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STOCK PREDICTION USING STOCHASTIC RECRUITMENT NUMBERS WITH EMPIRICAL STOCK-DEPENDENT DISTRIBUTION

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ABSTRACT

Probability distributions for the recruitment, conditional on the spawning stock biomass (SSB) were made using a kernel method. Predictions were made with recruitments according to these distributions for 10 years, using a Monte Carlo procedure, assuming constant weight at age, maturity ogive and natural mortality.

Examples are given for 3 stocks, Western mackerel, North Sea sandeel and North Sea herring. Three management strategies were studied, a fixed F, a fixed yearly catch and a regime aiming at stabilizing the SSB.

Due to the variable recruitment, attempts to stabilize the SSB increases the year to year variations in the yield. Attempting to take a fixed catch every year is hazardous, since the appearance of a few poor year classes may detoriate the stock so that the future recruitment suffers.

This simple approach may be a useful tool for evaluating management strategies in terms of risks and possible outcome of the fisheries.

Introduction

Management advise is commonly given in terms of a single recommended total allowable catch (TAC), which is assumed to represent the highest allowable catch within 'safe biological limits'. The basis for this kind of advice is a projection of the state of the stock, which depends on the starting values for numbers at age in the stock, the mortalities, weight at age, maturity ogive and the recruitment of new year classes. The typical prediction procedure simply transforms values for these parameters into predicted catches and biomasses for the next year or a few years ahead.

These parameters are, however, subject to substantial variation, and may be difficult to predict. For many stocks, the recruitment is the most important uncertain factor. Replacing the fixed value of one or more of these parameters with a statistical probability distribution, gives a prediction in terms of probability distributions of the outcomes, which probably is a more realistic representation of the actual state of knowledge. The problem then is to find realistic probability distributions for the input parameters.

When stochastic variables are substituted for fixed parameters, the effect of management strategies can be studied in terms of probabilities. A management strategy may be considered as a set of rules which determines future fishing mortalities, given the present state of the stock. The ultimate goals for the management are often multiple, and may be mutually incompatible. There may be a desire to maximize the yield, both immediately and in the long term. There may also be a need for stability over the years. The aim of the present study is to introduce a procedure for constructing a probability distribution for the recruitment, which takes the biomass of the spawning stock (SSB) into account, and then apply this to some simple management rules.

A Monte Carlo routine is used to transfer the recruitment distribution into distributions of catches and biomasses, assuming that the other input parameters are constant. The results are evaluated both in terms of expectation values for yield and biomass, and risks of selected events. This is done for three stocks: The Western mackerel stock, the North Sea herring, and the North Sea sandeel.

The mackerel has no apparent relation between stock and recruitment, although the recruitment seems to become more variable at lower SSB's (Fig. 1). The sandeel has apparently a strong connection between stock and recruitment in most years (Fig. 2). The herring also seems to have some stock dependence in its recruitment, at least at very low stock levels (Fig. 3). This is the only of these stocks where the data cover a stock collapse.

Methods.

Constructing an SSB-dependent recruitment probability distribution function.

The present strategy is to keep as close to the historical experience as posssible. The basis for the construction is the historical SSB - recruitment pairs (S_i,R_i in year i) taken from ICES Working Group assessments. The recruitment in the prediction year is then assumed to take on one of the historical values R_i, with a probability for each R_i which depends on how far the corresponding S_i is from the actual SSB (= S_a). More formally, this can be expressed by:

$$\text{Prob } \{R_a = R_i\} = \varphi(S_a,S_i)/\sum_k \varphi(S_a,S_k)$$

where φ is a weighting function. Essentially, one assumes that the recruitment in the prediction year most likely will be one of those which were generated by an SSB close to the present one. This approach is commonly called a kernel method. A convenient form of the weighting function φ is that of a probability function with expectation value at S_i. The lognormal probability density function is used in the examples in the present study. This is used because it gives a region of influence for each S_i which is proportional to S_i. Other functions (Cauchy functions, boxcar functions etc.) have been used by others for a similar purpose (Evans and Rice, 1988).

With a lognormal p.d.f.

$$\varphi(S_a,S_i) = \frac{1}{\sigma\sqrt{2\pi}}\,\frac{1}{S_a}\exp\left\{\frac{-\left(\log\frac{S_a}{S_i}-\frac{\sigma^2}{2}\right)^2}{2\sigma^2}\right\}$$

the parameter σ has to be chosen. This will determine how far away from S_i, the R_i still will have any appreciable influence on the distribution of R_a. The parameter σ was chosen according to the cross validation principle: The σ was used which minimized the sum of squared residuals obtained by estimating each R_i using all the other S_i,R_i pairs. In the case of the mackerel, this gave a very small σ ,implying that the recruitment in the pair closest to S_a would almost certainly be reproduced. Therefore, a uniform distribution where each R_i has equal probability, irrespective of the actual SSB, was applied in this case.

