AN ILLUSTRATIVE EXAMPLE OF A MANAGEMENT PROCEDURE FOR EASTERN NORTH ATLANTIC BLUEFIN TUNA

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SUMMARY

This document provides an illustrative example of the development of Candidate Management Procedures (MPs) for the Eastern North Atlantic bluefin tuna resource. Its purpose is to draw attention to key components of this process, including the specification of a number of alternative Operating Models (OMs) which describe plausible dynamics for the resource, the choices of abundance indices for use for input to MPs and of the error structures associated with the generation of future data corresponding to those indices, and consideration of key performance statistics related to future catch levels and resource conservation to allow consideration of the different trade-offs between these for alternative MPs. The MPs examined use a combination of target and slope based approaches applied to simulated future abundance indices from Japanese longline operations and a larval survey in an area of the western Mediterranean. MP trials are carried out for four OMs which reflect alternative resource assessments and choices for relationships between recruitment and spawning biomass. The greatest challenge appears to come from a scenario with both high and low recruitment regimes when there is a change from the former to the latter. If catches are allowed to go high to benefit from the period of high recruitment, can the change in regime be identified sufficiently soon to allow for adequate catch limit reductions to ensure resource conservation during the later years of lower recruitments?

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Introduction

The Management Strategy Evaluation (MSE)/Management Procedure (MP) process is subtle and sometimes complex, and therefore it can be difficult to grasp the essences and implications if presented only in an abstract way. In an attempt to aid the process for enhanced understanding, this document provides an illustrative example of the development of Candidate Management Procedures (MPs) for the Eastern North Atlantic bluefin tuna resource. Its purpose is to draw attention to key components of this process, especially the catch vs resource depletion risk considerations that arise, so as to guide the further development of the MSE/MP process for bluefin tuna within ICCAT.

The document first develops Operating Models (OMs) to be used to test candidate MPs (CMPs) which are based on statistical catch-at-length (SCAL) assessments of the resource using the most recent data available, and also sets out a few options for projecting these dynamics into the future in line with plausible future recruitment scenarios. The data series to be used as input to the CMPs are specified, and the process used to generate future associated observed values for these developed. Some relatively simple empirical CMPs are specified, and these are applied to the four OMs specified for the resource to determine catch vs resource depletion risk performance. Finally the implications of the outcomes from these calculations for the further development of the ICCAT MSE/MP process for bluefin tuna are discussed.

Data and Methods

Data

The testing of the illustrative MPs in this paper requires the availability of a set of OMs, which in turn are conditioned on the data available by developing them as SCAL assessments of the resource. The data used for input to those assessments are listed in Appendix A, and are as originally provided in Bonhommeau *et al.* (2014). Note that the assessment runs from 1950 to 2013.

SCAL assessments

Appendix B provides details of the SCAL methodology applied, together with specifications for the Reference Case (RC) OM. Figure 1 shows the spawning biomass and recruitment time series estimated for the RC, and is followed by some further results and diagnostics: Figure 2 shows the stock-recruitment (SR) relationship and corresponding residuals, Figure 3 shows the fits to the relative abundance index series for RC, and Figure 4 plots the commercial selectivities and the fits to CAL data.

It is immediately evident from Figure 2 that although the assessment model does respond to the recent increases in the JLL_NEA and larval indices, the estimated abundance fails to increase to as large an extent as these indices. To develop an alternative OM (scenario S1) that fits these indices better, the assessment was repeated giving more weight (x12) for index data from 2010 onwards for the JLL_NEA and larval index series.

Projections

The projection methodology used is detailed in Appendix C. Note that although the assessment extends only to 2013, the 2014 catch is taken as equal to the 2014 TAC and the Commission has sets catch limits for 2015 to 2017 (details in Appendix C).

However the time series of recruitments estimated for the RC are suggestive of a shift from a lower to a higher productivity in 1983 (see Figure 5). Scenario S2 thus supposes a regime shift that year, so that periods before and after that date reflect different average recruitments and hence also different average pristine (unexploited) abundances. In 2013 the higher recruitment scenario applies, but there is no guarantee that that will continue through all future years. Hence two further OMs are defined: in the first (S2a) the high recruitment does continue throughout the projection period, whereas in the second (S2b) the resource reverts to the lower recruitment regime from 2020 onwards.

Figure 6 shows the historical spawning biomass trajectories for the RC, S1 and S2 (note that the S2a and S2b scenarios are not distinguished here as they diverge only in the future).

Candidate Management Procedures

In the interests of simplicity for this illustrative exercise, the MPs investigated have been restricted to two indices of abundance, the JPLL_NEA and the larval indices. These were selected, in part, because both seem likely to continue and because both reflect the large recent upward change in the abundance of the resource.

Further these MPs are empirical, computing TACs directly from the abundance indices. There are two common and simple approaches to developing such empirical MPs: target based (the TAC is adjusted up or down depending on whether the index is above or below a chosen target level) and slope-based where this adjustment is up or down as the recent trend in the index is either positive or negative. Usually the former approach is preferred as it provides more stable outputs, but that alone is not appropriate here given the two regime nature of the resource (e.g. an appropriate target under the higher recruitment scenario would be unachievable for the lower recruitment scenario and hence lead to TACs reducing to zero). Thus a combination of the two approaches has been attempted. The first of these takes the following form.

<u>CMP1_x</u>:

$$TAC_y = TAC_{y-1}\left[1+\lambda_{up/down}s_y + \rho_{up/down}\left(\frac{J_y}{J_{\text{targ}}}-1\right)\right] \qquad (1)$$

where

s_y is the average of trend estimates for each of the two indices, where this trend estimate is provided by the slope of a log-linear regression of the index against year over the last ten years (*y*-10 to *y*-1);

$$\frac{J_y}{J_{\text{targ}}} = \sum_i \frac{J_y^i}{J_{\text{targ}}^i} \Big/ \sum_i 1$$

where J_y^i is the average of the values of index *i* over the most recent five years (*y*-5 to *y*-1); and

$\lambda_{up/down}$, $\rho_{up/down}$ and J_{targ}^i are control parameters whose values are selected to attempt to achieved an appropriate trade-off amongst performance statistics for conflicting objectives (such as high catches and low risk of unintended resource depletion), with this trade-off performance showing reasonable robustness across the range of plausible scenarios (OMs) considered.

Furthermore in the interests of industrial stability, a constraint of a maximum interannual change in the TAC of 15% (both up or down) is imposed.

In addition, variants of this MP place different caps on the maximum the TAC is permitted to achieve, and are defined by *x* where *x* is that maximum, i.e. if from the formulae and rules above it turns out that $TAC_y > x$, then TAC_y is set equal to *x*. Such constraints can prove helpful in situations where the TAC might have climbed well above *x*, and consequently it proves difficult to reduce the TAC sufficiently fast (given the restrictions on the maximal inter-annual TAC change) to adjust for a possible large drop in resource abundance because of a series of poor recruitments.

However, even with that cap on the maximum TAC, it may prove necessary to override the constraint on the maximum interannual decrease in the TAC if resource abundance appears to have dropped too low. This leads to a second class of MPs, CMP2, which is described below.

<u>CMP2_x</u>

For these MPs, equation 1 and the TAC maximum of *x* apply as before, but there is an extra penalty if $\frac{J_y}{J_{\text{targ}}}$ falls below a specified level:

$$D_y = \begin{cases} 0 & \text{for } \dfrac{J_y}{J_{\text{targ}}} > 0.75 \\ \text{linear between 0\% and 30\%} & \text{for } 0.70 \le \dfrac{J_y}{J_{\text{targ}}} \le 0.75 \\ 0.3TAC_y & 0.40 \le \dfrac{J_y}{J_{\text{targ}}} \le 0.75 \\ 1.0 & \dfrac{J_y}{J_{\text{targ}}} < 0.4 \end{cases} \qquad (2)$$

The final TAC_y^* is computed as $TAC_y^* = TAC_y(1 - D_y)$, where TAC_y is calculated from equation 1 (without any changes to the values of the control parameters) and after the application of the maximum interannual change in the TAC.

Results

It is frequently useful to initiate an MP development exercise by checking results for different constant catch levels, and further under deterministic conditions (no fluctuations about the stock-recruitment function – if an MP won't work adequately in the absence of such fluctuations, it certainly will not do so when they are introduced).

Figure 7 shows the spawning biomass projections under those circumstances. It is immediately evident that while a fixed TAC of 15 000t is not problematic for any of the four OMs over the projection period considered, spawning biomass does drop unacceptably low for two (at least) of these OMs when that amount is increased to 30 000t.

CMP1_x

The following control parameters were selected for CMP 1:

Control parameter	Value
λ_{up}	0.03
λ_{down}	0.15
ρ_{up}	0.03
ρ_{down}	0.15
J_{targ} - JPLL_NEA	0.95
J_{targ} – larval	1.70

where the values of J_{targ} are about 50% of the average of the levels to be expected for S2a and S2b in the absence of exploitation.

Results have been explored for values of x = no_cap, 40 000 and 30 000t. Figure 8 shows the results for the 40 000t cap particularly for catch and spawning biomass and their probability intervals for all four OMs, with some no_cap results are shown to provide a contrast. Figure 9 repeats this for the 30 000t cap, and Figure 10 contrasts results for the three variants of CMP1 for the lower 2.5%iles for spawning biomass, and the median and upper 2.5%iles for catch.

Figure 11 contrasts CMP1 and CMP2 behaviour for spawning biomass and catch trajectories for all four OMs (i.e. to check whether more stringent rules for catch reductions when the combined abundance index J drops to low levels are successful at avoiding instances of very low abundances, particularly for the fourth OM where there is a switch from the higher to the lower recruitment regime. Figure 11 is for the case of a 40 000t cap on the TAC; Figure 12 repeats those results for a 30 000t cap.

Discussion

Figure 8 reflects satisfactory performance for the RC and the higher recruitment regime scenario S2a under CMP1. However TACs rise too high for scenario S1 (which reflects a better fit to recent JLL_NEA and larval abundance indices) and S2b (the switch to the lower recruitment regime), and these lead to subsequent undesirable levels of decline in spawning biomass. This decline is ameliorated somewhat for scenario S1 given the 40 000t TAC cap, but it needs this cap to be lowered to 30 000t to see some small improvement in this regard for scenario S2b (Figure 9). However, such amelioration comes at a cost, particularly in terms of catch under scenario S2a, as is evident from the comparisons across the three choices for the level of this TAC cap in Figure 10.

Given the extra restrictions of CMP2 plus the 30 000t TAC cap, there is some further improvement as regards resource depletion for scenario S2b, but this comes at the further expense of greater (sometimes substantial) TAC declines after 2030 (see Figure 12).

More sophisticated algorithms might attain better performance still than evident in Figures 11 and 12, but their development is not really an immediate priority, given the illustrative nature intended for this document. The problem arises because highly noisy (CV > 70%) indices of abundance provide indications of stock decline that are too imprecise and too delayed to give a clear indication of the immediate status of the resource. Certainly a more refined further attempt at an MP might include further information inputs to offset this.

