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TRIAL RUNS WITH A MULTISPECIES VIRTUAL POPULATION ANALYSIS BASED ENTIRELY ON NUMBERS OF PREY ORGANISMS OBSERVED IN STOMACHS

by

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Abstract.

On theoretical grounds the Multispecies Virtual Population Analysis (MSVPA) model as presently applied within ICES appears to be unduly complicated. In stead of putting in consumption rates in terms of weight, weight fractions of various prey categories and average prey weights, the use of the associated rations in numbers and number fractions of prey would lead to model simplifications without changing the results. Using the same MSVPA program comparable runs were made with the standard input and a revised data set, in which rations and prey fractions for cod as predator were changed to reflect numbers consumed and with average prey weights set equal to 1. This change in input mimicks a number-based MSVPA without having to make program changes. The revision had to be restricted to cod, because for other species rations in numbers were not readily available. The results of this test indicate that for all practical purposes indeed the same answers are obtained, both in the Helgason/Gislason and in the Pope mode of the program. The small differences observed are probably entirely due to rounding errors, which tend to magnify in VPA algorithms.

Except for reasons of simplicity, there appears little virtue in pursuing any changes in the present program because of the compatibility of the results. However, the formulation of a MSVPA model based entirely on numbers eaten has considerable implications for future sampling programs, because weights no longer being demanded analyses of stomach contents could be completed at sea at the time of sampling. Since available analytical labour imposes a formidable bottleneck in stomach sampling programs, any possibility to reduce the workload should be seized. Thus an annual monitoring program for stomach contents in terms of numbers might be feasable whereas one in terms of weights is not. Also the delay between sampling time and availability of results could be sharply reduced.

Introduction.

During the 1984 meeting of the *ad hoc* Multispecies Assessment Working Group (ANONYMOUS, 1984) one of the outstanding problems concerned the bias caused by discrepancies between mean weights of prey age groups in the sea and the mean weights of these prey categories in stomachs of different predator categories. The difference between these two parameters is a direct consequence of the size selection of predators. Essentially, the problem arised directly from the formulation of the model, which considers predation in terms of weights whereas the predation mortalities must be expressed in numbers. At the time of the meeting a 'fiddling factor' was introduced to make the necessary corrections, but from a theoretical point of view the procedure was not satisfactory. During the 1985 meeting of the group (ANONYMOUS, 1986) the adjustment problem was unanimously resolved. Without questioning the appropriateness of the solution reached, it was felt that the model had become unnecessarily complicated, the reason being that numbers consumed can be directly derived from the input data. Thus there appeared no need to go through elaborate procedures within the model when a simple change in input could effectively yield the same result.

This contribution discusses the mathematical coherence between MSVPA based entirely on numbers of organisms consumed and the standard MSVPA based on weights. Subsequently, an actual test was performed on the results of the two types of models using real data.

Thanks are due to Per Sparre for providing me with copies of his MSVPA program and of the data file and to Willem Dekker for his help in getting the program running on our computer system.

Formulation of predation mortality in MSVPA.

The original formulation of the predation mortality (M2) in MSVPA by SPARRE (1984) reads:

$$M2(y,a)= \frac{1}{N(y,a) \cdot w(a)} \cdot \sum_{b} N(y,b) \cdot RW(b) \cdot \frac{sw(b,a) \cdot N(y,a) \cdot w(a)}{\sum_{i} sw(b,i) \cdot N(y,i) \cdot w(i)} \qquad [1]$$

N represents the average number of fish in the sea and w the corresponding average weight; RW is the weight ration consumed and sw the suitability as referring to available biomass of food. The index y is used for years, a and i for prey and b for predators. For convenience I have combined species and age group identifiers to a single index.

Equation [1] simply says that the predation mortality is the consumption in weight (CONW) of all predators times the weight fraction (fw) of the prey considered divided by the mean biomass (B) of the prey:

$$M2W(y,a)= \frac{1}{B(y,a)} \cdot \sum_{b} CONW(y,b) \cdot fw(b,a) \qquad [2]$$

Because predation is clearly expressed in terms of biomass losses, the resulting predation mortality is also in terms of biomass as indicated by the symbol M2W.

Since it was found that as a direct consequence of the size preference of the predators the average weight of prey by age group in the stomachs may deviate considerably from the mean weight in the population, it follows that setting predation mortality in numbers (M2N) equal to M2W would result in considerable bias.