Prediction.

The starting values for the predictions, as well as the fixed values for weight at age, maturity at age, the natural mortality and the fishing pattern, were taken from the latest available Working Group reports (Anon. 1991a, Anon 1990, Anon. 1991b for mackerel, sandeel and herring respectively). The predictions were run on a quarterly basis for 10 years ahead (except for herring which was run on a yearly basis), with recruitments drawn randomly according to the SSB dependent distribution. This procedure was repeated 100 times for each scenario.

Three types of management strategies were studied:

1: A fixed fishing level for the whole period. The fishing pattern is not changed, the level is given relative to the *status quo*

2: A fixed catch was supposed to be taken each year. The fishisng level was determined accordingly at the beginning of the year. A maximum F of 5 times the *status quo* level was permitted.

3: To aim for a stabile SSB at a given level. For each year the fishing level was adjusted according to

$$F_{act} = F_{std} * (1 + (SSB_{act}/SSB_{std} - 1) * q)$$

where F_{std} is the reference value corresponding to the *status quo* level of exploitation and SSB_{std} is the desired level of SSB. The factor q is a smoothing factor.

Measures of managemet results.

The present approach gives in principle the results in terms of statistical distributions. For practical purposes, measures containing the information of interest have to be extracted from these distributions. The following are used here:

1. *Mean values year by year.* These give an idea of the overall effects and the trend over time.

2. *Internal SD.* This is the empirical Standard Deviations in the yearly results within each run, and gives an indication of the stability of the results from year to year. Taken over the 100 runs, this is in itself a stochastic variable.

3. *Risk* of passing certain levels of catches or SSB's. There are two reasons for considering these risks. One is to see how likely 'unacceptable' values may be. The other pertains to the SSB-dependent distributions. Since these are empirical distributions based on historical data, great caution should be excerted in interpreting the results if the SSB comes outside the range of historical experience.

Results.

Recruitment distributions.

The historical stock-recruitment pairs and the running mean of the recruitment distribution is shown in figs. 1-3. As noted previously, a stock - independent distribuiton was preferred for the mackerel. The figure for sandeel shows a common property of the kernel approach. If the historical data indicate a rapid decline in he recruitment towards low SSB's, the kernel procedure tends to give expectation values for the recruitment above most of the observations at low SSB's and *vice versa* at high SSB's. For the herring, this effect is largely abolished by the large number of observations at very low SSB's during the collapse in the 1970's.

Mackerel.

With the fixed F regime, increasing F will of course increase the yield and decrease the SSB, as long as the recruitment is unaffected by the state of the stock. As time passes, yield at low F will tend to increase due to the build-up of the underlying stock, while the opposite takes place for the large F's. Unless F is very small, the mean catch towards the end of the 10 year period is little sensitive to the F-level. However, one must expect that the year to year variations in yield become more prominent at higher F's, since the recruitment fluctuations are less effectively buffered. This is reflected in the higher fractions of large internal CV. By increasing the F above the present level, there is also a rapid increase in the risk of bringing the SSB below the lowest historical level, i.e. into the region where there is no information in the historical data about the recruitment level.

With a regime with a fixed yield, the most important aspect is the risk that the situation gets 'out of hand', i.e. that the SSB declines below the historical low, or that the stock becomes so small that it is impossible to take the planned catch. According to the data here, the stock should sustain a yearly catch of 600000 tonnes quite well. This is close to the actual yearly catch the later years. Problems arise at 750000 tonnes, and 1 million tonnes yearly almost certainly leads to disaster.

The SSB-stabilizing regime reduces the risk of low SSB's, but the effect is not very impressive. The price to be paid is an increase in the risk that the catches occasionally become quite small.

Sandeel.

Also in this case, where the recruitment is assumed to be quite strongly influenced by the SSB, a higher F level leads to higher catches in the short term. Towards the end of the 10 years period, the mean yield at the highest F- levels are still declining, however, and become lower than the yield at intermediate F's. Increasing F also increases the risk that the SSB will fall below the historical minimum of approximately 500000 tonnes.

The regime with a fixed yield works quite well with a yearly yield below 600000 tonnes. Above this level, the risk of reducing the stock to hazardous levels increases rapidly.

