HM2 (HERRING MODEL 2). A SINGLE SPECIES COMPUTER MODEL OF THE NORWEGIAN SPRING SPAWNING HERRING STOCK

by

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ABSTRACT

HM2 represents an intermediate, experimental stage of a model that is being developed with the double purpose of being used as an independent single species model for the Norwegian Spring Spawning Herring and of being integrated into the Multispecies Model for the Barents sea (MULTSPEC). The paper describes its development history, and the presently used algorithms for maturation, recruitment, and growth are described and discussed, as well as its input and output options. A brief outline is given of the plans for further development of the model.

INTRODUCTION

The herring model HM2 has part of its origin in a FORTRAN programme written in 1972 by Carl Christian Hauge of the Christian Michelsens Institute, Bergen, under guidance from Johannes Hamre of the Institute of Marine Research, Bergen, in order to simulate population dynamics in an exploited stock (Hauge, 1972). The programme was later modified by Knut Hestenes of the Institute of Marine Research and Johannes Hamre , in order to simulate the Norwegian Spring Spawning Herring Stock. That programme was called PN157H, and introduced algorithms for density dependent growth and recruitment that are also included in HM2.

The concept in the two programmes has also been used as the biological part of of a bioeconomical analysis of the Norwegian Spring Spawning Herring, carried out by Sigfus Kristmannsson of the Institute of Fishery Technology Research in Tromsø , Norway, with assistance from Johannes Hamre.

HM2 is written in Pascal and does basically the same job as PN157H, although the user interface is more flexible. Given the same start-parameters, the two programmes will give the same results.

The purpose of writing HM2 was to get a well documented basis for the further development of a single species herring model that both could function well on its own and could be easily integrated into the Multispecies Model for the Barents Sea (Tjelmeland and Bogstad, 1989). The first step in this process was a model named HM1, which is documented in a Work Note (Dommasnes, 1986). HM2 represents a further development of HM1.

At its present stage of development, HM2 will be useful for simulating the reactions of the Norwegian Spring Spawning Herring stock to different fishing patterns. It will also be used to try out various algorithms for growth, maturation, and recruitment.

The programme HM2 and its documentation (Dommasnes, A. 1988) has been made available to scientists at the Institute of Marine Research, in order to allow them to test it out and influence its further development.

Because one of the aims in writing HM2 is to develop a programme that can be integrated in MULTSPEC, it has an internal structure which is similar to that used by the capelin part of MULTSPEC. This makes HM2 considerably larger and more elaborate - and slower - than is really necessary to produce the output given by this version.

ALGORITHMS

HM2 is, basically, a Beverton and Holt model (Beverton and Holt, 1957) which starts in January with numbers for each yearclass supplied by the user, and updates the numbers one month at a time, using information about mortality which is also supplied by the user.

Growth

Growth in length is determined by density alone. This is done by referring to two stock situations - Stock situation 1 and Stock situation 2, each characterized by mean length in each age group and total stock biomass. When the programme starts, Stock situation 1 is represented by the year 1950 when the total stock was 15 million tonnes, and Stock situation 2 by the year 1970 when the total stock was 1 million tonnes. The programme will, however, replace one of these years with the year the program starts. Which year is replaced, depends on whether the stock biomass in the start year is closest to 1950 or 1970. Using an iteration procedure, a set of mean lengths on 1 January for the current year is calculated that depends on the size of the stock at that time. Growth in the current year for each age is the difference between the mean length for that age and the mean length for the next age. The growth period is July - October for 0-group herring and June - October for older herring.

Maturation and spawning stock

Maturation is dependent on length alone, and is determined in January. A sigmoid function determines the proportion of each length group that matures. The function presently used is:

MATNUM = NUM / (1 + exp((LM50-ML) * LN(BASE)))

MATNUM	is the number of maturing herring in the length group.
NUM	is the total number of herring in the length group.
ML	is the mean length in the length group.
BASE	is the base in the logarithmic expression.
LM50	is the length where 50% of the herring is maturing.

In the present model BASE=9.0 and LM50=31.2. This gives a maturation curve as shown in Fig. 1.