During the meeting of the ad hoc working group in 1984 the 'fiddling factor' introduced was a replacement of mean weights in the sea (w) by mean weights in the stomach (wst) in the fraction term of equation [1]. This had very little effect, because [1] would still reduce to [2] and predation mortalities would remain in terms of biomass. Also it could be argued that any change in the weights used in this term will be largely compensated by corresponding adjustments in the suitability indices and not in the estimated numbers in the population. Altogether, the correction procedure appeared to be rather trivial.

The predation mortality in numbers caused by any particular predator can be related to the corresponding mortality in weights by including a correction term for the mean weight in the sea and the mean weight in the stomach of this predator:

$$M2N(y,b,a) = M2W(y,b,a) \cdot [w(a)/wst(b,a)] \qquad [4]$$

Including this correction term in [1] yields:

$$M2N(y,a) = \frac{1}{N(y,a)} \cdot \sum_{b} N(y,b) \cdot \frac{RW(b)}{wst(b,a)} \cdot \frac{sw(b,a) \cdot N(y,a) \cdot wst(a)}{\sum_{i} sw(b,i) \cdot N(y,i) \cdot wst(i)} \qquad [5]$$

This model has now been accepted for standard MSVPA runs by the working group (ANONYMOUS, 1986). Although in the fraction term the weights in the sea were also replaced by weights in the stomachs (wst), this appears to be mathematically trivial because of the scaling procedures. In my opinion it would seem more appropriate to keep the weights in the sea here, because suitability is essentially a composite ecological parameter, which should take into account size preference.

However, it would seem that this model is unduly complicated because there is a strict relationship between consumption in terms of weight, consumption in numbers and average prey weights. Clearly, rations in weights (RW) and numbers (RN) are related by

$$RW(b) = RN(b) \cdot \overline{wst}(b) \qquad [6]$$

and fractions in numbers (fn) to fractions in weights (fw) by

$$fn(y,b,a) = fw(y,b,a) \cdot [\ \overline{wst}(a)/wst(b,a)\ ] \qquad [7]$$

where $\overline{wst}$ represents the average prey weight over all prey.

Substituting [6] in [5] yields exactly the term for the fraction in numbers according to [7] so that [5] reduces to:

$$M2N(y,a) = \frac{1}{N(y,a)} \cdot \sum_{b} N(y,b) \cdot RN(b) \cdot fn(y,b,a) \qquad [8]$$

Since the fraction in numbers may be written in terms of suitabilities in exactly the same way as fractions in weights:

$$fn(y,b,a) = \frac{sn(b,a) \cdot N(y,a)}{\sum_i sn(b,i) \cdot N(y,i)} \qquad [9]$$

equation [8] may also be written as

$$M2N(y,a) = \frac{1}{N(y,a)} \cdot \sum_b N(y,b) \cdot RN(b) \cdot \frac{sn(b,a) \cdot N(y,a)}{\sum_i sn(b,i) \cdot N(y,i)} \qquad [10]$$

This equation is thus mathematically entirely equivalent to [6], but does not include any weight terms and therefore gets around all problems originally encountered.

Test runs with MSVPA based on numbers.

Methods.

Extensive trials to get the MSVPA program running on a PDP11/44 (512 KB) failed, but on a recently installed MICROVAX 2! (9MB) it ran without major difficulties. Since time did not permit major revisions to the program, we choose to mimick a number-based MSVPA using the standard program by making appropriate changes in the input file. This could be easily achieved by dividing the weights of each prey age group consumed by each predator age group by the corresponding average prey weight and setting all prey weights equal to 1. Thus whereever prey weights were used in the program effectively a nul-action was performed. In addition the rations in weights were replaced by rations in numbers. However, because the latter data were only readily available for cod, only for this predator species the input data were altered. The rest was kept unchanged. It should be noted that only the results for the MSVPA proper gave sensible results, because all the auxiliary subroutines for specific output need realistic prey weights.

No adjustments were made to the quantity of 'other food', which is presented as a single input value for all species. Earlier experience had shown that in the Helgason/Gislason mode of the program the effect of changing this value is limited as long as it is beyond a certain minimum value.

Trial runs were made with the standard and the altered input file in both the Helgason/Gislason and the Pope mode of the program.

Results.