The regime attempting to stabilize the SSB at 1 millinon tonnes, gives large fluctuations in the yield in the first years. The 1988 year class, which according to the initial data is very large, enters the spawning stock in 1990 (year 1), and leads to a drastic increase in the fishing mortality this year. Thereafter, the mean SSB is brought effectively down to the target level. With a sufficiently large smoothing factor (q), the risk of reducing the SSB below 500 000 tonnes is very small, but the yield becomes quite variable.

The actual fishery in 1989 (year 0) was slightly above 1 million tonnes, while it was only approximately 600 000 tonnes in 1990 (year 1). This is quite different from the predicted numbers. The most likely explanation for this is that the 1988 year-class may have been overestimated.

Herring.

With a fixed F, the catches tend to stabilize slightly above the present level. This is indicated by the low frequency of high internal CV and the low risk of getting catches below the low level of 450 000 tonnes. The SSB never was below 1 million tonnes with F- values at or below the *status quo* level. By increasing the fishing mortality above this level, this picture changes dramatically. With an F at 3 times the *status quo* level, i e. F=0.92, a new collapse seems almost inevitable. This is due both to the exploitation as such, but also to a near 50% reduction in mean recruitment, compared to the *status quo* level.

Attempting a fixed yield works well for a yield of 500 000 tonnes, but becomes quite dangerous already at 750 000 tonnes. In the worst case it becomes impossible to take this catch already in year 3. At year 10, the risk that this happens is 38%. Applying a fixed yield at an even higher level is even worse.

The SSB stabilizing regime was studied for a target SSB of 2000000 tonnes. This led to a stabilisation of the SSB somewhat above the target level, with little risk of reducing the SSB to dangerous levels. The mean catches were about the baseline level, but they were less stable than with the fixed F.

Discussion.

The most important advantage of this kind of approach is that it gives more realistic dynamical properties to the system, since it intoduces a feedback mechanism for the recruitment and takes the stochastic nature of the recruitment into account.

The kernel method, which has been used here, has also been proposed by others for a similar purpose (Evans and Rice, 1988).

The advantage of this approach is that one avoids *a priori* assumptions about the form of the stock - recruitment relationship. The disadvantage is that the expected recruitment will depend strongly on the available data. Since the expectation value of the recruitment is a weighted mean, it will tend towards the mean recruitment at extreme levels of the SSB. An example of this is seen in the sandeel data.

The management strategies discussed here are simple examples, but illustrate some important points. One is that attempting to stabilize one variable will lead to increased variation in the others. Accordingly, stabilizing the SSB is not promising as a means of stabilizing the yield. Also, a strong emphasis on stabilizing the yield may be dangerous, unless the fixed yield is a good deal below the production potential of the stock.

With a fixed F at a moderate level, the mean yield and SSB tend to stabilize as time passes. If the F is high enough, this does not happen. In this case, a sequence of poor year-classes will bring the SSB down to a level where the likely recruitment is poorer, and the probability of restoring the stock is small, unless the fishery is reduced. Therefore, a higher F implies a higher yield, but also a higher risk of deteriorating the stock.

The results in absolute values in the present examples are highly dependent on the parameter values for weight, maturity ogive and natural mortality, which also may vary from year to year. A natural extension of the model would be to include some or all of these as stochastic variables. In principle, the kernel approach can be applied also for these parameters if there is reason to believe that they may be dependent on variables generated by the prediction. In particular, this applies to modelling natural mortality in multispecies models like MSVPA, and to density - dependent growth and maturity.

References

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Table 1a
Western mackerel.

Mean yearly yield and SSB as function of relative fishing mortality.
Unit 1000 tonnes.

	Mean yield					Mean SSB				
Rel.F=>	0.5	0.8	1.0	1.5	2.0	0.5	0.8	1.0	1.5	2.0
Abs.F(4-8)	.14	.22	.28	.42	.56	.14	.22	.28	.42	.56
Year										
0	352	544	665	945	1195	2340	2288	2254	2172	2095
1	420	614	724	942	1094	2812	2617	2497	2227	1996
2	475	663	758	918	1002	3124	2782	2582	2162	1834
3	520	693	771	880	915	3276	2798	2533	2009	1633
4	539	693	755	826	835	3364	2779	2468	1889	1503
5	560	698	748	796	795	3451	2776	2433	1827	1447
6	569	694	736	774	775	3506	2768	2407	1794	1424
7	572	686	723	756	758	3526	2742	2371	1756	1395
8	575	680	713	742	743	3550	2722	2340	1723	1367
9	570	670	700	727	729	3542	2687	2301	1690	1340
10	569	662	691	716	717	3534	2656	2269	1662	1320
Int. CV of yield:										
<10%	9	45	66	26	4					
10-20%	81	55	33	59	41					
>20%	10	0	1	15	55					

Table 1b
Western mackerel

Risk (%) of yield and SSB below critical levels with constant F.