However this does serve to draw attention to some key considerations in the MP development process for North Atlantic bluefin tuna:

a) careful consideration is needed as to what monitoring data (particularly abundance indices) will almost certainly be available in the future, so that any candidate MPs can be designed around those;

b) equally, as careful consideration is needed regarding specification of the error structures associated with such information (specifically biases and variances) for projection purposes for the MP testing process – hopefully such may lead to defensibly better precision than the >70% CVs applied in these illustrative analyses; and

c) thorough discussion is needed to specify future realistic recruitment scenarios and to accord then some form of relative plausibility weights for the eventual process of selecting an MP that gives an acceptable catch vs depletion risk trade-off.

Reference

Bonhommeau S., Kimoto, A., Fromentin, J.M., Kell, L., Arrizabalaga, H., Walter, J.F., Ortiz de Urbina, J., Zarrad, R., Kitakado, T., Takeuchi, Y., Ortiz, M. and Palma, C. 2014. Update of the Eastern and Mediterranean Atlantic bluefin tuna stock. SCRS/2014/113. Col. Vol. Sci. Pap. ICCAT.

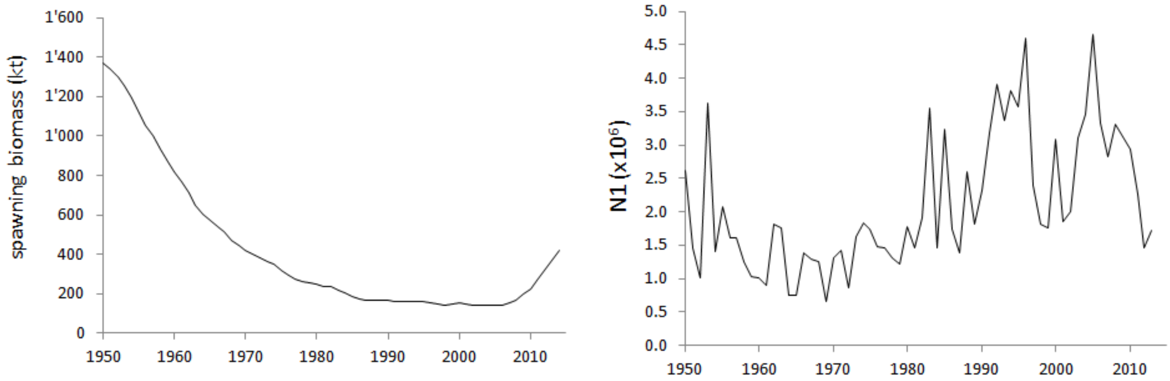

Figure 1: Spawning biomass and recruitment (number of 1-year-olds, N_1) trajectories for Eastern North Atlantic bluefin tuna for the SCAL Reference Case.

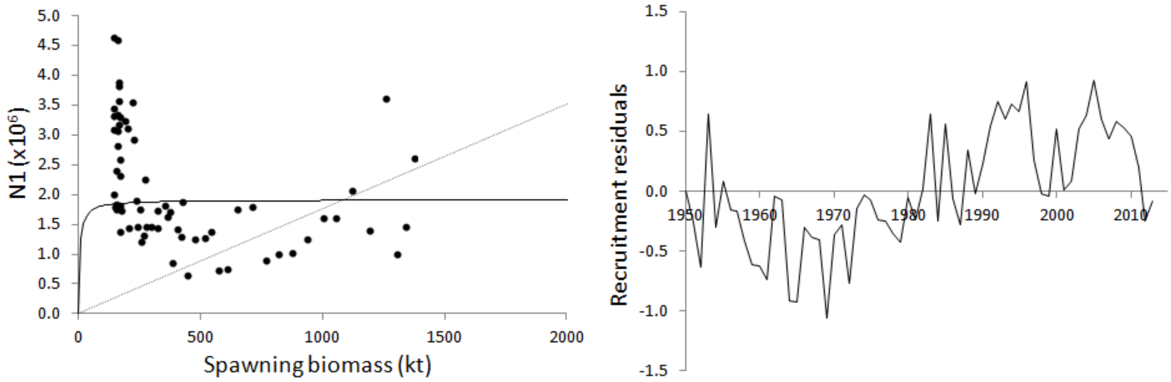

Figure 2: Stock-recruitment relationships (left-hand column) and time series of stock-recruitment residuals for the SCAL Reference Case. Spawning stock biomass (B^{sp}) is in mt. The replacement line is also shown; this intercepts the stock-recruitment plot where $B^{sp} = K^{sp}$.

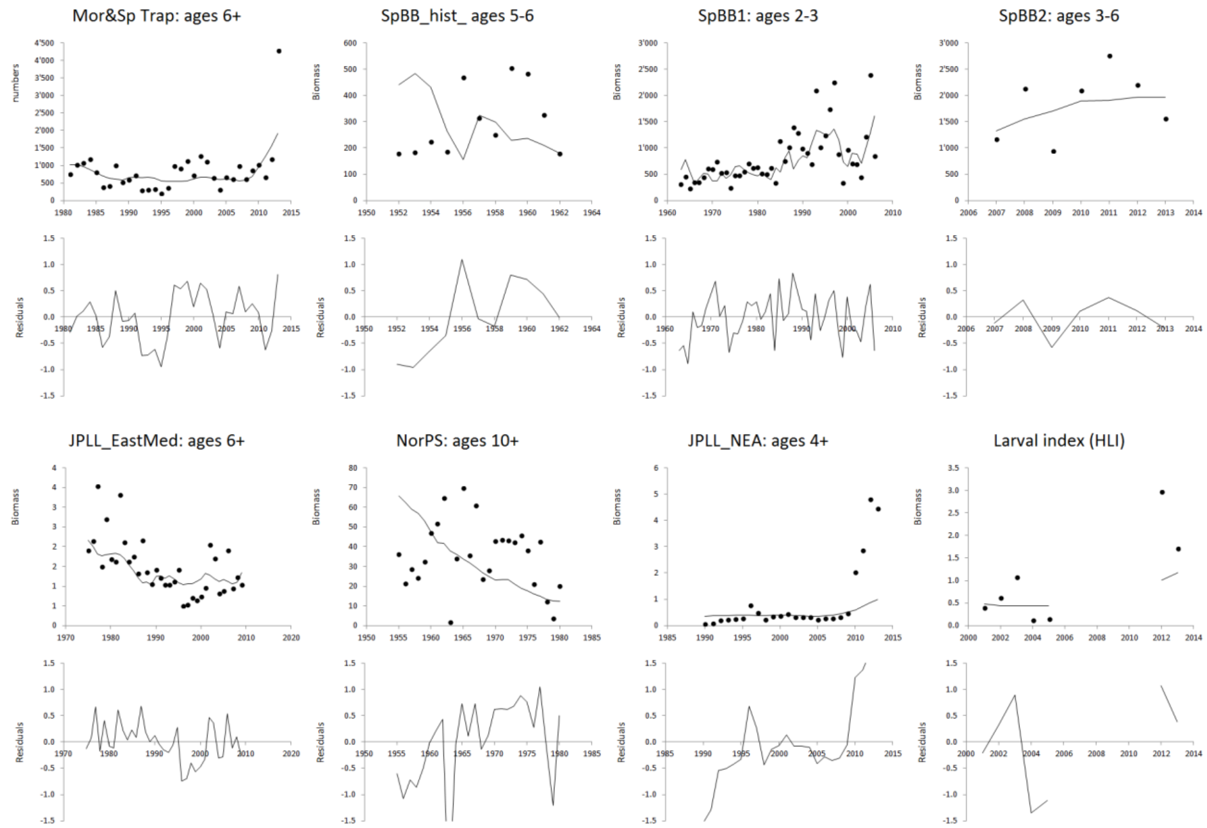

Figure 3: Fits of the SCAL Reference Case to the various CPUE series and the corresponding standardised residuals.

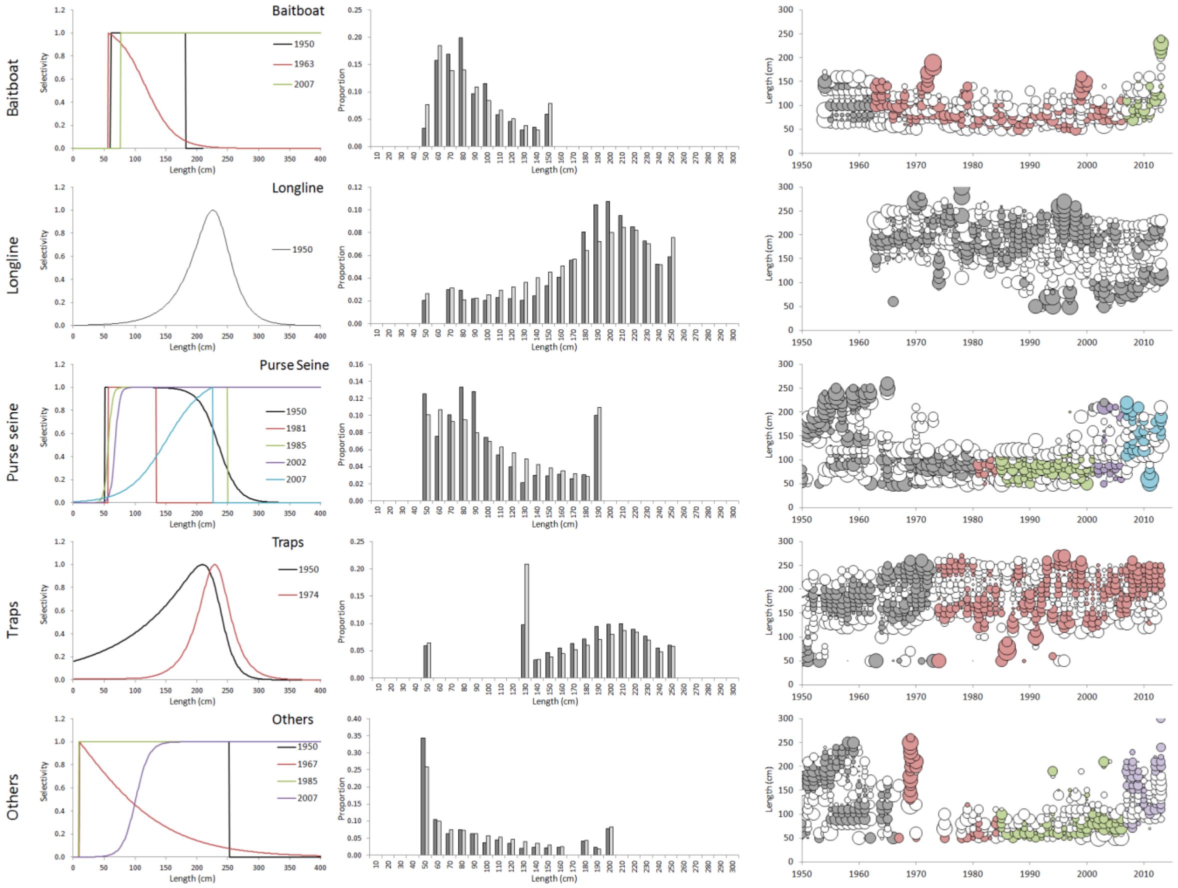

Figure 4: Commercial selectivities-at-length (first column), fits to the CAL data aggregated over years (second column) and bubble plots of the corresponding standardised residuals. The area of the bubble is proportional to the magnitude of the residual. For positive residuals the bubbles are grey, whereas for negative residuals the bubbles are white.

