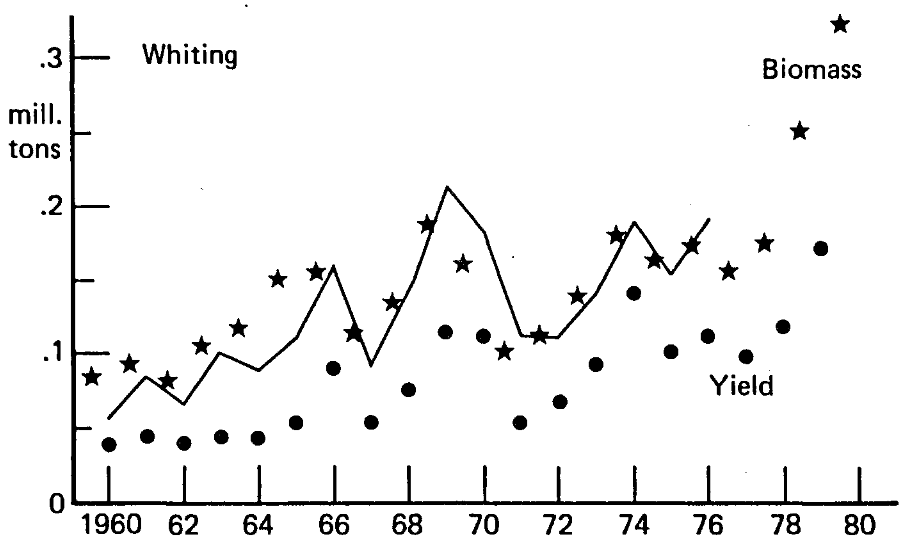
Bearing this in mind and in view of our scanty knowledge of the feeding habits of most North Sea fishes it is not surprising that there are other cases (sprat, Norway pout) where calculated yields deviate suspiciously from observations.

Norway Pout



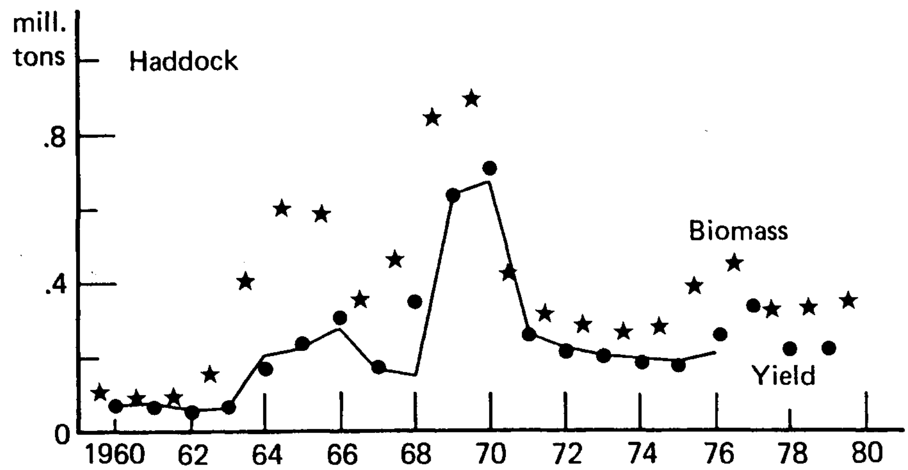
Like sandeels, Norway pout was allotted a constant recruitment parameter. In nature there probably was an outstanding yearclass in 1967 whereas the program produces very strong yearclasses in 1968 and 1969. The cause of this discrepancy is not known. However, if saithe eat more Norway pout than assumed, then the rapidly increasing saithe population may have checked the growth of the Norway pout population.