	Below level at least once					Below level in year 10				
Rel. F=>	0.5	0.8	1.0	1.5	2.0	0.5	0.8	1.0	1.5	2.0
Abs.F(4-8)	.14	.22	.28	.42	.56	.14	.22	.28	.42	.56
Level (1000 tonnes):										
Yield:										
900	100	100	100	100	100	100	100	97	93	88
600	100	100	26	26	37	64	29	21	18	19
450	100	5	2	4	5	8	2	2	2	2
200	0	0	0	0	0	0	0	0	0	0
SSB:										
1500	0	0	5	54	94	0	0	44	29	77
1000	0	0	0	7	24	0	0	0	2	11

Table 1c
Western mackerel

Fixed yearly yield

	Risk (%) of yield below target.				Risk of SSB < 1500000 tonnes			
Target yield=>	500	600	750	1000	500	600	750	1000
Year								
0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	25
4	0	0	0	6	0	0	2	48
5	0	0	0	31	0	0	4	64
6	0	0	0	43	0	0	10	70
7	0	0	1	49	0	0	12	83
8	0	0	3	66	0	1	15	89
9	0	0	3	75	0	1	18	93
10	0	0	4	83	0	1	23	97

Table 1d
Western mackerel.

Mean yearly yield, SSB and F with a fixed target SSB.
Unit 1000 tonnes.

Target SSB = 2000	Mean yield			Mean SSB			Mean F(4-8)		
q =>	0.5	1.0	1.5	0.5	1.0	1.5	0.5	1.0	1.5
Year									
0	704	739	772	2241	2228	2216	.30	.32	.33
1	778	821	856	2459	2426	2396	.31	.33	.33
2	817	855	878	2498	2428	2369	.31	.34	.36
3	810	822	821	2407	2312	2241	.31	.33	.34
4	772	767	754	2323	2228	2165	.31	.32	.32
5	754	744	734	2284	2199	2149	.30	.31	.31
6	737	730	724	2262	2187	2147	.30	.31	.31
7	721	716	713	2232	2166	2131	.30	.30	.31
8	710	706	704	2210	2151	2119	.30	.30	.31
9	696	692	689	2181	2127	2098	.29	.30	.30
10	685	681	679	2157	2110	2084	.29	.30	.30
Int. CV of yield:									
<10%	31	16	12						
10-20%	56	63	54						
>20%	13	21	34						

Table 1e
Western mackerel

Fixed target SSB = 2000 000 tonnes
Risk (%) of yield and SSB below critical levels.

	Below limit at least once			Below limit in year 10		
q =>	0.5	1.0	1.5	0.5	1.0	1.5
Limit (1000 tonnes):						
Yield:						
900	100	100	100	94	90	89
600	45	54	61	25	28	31
450	8	16	22	2	7	10
200	0	0	0	0	0	0
SSB:						
1500	7	6	5	2	2	2
1000	0	0	0	0	0	0

Table 2a
North sea sandeel.

Mean yearly yield and SSB as function of relative fishing mortality.
Unit 1000 tonnes.

	Mean yield					Mean SSB				
Rel.F=>	0.5	0.8	1.0	1.5	2.0	0.5	0.8	1.0	1.5	2.0
Abs.F(1-2)=>	.32	.52	.65	.97	1.29	.32	.52	.65	.97	1.29
Year										
0	497	750	903	1239	1519	757	757	757	757	757
1	763	1013	1127	1239	1359	1988	1792	1674	1417	1204
2	692	871	945	1056	1091	1785	1417	1229	896	685
3	665	857	939	1040	1050	1779	1371	1178	868	655
4	694	884	962	1020	1008	1860	1415	1202	822	533
5	700	881	947	993	969	1925	1430	1203	800	567
6	674	849	908	953	913	1897	1403	1161	767	536
7	660	838	896	921	882	1839	1346	1113	731	499
8	654	822	876	890	847	1850	1369	1126	710	490
9	647	805	851	880	819	1798	1299	1066	681	463
10	649	812	853	876	805	1807	1311	1061	684	451
Int. CV of yield:										
<10%	0	0	2	1	2					
10-20%	20	28	31	20	8					
20-30%	50	53	47	44	35					
>30%	30	19	20	35	55					

Table 2b
North Sea sandeel.

