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Input Data for a Multispecies Yield Assessment Model of North Sea Fisheries

by

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Introduction

The model is a multispecies extension to the Beverton and Holt (1957) yield equation with food and density dependent growth. It was outlined in a previous ICES meetimg document (C.M.1973/H:2o) and described in more detail in an unpublished paper (Andersen, Lassen and Ursin, 1973) available on request to the authors. The description of a few changes in the model is deferred to a forthcoming revision of the manuscript whereas a brief summary in mathematical terms is attached below.

A substantial amount of data is necessary as input. Much of the relevant information apparently is not explicit in any publication but may be in the possession of experts in various countries whose cooperation is urgently needed. Colleagues working on subjects relevant to the model are requested to look carefully into the tables given below and react (preferably in writing) against data which they believe in error so that whereever possible facts can substitute guesses and qualified guesses can substitute the author's unqualified ones.

The data presented is being used in trial runs of an assessment program written in FORTRAN IV for an IBM 37o/165 situated at the Danish Technical University.

All data is supposed to refer to the situation on 1.April 196o. The immediate aim is of course to have this data set refined as much as possible. The next steps are (1) to provide similar data sets for the situation about 195o (before intensive fishing for industrial purposes began) and (2) for the most recent year possible. Moreover, (3) to provide fishing mortality coefficients for each species as a function of body size for all years since 195o (similar to Table 2 below). To a large extent this must be done by interpolation, but it is important that such interpolation is done by a well informed person to ensure that no available indication of trends is omitted.

Armed with data as specified the yield by year and age group of each species since 195o can be simulated and poorly estimated parameters adjusted until the simulated catches agree with observed catches - or until it is realized that the model must be rejected as not sufficiently realistic.

The sensitivity of the comparison of simulated and observed catches depends on the extent to which observed catches can be distributed on age groups: another job which may be rather hazardous if not attended to by experts.

Another check of the realism of the model can be made by means of the two extensive data sets for 196o (attached) and a quite recent year (not yet prepared). When the computer program takes the situation in 195o (data not yet prepared) as an exit and simulates the development using supplied year-by-year data for fishing mortality, then the simulated population numbers and biomasses for 196o and the recent year should compare well with the data sets for those years.

Only when and if the model passes such tests satisfactorily can it be considered ready for cautious use in current assessment work.

The Species Considered

The species list includes eleven fishes, three bottom invertebrates of different size, three plankton invertebrates of different size, phytoplankton (unspecified) in suspension, phytoplankton near the bottom or settled on it but not yet dead, and detritus near the bottom or settled on it. The bottom and plankton invertebrates have no names: they represent the entire biomass of invertebrates of their respective size classes. The eleven fish species are:

plaice	coalfish (saithe)
dab	cod
long rough dab	haddock
	whiting
mackerel	Norway pout
herring	
sandeel	

They represent 93 pct of total landings from the North Sea in 1956 and 91 pct in 197o. Dab and long rough dab are of no consequence to the fishery but represent considerable biomass. Among the nine much fished species Norway pout seems to have the smallest biomass. When dab and long rough dab are added to the nine the list probably contains the eleven species most abundant by weight in the North Sea. The biomass of all other species was disregarded as insignificant. Next to be included, had the list been longer, were sole and sprat, both interesting species, the sole because it fetches high prices and sprat because the stock seems to increase in recent years.

Computer time, however, is restrictive. The total number of categories accounted for in the program (counting each age group as one category) is 75 with the implication that the main computational job is the numerical solution of about 225 simultaneous differential equations. It is scarcely advisable to increase the number of categories. Should it be decided to include sole and sprat a corresponding number of age groups of other species might be excluded or some species (e.g., cod and coalfish, dab and long rough dab) might be pooled and treated as one with intermediate parameter values.

Input Data

The North Sea is defined as ICES region IV considered to have an area of 5 E11 m^2 (i.e., $5x1o^{11}$ m^2 = $5x1o^5$ km^2) and a volume of 5.5 E13 m^3.

Table 1 gives numbers and body weights and their product for each age group of each species as they are assumed to have been on 1.April 196o. The age is counted from the alleged birthday (see below). The data was collected by a crude search in available reports. Particularly the numbers of pre-recruits and their body size on 1.April were difficult to find and are mostly guessed. In the case of mackerel an arbitrary reduction of published stock size data was made because it is unlikely that the entire winter stock in the Northern North Sea is actually feeding in the North Sea and preyed upon there all the year round.