Whiting



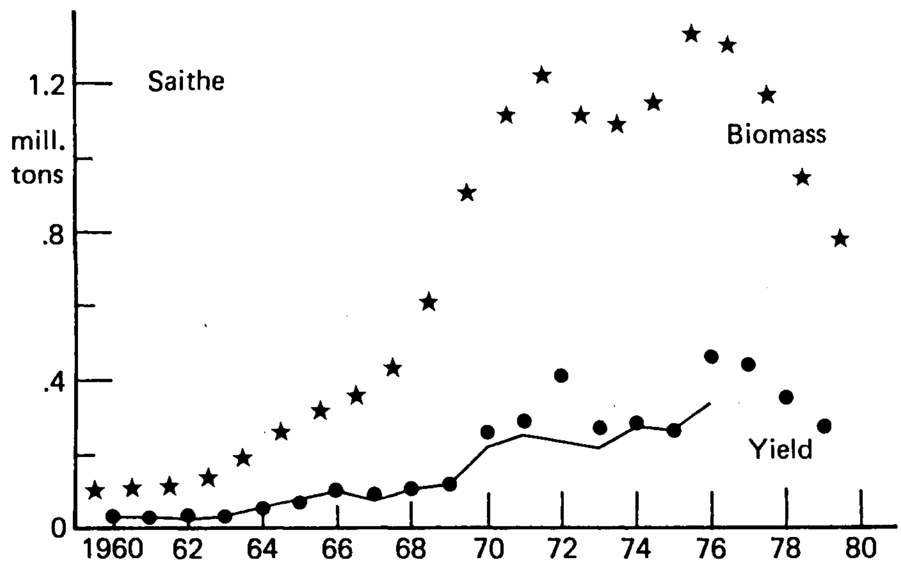
Calculated yield is far below actual yield. Most whiting landed for human consumption are big for their age. This is not accounted for in the model where whiting grow like average North Sea whiting. The catches by numbers are approximately as in the Roundfish Working Group reports.

Haddock



Yield and biomass maxima are caused by the outstanding yearclasses of 1962 and 1967 and, in the predictions, by the 1974 yearclass.

Saithe

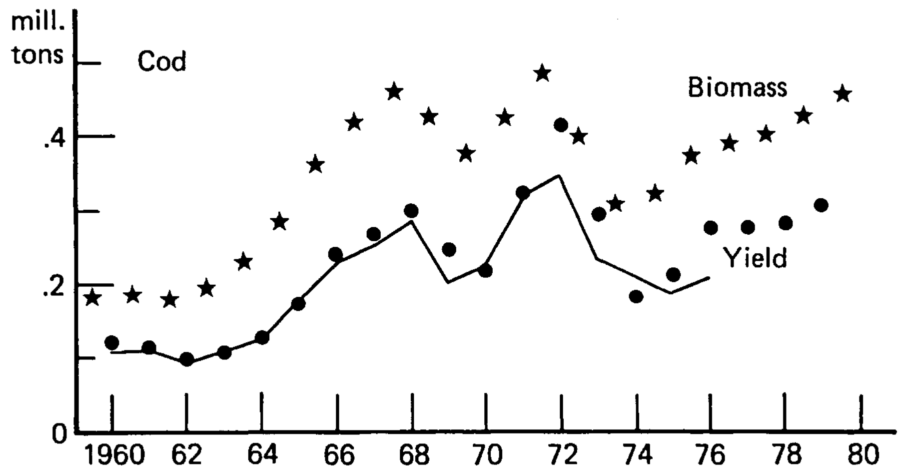


There are obvious discrepancies between calculated yield and observed yield in 1972 and 1976. This is when the outstanding yearclasses of 1968 and 1973 dominate the catches. There is no similar discrepancy with respect to numbers caught.

Perhaps there was a growth rate reduction for these yearclasses, but nothing is known about it. The calculated growth rates are normal in spite of the large size of the stock.

