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PHALANX ANALYSIS: AN EXTENSION OF JONES' LENGTH COHORT ANALYSIS TO MULTISPECIES COHORT ANALYSIS

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ABSTRACT

Phalanx analysis (multispecies length cohort analysis) is described. This method calculates fishing mortality and population numbers at length, given information on the growth and feeding characteristics and the catch length distributions from a multispecies fishery. The approach can also be adapted to provide a method for calculating the steady state yields which would result from a change in fishing patterns. It is thus a multispecies extension of Jones' length cohort analysis.

An example of the use of phalanx analysis is shown based on constructed data which represent the North Sea roundfish. This illustrates the results obtained and also indicates that the method might be used in consideration both of changes in overall size compositions resulting from changes in fishing patterns and of size dependent mortality rates.

INTRODUCTION

Multispecies fisheries models are apt to require large and complete data sets if they are to be used successfully. Models based on catch-at-age data are particularly demanding in this respect, which makes them difficult to use even for developed fisheries such as those in the North Sea, and virtually impossible to use for areas where catch-at-age data have not been routinely collected for the most numerous species for a number of years. For the fisheries of many areas a more realistic alternative to such a data set would be average catch composition by length, in which case extensions of Jones' length cohort analysis to a multispecies fishery are highly desirable. Jones (1974; 1976) shows how cohort analysis can be adapted to assess numbers at length data and how to invert this model to assess the effects of changes in mesh size and of fishing effort. The same approach can be used to convert Pope's (1979) multispecies age cohort analysis to a multispecies length cohort analysis. One method of extending length cohort analysis is described in this paper.

THEORY

Jones' length cohort analysis (Jones, 1974) is based on the extension of Pope's (1972) cohort analysis formula to variable time intervals. Assuming von Bertalanffy growth, Jones modifies Pope's annual cohort formula

$$N_t = C_t \exp(M/2) + N_{t+1} \exp(M) \tag{1}$$

to the form

$$N_1 = N_2\left\{\frac{L_\infty - L_1}{L_\infty - L_2}\right\}^{M/K} + C_{1/2}\left\{\frac{L_\infty - L_1}{L_\infty - L_2}\right\}^{M/2K} \tag{2}$$

where N_1 and N_2 are the numbers in the sea at length L_1 and L_2 respectively and $C_{1/2}$ is the catch numbers in the interval L_1-L_2. This enables catch at length data to be used instead of catch at age data in a cohort analysis. The drawback is that the method requires the data to apply to a steady state condition. In practice this is approximated to by averaging the catch at length data for a number of years. Thus only average results can be obtained. Nevertheless the method is useful as a quick summary of events which can be based on less years' data than a standard virtual population analysis (VPA).

Pope (1979) gives as the basic formula of multispecies cohort analysis

$$N_t = (C_t + D_t) \exp(M/2) + N_{t+1} \exp(M). \tag{3}$$

Thus it is perfectly possible to convert this to a length cohort form as

$$N_1 = (C_{1/2} + D_{1/2})\left\{\frac{L_\infty - L_1}{L_\infty - L_2}\right\}^{M/2K} + N_2\left\{\frac{L_\infty - L_1}{L_\infty - L_2}\right\}^{M/K} \tag{4}$$

where M now refers to the natural mortality not generated by the predation of fish included in the analysis. $D_{1/2}$ is the number of fish eaten by other fish included in the analysis between length L_1 and L_2. This can be straightforwardly calculated as in Pope (1979), but using length rather than age makes the calculation of ration size and food preference simpler. For example, food preference can be specified as the product of a species preference and a log normal prey size preference as suggested by Ursin (1973). Feeding rate can be expressed as a function of body size. For example, Dann (1973) suggests the formula

$$\phi_L = \frac{2 \times 0.00016}{0.06} \times L^2 \qquad (5)$$

for the daily ration (ϕ_L) of cod length L.

The proportion of the diet coming from species included in the analysis can be given as a sigmoidal relationship with length such as that given by Sparre (1979). Thus the length form of analysis considerably facilitates the computations. Using either approach the D's can be estimated by successive approximations as in Pope (1979). Details of the calculations are set out in the mathematical appendix. Since multispecies length cohort analysis is a somewhat clumsy title it is suggested that this technique be called 'phalanx analysis'.

Jones (1976) considers the effect of a mesh change or effort change on catch-at-length data using an approach based on Jones (1961). This approach is not possible with the phalanx analysis because a change in the coefficient of fishing mortality will lead to a change in that of natural mortality. The problem can however be solved by holding the numbers, in the smallest length group of each species, constant. The numbers at each successively greater length are then calculated using preliminary estimates of total mortality based on the new level of fishing mortality and the natural mortality obtained in the phalanx analysis. These population sizes are used to calculate predation levels which in turn are used to calculate better estimates of natural mortality due to predation. It is then possible to recalculate the population numbers at length using the improved estimates of total mortality which can be used to improve the predation estimates. This cycle of calculations is repeated until changes in the natural mortality estimates are less than some specified level. Details of calculations are shown in the mathematical appendix.

One virtue of this approach is that a stock/recruitment relationship could be easily incorporated in these calculations. This would modify the numbers in the smallest length group of each species in line with the biomass of fish of spawning size. This could be simply included in the iterations indicated above.