Table 2 tabulates fishing mortality coefficients for 196o as a function of body weight. It may be argued that in some cases age rather than weight is the important agent in determining fishing mortality. Most regulation measures, however, refer to body size one way or another. Changes in such regulations are easily introduced into tables such as Table 2. The program interpolates linearly in the tables. For body weights below the first entry the mortality is assumed zero. For weights above the last entry the mortality stated in the last entry is used. The actual number of entries for each species must ensure satisfactory representation of mortality changes with body size.

There are two mortality coefficients both dimensioned $years^{-1}$:F, the instantaneous coefficient of fishing mortality and D, the instantaneous coefficient of discard mortality. Discarded fish not surviving join the detritus compartment of the model.

The fishing and discard mortalities are supposed to cover all kinds of fishing effort including, e.g., the Waddensea shrimp fishery. Separate tables for each fishery should be prepared and manually squeezed into a common table before introduced into Table 2. If more convenient a subprogram could be written to do that.

The discard mortalities listed in Table 2 are mostly the author's unqualified guess. Most of them probably must be guessed anyway.

According to the plan a table like Table 2 should be prepared for each year since 195o to be stored on disc and read into core one at a time as the computer calculates yields and stocks for successive years.

Invertebrates are so cursorily treated in the program that the fishery for them was disregarded.

Table 3 states the spawning date, the age at first maturity and the egg size. The program is based on time units of one month. Spawning accordingly must occur when a new month begins. There is no hatching time in the model: the "eggs" start eating immediately. For winter spawners with a slow development that presents the problem whether the spawning date in the model should be the average day of spawning or of concluding the yolk sac stage.

On spawning a proportion of the spawning fish's tissue is transformed into eggs. In the program it is done by assuming that 14 pct of the biomass of the spawning age groups is spawned. The percentage is difficult to assess. Multiplying published egg sizes by published egg numbers sometimes gives incredibly large spawning losses probably, because eggs contain more water than the body of the fish. Of course it is only the female stock that produces eggs, but a spawning strain probably also causes weight losses in the male. The scattered literature on the topic seems to need a reviewer.

The age at first maturity is an integral number of years (or months, for the small invertebrates).

It would be simple to vary the proportion spawned by each age group so that a gradual onset of maturity could be simulated.

Table 4 gives the primary production at various dates in the course of the year. The program performs linear interpolation in the table. The dates are with one month's interval, but it may be desirable to use shorter intervals when the production rate changes rapidly. The second column of the table measures production as numbers per year of cells of weight 2E-9g each in the entire North Sea (region IV, 5 E11 m^2). In column three these figures are recalculated as grams carbon per m^2 per year, assuming .1g carbon per gram biomass. The bottom figures are the mean annual production calculated as the mean of the monthly values.

It is not the immediate intention to include a different table for each year. Should it however be possible to procure data indicating a trend since 195o, or to obtain information on years or months with unusual production rates it would be interesting to see if observed variations in year class strength of fishes could be simulated. As the program is arranged now it has no obvious means of simulating such changes.

There are other parameters in the model than those discussed above particularly such describing growth and feeding. The model, however, adopts a growth curve slightly different from the simple von Bertalanffy equation. This was necessary mainly because of the failure of the usual curve to describe satisfactorily the larval and prerecruit growth. Few other authors have used the present variety of the growth equation so that contributions to improvement of the parameter values can scarcely be expected. The listing of parameter values as used as present is therefore deferred to a later occasion.

Outline of the Mathematical Formulation

as described by Andersen, Lassen and Ursin (1973).

The Beverton and Holt simple theory of fishing is assumed known. For each species i these authors have three differential equations:

$$\frac{dw_i}{dt} = H_i w_i^{2/3} - k_i w_i \quad (1)$$

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

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

Include a fourth equation:

$$\frac{dR_i}{dt} = f_i h_i w_i^{2/3} \quad (4)$$

where R_i is food consumed by the species in question. Putting the rate of food consumption proportional to $w^{2/3}$ 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 is called the feeding level ($0 \leq f \leq 1$). The fraction v of food consumed ends up in the fish body, i.e., it equals the positive term of (1).

Thus,

$$\frac{dw_i}{dt} = v_i \frac{dR_i}{dt} - k_i w_i = v_i f_i h_i w_i^{2/3} - k w_i \qquad (1A)$$

so that $H = vfh$.

The feeding level is determined by the expression

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

where V is the water volume. $1/q_i$ is known in literature on primary production as the half saturation q_i is a coefficient of the rate of search for food constant. $V\varphi_i$ is the sum of biomass of all kinds of prey , each weighted by its availability G $(0 \leq G \leq 1)$ 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 group consumed by the predator i.