Table 1 shows the total biomasses of exploitable species obtained in the four runs. In 1981, which represents the reference year for which the suitability indices are tuned to yield the observed prey fractions in stomachs, the difference in the Helgason/Gislason mode is only 0.1%. For other years differences may go up to ±2% without any particular trend. In the Pope mode the results are even more similar.

As an example of more detailed results fishing mortalities, stock numbers, predation mortalities and predation in numbers are given for cod for the Helgason/Gislason runs in tables 2a and b. This stock has been chosen because predation of cod is largely depending on predation by cod. Other species would show the combined effect of a large number of predator species, while only cod predation was treated in terms of numbers. Thus if there is any effect of the change in input, this should show up most markedly in the cod itself. Comparable tables for the Pope mode of the program are not presented, because they were equally similar.

Again the difference in 1981 between the two runs is only marginal. Slightly larger differences appear in other years, but the same trends and the same levels of predation mortality are apparent in both versions. The conclusion seems justified that for all practical purposes the same answers are obtained, whether or not predation is given in weights or in numbers.

Discussion.

Our main concern has been whether or not the number-based MSVPA gives comparable results to the standard MSVPA. Although from a theoretical point of view it should, this was not entirely certain, because of the treatment of other food, which in general remains a rather untractable parameter. The comparison of the actual results indicates that in the Helgason/Gislason and the Pope mode the two models indeed give the same answers in accordance with theoretical expectance. The reason why the results are not exactly the same up to the last digital point must be sought in rounding errors, which tend to magnify in VPA type of algorithms.

Strictly, there would seem a difference in underlying assumptions of the two models. The standard MSVPA assumes that weight rations consumed are constant, whereas the new model assumes number of prey consumed to be constant from year to year. However, because the standard MSVPA has to make the additional assumption that prey weights remain constant in order to allow for the correction to the predation mortality, implicitly this boils down to accepting a constant ration in numbers.

In table 3 a listing is given of observed weights and numbers of prey per stomach of cod and the corresponding prey weights by quarter in 1980, 1981 and 1982 in the southern North Sea (Roundfish area 6). and means, standard deviations and coefficients of variation were calculated for each of the three factors. These results do in fact indicate that the assumption of a constant number of prey consumed is at least not worse than any of the others.

Because the two models appear to be mathematically compatible, it would seem trivial to argue about preference for any of them particularly. Except that the number based version is simpler and requests less input, it does not produce any better results. And if biomasses consumed by various predators are required, one would be anyhow obliged to put in prey weights in order to calculate these. However, there is one important other aspect. The standard MSVPA requires that stomach samples are preserved for subsequent analysis in the laboratory to do the necessary weighing and particularly this procedure makes stomach analysis so time consuming. If one really only needs numbers of prey per size class per stomach from the MSVPA point of view, the logistics of stomach sampling programs could be completely revised, because it would not seem particularly difficult to sort freshly collected stomachs at sea for numbers of prey organisms. Therefore, whereas an annually repeated monitoring program for stomach contents in the present set up is not feasible, the introduction of the number based model might resolve the bottleneck imposed by analytical labour required.

References.

ANONYMOUS, 1984. Report of the ad hoc Multispecies Assessment Working Group, Copenhagen, 18-22 november 1985. ICES C.M. 1984/Assess:20.

ANONYMOUS, 1986. Report of the ad hoc Multispecies Assessment Working Group, Copenhagen, 13-19 november 1985. ICES C.M. 1986/Assess:9.

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Table 1
Total biomass of exploited fish stocks by year in four MSVPA runs.

YEAR	Helgason/Gislason mode Standard	Helgason/Gislason mode Number-based	Pope mode Standard	Pope mode Number-based
1974	10965869.	11097836.	10095303.	10081849.
1975	9372476.	9560601.	8657828.	8745197.
1976	8250980.	8303029.	7791550.	7789815.
1977	7581797.	7505974.	7023793.	7006943.
1978	6915171.	7014615.	6533293.	6551781.
1979	7032251.	7195117.	6546439.	6611464.
1980	7261610.	7466536.	6892913.	7104406.
1981	6292158.	6285618.	6221683.	6182063.
1982	6771952.	6810105.	6450457.	6474230.
1983	7127587.	7183917.	6821086.	6884736.
1984	7808454.	7906093.	7529718.	7670169.