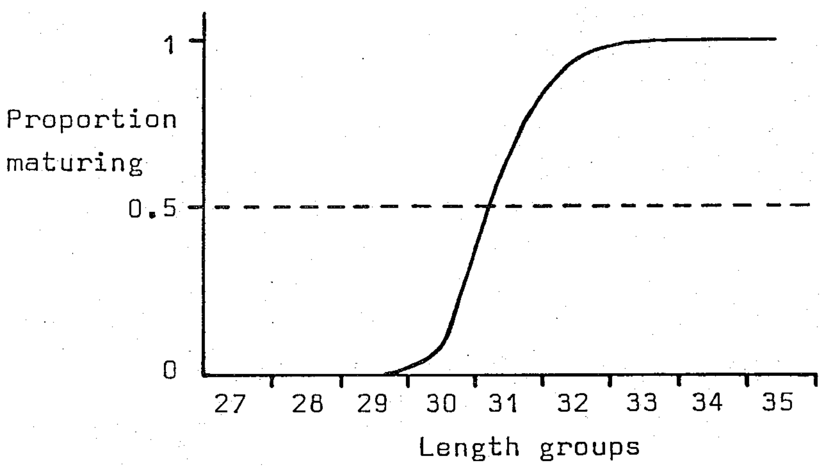

Figure 1. Maturation according to the algorithms used in model HM2 (Base=9.0, LM50=31.2).

Recruitment

Spawning takes place in March. The resulting number of larvae is calculated from the biomass of the spawning stock in January.

The larvae are assumed to join the main stock in June. Between March and June no mortality is applied to the larvae, meaning that earlier mortality is taken care of by the recruitment function.

Two basic recruitment functions are available to calculate the number of larvae that results from a given parent stock. They can be described in the following way:

Function 1:
RECRUITS = 31.0 * (1 - exp(exp(-1.75) - exp(0.5*(PARSTOCK-3.5))))

PARSTOCK is the spawning stock biomass in million tonnes, and RECRUITS is the number of recruits, with the dimension 10E9.

Function 2 is more complicated, and internally in the programme it consists of two functions:

Function 2A:
RECRUITS = PARSTOCK / (0.05*PARSTOCK+0.09)

Function 2B:
RECRUITS = 10*PARSTOCK

The curves for the different recruitment functions are shown in Fig. 2.

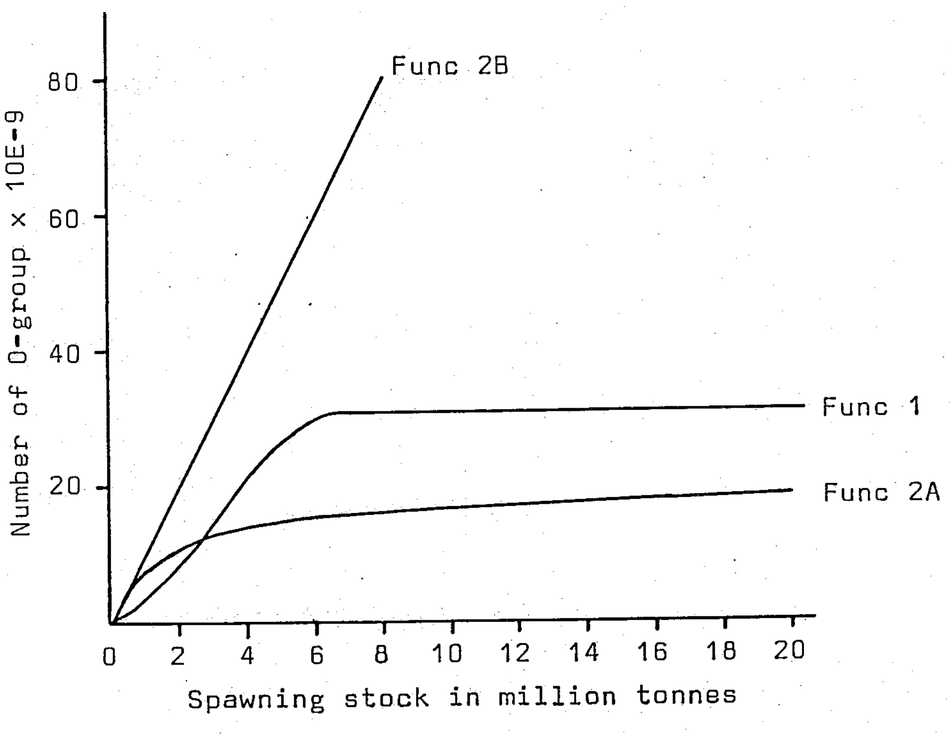

Figure 2. Recruitment according to the algotithms used in model HM2 without "stochastic recruitment".