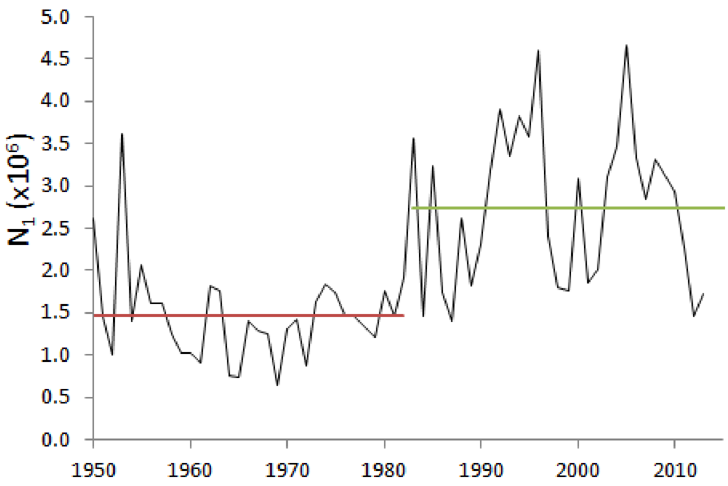

Figure 5: Time series of recruitment for the SCAL Reference Case. The horizontal lines represent the 1950-1982 average (red line) and 1983-2013 average (green line).

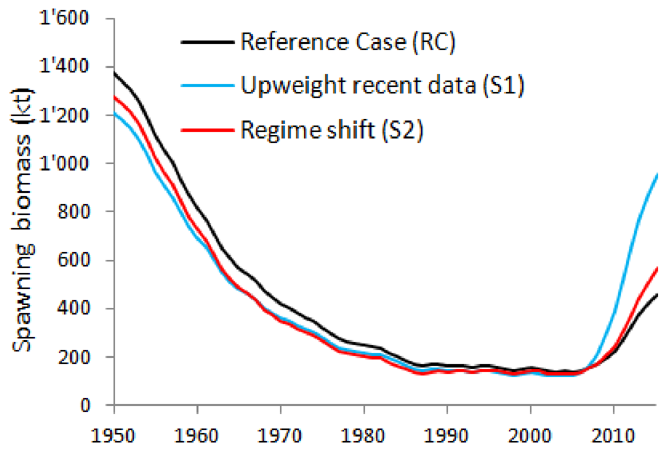

Figure 6: Spawning biomass trajectories for the four OMs considered: the SCAL Reference Case (RC); a SCAL run upweighting recent CPUE data (S1), and a SCAL run with a change in mean recruitment and hence carrying capacity in 1983 (S2). Note that two different options are considered for future changes for S2.

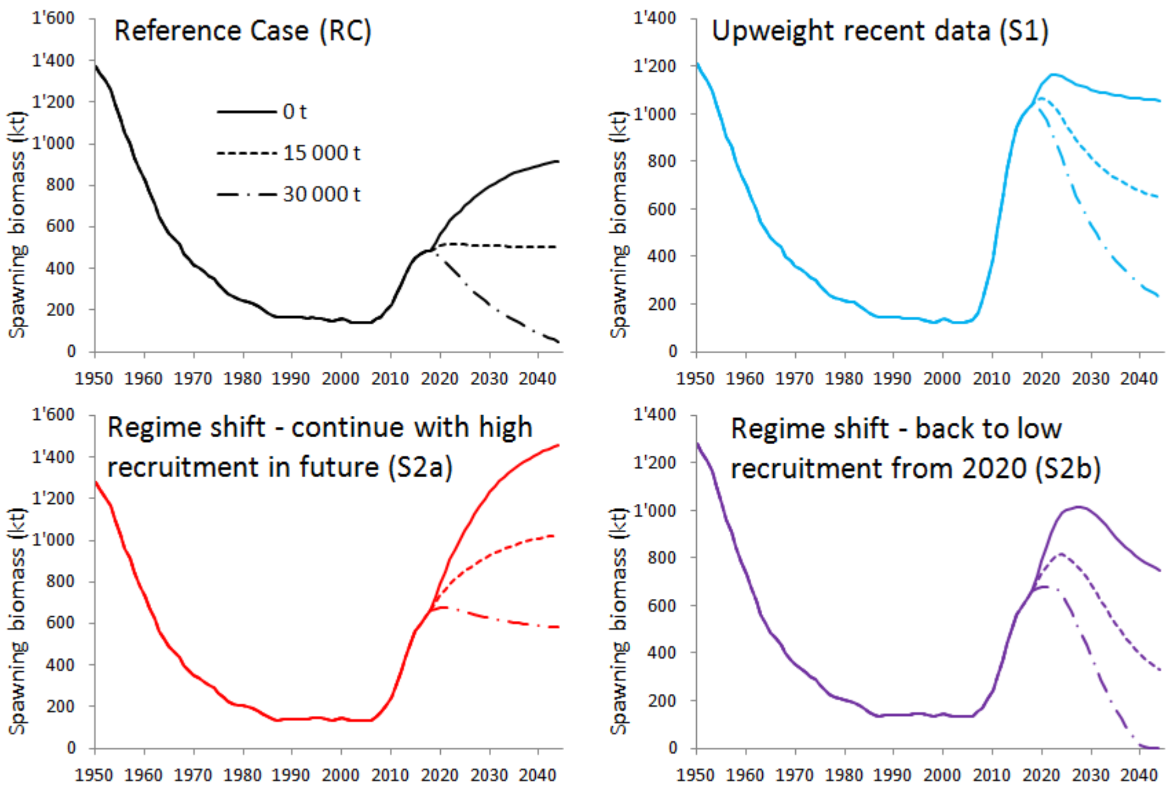

Figure 7: Deterministic constant catch projections (0, 15 000 and 30 000 t from 2018 onwards) for the four OMs.

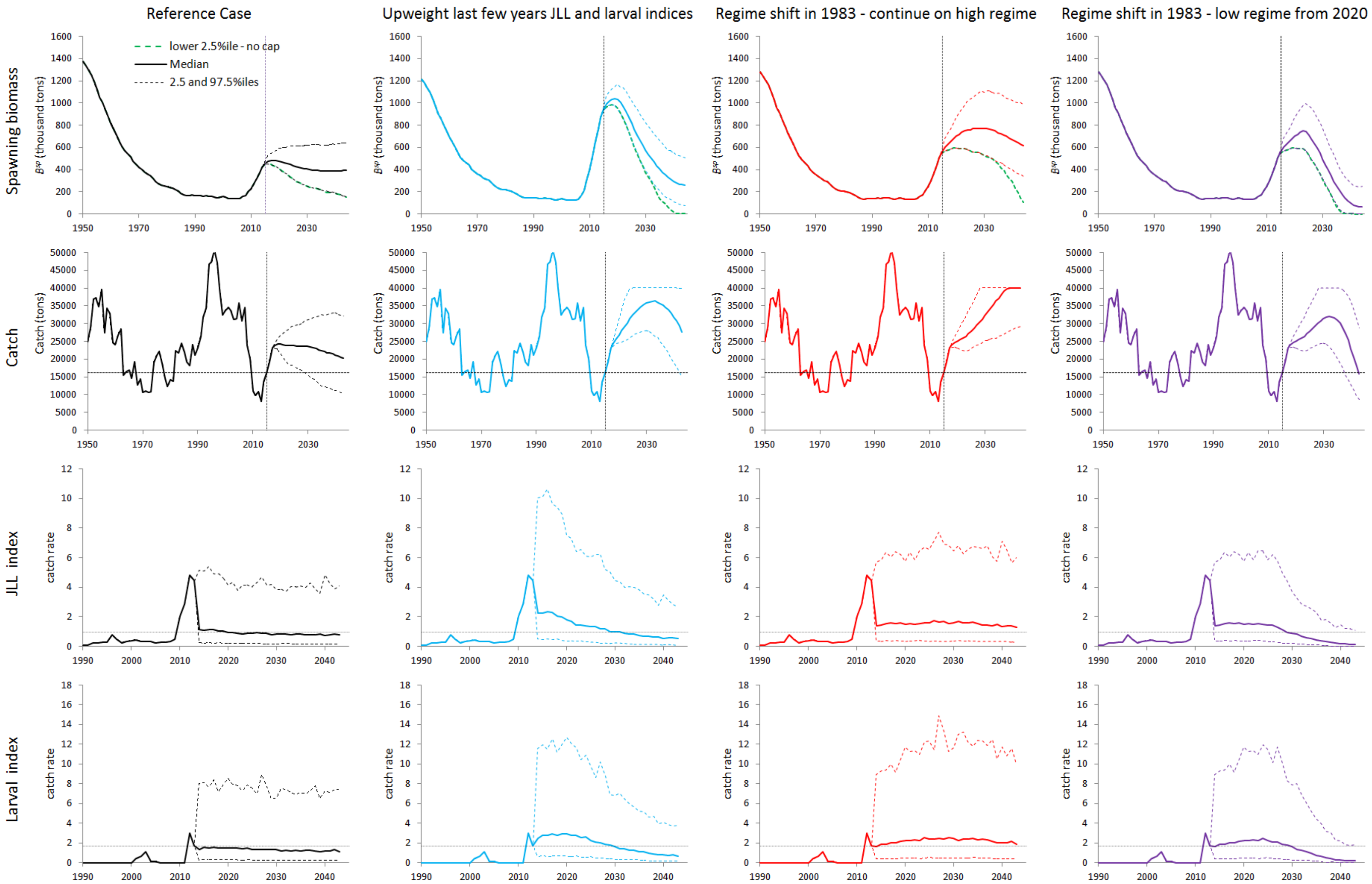

Figure 8: Stochastic projections (1000 simulations, median and 95%iles) under CMP1_40000 (i.e. upper cap of 40 000t on the TAC) for the four OMs. The lower 2.5%ile spawning biomass under CMP1_nocap (no upper limit on the TAC) is also shown in green.