Risk (%) of yield and SSB below critical levels.

	Below level at least once					Below level in year 10				
Rel. F=>	0.5	0.8	1.0	1.5	2.0	0.5	0.8	1.0	1.5	2.0
Abs.F(1-2)=>	.32	.52	.65	.97	1.29	.32	.52	.65	.97	1.29
Level (1000 tonnes):										
Yield:										
1200	100	100	100	100	100	100	95	89	92	90
900	100	100	100	90	92	83	64	59	54	62
600	100	70	50	43	57	44	20	13	17	32
450	61	23	17	20	27	14	2	4	4	12
200	3	1	0	0	0	1	0	0	0	0
SSB:										
1000	100	100	100	100	100	6	22	35	94	100
500	0	6	22	78	91	0	1	4	27	52

Table 2c
North Sea sandeel

Fixed yearly yield

	Risk (%) of yield below target.				Risk of SSB < 500000 tonnes			
Target yield=>	500	600	750	1000	500	600	750	1000
Year								
0	0	0	0	0	0	0	0	0
1	0	0	0	1	0	0	0	0
2	0	0	5	23	0	0	5	28
3	0	2	12	41	0	8	24	48
4	0	2	17	51	0	8	30	70
5	0	3	25	72	0	10	39	76
6	0	5	35	82	0	8	47	88
7	0	6	39	88	2	15	52	96
8	0	8	48	96	2	15	61	97
9	0	8	57	96	2	20	66	99
10	0	10	63	98	3	18	73	100

Table 2d
North Sea sandeel

Mean yearly yield, SSB and F with a fixed target SSB.
Unit 1000 tonnes.

Target SSB = 1000	Mean yield			Mean SSB			Mean F(1-2)		
q =>	0.5	1.0	1.5	0.5	1.0	1.5	0.5	1.0	1.5
Year									
0	812	716	615	757	757	757	.57	.49	.41
1	1399	1667	1922	1744	1819	1896	.87	1.15	1.47
2	891	752	555	1052	885	736	.67	.60	.44
3	942	948	1003	1078	1066	1109	.67	.68	.74
4	967	932	863	1102	1037	979	.68	.67	.63
5	955	958	988	1106	1080	1091	.68	.70	.73
6	921	916	897	1086	1051	1029	.67	.68	.68
7	906	907	906	1051	1033	1029	.66	.67	.67
8	887	880	874	1065	1038	1027	.67	.67	.67
9	852	839	829	1014	991	988	.65	.64	.63
10	857	865	870	1021	1017	1024	.65	.66	.67

Int. CV of yield:			
<10%	0	0	0
10-20%	5	0	0
20-30%	33	4	0
>30%	62	96	100

Table 2e
North Sea sandeel

Risk (%) of yield and SSB below critical levels.

	Below level at least once			Below level in year 10		
qf =>	0.5	1.0	1.5	0.5	1.0	1.5
Level (1000 tonnes):						
Yield:						
1200	100	100	100	89	87	85
900	100	100	100	56	56	52
600	77	87	100	24	30	28
450	40	74	87	5	15	19
200	0	8	49	0	2	5
SSB:						
1000	100	6	5	43	2	2
500	30	0	0	4	0	0

Table 3a
North Sea herring.

Mean yearly yield and SSB as function of relative fishing mortality.
Unit 1000 tonnes.

	Mean yield						Mean SSB					
Rel.F=>	0.5	0.8	1.0	1.5	2.0	3.0	0.5	0.8	1.0	1.5	2.0	3.0
Abs.F(2-8)=>	.15	.25	.31	.46	.62	.92	.15	.31	.46	.62	.92	
Year												
0	128	428	521	733	919	1225	1462	1376	1321	1195	1080	884
1	336	482	561	707	796	796	1750	1515	1376	1084	855	533
2	381	512	572	666	715	777	2116	1716	1494	1062	760	398
3	434	551	592	657	742	713	2409	1831	1532	1012	699	376
4	490	598	620	683	804	626	2729	1966	1582	1005	740	353
5	530	624	632	712	821	551	3055	2119	1650	1049	811	310
6	559	647	638	728	810	492	3290	2209	1684	1103	831	271
7	579	661	643	730	790	456	3436	2281	1694	1130	815	242
8	587	665	647	725	790	422	3529	2319	1703	1130	791	225
9	588	666	647	715	780	402	3546	2324	1712	1116	791	209
10	585	669	648	707	777	389	3522	2317	1709	1098	782	200
Int. CV of yield:												
<10%	0	15	32	2	1	0						
10-20%	25	43	49	66	64	0						
>20%	75	42	19	32	35	100						

Table 3b
North Sea herring

Risk (%) of yield and SSB below critical levels.