WORKED EXAMPLE

The absence of published tables of international catch-at-length data made it impossible in the short term to present a detailed analysis of the North Sea fisheries using phalanx analysis. An illustrative example has however been constructed based on the North Sea roundfish. Thus species A, B and C in the results are somewhat like cod, haddock and whiting. Table 1 shows the input values used for the various coefficients of growth, mortality and feeding. Tables 2, 3 and 4 show the results of the phalanx analysis for species A, B and C respectively. Reducing the fishing mortality by 50% on all species results in the changes in the predation levels. The effects of this are shown for species A in Table 5. By making a series of such changes yield curves can be constructed (see Figure 1) for the three species. In this case these are somewhat artificial because almost all growth is obtained at the expense of smaller fish sizes of the same three species since there are no smaller food species in this example. The yield curves thus tend to increase sharply with increasing fishing. The lack of a stock/recruitment relationship is also a serious defect in the model in its current form.

The length distribution obtained from the phalanx analysis is compared with the overall length distributions for the North Sea obtained from English groundfish surveys (Figure 2). The change in numbers with length can be seen to be rather similar in these two series. Whether or not this is more than a coincidence remains to be determined. It does however indicate that phalanx analysis could be used in a consideration of how overall length distributions may change with changes in exploitation patterns.

In the example the only preferences predators have for different species are based on weight differences. Consequently the predation mortality at length is much the same for the three species considered, as can be seen from Figure 3. This also indicates that the predation mortality declined exponentially with length in a very regular fashion. Similar mortalities at length based on a phalanx analysis of all important North Sea fish species would obviously shed considerable light on the relationship between natural mortality and growth.

DISCUSSION

The model presented of a multispecies length cohort model has essentially the same virtues and drawbacks as Jones' (1974) length cohort analysis. It is less demanding of data than the equivalent multispecies age cohort models. There would seem some prospect of using such a model on a tropical developing fishery where average catch length and growth parameters might be inferred but where annual catch-at-age data are not a practical possibility. It will also be worth developing the model for the North Sea fisheries where it can be contrasted with age models. Its main use, however, is likely to be in regions for which there are less data than is the case for the North Sea.

Since the method gives mortality components and population sizes by length it should be useful in interpreting the structures of numbers at size observed in the North Sea. The method should also be of value in obtaining insights into the relationship between growth parameters and natural mortality. Clearly, it is more important to gain insights into such problems of the workings of the marine ecosystem than to provide just another bookkeeping model of multispecies fisheries. It is therefore to be hoped that a full phalanx analysis of the North Sea will provide a stimulus for further simplifications in our models of the North Sea.

Developments of this model to consider the effects of seasonal recruitment and growth are clearly important. To assist in this work it would be very useful if working groups or national scientists could make the length distributions of catches available on a regular basis. Ideally, these would be presented by month or quarter rather than as annual distributions.

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MATHEMATICAL APPENDIX

The sequence of calculations performed in making a multispecies length cohort analysis is shown in flow chart A. The (supposed) consequences to species yield caused by altering fishing mortality rates result from the calculations shown in flow chart B. Flow chart B should be regarded as an extension of flow chart A where many of the basic variables are calculated.

In these flow charts the variables shown in Tables A1, A2 and A3 are used. In general, these are expressed in terms of the following: fish stock is designated by the index i or, in the case of a predator, by the index I; length interval is designated by the index l or, in the case of a predator, by the index L; all lengths of all species are regarded as potential predators; all but the greatest length of each species are regarded as potential prey; at present the fish of the greatest length group of each species are regarded as exempt from predation for the sake of simplicity; the largest lengths of each species are designated by the index $\hat{l}$ and the smallest by l_{min}.

Predation in the model is considered to consist only of predation by those length groups (L) of species (I) for which catch data are input. This source of mortality creates the M2(i,l) component of natural mortality of the prey species i of length L. The M1(i) component is that part of the natural mortality of stock i caused by predation by species external to the model or from other causes. At present it is set at an arbitrary low value of 0.1 for all lengths of each species.

Table 1 Stock specific coefficients

	Species A	Species B	Species C	Symbol in Appendix
L infinity	130.00	85.00	55.00	$L_\infty(i)$
M/K	1.00	0.80	0.80	M1(i)/K(i)
Natural M1	0.10	0.10	0.10	M1(i)
F/Z for L max	0.70	0.70	0.70	F/Z(i)
Wt/len A	0.000010	0.000009	0.000008	a(i)
Wt/len B	3.00	3.00	3.00	b(i)
Av. prey/pred	-4.60	-4.60	-4.60	$\mu(i)$
Sd. prey/pred	1.00	1.00	1.00	$\sigma(i)$
Ration coef.	0.000020	0.000000	0.000016	f(i)
Ration power	3.00	3.00	3.00	g(i)
Food ogive p	0.50	0.50	0.50	p(i)
Food ogive q	30.00	30.00	30.00	q(i)
Food ogive r	0.50	0.50	0.50	r(i)
Largest len.	120	81	50	
No. of len. S	23	24	40	
Length inc.	5	3	1	