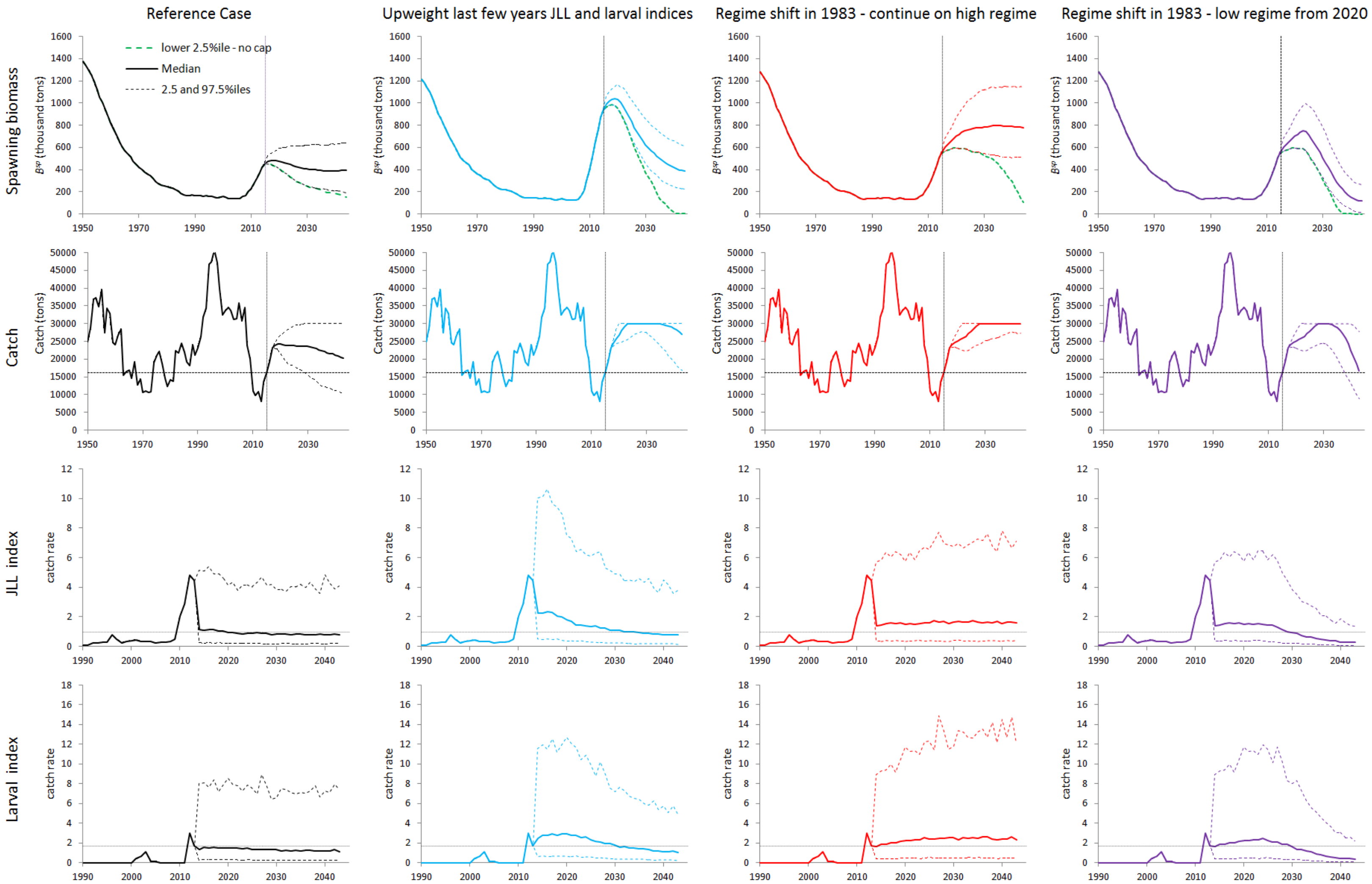

Figure 9: Stochastic projections (1000 simulations, median and 95%iles) under CMP1_30000 (i.e. upper cap of 30 000t on the TAC) for the four OMs. The lower 2.5%ile spawning biomass under CMP1_nocap (no upper limit on the TAC) is also shown in green.

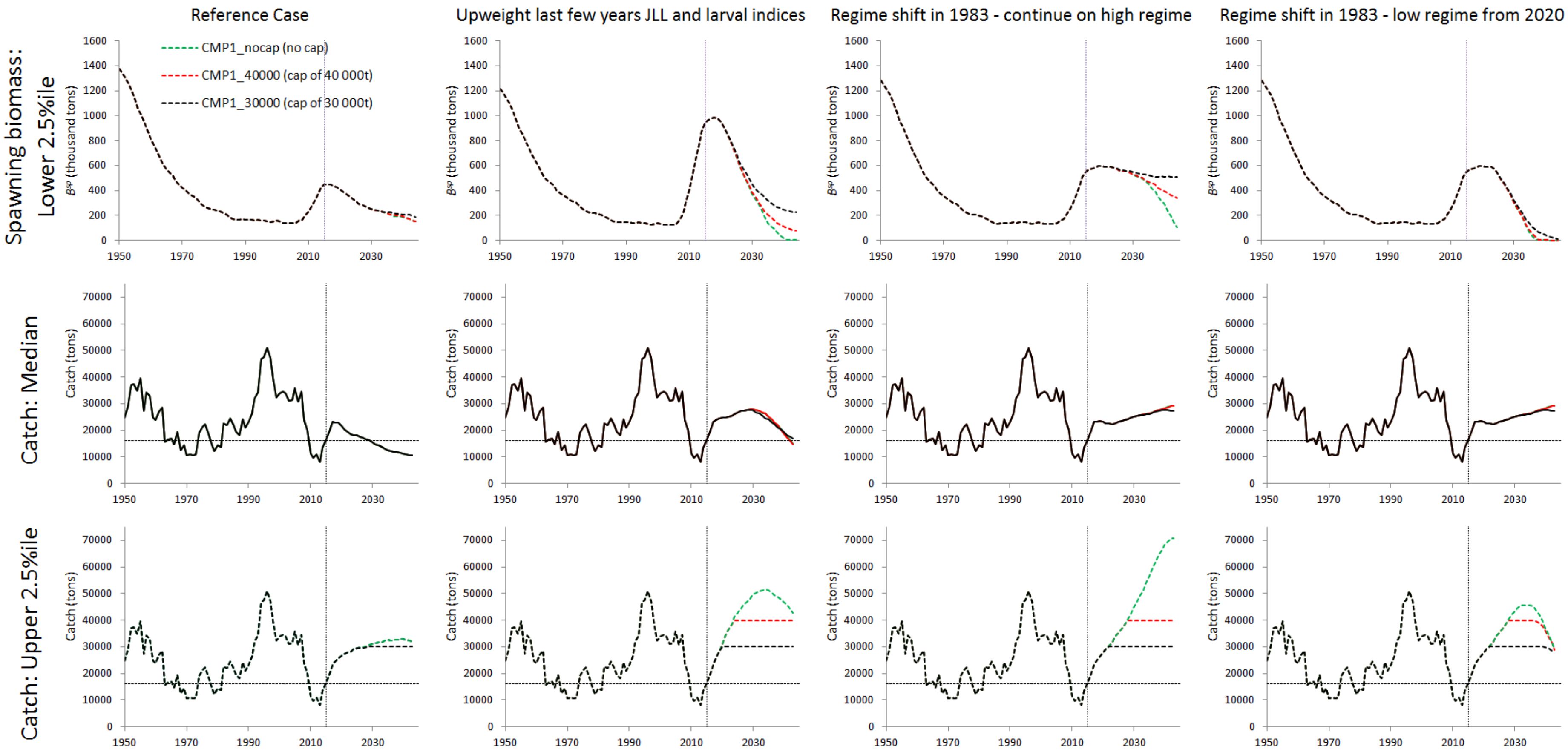

Figure 10: Comparison of various performance statistics for CMP1_nocap vs CMP1_30000 vs CMP1_40000 for the four OMs

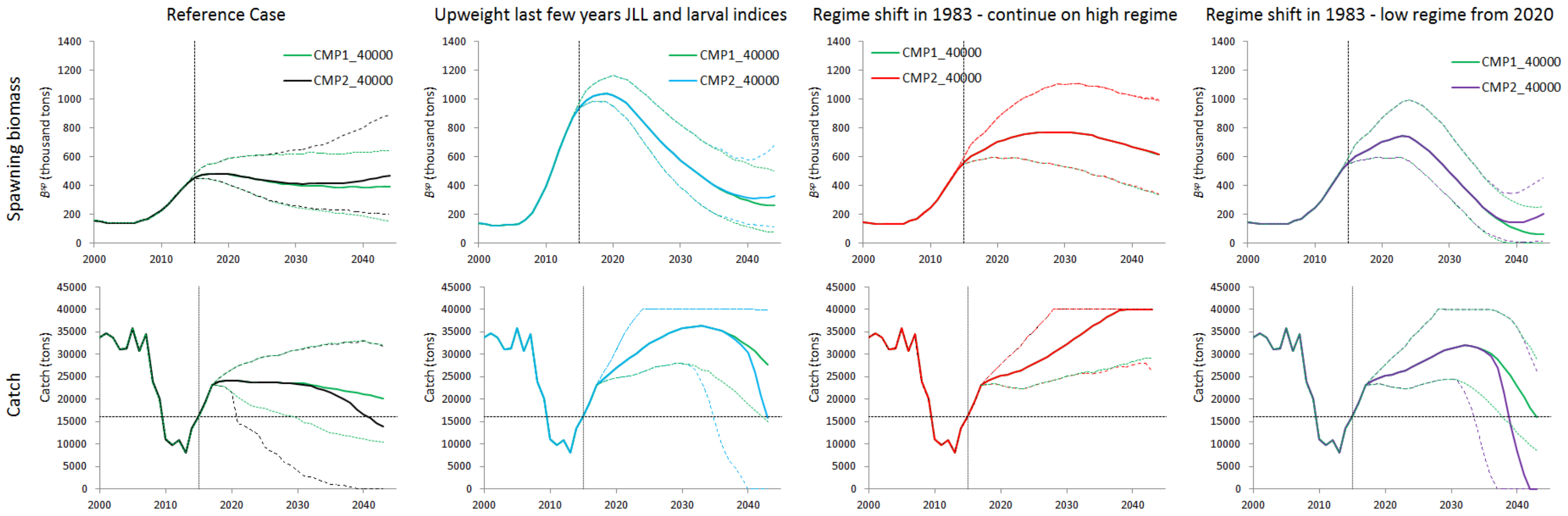

Figure 11: Comparisons of catch and spawning biomass performance for CMP1_40000 vs CMP2_40000 (extra decrease) for the four OMs.

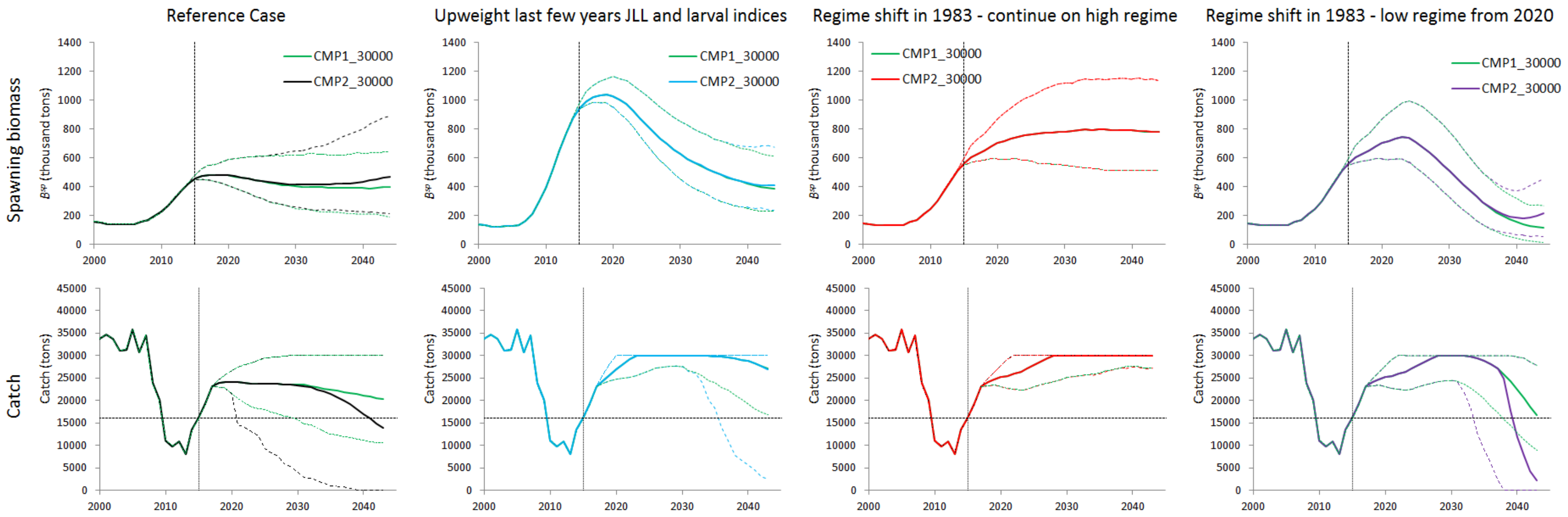

Figure 12: Comparisons of catch and spawning biomass performance for CMP1_30000 vs CMP2_30000 (extra decrease) for the four OMs.