	Below level at least once						Below level in year 10					
Rel. F=>	0.5	0.8	1.0	1.5	2.0	3.0	0.5	0.8	1.0	1.5	2.0	3.0
Abs.F(2-8)=>	.15	.25	.31	.46	.62	.92	.15	.25	.46	.62	.92	
Level (1000 tonnes):												
Yield:												
1200	100	100	100	100	100	100	100	100	100	99	100	100
900	100	100	100	100	100	100	100	97	92	87	74	100
600	100	100	100	92	66	100	59	29	45	27	17	86
450	100	100	12	0	7	91	5	5	2	0	1	64
SSB:												
1500	100	100	100	100	100	100	0	2	44	96	100	100
1000	0	0	0	98	100	100	0	0	0	32	88	100
750	0	0	0	11	99	100	0	0	0	4	47	100
500	0	0	0	0	17	100	0	0	0	0	3	100

Table 3c
North Sea herring

Fixed yearly yield

	Risk (%) of yield below target.				Risk (%) of SSB < 800 000 tonnes			
Target yield=>	500	600	750	1000	500	600	750	1000
Year								
0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	92
2	0	0	0	58	0	0	43	83
3	0	0	2	67	0	7	67	93
4	0	0	9	78	0	12	61	91
5	0	0	15	86	0	15	57	94
6	0	0	23	90	0	19	56	97
7	0	0	30	94	0	15	58	98
8	0	0	32	96	0	13	58	100
9	0	1	38	100	0	10	56	100
10	0	1	42	100	0	12	65	100

Table 3d
North Sea herring

Mean yearly yield, SSB and F with a fixed target SSB.
Unit 1000 tonnes.

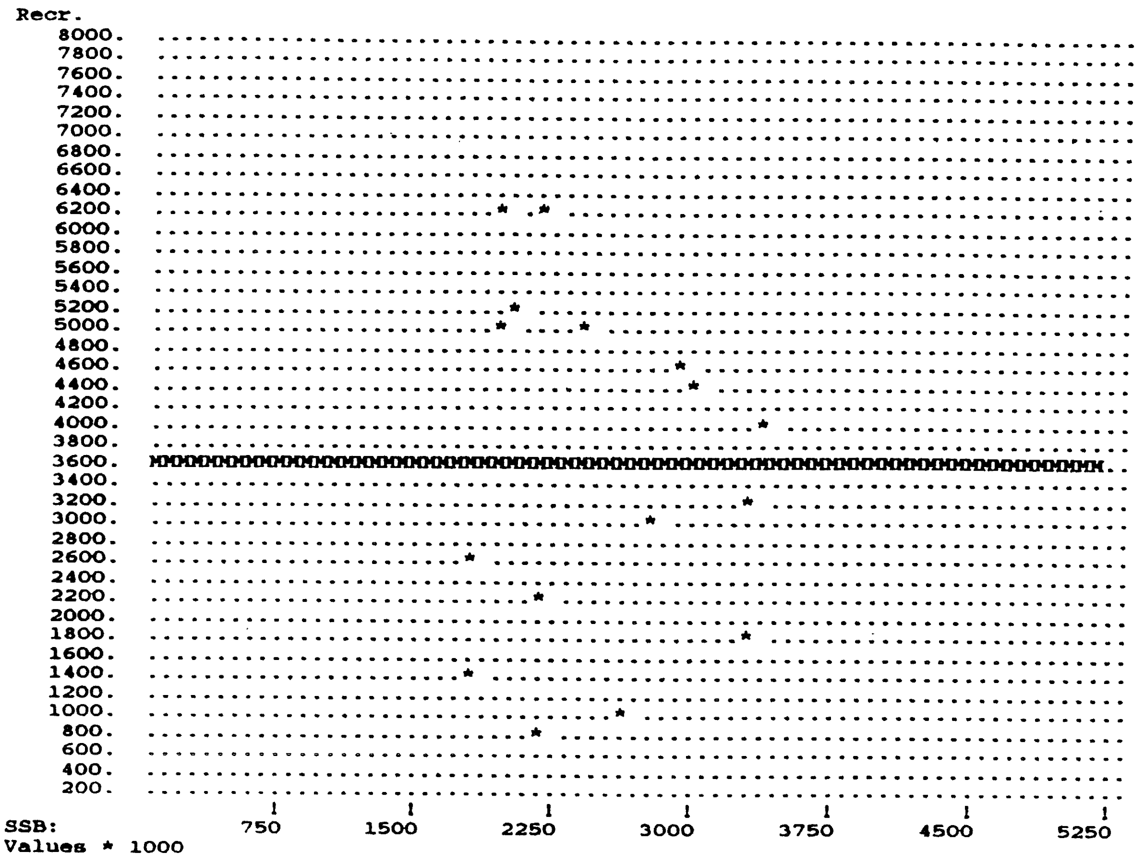
Target SSB = 2000	Mean yield			Mean SSB			Mean F		
q =>	0.5	1.0	1.5	0.5	1.0	1.5	0.5	1.0	1.5
Year									
0	497	473	449	1335	1349	1364	.29	.28	.26
1	483	404	323	1443	1511	1580	.26	.21	.16
2	526	491	472	1625	1753	1876	.26	.23	.21
3	590	615	674	1695	1835	1947	.28	.27	.28
4	638	676	737	1768	1896	1970	.28	.28	.30
5	664	712	753	1851	1958	2005	.29	.29	.30
6	685	734	763	1871	1963	1982	.30	.30	.30
7	690	731	743	1874	1954	1968	.30	.30	.30
8	690	721	730	1878	1943	1951	.30	.30	.30
9	684	704	705	1870	1917	1938	.30	.30	.30
10	678	689	695	1852	1897	1931	.30	.30	.29
Int. CV of yield:									
<10%	19	3	0						
10-20%	34	19	9						
20-30%	33	39	19						
>30%	14	39	72						