Table 2 Results from phalanx analysis for Species A

LENGTH	POPULATION	CATCH	PREDATION	ZΔT	FΔT	M2ΔT	Z	F	M2	M1	ΔT	WT
10	663851.7	.0	265029.9	.567	.000	.524	1.331	.000	1.231	.100	.426	.020
15	376722.7	.0	78913.8	.286	.000	.241	.642	.000	.542	.100	.445	.056
20	283150.6	.0	35779.6	.185	.000	.139	.398	.000	.298	.100	.465	.118
25	235314.2	2167.0	16654.1	.134	.010	.076	.275	.020	155	.100	.488	.216
30	205737.9	21177.0	7204.8	.204	.114	.039	.398	.222	.076	.100	.513	.357
35	167786.7	30775.0	2775.6	.284	.211	.019	.525	.390	.035	.100	.541	.548
40	126299.7	33633.0	956.1	.388	322	.009	.679	.563	016	.100	.572	.798
45	85668.3	25392.0	303.6	.430	.365	.004	.710	.603	.007	.100	.606	1.115
50	55700.6	13574.0	97.9	.357	.290	.002	553	.450	.003	.100	.645	1.505
55	38981.6	8395.0	33.7	.322	.252	.001	.467	.366	.001	.100	.690	1.977
60	28239.9	5539.0	12.1	.302	.228	.000	.408	.307	.001	.100	.741	2.539
65	20873.7	3709.0	4.5	.285	.205	.000	.356	.256	.000	.100	.800	3.198
70	15700.2	2538.0	1.7	.272	.185	000	.313	.213	.000	.100	.870	3.963
75	11960.2	2076.0	.7	.296	.201	.000	.311	211	.000	.100	.953	4.841
80	8892.9	1624.0	.3	.319	214	.000	.303	.203	.000	.100	1.054	5.840
85	6462.7	1292.0	.1	.356	.238	.000	.302	.202	.000	.100	1.178	6.967
90	4526.4	999.0	.0	.403	269	.000	.302	.202	.000	.100	1.335	8.231
95	3026.1	1071.0	.0	.636	.482	.000	.413	312	.000	.100	1.542	9.639
100	1602.2	858.0	.0	1.066	.883	.000	.585	.485	000	.100	1.823	11.200
105	552.0	219.0	.0	.809	586	.000	.363	.263	.000	.100	2.231	12.920
110	245.7	141.0	.0	1.374	1.087	.000	.478	.378	.000	.100	2.877	14.808
115	62.2	49.0	.0	3.773	3.367	.000	.931	.831	.000	100	4.055	16.871
120	1.4	1.0	.0	.000	.000	.000	.000	.233	.000	.100		

Table 3 Results from phalanx analysis for Species B

LENGTH	POPULATION	CATCH	PREDATION	ZΔT	FΔT	M2ΔT	Z	F	M2	M1	ΔT	WT
12	3885583.5	.0	1205175.2	.423	.000	.389	1.259	.000	1.159	.100	.336	.022
15	2546269.5	.0	532326.7	.284	.000	.249	.811	.000	.711	.100	.350	.040
18	1916416.0	.0	299450.6	.220	.000	.183	.600	.000	.500	.100	.366	.067
21	1537888.0	.0	183074.0	.178	.000	.140	.464	.000	.364	.100	.384	.103
24	1287020.7	6917.0	114338.9	.152	.006	.105	.377	.016	.261	.100	.403	.149
27	1105459.7	97168.0	68483.9	.220	.104	.073	.518	.245	.173	.100	.425	.208
30	886955.5	171156.0	36795.9	.332	.236	.051	.740	.527	.113	.100	.449	.281
33	636368.6	200169.0	17039.6	.493	.410	.035	1.036	.863	.073	.100	.475	.370
36	388802.6	142053.0	6930.4	.567	.492	.024	1.121	.973	.047	.100	.505	.475
39	220646.7	99433.0	2516.7	.717	.647	.016	1.330	1.199	.030	.100	.540	.598
42	107687.2	40236.0	893.5	.577	.507	.011	.996	.877	.019	.100	.579	.741
45	60505.2	21510.0	347.7	.549	.479	.008	.880	.768	012	.100	.624	.905
48	34945.2	12935.0	136.1	.579	.506	.005	.856	.748	.008	.100	.676	1.092
51	19581.8	8836.0	49.2	.737	.660	.004	.997	.892	.005	.100	.739	1.302
54	9369.9	5217.0	14.8	.987	.903	.003	1.213	1.109	.003	.100	.814	1.539
57	3490.9	2007.0	3.8	1.054	.961	.002	1.162	1.060	.002	.100	.907	1.802
60	1216.9	465.0	1.1	.653	.549	.001	.638	.537	.001	.100	1.023	2.093
63	633.6	158.0	.5	.460	.342	.001	.392	.291	.001	.100	1.173	2.415
66	399.9	104.0	.2	.506	.368	.001	.368	.267	.001	.100	1.375	2.768
69	241.2	31.0	.1	.362	.195	.001	.218	118	000	100	1.661	3.154
72	167.9	19.0	.1	.401	.190	.001	.191	.091	.000	.100	2.099	3.574
75	112.4	26.0	.0	.681	.395	.000	.239	.138	.000	.100	2.853	4.029
78	56.9	9.0	.0	.795	.346	.001	178	.077	.000	.100	4.477	4.522
81	25.7	18.0	.0	.000	.000	.000	.000	233	.000	.100		