That deals with the necessary amendments to the growth sector of the Beverton and Holt model. In practice the negative term of (1) is written $kw^{5/6}$ in stead of kw, but that is not important in the present context.

The mortality sector as described by (2) also needs a small refinement. The natural mortality coefficient M of Beverton and Holt covers all sources of mortality except fishing mortality. In order to describe inter-specific relationships M must be partitioned into $M=M1+M2$ where $M2$ is the grazing, or predation, mortality:

$$\frac{dN}{dt} = -(F_i + M1_i + M2_i)\, N_i \qquad (2A)$$

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

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

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:

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

$$\sum_i M2_i w_i N_i = \sum_i f_i h_i w_i^{2/3} N_i$$

This is particularly useful when there is kept a complete account of phosphorus circulation.

Table 1. Assumed initial stock size on 1. April 196o.

	Age (years)	Numbers (millions)	Weight (g)	Biomass (thousands tons)
1 Plaice				
1	.167	4ooo	.1o	.4
2	1.167	4oo	8.o	3.2
3	2.167	3oo	38	11.4
4	3.167	26o	1oo	26.o
5	4.167	2oo	17o	34.o
6	5.167	14o	27o	37.8
7	6.167+	17o	4oo	68.o
Total biomass				18o.8
2 Dab				
8	.ooo	4.3E8	.ooo14	6o.2
9	1.ooo	1oooo	1.2	12.o
1o	2.ooo	41oo	17	69.7
11	3.ooo	27oo	32	86.4
12	4.ooo+	27oo	8o	216.o
Total biomass				444.3
3 Long rough dab				
13	.o83	22oo	.o1	.o22
14	1.o83	22oo	2.5	5.5
15	2.o83+	35oo	39	136.5
Total biomass				142.o22
4 Coalfish (Saithe)				
16	.o83	21o	.1	.o21
17	1.o83	11o	7o	7.7
18	2.o83	53	3oo	15.9
19	3.o83	27	74o	19.98
2o	4.o83+	27	14oo	37.8
Total biomass				81.4o1
5 Cod				
21	.o83	26o	.1	.o26
22	1.o83	84	7o	5.88
23	2.o83	43	6oo	25.8
24	3.o83	22	15oo	33.o
25	4.o83	11	27oo	29.7
26	5.o83	6	41oo	24.6
27	6.o83+	4	57oo	22.8
Total biomass				141.8o6
6 Haddoch				
28	.o83	36oo	.1	.36
29	1.o83	9oo	39	35.1
3o	2 o83	37o	137	5o.69
31	3.o83	14o	254	35.56
32	4.o83+	9o	49o	44.1o
Total biomass				165.81

	Age (years)	Numbers (millions)	Weight (g)	Biomass (thousands tons)
7 Whiting				
33	o.ooo	2.7E7	.ooo6	16.2
34	1.ooo	32oo	24	76.8
35	2.ooo	82o	86	7o.52
36	3.ooo	32o	139	44.48
37	4.ooo	13o	192	24.96
38	5.ooo+	87	35o	3o.45
Total biomass				263.41
8 Norway pout				
39	.167	1.oE5	.1	1o
4o	1.167	48oo	12	57.6
41	2.167+	22o	3o	6.6
Total biomass				74.2
9 Mackerel				
42	.833	2ooo	25	5o
43	1.833	15oo	125	187.5
44	2.833	13oo	245	318.5
45	3.833	1ooo	336	336
46	4.833+	3ooo	55o	165o
Total biomass				2542.o
1o Herring				
47	.583	81oo	1	8.1
48	1.583	72oo	32	23o.4
49	2.583	45oo	1oo	45o.o
5o	3.583	27oo	128	345.6
51	4.583+	45oo	175	787.5
Total biomass				1821.6
11 Sandeel				
52	.25o	48ooo	.4	19.2
53	1.25o	12ooo	4.3	51.6
54	2.25o	7ooo	11	77.o
55	3.25o	32oo	19	6o.8
56	4.25o+	29oo	3o	87.o
Total biomass				295.6
1-11, total biomass of fish				6153
12 Benthos species A				
57	.ooo	1.4E11	1E-5	14oo
58	1.ooo	2.5E7	8E-2	2ooo
59	2.ooo	5.oE6	5E-1	25oo
6o	3.ooo+	5.oE6	1E-o	5ooo
Total biomass				1o9oo
13 Benthos species B				
61	.ooo	3.2E11	1E-6	32o
62	.o83+	1.oE9	2E-3	2ooo
Total biomass				232o