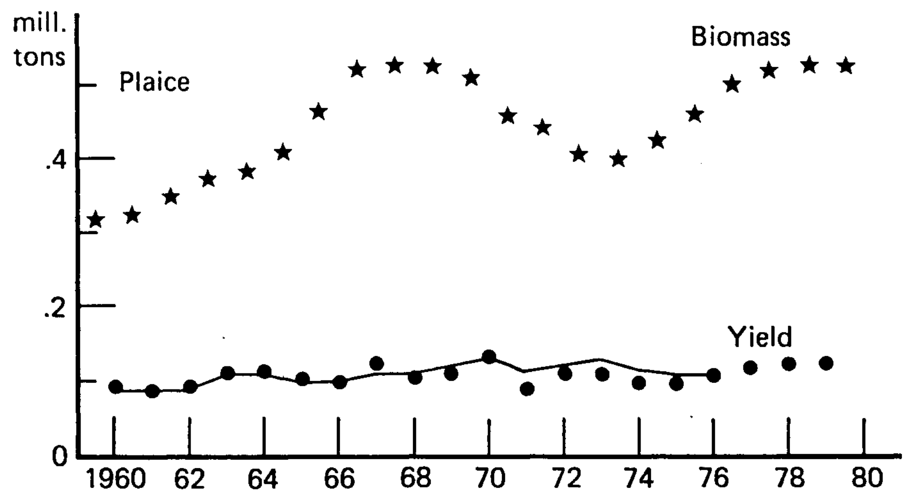
The predicted reduction in saithe catches in 1977.79 is due to the decreasing influence of the 1973 yearclass. Since the yield of this yearclass is overestimated, the yield reduction is also overemphazed.

Cod



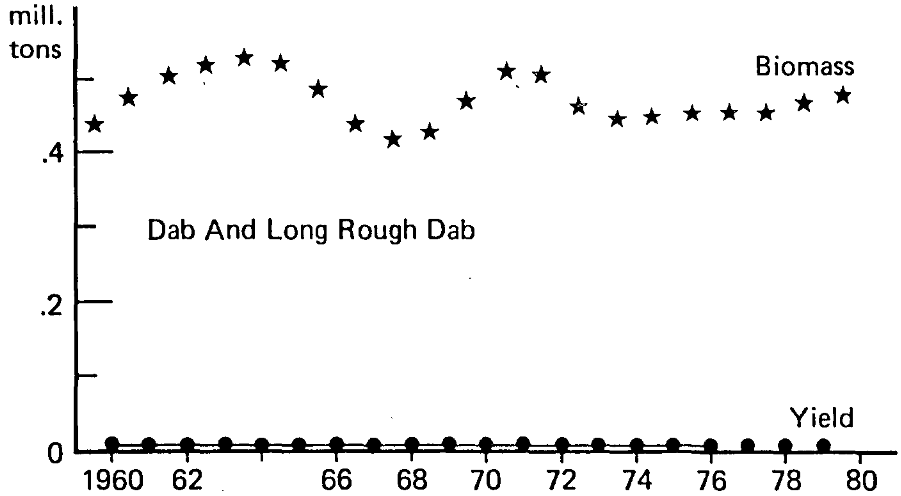
Yearclass strength varies little in North Sea cod. However, the good yearclasses of 1969 and 197o made quite an impact together.

Plaice



The large biomass about 1967 is caused by the outstanding 1963 yearclass. Another biomass increase in recent years is due to the fairly good yearclasses of 1972 and 1973.

Dab and Long Rough Dab



These species are almost unexploited, but seem to contribute considerably to demersal fish biomass.

Effects of Strong Yearclasses upon Yield Forecasts

Predictions for 1977-79 are based on the assumption that no outstanding yearclasses turn up in 1976-79.

In order to examplify the effect of a strong yearclass in a species interaction model let us assume that either mackerel, haddock or cod produced an outstanding yearclass in 1976, e.g. for mackerel as in 1962, for haddock as in 1967 and for cod as in 197o. We assume throughout that fishing mortality rates remain as they were in 1976, i.e. that the fishing patterns do not change.

Table 1 shows first the yield in 1979 with yearclass strengths as in the preceding paragraph (the column marked "Standard"). The following columns show the yields predicted in the three cases mentioned. The results are given both as weights and as percentage deviation from standard. Table 2 gives similar values for biomass on 1. January 198o.

The mackerel case is the most interesting one because of the large biomasses involved and because the strong yearclass is seven times stronger than a normal one. Total yield decreases considerably and is in fact similar to the yields of 1971 and 1972 which were influenced by the strong 1969 yearclass of mackerel. Most species except mackerel show reduced catches and biomasses. These are immediate losses. The gain in terms of increased mackerel catches would occur in the nineteen eighties. The primary losers are sprat, sandeels and Norway pout which are consumed by mackerel to such an extent that by 1979 they have lost 39 pCt in yield and biomass.