Table 4 Results from phalanx analysis for Species C

LENGTH	POPULATION	CATCH	PREDATION	ZΔT	FΔT	M2ΔT	Z	F	M2	M1	ΔT	WT
11	27770472.0	.0	8632000.0	.401	.000	.382	2.179	.000	2.079	.100	.184	.012
12	18600860.0	.0	4759038.0	.323	.000	.304	1.717	.000	1.617	100	.188	.016
13	13463034.0	.0	2882680.5	.268	.000	.249	1.392	.000	1.292	.100	.193	.020
14	10294690.0	.0	1884607.7	.230	.000	.210	1.162	.000	1.062	.100	.198	.024
15	8183042.0	.0	1309039.5	.202	.000	.182	.997	.000	.897	.100	.203	.030
16	6686751.0	.0	952918.7	.182	.000	.161	.875	.000	.775	.100	.208	.036
17	5575303.0	.0	718706.4	.167	.000	.145	.781	.000	.681	.100	.213	.043
18	4719803.0	.0	556484.9	.155	.000	.133	.706	.000	.606	.100	.219	.051
19	4043559.5	.0	439268.6	.145	.000	.122	.643	.000	.543	.100	.225	.059
20	3498227.5	.0	351674.4	.137	.000	.113	.589	.000	.489	.100	.232	.069
21	3051700.0	.0	284501.8	.129	.000	.105	.541	.000	.441	.100	.239	.080
22	2681649.5	.0	231976.9	.123	.000	.098	.499	.000	.399	.100	.246	.091
23	2371923.5	.0	190301.7	.117	.000	.091	.460	.000	.360	.100	.254	.104
24	2110461.0	1076.0	156828.7	.112	.001	.085	.427	.002	.324	.100	.262	.118
25	1887010.7	103078.0	126048.5	.166	.062	.076	.611	.230	.281	.100	.271	.133
26	1598806.7	221651.0	94072.3	.259	.162	.069	.924	.579	.246	.100	.281	.149
27	1233422.2	201647.0	65948.1	.286	.194	.063	.983	.666	.218	.100	.291	.166
28	926583.5	202715.0	44085.6	.354	.266	.058	1.174	.882	.192	.100	.302	.185
29	650069.1	144332.0	28386.4	.355	.271	.053	1.132	.863	.170	.100	.314	.205
30	455696.2	112365.0	17991.8	.386	.305	.049	1.182	.933	.149	.100	.327	.227
31	309741.6	93577.0	10810.4	.465	.386	.045	1.364	1.134	.131	.100	.340	.250
32	194644.1	50435.0	6418.1	.399	.323	.041	1.123	.907	.115	.100	.356	.275
33	130576.7	39989.0	3823.8	.467	.393	.038	1.256	1.055	.101	.100	.372	.301
34	81835.2	23576.0	2226.3	.439	.365	.035	1.125	.936	.088	.100	.390	.329
35	52757.4	14207.0	1334.2	.411	.338	.032	1.002	.825	.077	.100	.410	.358
36	34971.6	7613.0	840.2	.340	.267	.029	.785	.617	.068	.100	.433	.389
37	24903.1	7751.0	516.9	.475	.403	.027	1.039	.880	.059	.100	.457	.422
38	15484.6	3155.0	318.1	.324	.250	.025	.667	.515	.052	.100	.485	.457
39	11204.3	3693.0	195.2	.508	.434	.023	.985	.840	.044	.100	.516	.493
40	6739.2	2048.0	110.8	.472	.395	.021	.855	.716	.039	.100	.552	.531
41	4204.4	1356.0	63.4	.505	.426	.020	.852	.719	.034	.100	.593	.572
42	2536.3	528.0	38.5	.345	.262	.019	.538	.409	.030	.100	.640	.614
43	1796.9	441.0	25.0	.403	.315	.018	.579	.453	.026	.100	.696	.659
44	1201.0	432.0	14.5	.590	.497	.017	.773	.651	.022	.100	.762	.705
45	666.0	196.0	8.0	.495	.395	.016	.588	.468	.019	.100	.843	.754
46	405.9	99.0	4.9	.434	.324	.016	.461	.344	.017	.100	.942	.804
47	262.8	102.0	2.8	.689	.567	.015	.645	530	.014	100	1.068	.857
48	132.0	85.0	1.0	1.372	1.233	.015	1 112	1 000	.012	.100	1.233	913
49	33.5	13.0	.3	.756	.595	.016	.519	.408	.011	.100	1.459	.970
50	15.7	11.0	.0	.000	000	.000	000	233	.000	.100		

Table 5 Results from multispecies length yield change analysis for Species A (F on all lengths on all species = F_{cohort} x 0.5)