	Age (years)	Numbers (millions)	Weight (g)	Biomass (thousands tons)
14 Benthos species C				
63	.000	1.6E12	1E 7	160
64	.083+	1.0E11	1E-5	1000
Total biomass				1160
12-14, total biomass of benthos				14380
15 Zooplankton species A				
65	.083	5.0E8	3.0E-5	15
66	1.083	1.0E7	1.5E-1	1500
67	2.083	1.0E6	3.0E-1	300
68	3.083+	1.0E5	4.5E-1	45
Total biomass				1860
16 Zooplankton species B				
69	.000	6.0E10	5.5E-6	330
70	.083+	1.2E9	1.8E-3	2160
Total biomass				2490
17 Zooplankton species C				
71	.000	8.7E11	2.7E-7	234.9
72	.083+	1.6E10	9.0E-5	1440.0
Total biomass				1674.9
15-17, total biomass of zooplankton				6025
12-17, " " " invertebrates				20405
1-17, " " " animals				26558
18 Algae, pelagic				
73	0+	6E16	2E-9	120000
19 Algae, demersal				
74	0+	1E16	2E-9	20000
18-19, total biomass of plants				140000
1-19, " " " and animals				166558
20 Detritus, demersal				
75	0+	1E16	2E-9	20000

Table 2. Fishing mortality coefficients (F) and discard mortality coefficients (D) as a function of body weight, in 196o (mostly guesses). On interpolation and extrapolation, see text.

	Body weight	F ($years^{-1}$)	D ($years^{-1}$)
1 Plaice			
	.7	o	o
	2.2	.3	o
	1o	.3	o
	2o	.1	o
	34	.o2	.1
	81	o	.2
	14o	1.o	.2
	18o	1.o	.1
	2oo	.43	.o5
	25o	.43	o
2 Dab			
	.3	o	o
	.7	.o3	o
	2	.o3	o
	2.5	.o1	o
	12	.o15	.2
	21	.o15	.3
	45	.o15	.3
	59	.o35	.37
3 Long rough dab			
	4	o	o
	6	.o2	o
	11	.o2	.2
4 Coalfish (saithe)			
	3oo	o	o
	54o	.45	o
5 Cod			
	4	o	o
	1o	.3	o
	2o	.34	o
	75	.3	.2
	24o	.19	.2
	52o	.65	.2
	65o	.72	o
6 Haddock			
	2	o	o
	8	.o2	o
	45	.o2	.2
	15o	.1	.2
	2oo	.75	.2
	3oo	.75	o

	Body weight	F (years^{-1})	D (years^{-1})
7 Whiting			
	.5	o	o
	1	.o3	o
	2	.11	o
	9	.11	o
	27	.o8	o
	55	.o8	.2
	13o	.o8	.2
	18o	.52	.2
	25o	.52	o
8 Norway pout			
	2	o	o
	1o	.7	o
9 Mackerel			
	15o	o	o
	2oo	.o3	o
1o Herring			
	5	o	o
	15	.o4	o
	7o	.22	o
	157	.68	o
	191	.47	o
	216	.28	o
	242	.23	o
11 Sandeel			
	1	o	o
	2	.25	o
	4	.25	o
	8	.45	o

Table 3. Spawning

		Date	Age at fish maturity	Egg size (mg)
1	Plaice	1. February	4 years	1.oo
2	Dab	1. April	2 "	.14
3	Long rough dab	1. March	2 "	6.oo
4	Coalfish (saithe)	1. March	4 "	.6o
5	Cod	1. March	4 "	.6o
6	Haddock	1. March	3 "	.6o
7	Whiting	1. April	3 "	.6o
8	Norway pout	1. February	2 "	.6o
9	Mackerel	1. June	3 "	2.oo
1o	Herring	1. September	4 "	.6o
11	Sandeel	1. January	2 "	.2o
12	Benthos sp. A	1. April	1 "	.o1
13	" " B	1. of each month	1 month	.oo1
14	" " C	1. of each month	1 "	.ooo1
15	Zooplankton sp A	1. March	1 year	.o3
16	" " B	1. of each month	1 month	.o55
17	" " C	1. of each month	1 "	.oo27

Table 4. Monthly rates of primary production 196o as used in the program.

Date	No. of cells per year	g C/m^2/year
15 January	3.oE22	12
15 February	2.8E23	112
15 March	1.1E24	44o
15 April	8.oE23	32o
15 May	5.1E23	2o4
15 June	1.8E23	72
15 July	1.8E23	72
15 August	1.1E23	44
15 September	4.5E23	18o
15 October	2.1E23	84
15 November	4.4E22	17.6
15 December	2.2E22	8.8
Mean	3.26E23	13o.53