With only the haddock 1976 yearclass differing from the standard situation we see a smaller impact than in the case of mackerel. Haddock biomass is smaller and, to a large extent a benthos feeder, haddock is less voracious. Anyway, a yearclass of the same strength as in 1967 is not as outstanding today as it used to be (see the preceding paragraph). It is only five times stronger than the "average" yearclasses of 1977-79.

Wheras it is a dubious achievement to obtain a strong mackerel yearclass it is obviously advantageous with haddock. Total yield increases (by 16 pCt in 1979) and only the less valuable sandeels suffer markedly. These, as already mentioned, are supposed consumed with a preference by haddock. The yields of 2-group and 3-group haddock of the 1967 yearclass were almost equal (640 000 tons and 672 000 tons) whereas the prediction refers a larger part of the yield to the 3-group because of a lower F value for the 2-group. The corresponding figures are 526 000 and 938 000 tons.

The introduction of a strong cod yearclass in 1976 makes little impact upon the fish stocks. The 1970 yearclass was only 1.7 times the "average" yearclass. Placed in an environment of fair-sized yearclasses it is not impressive.

Table 1. North Sea yield in 1979 as predicted with the standard procedure of assuming average recruitment by all species (1st column) and as predicted on the assumption that mackerel, haddock or cod produced an outstanding yearclass in 1976. Percentage gains or losses are relative to the standard. Unit: 1000 tons.

		Outstanding 1976 yearclass produced by					
	Standard	Mackerel		Haddock		Cod	
	Weight	Weight	pCt	Weight	pCt	Weight	pCt
Mackerel	220	289	+31	220	0	220	0
Herring	107	102	- 5	105	- 2	103	- 4
Sprat	604	350	-42	618	+ 2	591	- 2
Sandeels	575	449	-22	297	-48	568	- 1
Norway pout	681	330	-52	776	+14	692	+ 2
Whiting	173	113	-35	172	- 1	163	- 6
Haddock	228	205	-10	938	+311	221	- 3
Saithe	286	284	- 1	288	+ 1	286	0
Cod	308	292	- 5	307	0	375	+18
Plaice	125	125	0	124	- 1	125	0
Dab + long rough dab	12	11	- 8	12	0	12	0
Mackerel + herring	327	391	+20	325	- 1	323	- 1
Sprat + sandeels + Norway pout	1860	1129	-39	1691	- 9	1851	0
Cod+saithe+haddock+whiting	995	894	-10	1705	+71	1045	+ 5
All species	3319	2550	-23	3857	+16	3356	+ 1

Table 2. Biomass on 1st January 1980 as predicted on the same assumptions as in Table 1. Unit: 1000 tons.

		Outstanding 1976 yearclass produced by					
	Standard	Mackerel		Haddock		Cod	
	Weight	Weight	pCt	Weight	pCt	Weight	pCt
Mackerel	1700	3008	+77	1713	+ 1	1680	- 1
Herring	152	127	-16	147	- 3	146	- 4
Sprat	1249	709	-43	1316	+ 5	1237	- 1
Sandeels	1315	1015	-23	557	- 58	1297	- 1
Norway pout	1172	546	-53	1128	- 4	1142	- 3
Whiting	320	182	-43	325	+ 2	304	- 5
Haddock	352	259	-26	723	+105	326	- 7
Saithe	785	758	- 3	786	0	774	- 1
Cod	456	419	- 8	460	+ 1	514	+13
Plaice	527	520	- 1	521	- 1	524	- 1
Dab + long rough dab	483	435	-10	478	- 1	464	- 4
Mackerel + herring	1852	3135	+69	1860	0	1826	- 1
Sprat + sandeels + Norway pout	3736	2270	-39	3001	- 20	3676	- 2
Cod + saithe + haddock + whiting	1913	1618	-15	2294	+ 20	1918	0
All species	8511	7978	- 6	8154	- 4	8408	- 1

Appendix: Outline of the Model

The Beverton and Holt (1957) theory of fishing has three basic differential equations in time for each species i:

$$\frac{dw_i}{dt} = H_i w_i^m - k_i w_i^n \qquad (1)$$

$$\frac{dN_i}{dt} = -(F_i + M_i)N_i \qquad (2)$$

$$\frac{dY_i}{dt} = F_i N_i w_i \qquad (3)$$

(1) is the change in body weight w_i as a function of body weight and the rates of uptake and breakdown.