LENGTH	POPULATION	CATCH	PREDATION	Z∆T	F∆T	M2∆T	Z	F	M2	M1	∆T	WT
10	663851.7	.0	245529.1	.517	.000	.474	1.216	.000	1.113	.100	.426	.020
15	395702.1	.0	130799.0	.457	.000	.412	1.028	.000	.926	.100	.445	.056
20	250531.7	.0	70382.9	.386	.000	.339	.829	.000	.728	.100	.465	.118
25	170358.2	730.2	34116.5	.284	.005	.230	.582	.010	.472	.100	.488	.216
30	128222.6	6472.4	15623.1	.246	.057	.137	.479	.111	.268	.100	.513	.357
35	100273.2	9422.0	6793.9	.236	.105	.076	.436	.195	.141	.100	.541	.548
40	79217.6	11234.4	2814.2	.258	.161	.040	.452	.282	.071	.100	.572	.798
45	61175.1	9824.2	1123.8	.264	.183	.021	.436	.301	.034	.100	.606	1.115
50	46966.5	6117.5	453.2	.220	.145	.011	.342	.225	.017	.100	.645	1.505
55	37674.9	4306.9	188.9	.201	.126	.006	.291	.183	.008	.100	.690	1.977
60	30823.8	3194.1	80.5	.191	.114	.003	.257	.154	004	.100	.741	2.539
65	25469.6	2379.2	35.0	.184	.102	.002	.230	.128	.002	.100	.800	3.198
70	21193.1	1793.3	15.5	.180	.092	.001	.207	.106	.001	.100	.870	3.963
75	17696.9	1614.6	6.9	.196	.100	.000	.206	.105	.000	.100	.953	4.841
80	14543.9	1400.7	3.1	.213	.107	.000	.202	.101	.000	.100	1.054	5.840
85	11759.6	1247.5	1.4	.237	.119	.000	.201	.101	.000	.100	1.178	6.967
90	9277.5	1095.0	.6	.268	135	.000	.201	.101	.000	.100	1.335	8.231
95	7095.3	1411.8	.3	.395	.241	.000	.256	.156	.000	.100	1.542	9.639
100	4779.7	1570.5	.1	.624	.442	.000	.342	.242	.000	.100	1.823	11.200
105	2560.9	586.3	.0	.516	.293	.000	.231	.131	.000	.100	2.231	12.920
110	1528.1	563.9	.0	.831	.543	.000	.289	.189	.000	.100	2.877	14.808
115	665.6	470.0	.0	2.089	1.684	.000	.515	.415	.000	.100	4.055	16.871

CHANGE IN F = .50 CATCH WT. = 157706.22

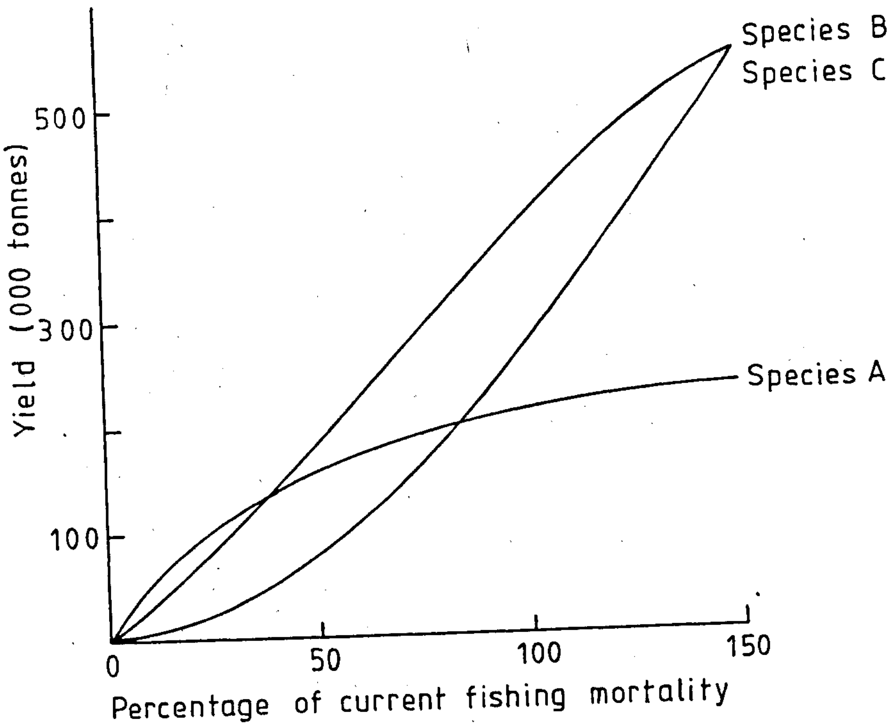


Figure 1 Yield curves for species A, B and C when all fishing mortalities are changed in the same proportion.