Appendix A - The data

Table A1: Catches in mt.

	Baitboat	Longline	Purse seine	Traps	Other
1950	2865.0	0	2856.9	12198.0	6948.7
1951	3979.0	0	7259.3	9717.0	7840.1
1952	3786.0	0	15752.8	9831.0	7600.3
1953	3556.0	0	11281.0	14626.0	7866.3
1954	4430.0	0	13390.5	11576.0	5455.6
1955	4448.0	0	14294.6	11671.0	9199.3
1956	2791.0	0.0	5932.5	16323.0	2375.2
1957	3154.0	33.0	7057.6	20026.0	4045.0
1958	2829.0	2.0	7004.1	20918.0	2116.6
1959	3052.0	56.0	3628.8	14443.0	3512.5
1960	1198.0	481.0	6725.8	13320.0	2235.5
1961	1453.0	223.0	12019.0	10619.0	2553.2
1962	1537.0	2484.0	10777.3	11875.0	1884.0
1963	1178.0	2418.0	3119.1	6531.0	2244.1
1964	1079.0	882.0	4781.1	8140.0	1697.1
1965	1820.0	834.0	3846.8	9044.0	1313.4
1966	3347.0	581.0	4653.7	5373.0	702.0
1967	1805.0	441.0	6981.9	7877.0	2203.0
1968	1474.0	808.0	4547.0	4872.0	918.0
1969	1826.0	601.0	5148.7	5988.0	894.0
1970	3017.0	343.0	3269.3	3180.0	857.0
1971	3055.0	383.0	4586.8	2211.0	720.0
1972	3032.0	497.0	5045.5	1837.0	276.0
1973	3142.0	611.0	5257.5	1546.0	182.0
1974	2348.0	4651.0	9577.7	2382.0	168.0
1975	2918.5	4323.0	11677.0	2027.0	266.3
1976	1709.8	3291.0	14830.0	2008.0	354.6
1977	2813.3	2445.0	10989.0	1717.0	753.3
1978	3593.0	912.0	7556.0	1458.0	1125.5
1979	2033.9	970.0	6369.0	1350.0	1500.2
1980	1499.8	1255.0	8978.0	1642.0	875.5
1981	1222.5	917.0	8795.0	2011.0	828.1
1982	884.3	4255.0	12786.0	3673.0	809.8
1983	1882.4	3606.0	10746.0	3254.0	2293.9
1984	3961.1	2737.0	10261.0	4507.0	2961.0
1985	2281.5	1778.6	11305.0	2390.0	4255.1
1986	1413.8	1644.8	9609.0	1740.0	4839.6
1987	1820.8	1723.3	8857.0	1953.0	3865.5
1988	1935.9	2396.0	11198.0	3658.0	4929.7
1989	1970.6	2083.2	9450.0	2789.0	4768.1
1990	1717.9	2522.0	11304.0	4376.0	3326.7
1991	1592.6	6066.3	13291.0	2993.0	2485.7
1992	1298.6	6416.2	18269.0	2186.0	3679.1
1993	3495.1	5058.9	19321.0	2001.0	4391.7
1994	1979.6	9223.7	26296.0	2834.0	6406.8
1995	2807.4	12867.2	24046.0	1924.0	5645.0
1996	4989.6	12959.0	26344.0	2522.0	3992.1
1997	3524.9	10206.0	25006.0	4367.0	4050.3
1998	2561.5	7049.1	21983.0	4259.0	3865.1
1999	1496.0	6483.2	15636.0	3711.0	5128.9
2000	1821.7	7052.3	17341.3	3735.3	3814.7
2001	2275.0	7053.0	17324.4	4762.6	3190.1
2002	2568.0	5510.8	18540.3	3750.6	3400.5
2003	1379.5	5226.5	17657.4	2302.4	4596.6
2004	1807.0	4638.2	19862.5	2137.3	2935.2
2005	2022.9	5814.6	23345.9	2522.7	2139.4
2006	1115.6	4649.6	20352.1	2717.6	1854.4
2007	2031.5	4360.8	22951.5	3883.0	1288.3
2008	1794.4	4740.5	12641.3	3317.2	1343.0
2009	1297.7	3301.9	11394.5	3308.3	752.9
2010	645.5	2068.9	5057.9	2587.8	787.0
2011	635.9	2025.7	4305.9	2301.6	503.6
2012	282.25	1750.15	6105.19	2436.58	276.57
2013	245.02	620.8	5113.22	1825.17	288.44

Table A2: Commercial fleet catch-at-length numbers for each fleet considered

Baitboat	30-	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250+
1954	0	0	0	0	2117	614	1622	237	1072	678	7239	28317	23200	7524	4097	1216	0	0	0	0	0	0	0
1955	0	0	1558	9646	22421	25314	19711	47609	13532	12049	6220	12395	8230	2567	1320	391	0	0	0	0	0	0	0
1956	0	0	747	4624	11063	12226	9690	22858	6647	5877	4058	10152	7395	2349	1242	368	0	0	0	0	0	0	0
1957	0	0	826	5118	12277	13541	10749	25301	7372	6515	4603	11673	8542	2716	1438	426	0	0	0	0	0	0	0
1958	0	0	731	4526	10878	11982	9523	22379	6531	5768	4141	10600	7781	2476	1311	389	0	0	0	0	0	0	0
1959	0	0	1111	6877	15931	18032	14011	33936	9621	8573	4251	8121	5281	1640	837	248	0	0	0	0	0	0	0
1960	0	0	359	2225	4499	4977	3578	8641	3673	3507	1913	4243	2998	945	508	160	11	0	0	0	0	0	0
1961	0	0	560	3469	6754	7634	5342	13262	5668	5462	2314	3967	2501	768	410	136	18	0	0	0	0	0	0
1962	0	0	620	3840	7499	8501	5964	14845	6224	5986	2435	3929	2394	730	386	131	20	0	0	0	0	0	0
1963	0	0	440	2722	5556	6265	4527	11127	4305	4080	1837	3340	2161	669	354	114	11	0	0	0	0	0	0
1964	0	0	423	2620	5486	6215	4561	11215	4021	3769	1649	2859	1793	551	288	91	8	0	0	0	0	0	0
1965	0	0	739	4570	9564	10941	8019	19902	6879	6429	2434	3319	1769	522	260	89	13	6	63	231	334	196	63
1966	0	0	817	5061	32126	37110	22927	55835	10589	8630	2570	2154	533	118	12	2	1	3	36	182	388	270	94
1967	0	0	531	3281	11290	13043	12605	30794	6477	5401	730	292	91	71	90	63	44	7	42	158	347	355	151
1968	0	0	2637	16322	10057	11619	3841	10077	5772	5798	2302	1976	508	57	10	24	22	1	8	114	264	311	393
1969	0	0	3939	24398	31940	36897	6302	15508	3713	3255	552	423	178	85	0	0	0	0	6	154	356	503	221
1970	0	0	4875	30200	29454	34025	5243	14152	8899	6825	4147	3855	1751	1132	828	165	0	0	11	81	522	983	957
1971	0	0	226	1402	25215	29127	6081	15317	6207	6281	5945	7042	1974	822	495	100	0	3	15	102	434	973	1512
1972	0	0	141	873	24452	28309	2484	5236	2247	2346	2045	6787	3332	3133	2487	800	302	0	11	102	545	1201	1689
1973	0	0	187	1154	22101	25530	4649	11289	1999	1607	605	1691	1574	1380	3235	2994	2512	343	3	40	351	985	1951
1974	0	0	233	1443	24206	27961	10221	24887	4727	3840	1124	1104	309	120	33	22	37	55	38	114	257	545	1628
1975	0	0	2148	13305	51018	58935	2955	7512	2983	2872	646	669	220	93	12	20	4	3	70	141	343	932	3042
1976	0	0	48	1747	15067	26840	5989	6034	697	858	665	733	676	346	95	33	0	0	1	173	171	594	2047
1977	0	0	1004	8262	25875	57885	8458	11623	4915	2416	574	164	110	128	111	51	0	38	1	154	539	584	2939
1978	0	0	4486	50605	37076	30788	2753	6750	4484	9557	3854	2632	1003	201	46	21	102	219	352	831	1496	1473	2187
1979	0	0	1608	10625	3253	8504	5594	9821	5434	9069	2111	2229	843	484	250	20	750	354	82	163	246	331	1304
1980	0	0	6917	42530	9928	13560	3512	4275	1122	1014	1062	1970	1517	956	743	64	101	39	131	304	236	201	701
1981	0	0	3746	26170	25012	12064	1614	2876	1061	598	409	375	381	331	160	86	17	37	111	520	553	222	541
1982	0	66	2472	14151	9864	18638	3906	4427	1770	1151	1232	600	386	355	277	205	46	0	2	52	16	33	121
1983	0	713	33283	138203	8596	38473	5072	2069	1089	524	281	10	78	17	20	25	2	72	119	438	345	232	235
1984	0	0	2096	37819	19063	110343	31182	17669	9195	2754	6322	2623	3166	1584	445	284	23	192	97	2	1	0	95
1985	0	0	7873	50417	60121	28682	17876	16842	3045	3943	1010	703	480	164	22	0	0	26	39	130	247	104	65
1986	0	0	14743	80489	5464	25899	13489	3096	1282	3646	750	480	290	55	0	11	29	14	34	75	129	36	38
1987	0	0	3619	25170	61326	56370	4348	1638	932	2729	598	1818	1036	138	120	0	62	102	62	86	21	51	51
1988	0	671	88434	113618	32376	29472	4621	4225	1422	1368	1061	789	415	493	36	8	0	0	0	0	0	0	0
1989	0	23	5904	108768	79781	30949	8687	3062	1412	1116	920	428	344	95	29	4	3	0	0	0	0	0	0
1990	0	278	13833	56317	12620	31672	12851	11964	1800	2372	4191	1652	432	14	1	3	5	0	0	0	0	0	0
1991	0	0	712	45513	21585	43736	6971	1694	5090	2447	2576	447	523	471	251	128	32	122	32	16	35	0	0
1992	0	751	11062	26333	6624	43517	21949	1765	1505	1050	756	281	548	22	43	0	28	0	0	0	0	0	0
1993	0	238	3737	20099	68898	93411	15071	31935	8758	8528	2843	1253	726	661	7	7	0	0	0	0	0	0	0
1994	0	0	1434	27341	91397	11178	17943	4131	4814	3327	4088	1513	433	62	10	31	14	29	14	22	43	36	72
1995	0	0	24040	114513	18446	28001	64910	12177	5121	2299	725	282	210	19	7	3	0	0	0	0	0	0	93
1996	0	319	83794	160460	52815	42532	46611	26816	15497	17219	6598	2735	234	234	78	33	37	88	83	45	41	31	101
1997	0	171	26486	65516	21274	24129	57618	12041	5315	6645	3395	1951	237	106	42	106	205	360	237	288	382	382	1414
1998	0	157	34295	19312	25058	27809	15701	12909	20225	7688	1112	517	734	490	289	44	31	56	105	257	153	159	362
1999	0	2	1418	5458	2582	2444	2404	939	7163	5196	11015	3791	1733	1037	194	86	67	44	50	30	37	13	46
2000	0	0	607	31951	18065	8663	5900	4265	4281	2291	2305	4470	2488	624	758	1158	833	390	179	98	51	16	88
2001	0	0	0	631	41603	62489	10869	13175	3619	2682	1211	570	1233	1421	334	249	554	339	236	216	126	36	48
2002	0	0	176	28862	15099	59540	38584	20500	4075	1656	1005	359	158	71	156	383	375	420	260	177	91	47	39
2003	54	0	321	1296	20266	11152	11821	6210	828	399	593	1428	674	141	111	386	1142	1149	546	308	93	43	16
2004	0	0	65	38085	50135	33680	3922	5413	4912	1528	952	766	412	324	178	72	141	451	551	323	109	62	37
2005	0	0	0	82599	71765	7065	25822	3295	2495	1384	2010	1118	422	59	139	62	54	107	238	183	37	13	12
2006	0	0	0	8312	31898	7005	13495	1525	6101	1471	779	312	631	686	239	85	64	61	218	51	114	36	0
2007	0	0	1	0	5008	27117	3795	11733	16827	5635	2964	4011	1238	844	299	115	103	551	187	120	69	21	17
2008	0	0	1	11	11100	16097	19278	11538	8305	7541	2782	429	54	246	257	212	233	339	272	270	158	96	52
2009	0	0	0	47	930	8964	8222	7721	6143	2275	1252	1404	2325	1535	418	372	278	213	210	121	53	34	21
2010	0	0	0	66	1731	7823	12847	2035	2911	2001	1250	346	151	441	375	102	86	102	59	20	14	23	20
2011	0	0	0	0	656	5006	758	2895	2445	1379	1393	2119	1009	426	126	232	103	83	105	67	33	12	5
2012	0	0	0	0	0	0	117	1683	2215	1268	1450	148	82	61	24	26	47	50	42	60	53	24	2
2013	0	0	0	0	8	0	441	10	216	411	237	247	22	223	27	116	31	73	156	172	212	95	41