Function 1 represents a curve that increases asymptotically towards 31.0*10E9 recruits.

Function 2A represents a curve that increases more slowly than Function 1, asymptotically, towards a value of 20*10E9 recruits.

Function 2B represents a direct linear relationship between parent stock biomass and number of recruits.

If "Function 2" has been selected, then Function 2A and Function 2B are used in the following way:

If the recruitment is not stochastic
and the year=1991 or 1999 or ....(period of 8 years)
then use function 2B else use function 2A

The years 1991, 1999,..... represent "boon years" with very good recruitment as described by Function 2B. In between, there are periods of rather poor recruitment, as described by Function 2A.

In addition to the choice of recruitment functions, the user can select "stochastic recruitment", which means that the number of larvae calculated is multiplied by a "success-factor" in order to simulate the highly variable relationship that is observed in nature between parent stocks and number of recruits. The success-factor is randomly selected from a table of 28 possible numbers as given in Table 1, and represents the ratio between the observed and the predicted number of larvae in the periods 1950 - 69 and 1973 - 80. The data are partly based on Dragesund, Hamre and Ulltang (1980), but also unpublished information has been used.

Function 2A is never used if stochastic recruitment has been selected.

INPUT

The user can select a set of parameters through a system of menus. The parameters can be stored for later use. When the programme is started the user must either give a file name from which to read start data, or let the programme generate a fixed set of start data. When the user has finished entering data, the programme writes a report of the start data to a file.

The following parameters can be changed by the user:

condition factors (length dependent)

natural mortality
fishing mortality/catch per year
distribution of catch on months through the year
recruitment to fishery (length dependent)

numbers and mean lengths in each age group
(at the start of the program)

recruitment function (choice of two)
stochastic recruitment (yes or no)

choice of two output reports (comprehensive or condensed)
number of years to run the model
number of times to run the model
(if stochastic recruitment has been selected)

file names
(for startdata, report on startparameters, and results)

OUTPUT

Two types of output reports are possible: one rather comprehensive report and one condensed version.

The comprehensive report gives the following information:

mean lengths and numbers for each age group for each month
biomass for the total stock and the spawning stock for each month

catch in numbers of each age group for each month
weight of total catch in each month
mean weight of the herring caught each month
fishing mortality each month for the herring that is fully recruited

The condensed report is intended for use when the programme is repeated many times to see the possible effect of stochastic recruitment, and gives the following information:

success-factor, spawning stock, and catch for each run
mean and standard deviation of the same parameters for all the runs

An example of the kind of tables given in the comprehensive report and the condensed report is given in Tables 2 and 3, respectively.

DISCUSSION

The algorithm used for density-dependent growth is rather primitive, and it only takes into account the biomass of the stock in the total area of distribution. Factors like geographical distribution, temperature, and availability of food in the present year and previous years are not taken into account. These factors may be as important as the total stock biomass, or even more important. In particular, local variations in density, temperature, and availability of food may lead to quite different growth patterns for different components of the stock. In order to make the model more realistic, a new growth algorithm must be developed that takes into account the effects of temperature and food availability as well as density - or allows the user to compensate for these effects in the input menus. New versions of the program, which allow for the division of the stock into different areas, can make the simulation more realistic.

In the present version of the model maturation, weight, and recruitment to the fishery are all length dependent. Thus, too high mean lengths will give too early maturation, too high spawning stock and too high total biomass, and the yearclasses will enter the fishery at a too early age. Too low mean lengths will have the opposite effect. A good algorithm for growth is therefore essential for good simulation. In addition, a number of other weaknesses in the model may be masked by a poor growth algorithm.

The algorithm for maturation is of the same kind as the one used by MULTSPEC for capelin (Tjelmeland and Bogstad, 1989). The constants in the algorithm may need adjustment, but this can best be done when a better growth algorithm has been worked out.

The algorithms used for recruitment are not well documented at present. In addition, the optional "stochastic" recruitment is highly speculative. It is necessary to go carefully through the historical material that is available in order to substantiate the relationships that are expressed in the model - or adjust the recruitment algorithms.

Experience with the model shows that it is necessary to be able to adjust the model to known start situations, and it may be necessary to add menus that allow the user to control growth, maturation, and recruitment.