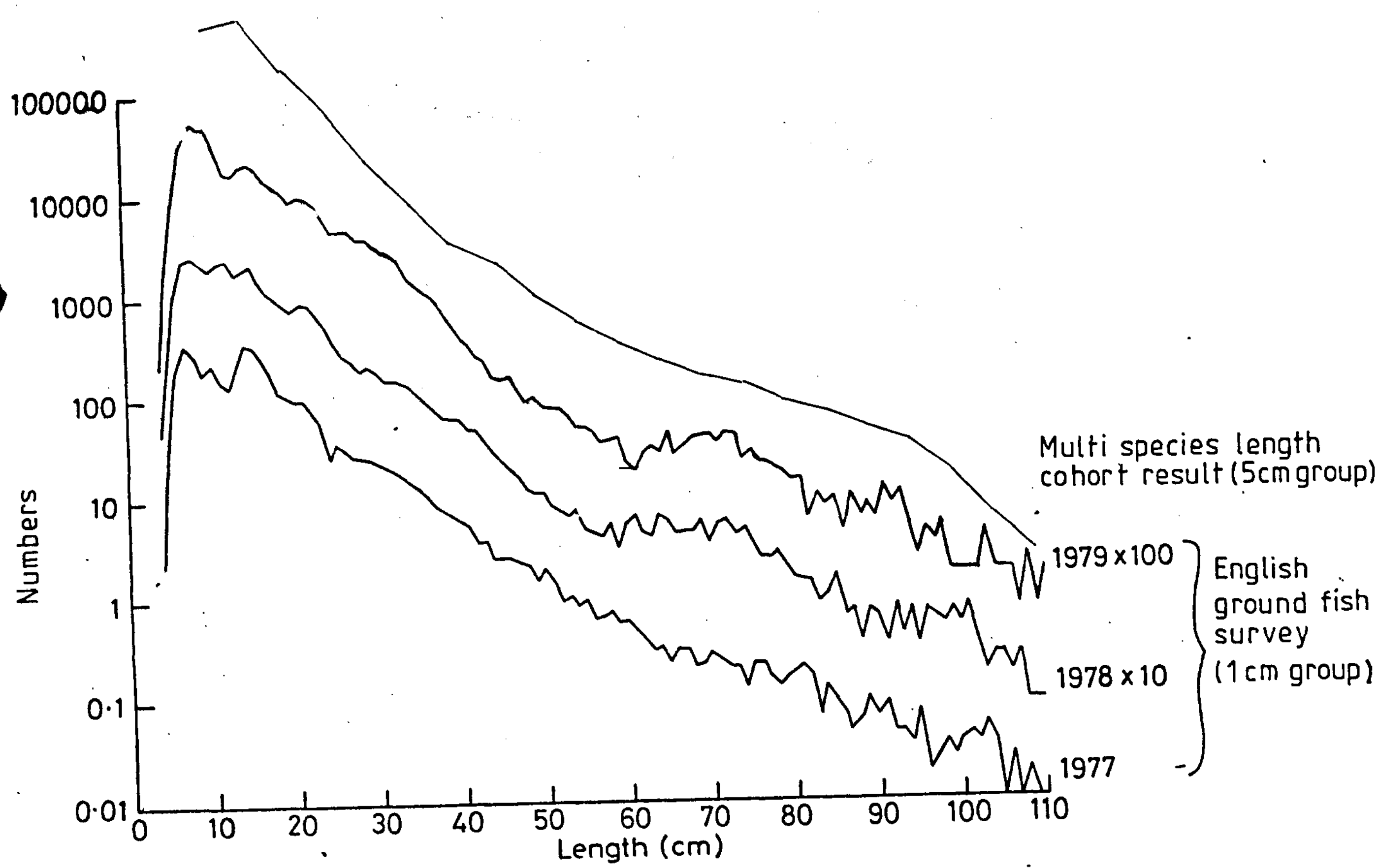


Figure 2 The total length distribution from phalanx analysis compared to those observed from groundfish surveys of the North Sea.

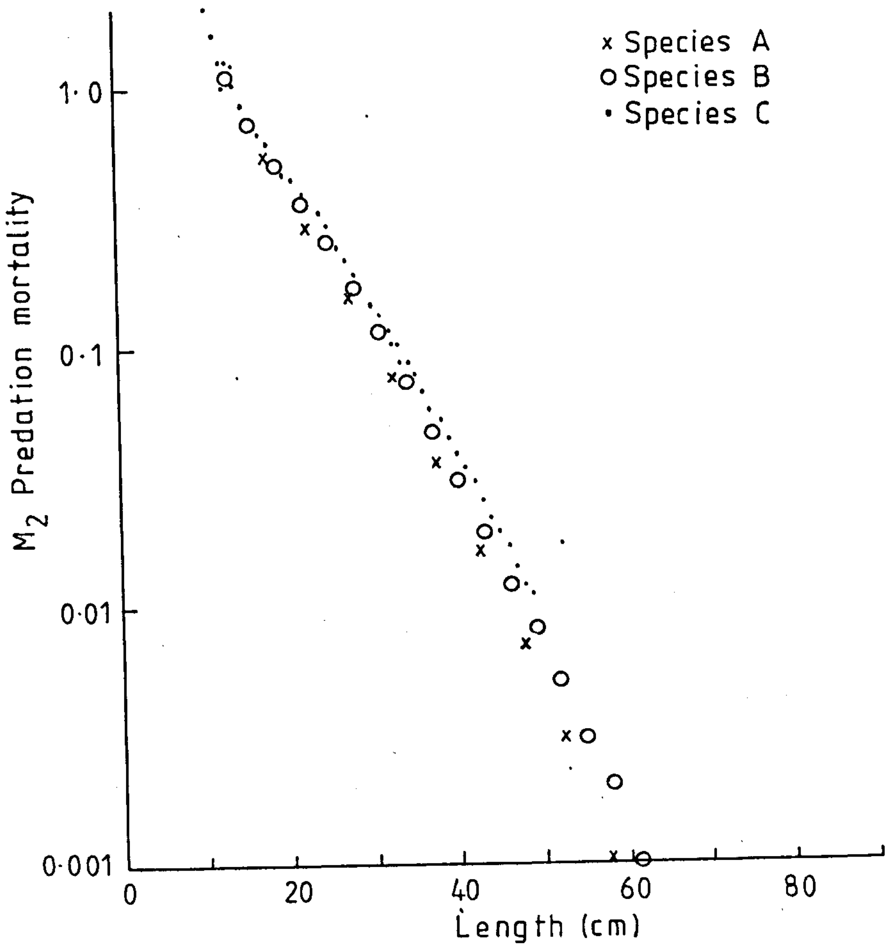


Figure 3 Phalanx analysis: predation mortality in the example as a function at length.