Table A2: Continued

Longline	30-	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250+
1960	0	0	0	0	0	0	0	0	0	0	78	116	140	54	75	683	1065	591	153	308	4	0	0
1961	0	0	0	0	0	0	0	0	0	0	32	49	59	23	31	286	448	255	74	151	23	17	9
1962	0	0	0	0	0	0	0	0	0	0	395	591	713	281	388	3461	5387	2998	778	1555	23	0	0
1963	0	0	10	59	32	37	34	89	52	89	382	439	814	228	408	2776	4267	3034	1019	1715	386	37	146
1964	0	0	8	47	24	29	10	27	16	16	8	31	172	103	119	1019	1657	994	539	618	155	73	15
1965	0	0	17	94	51	59	12	34	34	34	75	103	145	97	126	632	992	582	236	589	528	323	178
1966	0	0	12	76	41	47	21	58	42	44	12	41	94	67	84	213	390	399	334	400	408	237	168
1967	0	0	3	21	12	15	15	32	20	29	16	15	57	96	105	228	404	503	299	190	179	109	171
1968	0	0	14	83	23	51	30	79	56	58	17	49	112	82	93	240	410	790	541	437	443	480	266
1969	0	0	9	56	15	34	20	53	37	39	17	51	86	75	137	409	410	445	249	333	324	238	326
1970	0	0	1	3	2	2	0	1	1	2	5	15	20	21	146	174	121	139	48	66	69	61	633
1971	0	0	0	0	0	0	0	5	2	2	3	14	47	75	81	103	214	217	248	195	162	102	318
1972	0	0	1	16	6	7	11	22	11	18	4	108	48	27	79	187	338	370	192	285	327	174	113
1973	0	0	2	13	8	8	10	25	20	29	8	24	61	43	79	177	251	394	256	608	447	304	358
1974	0	0	2	10	271	5	1288	1291	1071	1168	774	2086	1956	1386	456	1414	1225	3115	2597	3931	4681	3502	2389
1975	0	0	1	13	115	102	82	100	361	714	462	466	491	363	502	889	880	2822	4101	5822	5999	4401	4150
1976	0	0	0	4	9	52	79	24	73	147	226	265	297	264	276	459	511	1171	1836	2414	4462	2458	2866
1977	0	0	0	0	20	5	35	7	44	39	69	177	238	426	974	1133	1674	1760	1900	1649	1574	1590	1172
1978	0	0	0	0	0	0	24	10	107	88	176	147	132	370	102	172	276	124	39	178	376	1927	909
1979	0	0	0	0	2	28	20	20	110	76	92	369	943	1070	2007	1717	1230	386	136	126	59	51	73
1980	0	0	0	0	0	15	48	62	50	40	75	189	197	295	514	606	979	763	1123	714	373	143	120
1981	0	2	0	4	17	5	26	55	18	26	88	42	208	241	564	753	701	592	705	774	287	224	393
1982	0	0	0	0	0	34	0	75	292	81	80	185	581	563	3897	2159	646	813	2838	2678	7119	1526	1725
1983	0	0	5	17	45	143	170	239	183	455	745	717	991	1529	1945	1741	1840	3953	1957	1722	1954	1297	482
1984	0	0	12	9	58	81	85	80	163	160	232	332	526	785	1081	1858	3548	2493	2078	1242	706	493	629
1985	0	5	20	16	97	113	130	136	138	128	225	329	406	456	589	380	593	797	1077	1354	1524	1179	1231
1986	0	0	0	12	104	211	78	389	202	222	537	495	641	440	518	491	704	1384	1634	1564	1081	517	182
1987	0	0	0	0	58	87	26	89	104	100	120	292	501	735	748	785	798	982	972	1234	1212	1219	779
1988	0	0	0	0	25	86	72	289	178	250	132	190	479	1016	1019	1510	1419	1600	1811	1419	1132	877	602
1989	0	0	0	0	188	409	292	753	501	358	469	564	694	1110	1271	1257	1104	1080	1189	668	925	667	1054
1990	0	7	357	73	182	803	392	555	394	325	330	616	899	1002	1342	1961	2276	2524	1988	1149	741	594	723
1991	4004	4142	243	213	293	538	432	603	295	393	740	561	876	1562	1940	3163	7074	6294	7236	2934	1494	638	1761
1992	17	441	529	612	1246	736	507	798	795	611	1101	1626	1456	1300	2068	1972	4766	3505	6209	4302	3648	2606	1982
1993	1111	1389	589	1345	7248	1275	1448	193	870	1209	1545	2249	2031	1532	1469	1402	1648	2778	3231	2786	1841	1436	3345
1994	621	11959	16776	2929	15369	4554	1147	2425	2678	1811	950	2212	1587	4737	5024	4476	4870	3979	4574	5167	3527	3022	4136
1995	49	525	138	102	578	438	326	430	887	1014	2009	1902	5326	6157	3949	4328	6760	4635	5219	6939	6438	4144	9777
1996	0	0	26	748	892	2414	371	401	384	915	1001	1340	1628	2788	4487	5298	7443	7058	7374	7054	5938	4538	9220
1997	0	0	25767	3842	8745	19794	6727	3274	1632	2504	3042	902	2357	3224	4156	6057	8248	7305	7212	5408	3318	2479	4211
1998	0	0	0	0	0	39	3	114	317	140	159	422	677	1556	1790	2742	3731	8142	7759	5016	3284	2085	2525
1999	0	0	70	473	137	96	385	543	739	1412	1860	3253	1431	2142	3822	5816	5854	6237	5677	4341	1945	1053	1212
2000	0	105	541	71	892	226	111	1239	1748	1507	1920	1419	2409	2519	2494	4142	6846	6745	4953	3762	4280	1990	741
2001	0	0	141	481	859	511	9577	2534	803	971	926	846	2614	5903	7414	7681	6610	6239	4747	2933	1531	1149	701
2002	85	931	591	75	2239	2285	2267	1671	1140	867	744	811	958	1737	3013	6813	7805	4708	3909	2720	1717	588	547
2003	0	1402	6852	1466	2927	3631	2957	3592	1926	1731	1616	1622	2555	2304	2392	3075	4651	6289	4993	2461	1201	649	542
2004	0	893	938	844	2627	1167	1544	1161	690	1523	1118	1293	972	1763	3415	2933	2834	3446	4396	3071	1600	735	1072
2005	0	45	25	82	456	393	1355	481	552	710	996	1553	1890	1731	2495	2756	4546	5812	5905	3476	1897	713	616
2006	1	46	31	2720	7883	6933	11872	6473	1296	786	624	1094	1402	2249	2643	2275	2197	2174	2747	1578	1151	847	475
2007	0	735	434	56	3164	27042	2109	4510	2548	1824	1377	1063	1395	1221	2390	3838	3319	2946	3103	2053	1279	824	531
2008	1	0	22	215	14760	9765	6566	4278	3821	2183	3161	2714	2062	1636	4727	4840	3434	3723	3109	2034	1462	931	854
2009	1	4	143	652	558	6618	3094	1231	1259	1275	768	636	2808	6578	1697	2517	3156	2020	1357	869	534	330	324
2010	0	1	46	15	188	105	1261	1421	3425	3306	2318	1059	730	554	2139	5138	2240	867	826	589	268	144	116
2011	0	0	0	0	74	23	80	580	1108	770	1256	750	598	309	318	714	3591	3358	1075	748	593	256	177
2012	0	0	6	7	74	139	294	384	2132	1271	351	198	127	180	488	422	924	2551	3088	1025	327	173	181
2013	1	11	3	30	36	39	265	411	2122	2224	807	353	262	177	153	1092	1608	1709	2253	1589	445	87	92