Table 2a
Results of standard MSVPA for cod in Helgason/Gislason mode.

FISHING MORTALITY

AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.091	0.154	0.063	0.241	0.127	0.208	0.167	0.186	0.265	0.244	0.198
2	0.870	0.798	1.025	0.902	1.119	0.900	0.935	1.107	1.037	1.190	1.272
3	0.753	0.819	0.878	0.741	0.983	0.956	0.954	1.046	1.285	1.190	1.234
4	0.710	0.668	0.799	0.582	0.808	0.545	0.736	0.749	0.762	0.870	0.806
5	0.706	0.793	0.619	0.569	0.960	0.729	0.569	0.702	0.749	0.795	0.799
6	0.727	0.668	0.917	0.462	0.745	0.542	0.607	0.655	0.837	0.765	0.789
7	0.640	0.803	0.833	0.561	0.756	0.653	0.739	0.727	0.683	0.609	0.749
8	0.711	0.518	0.569	0.566	0.890	0.536	0.719	0.640	0.689	0.677	0.718
9	1.024	0.912	0.428	0.680	0.850	0.812	0.722	0.683	0.681	0.542	0.760
10	0.630	0.722	0.866	0.353	1.418	0.515	0.807	0.895	0.507	0.353	0.803
11	0.750	0.748	0.748	0.750	0.749	0.799	0.798	0.799	0.800	0.800	0.798

STOCK NUMBERS

AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
0	4131859.	2961483.	10790969.	7411942.	6419231.	8345256.	5114096.	7645576.	3555409.	5468764.	2130638.
1	287617.	377597.	179941.	706418.	410205.	409753.	861049.	329534.	523300.	236697.	559520.
2	123562.	108949.	175803.	88953.	289267.	172814.	164362.	348528.	107891.	199074.	89646.
3	22738.	33849.	34729.	45549.	25760.	66387.	50295.	45896.	78972.	26189.	41505.
4	32009.	8376.	11898.	11542.	17361.	7695.	20406.	15433.	12799.	17398.	6336.
5	9493.	12889.	3516.	4380.	5278.	6336.	3653.	8000.	5974.	4893.	5966.
6	1948.	3838.	4777.	1551.	2030.	1655.	2504.	1693.	3246.	2312.	1808.
7	965.	771.	1611.	1563.	800.	789.	788.	1117.	720.	1150.	881.
8	802.	417.	283.	573.	730.	308.	336.	308.	442.	298.	512.
9	543.	323.	203.	131.	267.	246.	147.	134.	133.	182.	124.
10	175.	160.	106.	108.	54.	93.	89.	59.	56.	55.	87.
11	370.	104.	69.	49.	91.	42.	49.	40.	44.	37.	44.
TOTAL STOCK BIOMASS ON 1. JANUARY	468811.	430771.	471118.	528591.	570636.	534494.	639790.	637830.	520464.	440090.	410882.

PREDATION MORTALITY

AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
0	2.193	2.601	2.527	2.695	2.552	2.072	2.542	2.482	2.509	2.080	2.985
1	0.680	0.410	0.442	0.452	0.537	0.506	0.538	0.731	0.502	0.527	0.312
2	0.225	0.146	0.126	0.137	0.153	0.134	0.141	0.178	0.179	0.178	0.112
3	0.045	0.026	0.024	0.024	0.026	0.023	0.027	0.031	0.028	0.029	0.017
4+	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

NUMBER OF PREDATION DEATHS

AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
0	3349328.	2508239.	9077905.	6331775.	5411407.	6663019.	4316541.	6410983.	2970031.	4346460.	1843209.
1	130218.	118606.	60469.	239194.	160558.	152389.	332376.	161264.	192105.	89409.	139985.
2	20890.	12583.	17282.	9875.	32889.	17337.	17628.	44682.	13962.	26736.	7726.
3	732.	616.	540.	767.	405.	973.	838.	889.	1230.	479.	425.
4+	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

Table 2b
Results of number-based MSVPA for cod in Helgason/Gislason mode.