Table A1   Stock variables

The following stock variables are used for all lengths of each species (i) on predator (I). Together with catch-at-length data by species they form the basic inputs to the multispecies length cohort analysis.

Variable	Use	
$L_\infty(i)$	) Von Bertalanffy coefficients	
$K(i)$	) for stock i used to calculate $\Delta t(i,l)$	
$M1(i)$	Non-predation mortality of stock i	
$F/Z(i)$	F/Z ratio for largest length group of stock i	
$a(i)$	) Weight length relationship coefficients	
$b(i)$	) for stock i used to calculate $Wt(i,l)$	
$f(I)$	) Ration requirement	
$g(I)$	) coefficients for stock I)	used to
$p(I)$	) Proportion of ration)	calculate
$q(I)$	) taken as predation)	$R(I,L)$
$r(I)$	) coefficients of ogive for stock I)	
$\mu(I)$	) Food size preference coefficients)	
$\sigma(I)$	) for stock I)	used to calculate
$\alpha(i,I)$	General preference matrix)	$A(i,l,I,L)$
	of stock I for stock i)	

Table A2 Stock length variables

The following variables apply to the length interval l of stock i or in the case of predators to the length interval L of stock I

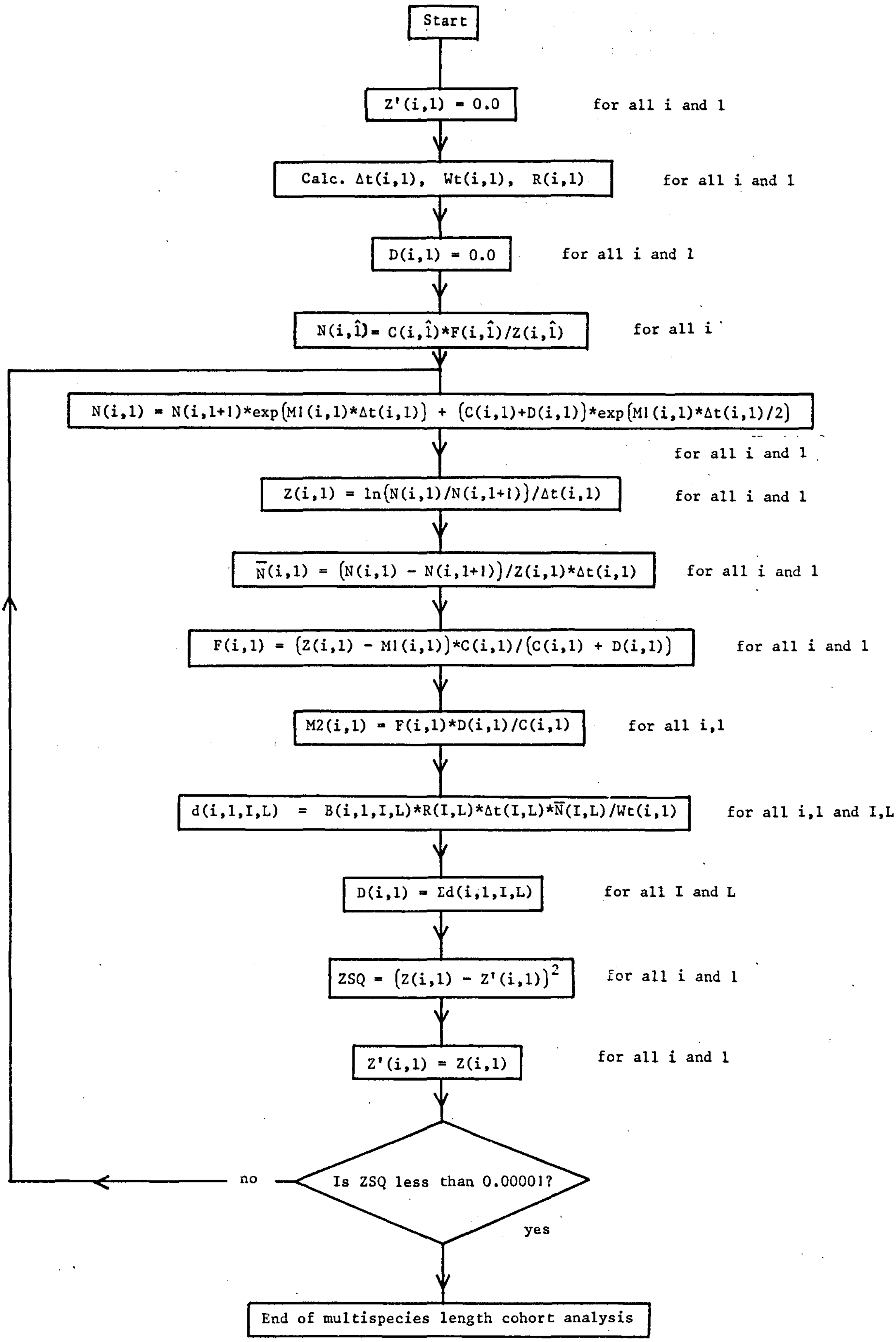
Variable	Use
N(i,l)	Population numbers at beginning of length interval
$\overline{N}$(i,l)	Average population numbers in the interval
C(i,l)	Catch numbers in the interval ($C_{1/2}$ in text)
D(i,l)	Predation numbers in the interval ($D_{1/2}$ in text)
Δt(i,l)	Time spent in the interval (see Jones, 1974)
F(i,l)	Fishing mortality rate in interval
F'(i,l)	New level of fishing mortality rate for yield assessment
M2(i,l)	Predation mortality in interval
Z(i,l)	Current total mortality in interval
Z'(i,l)	Total mortality in previous iteration
Lt(i,l)	Average length in interval
Wt(i,l)	Average weight in interval = $a(Lt)^b$
R(I,L)	Predators' ration from fish in analysis taken here as $f(Lt)^g * r/\left(1 + \exp\{-p(Lt-q)\}\right)$