Table A2: Continued

Purse seine	30-	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250+
1950	15217	0	3996	24752	13339	15409	72	188	112	492	501	1479	15066	10046	1617	549	226	340	206	242	116	68	28
1951	4230	0	480	2978	1605	1854	543	1450	867	1770	1867	5822	12989	23212	19212	11284	2924	680	1097	268	266	153	62
1952	385	0	123	770	410	474	288	1512	469	478	672	1295	12483	26269	18404	50877	25607	6586	2241	1283	715	389	163
1953	54178	0	366	2306	1228	1422	496	1315	776	867	693	5543	9218	13057	17819	29184	16276	7308	2433	1191	710	378	151
1954	192	0	558	3451	1861	2150	24	62	51	60	713	1267	1625	4409	9771	4098	9438	19339	15313	12094	5815	2789	782
1955	0	0	41	407	203	5653	18961	5360	6544	3060	5343	2016	7911	8645	5872	6781	9157	10610	12209	15183	8128	3604	609
1956	0	0	28	279	140	3884	12993	3660	4471	1846	355	437	1674	826	1081	599	653	1537	2242	5856	6530	4747	1892
1957	0	0	28	280	140	3897	13035	3672	4487	1850	352	302	1131	5666	9236	3843	5372	5608	4975	6151	3245	1312	234
1958	0	0	129	904	2683	5766	14816	6814	5802	2937	4391	15575	13290	4783	4283	3710	3488	2816	2149	2387	2102	2442	1593
1959	0	0	18	175	88	2435	8144	2294	2802	1156	177	140	67	238	650	297	957	1675	1808	3383	3562	2985	1004
1960	1195	0	264	1631	4107	3962	3961	8390	3497	3211	3886	12531	10017	3250	2100	1771	2271	2983	3523	4531	3854	2866	1183
1961	12870	0	478	2915	6832	6971	6496	14409	5541	5082	5065	15395	12180	3954	2196	1007	1540	3622	4574	10119	9706	7722	4139
1962	142608	0	355	1774	4593	4806	4070	8970	3105	3718	3035	7681	5977	1931	1067	503	334	586	1526	6536	11035	11222	6903
1963	796865	0	355	2183	5061	5509	4436	10305	3108	2867	2370	5941	4537	1451	825	356	454	1417	1519	788	405	284	384
1964	18917	0	1540	9538	12200	13708	9249	22389	7447	6831	3259	7171	5124	1673	901	366	186	598	1248	1213	1140	1867	3007
1965	623	0	1188	7057	7797	8908	5151	12888	4877	4550	1660	2349	1502	498	239	68	42	58	102	294	1127	3072	5119
1966	288479	51234	1156	7396	13653	18705	22747	32255	14697	13785	4031	4690	1534	499	156	35	0	142	421	305	469	903	2491
1967	461321	76221	1121	7232	15032	21799	29851	37512	18530	17082	4942	6281	2162	1052	116	214	137	245	275	364	718	1358	5848
1968	505125	0	261	2035	3476	11373	30581	15147	17357	16081	3625	6396	2050	338	354	214	28	50	134	182	229	443	2353
1969	15750	0	2653	16037	8955	23080	32763	27999	14022	15229	6025	2373	1347	474	810	788	689	326	241	454	471	800	3121
1970	24546	0	348	2366	4714	7212	6284	9364	3232	2756	1776	2045	2221	1836	1602	1207	1653	1486	1910	1148	157	189	1398
1971	42316	29	300	3894	10746	24662	18520	6368	3692	1581	369	330	856	2053	2879	3688	2984	1793	917	488	471	772	2756
1972	936	92	1727	2361	15722	78723	45952	19205	17825	6023	1745	1035	860	666	367	512	1326	317	260	340	543	846	2171
1973	0	4	369	5504	10924	27533	41597	17780	8909	2550	1532	1368	1325	1430	2475	3056	3388	925	612	506	666	946	2474
1974	2368	1856	30586	11324	15647	68069	20418	18964	22849	24327	5008	3452	1750	1677	1671	2347	4633	2871	945	1181	1671	2388	5274
1975	38651	2140	35017	25602	44238	170434	60000	35634	10245	9933	6798	5269	4480	3165	1459	2072	1855	2106	1056	2491	3183	2430	4938
1976	948	354	1973	9731	28920	65206	188745	90429	34500	21526	13818	5217	3018	2795	1225	1006	1524	1442	1072	1576	2176	2508	5910
1977	9294	10629	26910	33865	49962	67050	76900	34646	33622	12614	6076	3302	3101	2222	1278	481	308	508	974	1216	1849	2529	7390
1978	0	46	3593	17286	82729	18357	75981	52700	21243	5001	813	1256	371	1564	703	824	594	1368	1524	959	946	1152	3165
1979	2250	208	1041	1147	4851	17233	45098	24310	27690	12169	3552	1500	392	187	136	300	184	1156	1004	669	1947	1829	3524
1980	81	3128	28454	47949	46319	55725	76951	35518	24805	7587	4143	2256	1001	763	765	683	672	1477	1572	1749	2076	2141	3535
1981	2302	518	8893	25701	103975	109991	126060	34802	11862	3241	6870	4154	1367	1747	1117	1018	1000	980	1294	1186	714	560	1152
1982	818	6547	93867	165261	191120	99394	136240	75149	42118	13856	4985	2026	944	819	662	993	933	1104	1390	1860	1175	920	962
1983	49	2966	86318	125536	67865	73439	87736	54804	21574	9828	5821	4590	1853	2040	4542	2087	1614	4650	1367	1568	1471	1326	461
1984	0	11993	16004	29307	167398	196676	55555	20144	12111	9413	5747	2819	1857	1331	1643	1373	912	1470	1563	1986	2795	1528	1797
1985	5	376	10996	22281	63193	105627	101615	130493	52281	18280	6565	2948	2076	1366	246	247	221	525	912	1284	1027	530	380
1986	25	2705	84553	230356	44262	68595	100731	36862	52184	16171	5821	3370	2094	1477	989	557	576	391	476	980	834	602	453
1987	5	1305	29211	113214	57404	204733	99814	32360	20252	12436	4802	3135	1171	1088	654	516	612	1051	623	489	407	209	133
1988	26	3665	131094	221809	63191	52024	135034	78720	38254	19046	6998	4416	2178	1600	1349	892	761	1594	850	581	341	146	168
1989	12	1179	26450	108467	91955	161437	62390	44125	34774	31219	6675	1250	587	853	1851	654	394	794	354	395	342	196	353
1990	451	19816	129498	123270	142757	108799	129969	44950	30551	25430	5080	14087	532	335	631	652	1074	1433	721	413	385	188	270
1991	1097	4668	66390	79907	144042	143551	139795	51972	32565	25817	3928	20904	569	349	559	922	2002	2957	2361	1099	701	377	558
1992	0	19	17385	55207	123473	291451	157803	106628	47660	8459	2370	10274	4478	5399	5647	4800	3673	4656	5113	2082	869	296	348
1993	1711	916	111274	65736	205047	307925	191623	69950	28451	10931	10441	6936	4615	5560	5011	4986	3868	5182	5040	2005	819	639	1027
1994	30	943	16598	101541	229485	130521	101885	65507	29146	19142	15591	13516	14150	10457	8841	8218	11202	14130	14015	11078	3050	1302	1487
1995	3	236	34305	120037	56630	139232	169571	104514	29434	20176	15228	30112	13824	8257	7435	6468	4878	6102	12817	9486	3203	795	385
1996	0	3	27991	83352	367363	160007	157086	72772	#####	33163	18630	12035	10211	7229	4337	5479	6477	6664	13303	6565	3245	311	120
1997	0	33	8380	95729	74332	232981	96151	53662	62233	37438	31065	27505	18525	12331	9742	12939	12927	16596	3492	641	426	461	644
1998	0	0	32641	287929	42811	196631	204229	60696	50905	56336	28135	41297	35771	2756	1427	1369	705	1070	1054	1165	1345	410	826
1999	786	5369	46618	132168	85863	169699	29859	82298	50611	24897	11595	5427	3176	2062	1306	1665	14563	8363	1385	1675	1315	719	459
2000	0	87799	463700	187730	157066	204495	162048	28463	17553	20894	17967	19011	13519	3823	2090	1776	1421	1161	1192	1094	935	876	1692
2001	0	0	0	43	221989	84959	48545	53459	41932	12894	10113	5793	5559	14488	3201	4706	2255	11482	15577	1665	930	683	1513
2002	1630	188	71	11674	140779	166268	134667	43093	27164	20102	11715	13694	8624	3098	1507	2500	3303	4827	15787	2803	2058	1543	3086
2003	5545	511	0	310	52588	54176	24506	16035	8127	15824	16463	17040	11940	9622	4080	6538	2869	8350	15766	10699	2614	2269	2535
2004	0	0	0	28003	87411	69545	107822	32115	15651	11505	5120	3717	8986	17616	9899	1236	8916	12158	19771	2633	1900	1771	4083
2005	0	0	251	71833	91996	157414	144642	34599	19496	12818	12353	5166	6878	11847	10403	6816	5864	20023	26462	4700	459	536	362
2006	0	0	6021	60946	132605	16407	159179	37844	29271	12779	4069	13362	8014	3769	1574	11154	25556	9285	10055	5606	3287	114	343
2007	0	0	0	0	20734	8858	207	16322	79765	36820	31712	22287	6365	11427	2390	6268	15448	10839	25658	9158	883	1241	1620
2008	0	0	3	0	0	0	0	8890	18994	28918	19087	26157	7547	9283	3676	9009	7183	4046	2618	2738	2571	1663	3036
2009	0	0	0	0	0	0	276	0	11861	33452	13158	4767	15797	25102	478	12978	3909	3019	9338	789	281	224	401
2010	0	0	0	0	12	0	0	1061	3669	17300	2186	13784	6394	10443	3499	6242	3739	24	1	1	0	0	0
2011	0	0	21239	32181	9654	9654	3890	844	3630	6060	9523	7840	5926	7217	3671	3247	348	204	440	513	467	187	140
2012	0	0	0	0	0	114	114	341	2058	671	458	2971	2051	5393	19331	21642	806	119	142	0	0	0	0
2013	0	0	0	0	0	0	0	0	991	661	2221	5533	11740	11334	7946	11507	15322	3188	1441	0	0	0	0