A new version of this model is under development. It will run under the UNIX operating system, and will include the division of the stock into a number of areas, and migration between the areas. Natural mortality will be made length dependent, and it will be possible to use a different fishing mortality for each year. An effort will be made to improve algorithms for growth, maturity, and recruitment - possibly by using more traditional and straightforward solutions than those in the present model.

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Table 1. Spawning stock, observed number of recruits, predicted number of recruits, and ratio between observed and predicted number of recruits, using recruitment functions 1 and 2 (Predicted 1 and Success 1, Predicted 2 and Success 2, respectively) for 28 years in the period 1950-1980. Note that the program has been in mode STOCHASTIC during the calculation, so that for recruitment function 2 only FUNC2A has been used.

Recruitment function 1: R = 31.0 * (1 - exp(exp(-1.75) - exp(0.5 * ((P/1000) -3.5))

Recruitment function 2: R = P / (0.05*P + 90)

R = number of 0-group * 10E-9 in June
P = spawning stock in thousand tonnes

Spawning stock in thousand tonnes
Number of larvae actually observed * 10E-9
Number of larvae predicted by recruitment function * 10E-9
Success of spawning (observed number/predicted number)

Year:	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963
S.stock:	9400	9100	8800	7100	7600	8800	8900	10000	8500	7500	5500	4100	3300	2500
Observed:	97.4	26.1	27.9	21.0	16.9	9.2	11.1	9.7	13.7	75.0	47.5	18.3	7.2	26.3
Predicted 1:	31.0	31.0	31.0	30.9	31.0	31.0	31.0	31.0	31.0	31.0	28.6	21.4	16.1	10.9
Predicted 2:	16.8	16.7	16.6	16.0	16.2	16.6	16.6	16.9	16.5	16.1	15.1	13.9	12.9	11.6
Success 1:	3.1	0.8	0.9	0.7	0.5	0.3	0.4	0.3	0.4	2.4	1.7	0.9	0.4	2.4
Success 2:	5.8	1.6	1.7	1.3	1.0	0.6	0.7	0.6	0.8	4.6	3.2	1.3	0.6	2.3

Year:	1964	1965	1966	1967	1968	1969	1973	1974	1975	1976	1977	1978	1979	1980
S.stock:	3400	3700	2800	1400	280	90	110	90	80	120	240	290	330	380
Observed:	17.3	3.6	17.3	1.2	2.6	2.0	1.2	0.7	0.2	0.7	0.5	0.5	0.7	0.2
Predicted 1:	16.8	18.8	12.8	5.0	0.8	0.2	0.3	0.2	0.2	0.3	0.7	0.8	1.0	1.1
Predicted 2:	13.1	13.5	12.2	8.7	2.7	1.0	1.2	1.0	0.9	1.2	2.4	2.8	3.1	3.5
Success 1:	1.0	0.2	1.4	0.3	3.3	8.1	4.0	2.8	0.9	2.1	0.7	0.6	0.7	0.2
Success 2:	1.3	0.3	1.4	0.1	1.0	2.1	1.0	0.7	0.2	0.6	0.2	0.2	0.2	0.1

Table 2. Example of a comprehensive report from HM2.

RESULTS

Year 1988

Mean lengths for age groups

Age	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	-	-	-	-	-	5.0	6.8	8.5	10.3	12.0	12.0	12.0
1	12.0	12.0	12.0	12.0	12.0	14.1	16.2	18.4	20.5	22.6	22.6	22.6
2	22.6	22.6	22.5	22.5	22.5	23.7	24.9	26.2	27.4	28.6	28.5	28.5
3	28.7	28.7	28.6	28.5	28.5	29.0	29.6	30.1	30.6	31.1	31.0	31.0
4	31.3	31.3	31.2	31.2	31.2	31.5	31.8	32.2	32.5	32.8	32.8	32.8
5	33.0	33.0	32.9	32.9	32.9	33.2	33.4	33.7	33.9	34.2	34.1	34.1
6	34.2	34.2	34.2	34.2	34.2	34.4	34.6	34.8	35.0	35.2	35.2	35.2
7	35.2	35.2	35.2	35.2	35.2	35.4	35.5	35.7	35.8	36.0	36.0	36.0
8	36.0	36.0	36.0	36.0	36.0	36.1	36.3	36.5	36.6	36.8	36.8	36.8
9	36.8	36.8	36.8	36.8	36.8	36.9	37.0	37.2	37.3	37.4	37.4	37.4
10	37.4	37.4	37.4	37.4	37.4	37.5	37.6	37.7	37.8	37.9	37.9	37.9
11	37.9	37.9	37.9	37.9	37.9	38.0	38.0	38.1	38.2	38.2	38.2	38.2
12	38.2	38.2	38.2	38.2	38.2	38.3	38.3	38.3	38.4	38.4	38.4	38.4
13	38.4	38.4	38.4	38.4	38.4	38.5	38.5	38.5	38.5	38.6	38.6	38.6
14	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.6	38.7	38.7	38.7	38.7
15	38.7	38.7	38.7	38.7	38.7	38.7	38.7	38.7	38.7	38.7	38.7	38.7