Table A3 Predator/prey length variables

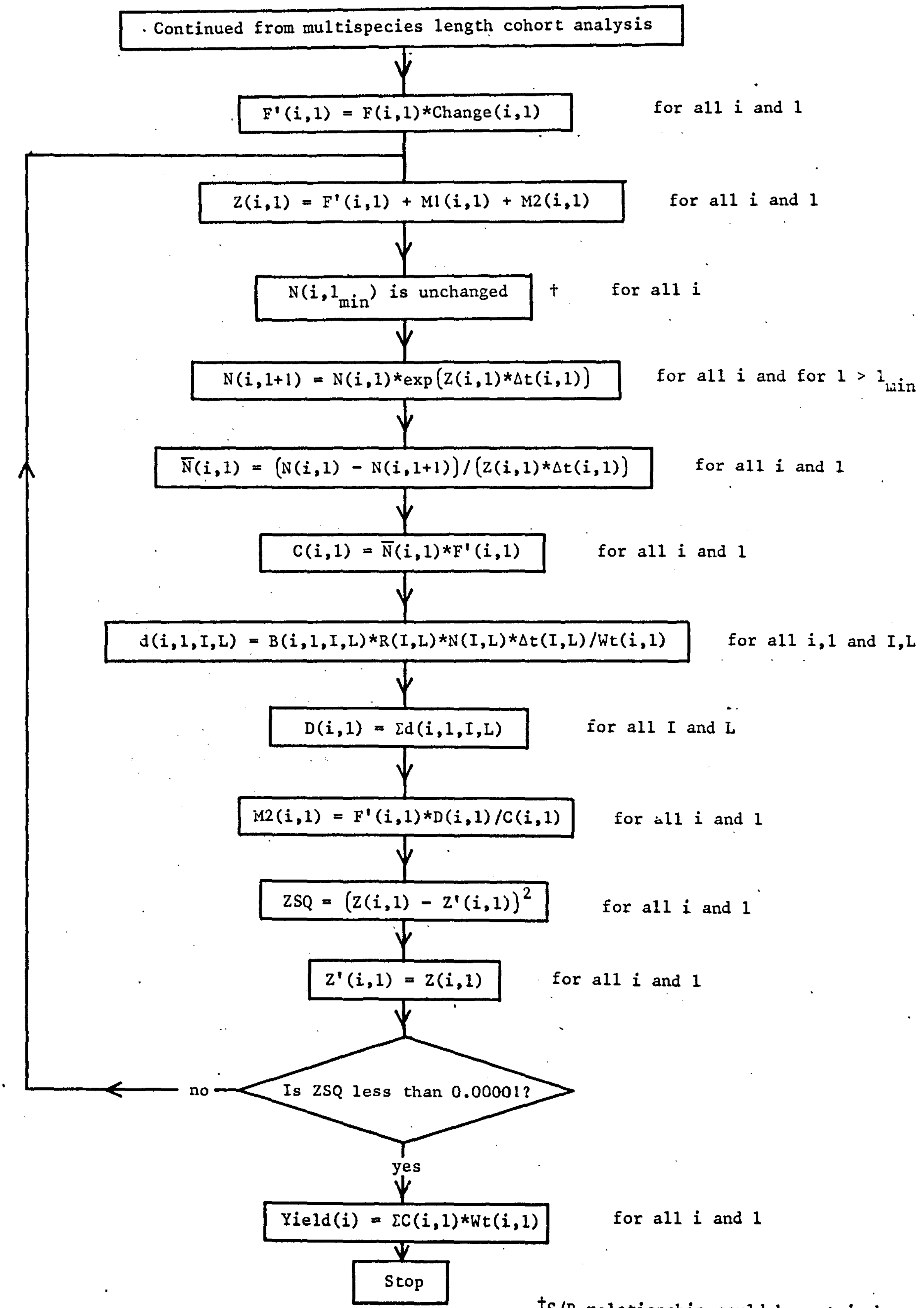
The following variables link predators of length interval L of stock I to their prey of length L of stock i

Variable	Use
A(i,l,I,L)	Preference of predators (I,L) for prey (i,l). This could be a matrix (see Pope, 1979) but here it is taken as $$\frac{\alpha(I)*}{\sqrt{2M}\ \sigma(I)} \exp - \tfrac{1}{2}\left(\frac{\ln\{Wt(i,l)/Wt(I,L)\}-\mu(I)}{\sigma(I)}\right)^2$$
B(i,l,I,L)	is diet proportion of predator (I,L) coming from prey (i,l) which is taken as $$\overline{N}(i,l)*\Delta t(i,l)*wt(i,l)*A(i,l,I,L)$$
d(i,l,I,L)	is number of prey (i,l) devoured by predator (I,L)

Flow chart A: multispecies length cohort analysis



Flow chart B: multispecies yield changes



†S/R relationship could be put in here.