FISHING MORTALITY

AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.090	0.155	0.064	0.244	0.128	0.209	0.165	0.190	0.269	0.246	0.197
2	0.871	0.795	1.024	0.902	1.121	0.899	0.931	1.107	1.039	1.192	1.271
3	0.753	0.818	0.878	0.740	0.982	0.956	0.953	1.046	1.284	1.190	1.234
4	0.710	0.668	0.799	0.582	0.808	0.545	0.736	0.749	0.762	0.870	0.806
5	0.706	0.793	0.619	0.569	0.960	0.729	0.569	0.702	0.749	0.795	0.799
6	0.727	0.668	0.917	0.462	0.745	0.542	0.607	0.655	0.837	0.765	0.789
7	0.640	0.803	0.833	0.561	0.756	0.653	0.739	0.727	0.683	0.609	0.749
8	0.711	0.518	0.569	0.566	0.890	0.536	0.719	0.640	0.688	0.677	0.718
9	1.024	0.912	0.428	0.680	0.850	0.812	0.722	0.683	0.681	0.542	0.760
10	0.630	0.722	0.866	0.353	1.418	0.515	0.807	0.895	0.507	0.353	0.803
11	0.750	0.748	0.748	0.750	0.749	0.799	0.798	0.799	0.800	0.780	0.798

STOCK NUMBERS

AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
0	4828572.	3500954.	11983912.	8638173.	7588544.	10555603.	6285630.	7638816.	3773778.	6131448.	2328900.
1	303174.	403479.	183711.	722802.	421620.	423731.	954538.	326891.	529552.	238541.	591514.
2	120675.	107563.	174417.	87298.	283976.	171030.	163424.	348530.	105404.	194647.	88570.
3	22773.	33890.	34729.	45564.	25751.	66392.	50422.	45901.	78963.	26185.	41537.
4	32009.	8376.	11898.	11542.	17361.	7695.	20406.	15433.	12799.	17398.	6336.
5	9493.	12889.	3516.	4380.	5278.	6336.	3653.	8000.	5974.	4893.	5966.
6	1948.	3838.	4777.	1551.	2030.	1655.	2504.	1693.	3246.	2312.	1808.
7	965.	771.	1611.	1563.	800.	789.	788.	1117.	720.	1150.	881.
8	802.	417.	283.	573.	730.	308.	336.	308.	442.	298.	512.
9	543.	323.	203.	131.	267.	246.	147.	134.	133.	182.	124.
10	175.	160.	106.	108.	54.	93.	89.	59.	56.	55.	87.
11	370.	104.	69.	49.	91.	42.	49.	40.	44.	37.	44.
TOTAL STOCK BIOMASS ON 1. JANUARY	478367.	442972.	483154.	544569.	581822.	559478.	679066.	636979.	522670.	443989.	421719.

PREDATION MORTALITY

AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
0	2.282	2.748	2.609	2.820	2.686	2.204	2.757	2.469	2.561	2.139	3.074
1	0.747	0.484	0.480	0.490	0.574	0.544	0.643	0.742	0.532	0.545	0.370
2	0.199	0.135	0.118	0.119	0.133	0.123	0.139	0.178	0.154	0.153	0.102
3	0.048	0.029	0.024	0.025	0.026	0.024	0.032	0.031	0.029	0.029	0.019
4+	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

NUMBER OF PREDATION DEATHS

AGE	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
0	3958155.	3001427.	10154022.	7448906.	6472043.	8584472.	5403602.	6397188.	3171570.	4915437.	2028082.
1	146245.	144288.	65893.	260283.	173284.	166451.	419714.	161635.	202559.	92214.	169982.
2	17993.	11174.	15892.	8256.	27688.	15419.	16635.	44695.	11521.	22364.	6691.
3	764.	651.	539.	778.	395.	975.	953.	893.	1218.	475.	457.
4+	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

Table 3

Mean weights of stomach contents, mean numbers of prey organisms and mean prey weights of cod sampled in different years (1980-1982) and quarters in the southern North Sea (Roundfish area 6) and associated coefficients of variation (CV).

Age group	W/Stomach		N/Stomach		Prey weight	
	Mean	CV	Mean	CV	Mean	CV
0	0.6	0.56	2.7	0.43	0.27	0.61
1	3.8	0.70	4.3	0.29	0.82	0.47
2	18.6	0.37	5.8	0.24	3.26	0.24
3	58.3	0.49	7.6	0.34	7.63	0.42
4	79.6	0.28	8.0	0.20	9.96	0.19
5	84.0	0.11	8.4	0.26	10.26	0.15
6+	141.0	0.14	9.7	0.32	15.24	0.23
Average		0.38		0.30		0.33