(2) is the change in numbers N_i as a function of numbers and of fishing (F_i) and natural (M_i) mortalities.

(3) is the yield rate of the fishery. F_i is proportional to the fishing intensity.
Include a fourth equation:

$$\frac{dR_i}{dt} = f_i h_i w_i^m \ (o \leq f_i \leq 1) \qquad (4)$$

where R_i is food consumed by the species in question. Putting the rate of food consumption proportional to w^m agrees with the positive term of (1). The proportionality constant is h_i when the fish eats all it can. When it is not allowed to do so it eats the fraction f_i of the maximum. f_i is called the feeding level ($= \xi / \xi_L$ in the notation of Beverton and Holt, 1957). The fraction v_i of food consumed ends up in the fish body, i.e., it equals the positive term of (1).

Thus

$$\frac{dw_i}{dt} = v_i \frac{dR_i}{dt} - k_i w_i^{\,n} = v_i f_i h_i w_i^{\,m} - k w_i^{\,n} \qquad (1A)$$

so that $H_i = v_i f_i h_i$

The feeding level is an implicit function of time and is determined by the expression

$$f_i = \frac{\varphi_i/V}{\varphi_i/V + 1/q_i} \qquad (5)$$

where V is the water volume. $1/q_i$ is known in literature on primary production as the half saturation constant. q_i is a coefficient of the rate of search for food. φ_i, also a function of time, is the sum of biomass of all kinds of prey, each weighted by its suitability G_{ij} to the predator:

$$\varphi_i = \sum_j \varphi_{ij} = \sum_j G_{ij} w_j N_j \qquad (6)$$

The suffix j designates the species or entity consumed by the predator i: if a prey species is represented by more than one agegroup the sum has a term for each agegroup. This deals with the necessary amendments to the growth sector of the Beverton and Holt model.

The mortality sector as described by (2) also needs refinement. The natural mortality coefficient M of Beverton and Holt covers all sources of mortality except fishing mortality. In order to describe interspecies relationships M must be partitioned into $M = \hat{M} + M2$ where M2 is the grazing, or predation, mortality:

$$\frac{dN_i}{dt} = -(F_i + \hat{M}_i + M2_i)N_i \qquad (2A)$$

$M2_i$ is the fraction consumed in time dt of the biomass of i by all groups preying upon i. With the notation introduced above this can be formalized as:

$$M2_i = \frac{1}{N_i w_i} \sum_j \frac{dR_j}{dt} N_j \frac{\varphi_{ji}}{\varphi_j} \qquad (7)$$

There remains to partition the unspecified natural mortality $\hat{M}_i$ into a density dependent larval mortality $M1_i$ supplying a workable stock-recruitment feedback, and an independent residual mortality which can be further partitioned if so desired. We put

$$M1_i = \frac{N_i}{\hat{R}_i} \; \frac{(dw_i/dt)_{max}}{w_i}$$

where $(dw_i/dt)_{max}$ is the highest possible growth rate at body weight w_i and $\hat{R}_i$ is a recruitment parameter (a number of fish) determining the highest possible recruitment which is achieved at a maximum feeding level and in the absence of all other mortality. With the growth equation used the relative growth rate is highest in small animals so that the longer the animal remains small (scarcity of food) the higher the mortality.

The main achievement of the Beverton and Holt model as the basis of a multispecies stock and yield model is the precise account of - and the dynamic relations between - food consumed and predation mortality as expressed by equating the instantaneous rate sums for all species in the system:

$$- \sum_i \left(\frac{dN_i}{dt}\right)_{predat} \cdot w_i = \sum \frac{dR_i}{dt} N_i \quad , \text{ or}$$

$$\sum_i M2_i w_i N_i = \sum_i f_i h_i w_i^{m} N_i$$