Stock
Numbers in millions of individuals
Weight and spawning stock in thousand tonnes

Age	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	0	0	0	0	0	262	259	256	254	251	248	246
1	262	259	256	254	251	248	246	243	240	237	232	229
2	143	141	137	132	131	130	128	127	125	120	114	113
3	267	264	242	222	219	217	214	212	210	198	186	184
4	150	148	133	118	117	116	115	113	112	105	98	97
5	6997	6922	6128	5426	5368	5310	5253	5196	5140	4798	4477	4429
6	18	18	16	14	14	14	13	13	13	12	11	11
7	10	10	9	8	8	8	7	7	7	7	6	6
8	15	15	13	12	11	11	11	11	11	10	9	9
9	28	28	24	22	21	21	21	21	20	19	18	18
10	23	23	20	18	17	17	17	17	17	16	15	14
11	44	44	38	34	33	33	33	32	32	30	28	28
12	41	41	36	32	31	31	30	30	30	28	26	26
13	1	1	1	1	1	1	1	1	1	1	1	1
14	21	21	18	16	16	16	16	15	15	14	13	13
15	31	31	27	24	24	23	23	23	23	21	20	19
Sum:	8051	7964	7098	6331	6262	6457	6387	6318	6250	5865	5502	5443
Weight:	2931.5	2930.4	2394.0	1932.3	1925.1	2247.9	2396.5	2530.8	2617.8	2457.8	2233.7	2130.8
Spawn:	2875.7	2875.7	2875.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Catch
Numbers in millions of individuals
Weight in thousand tonnes
Mean weight in grammes
Instantaneous fishing mortality per month for the fully recruited yearclasses

Age	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	1	2	0	0
2	0	3	3	0	0	0	0	0	4	5	0	0
3	0	20	18	0	0	0	0	0	10	10	0	0
4	0	14	13	0	0	0	0	0	6	6	0	0
5	0	723	639	0	0	0	0	0	289	270	0	0
6	0	2	2	0	0	0	0	0	1	1	0	0
7	0	1	1	0	0	0	0	0	0	0	0	0
8	0	2	1	0	0	0	0	0	1	1	0	0
9	0	3	3	0	0	0	0	0	1	1	0	0
10	0	2	2	0	0	0	0	0	1	1	0	0
11	0	5	4	0	0	0	0	0	2	2	0	0
12	0	4	4	0	0	0	0	0	2	2	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	2	2	0	0	0	0	0	1	1	0	0
15	0	3	3	0	0	0	0	0	1	1	0	0
Sum:	0	785	695	0	0	0	0	0	319	302	0	0
Weight:	0.0	308.3	250.8	0.0	0.0	0.0	0.0	0.0	146.1	137.4	0.0	0.0
M.wght:	-	392.7	361.1	-	-	-	-	-	457.6	455.8	-	-
F.mort:	0.00	0.12	0.12	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.00	0.00

Table 3. Example of a condensed report from HM2.

RESULTS
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Success = observed/predicted number of larvae
Catch = catch during the year in thousand tonnes
Sstock = spawning stock in March in thousand tonnes
Tstock = total stock in December in thousand tonnes
SumCT = catch during the year + total stock in December