Table 3e
North Sea herring

Risk (%) of yield and SSB below critical levels.

	Below limit at least once			Below limit in year 10		
qf =>	0.5	1.0	1.5	0.5	1.0	1.5
Limit (1000 tonnes):						
Yield:						
1200	100	100	100	89	99	97
900	100	100	100	56	86	82
600	100	100	100	24	38	42
450	43	84	87	5	9	11
SSB:						
1500	100	100	100	14	5	2
1000	0	0	0	0	0	2

Function type:
Uniform (no dependence of SSB)



M: mean   *: one obs.

Fig. 1

Western mackerel
Stock-recruitment pairs and expectation of recruitment

Data from Anon. 1991a.

Function type:
Lognormal distribution function
σ = 0.480

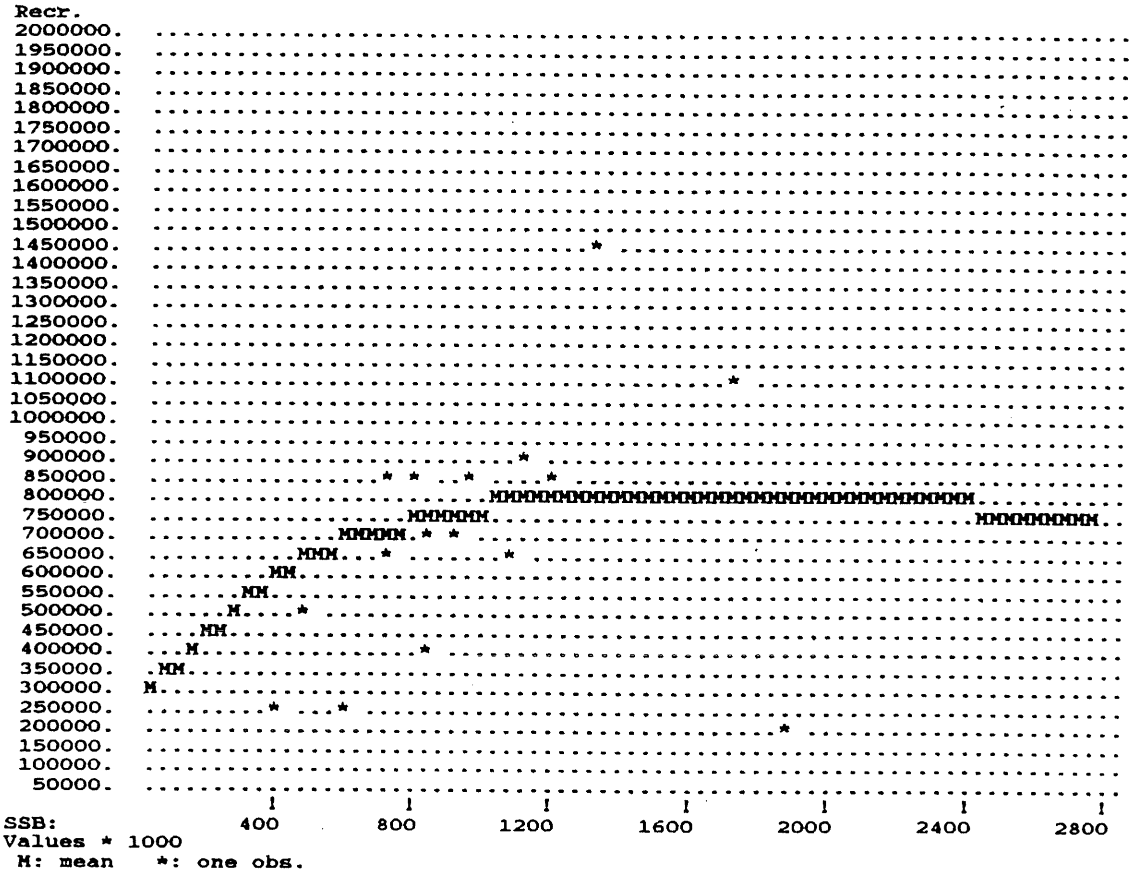


Fig. 2

North Sea sandeel
Stock-recruitment pairs and expectation of recruitment

Data from Anon 1991b

Function type:
Lognormal distribution function
σ = 0.234

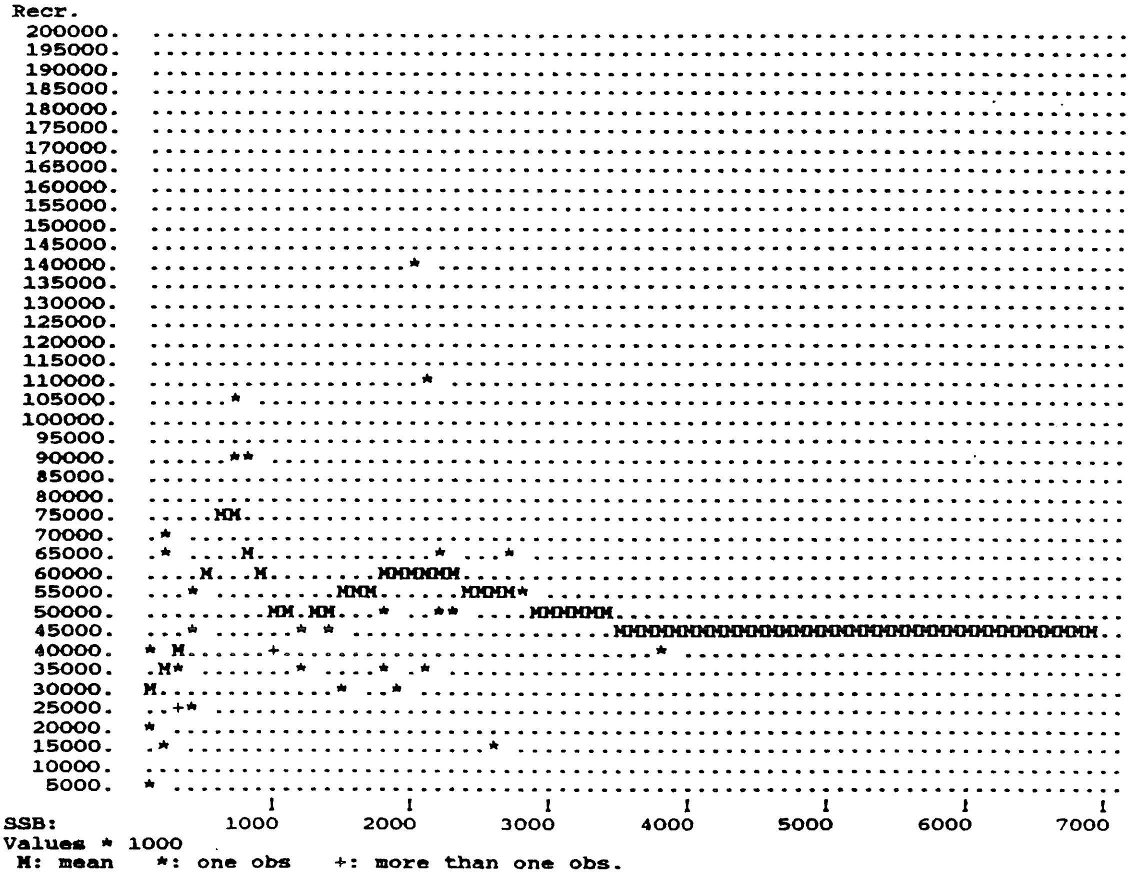


Fig. 3

<u>North Sea herring</u>
Stock-recruitment pairs and expectation of recruitment

Data from Anon. 1991c.