Run	1988			1989			1990			Catch	Tstock	SumCT
no.	Success	Catch	Sstock	Success	Catch	Sstock	Success	Catch	Sstock	1988-90	1990	1990
1	1.6	843	2876	0.2	605	2041	0.2	436	1448	1884	1260	1696
2	0.2	843	2876	1.0	605	2041	0.6	450	1448	1898	2130	2580
3	0.2	843	2876	1.6	605	2041	0.1	459	1448	1907	2555	3014
4	0.6	843	2876	0.7	605	2041	3.2	445	1448	1893	2159	2604
5	0.6	843	2876	4.6	605	2041	1.3	507	1448	1955	5578	6085
6	1.7	843	2876	3.2	605	2041	0.7	484	1448	1932	4117	4601
7	0.2	843	2876	0.7	605	2041	0.1	444	1448	1892	1708	2153
8	1.0	843	2876	0.6	605	2041	2.3	443	1448	1891	1895	2337
9	1.0	843	2876	0.3	605	2041	1.7	437	1448	1885	1529	1966
10	5.8	843	2876	1.3	605	2041	1.3	455	1448	1903	2487	2942
11	1.3	843	2876	0.2	605	2041	0.2	436	1448	1884	1264	1700
12	0.7	843	2876	1.4	605	2041	0.2	457	1448	1905	2440	2897
13	2.3	843	2876	5.8	605	2041	2.1	523	1448	1971	6724	7247
14	0.7	843	2876	0.3	605	2041	5.8	437	1448	1885	2045	2482
15	0.2	843	2876	1.7	605	2041	0.2	461	1448	1909	2682	3143
16	0.6	843	2876	0.6	605	2041	5.8	443	1448	1891	2338	2780
17	0.7	843	2876	0.7	605	2041	0.2	444	1448	1892	1730	2174
18	0.1	843	2876	0.1	605	2041	0.3	434	1448	1882	1154	1587
19	2.1	843	2876	1.7	605	2041	0.2	461	1448	1909	2682	3143
20	4.6	843	2876	0.2	605	2041	0.3	436	1448	1884	1302	1738
Mean:	1.3	843	2876	1.3	605	2041	1.3	455	1448			
St.dev.:	1.5	0	0	1.5	0	0	1.8	24	0			

Run	1991			1992			1993			Catch	Tstock	SumCT
no.	Success	Catch	Sstock	Success	Catch	Sstock	Success	Catch	Sstock	1991-93	1993	1993
1	1.7	340	1024	0.3	334	904	2.3	487	892	1161	2955	3442
2	0.7	498	1021	1.4	730	1629	1.3	843	2266	2071	4181	5024
3	1.3	577	1019	1.0	865	1919	1.3	933	2677	2375	4502	5435
4	0.6	477	1022	0.8	923	1348	4.6	1452	2491	2852	6425	7877
5	1.3	999	1007	2.3	1916	1788	5.8	2204	6293	5119	10186	12390
6	1.4	814	1013	0.6	1462	2084	1.0	1633	4740	3909	6394	8027
7	1.7	427	1022	0.7	519	1369	0.6	636	1462	1582	3511	4147
8	0.3	439	1022	1.3	762	1245	1.7	1141	2344	2342	4962	6103
9	1.3	377	1023	1.4	580	977	2.1	966	1921	1923	5072	6038
10	1.4	553	1019	0.1	932	1756	0.2	1217	2799	2701	4807	6024
11	1.3	340	1024	0.1	335	904	1.0	454	922	1130	2419	2874
12	0.6	556	1019	0.6	822	1853	0.6	838	2557	2216	3247	4085
13	1.4	1123	1003	0.2	2218	1519	3.2	2621	7062	5962	10174	12796
14	2.3	430	1023	1.7	1033	937	0.6	2022	1822	3485	9911	11932
15	0.3	597	1018	1.4	915	1958	1.6	914	2891	2426	4127	5041
16	0.6	482	1022	0.2	1124	1177	1.3	2003	2091	3609	8112	10115
17	1.7	429	1022	1.0	543	1365	0.6	693	1583	1666	3918	4612
18	0.2	318	1024	1.0	277	769	3.2	298	810	893	1793	2090
19	0.2	597	1018	3.2	914	1958	0.2	932	2892	2443	5380	6312
20	0.6	347	1024	0.6	348	938	0.8	401	1017	1096	1944	2345
Mean:	1.0	536	1019	1.0	878	1420	1.7	1134	2577			
St.dev.:	0.6	216	6	0.8	508	428	1.5	655	1680			

Concentrate of data, for all years and all runs
Success = observed/predicted number of larvae
Catch = catch during the year in thousand tonnes
Sstock = spawning stock in March in thousand tonnes
Tstock = total stock in December in thousand tonnes
SumCT = catch during the year + total stock in December
Means = means over years and runs
St.dev. = standard deviations over years and runs

	Success	Catch	Sstock	Tstock	SumCT
Mean:	1.3	742	1897	3362	4104
St.dev.:	1.3	415	961	2352	2681