Table A2: Continued

Traps	30-	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250+
1950	91094	0	23922	148171	79851	92242	673	1205	966	3616	3251	3170	4503	9574	9760	12268	18352	11271	4571	1337	694	407	168
1951	30757	0	3493	21655	11670	13478	4117	10597	6518	6867	2869	2421	3568	7031	7207	9507	14391	9285	4383	2391	1931	1109	452
1952	1110	0	354	2219	1183	1366	1033	4427	1603	1944	2848	2817	4122	8283	8474	11067	16719	10670	4894	2460	1914	1122	469
1953	212793	0	1439	9057	4825	5586	2253	5265	3422	4068	4273	4171	6126	12428	12717	16493	24780	15722	7005	3323	2455	1439	593
1954	341	0	991	6131	3308	3821	266	185	531	847	2973	3154	4869	9011	9454	12941	19701	14355	7262	2407	1653	1016	457
1955	56	0	38	231	126	144	258	107	616	924	3247	3393	5309	9705	10315	14190	21573	16613	8295	1261	334	287	175
1956	67	0	8	49	27	31	435	247	815	1361	5155	5226	7800	15348	16010	21123	31845	22435	10315	1599	331	276	164
1957	1	0	2	12	6	384	6	1155	2479	7622	5616	4538	22134	26707	26301	19668	10853	19372	14640	5586	2843	4764	2283
1958	173	1516	11343	2263	434	133	20	423	2207	5239	13288	15844	14230	17336	21765	21567	19645	9622	12006	10976	4847	6010	3600
1959	56	0	3	14	8	8	22	783	1644	591	1259	2925	5715	7520	8794	11288	17869	16243	14054	9241	4495	2415	343
1960	44	0	2	11	6	7	21	98	596	769	2467	3288	6393	8073	9372	17226	19753	15202	9411	6227	2781	1596	245
1961	374	0	3	14	7	9	24	205	549	651	789	2590	5964	4278	3359	13560	20116	14830	7462	3966	1484	755	160
1962	3501	0	2	0	2	1	4	4	239	716	1901	4922	6176	3581	7448	15883	18348	14591	9930	4752	2281	825	239
1963	152955	0	5	28	15	17	16	42	255	980	684	2166	2326	2804	1457	2221	2944	9124	9391	5177	2211	1030	327
1964	351	26	43	233	186	360	319	2434	3170	3368	2739	2346	2142	5217	2428	2228	2170	5130	10099	10197	4020	1722	317
1965	38	0	58	334	180	208	40	444	743	2811	1090	2248	3203	4828	5083	866	1586	2156	4067	8277	9658	5094	2598
1966	4245	754	4	24	13	14	6	141	188	1787	1715	7647	4265	3097	3493	2077	2387	1858	3229	3968	4063	1930	367
1967	8078	1335	1	6	4	5	5	780	598	781	2411	5517	6184	11250	1845	2329	3295	6003	3594	2925	4633	4241	2107
1968	1061	0	0	0	0	0	0	111	186	1120	2066	1833	2084	4528	6608	2080	1229	1782	3058	2556	2513	1497	1553
1969	35	0	470	30	1633	114	11	28	20	661	1219	3653	2046	1311	2804	3828	2356	2124	2360	3336	3592	2657	3545
1970	250	0	2	10	6	7	0	4	87	34	145	456	1312	1106	1783	1874	2707	3251	2390	1795	1573	785	852
1971	3071	0	0	0	0	0	0	37	2	78	3	179	479	1062	1104	1304	1597	964	796	862	907	1009	1591
1972	999	0	1	11	6	7	6	39	40	75	48	158	253	452	735	765	779	708	1526	1162	1036	730	918
1973	17446	730	1	6	4	4	4	24	15	70	100	173	140	200	287	461	606	667	1063	953	921	805	946
1974	1628	0	0	0	0	0	0	22	20	68	160	292	315	531	380	585	673	809	1480	960	1232	1416	1726
1975	0	0	15	29	8	0	0	0	23	107	266	356	310	334	195	393	343	379	697	1060	1684	1470	1525
1976	0	0	0	0	0	0	0	11	18	43	110	286	370	351	250	172	131	342	574	1118	1309	1447	1955
1977	0	0	8	15	4	0	14	0	0	24	36	109	263	318	306	220	199	458	686	954	1031	1259	1572
1978	0	0	0	0	0	0	0	0	0	8	38	56	186	188	347	286	371	382	421	840	890	905	1393
1979	0	0	0	0	0	0	0	0	4	12	119	290	356	362	337	639	544	889	824	613	741	587	896
1980	0	0	232	0	2	0	9	0	29	72	85	93	217	368	538	244	431	797	910	1044	1033	948	1191
1981	200	0	0	0	0	0	100	382	274	436	279	597	836	1039	1872	1501	898	1037	1451	1390	921	444	538
1982	0	0	0	0	0	8	289	523	169	488	502	405	749	1609	1702	2195	2265	2213	2163	3305	2070	1398	1219
1983	0	0	0	10	0	35	53	20	45	161	260	432	548	646	848	833	1315	3060	2016	2274	2504	1974	962
1984	0	0	84	56	406	532	350	392	378	338	360	526	1017	975	1488	1833	4002	4927	3932	3895	1897	1007	728
1985	18	0	3837	0	0	0	0	54	85	412	129	338	558	439	463	556	739	1740	2047	2016	1846	899	1044
1986	0	0	419	3077	14753	9442	1188	490	0	0	0	12	48	138	176	136	276	418	1007	1654	1421	788	768
1987	0	0	0	0	0	3	11	80	415	743	652	456	333	360	422	388	625	738	1189	1804	1608	952	822
1988	0	14	128	95	39	1	7	45	14	30	65	218	695	748	811	670	806	892	2231	2242	4005	2571	2157
1989	0	638	236	0	0	0	3	0	0	33	169	355	1171	1458	2639	1125	1580	1252	1632	1238	1869	956	1335
1990	0	0	0	0	0	0	0	4	13	52	683	151	663	2388	4745	3967	6543	2361	2080	916	2060	1114	1276
1991	0	0	352	0	228	1907	704	3129	1222	888	853	1798	1792	1115	1049	1495	2581	2977	2013	866	660	526	1377
1992	0	11	18	1	129	17	40	46	41	70	251	313	964	1533	1766	1598	1701	2237	2163	1215	690	323	382
1993	0	0	2	5	22	5	6	12	28	63	55	45	173	172	366	578	1113	1170	1380	1513	970	1249	1421
1994	0	0	0	4620	0	0	26	162	256	272	1558	2294	2936	2385	1100	1022	935	1108	1655	1251	1091	899	1678
1995	0	0	303	5	0	0	0	28	48	237	283	307	342	243	368	588	1555	1285	1588	1096	831	492	1370
1996	2	0	459	8	26	2	4	118	455	1333	2878	1433	1067	576	787	580	861	943	1215	746	1116	737	2787
1997	0	0	0	0	8	38	15	141	204	1461	3223	1863	2157	1320	1964	1839	2391	2433	4694	2637	2136	964	2214
1998	0	0	0	0	0	0	1	5	7	101	199	347	1137	1432	1542	1787	3508	2729	4056	3140	2246	1112	1909
1999	0	0	0	0	0	0	0	145	448	280	348	330	739	619	862	853	1356	1518	3805	3124	2234	1374	2452
2000	0	0	0	0	0	0	0	0	313	1138	1875	2255	1820	1742	2388	2119	2749	3304	3945	2277	1202	896	722
2001	0	0	0	0	0	13	274	504	1426	1461	1984	2142	2559	2611	2487	3628	3827	4297	4065	3127	1778	951	698
2002	0	0	0	0	1	9	149	271	712	641	869	851	1044	978	1389	1912	2274	3231	3255	2992	2404	1123	1117
2003	0	0	0	0	1	0	1	5	73	240	482	708	716	708	674	2097	2868	2142	1793	1267	1125	707	467
2004	0	0	0	0	0	11	19	71	84	131	252	301	312	293	319	638	1749	3125	1843	1546	1266	786	521
2005	0	0	0	0	0	5	22	39	48	82	143	187	360	561	970	1082	1367	3211	3194	2345	1405	496	378
2006	0	0	0	0	0	3	20	29	279	227	496	433	1888	1656	2587	1709	1772	1732	1407	1757	1467	1266	805
2007	0	0	0	0	0	11	22	56	124	177	550	434	2842	2499	2981	2309	2126	971	1531	2589	1980	1870	1252
2008	0	0	0	12	120	229	35	67	61	120	200	150	322	337	497	1403	2306	3095	2455	2723	1856	1183	2102
2009	0	0	0	0	0	0	0	0	73	336	367	645	606	582	965	1654	2080	2031	1883	2707	3031	2088	970
2010	0	0	0	0	0	0	0	2	4	797	24	63	1020	1436	666	1565	3094	2345	2051	1769	1013	856	734
2011	0	0	0	0	0	0	0	0	107	440	583	458	322	201	370	778	985	1675	1857	2241	1732	1086	947
2012	0	0	0	0	0	0	0	0	13	2	78	530	457	215	208	676	1492	2539	2307	2354	1693	946	739
2013	0	0	0	0	0	0	1	19	18	9	101	157	174	279	838	1231	1117	1987	3276	2691	1539	1295	1049

Table A2: Continued

Other	30-	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250+
1950	23324	0	6125	37937	20445	23618	251	335	344	1145	2119	2579	10355	10715	6438	7262	10519	6486	2555	607	178	104	43
1951	10483	0	1191	7381	3978	4594	1485	3639	2322	2797	2513	3361	5989	11532	10619	10135	11605	6908	3102	1025	658	378	154
1952	563	0	180	1127	601	694	521	2247	809	977	1498	1584	4054	8366	7165	13770	12412	6415	2834	1512	1260	933	453
1953	91604	0	619	3899	2077	2405	982	2271	1487	1788	2047	2403	3602	6888	7420	10104	12939	8148	3889	1806	1272	788	331
1954	231	0	671	4148	2238	2585	96	97	144	256	972	1076	1582	3165	3678	4188	6675	5630	3773	2936	2113	1199	656
1955	427	0	326	2112	1133	6005	16666	4868	5977	2885	2701	2346	3570	6452	6293	8075	12046	8208	5085	4400	3157	1508	544
1956	0	0	15	149	74	2064	6906	1946	2472	1052	155	210	474	110	264	714	1164	1971	1611	1073	1640	1146	561
1957	0	0	28	278	139	3925	12944	3742	4482	1931	365	283	396	869	1136	766	1424	2103	2347	2816	3190	1786	1070
1958	0	0	13	133	66	1848	6189	1795	2497	1143	721	439	207	666	1009	956	1280	659	499	870	1176	1167	795
1959	0	0	17	173	87	2413	8082	2467	2927	1221	251	800	375	330	470	594	1688	1356	1571	1475	3142	2673	1346
1960	767	0	35	275	141	1339	4810	2366	3257	3402	1767	1479	765	1857	1321	1192	1195	1242	545	532	930	813	286
1961	5649	0	44	352	165	1961	6997	3033	4701	4540	1276	2080	2229	1864	552	1831	1298	1389	984	540	400	640	544
1962	57663	0	31	51	48	666	2428	758	1589	2058	1451	2249	2441	1730	1846	1008	1148	658	198	356	436	418	432
1963	410364	0	13	186	75	2053	7420	2190	4358	4530	1176	3360	1745	2458	976	1280	102	653	606	530	148	410	11
1964	5187	0	261	1776	911	3855	10889	4051	6553	6123	1301	2592	1253	1692	730	530	277	166	111	557	19	50	89
1965	223	0	299	1806	960	2255	4525	2005	3315	4207	1004	1711	1205	1748	2110	182	223	262	151	39	38	75	151
1966	62116	11032	50	323	174	199	87	249	202	733	410	3089	1544	654	710	225	56	34	102	70	71	25	1
1967	73867	12205	8	58	33	58	114	333	225	233	476	1361	1378	2587	426	380	516	986	808	765	714	841	1298
1968	106840	0	0	0	0	0	0	33	62	269	549	407	469	1010	1504	343	184	107	181	188	299	137	421
1969	0	0	0	0	0	0	0	0	0	226	411	1286	613	358	748	835	188	282	161	262	314	246	519
1970	12004	0	68	477	273	307	0	171	239	373	220	2	88	5	106	221	698	845	1111	729	181	155	37
1971	42857	0	0	0	0	0	0	0	13	21	13	31	35	147	124	145	131	160	139	182	347	584	716
1972	19971	0	17	153	85	102	85	205	155	175	45	23	18	40	29	42	39	30	31	57	129	224	297
1973	39327	1646	5	28	268	309	65	161	43	43	20	23	18	39	27	37	30	22	26	46	65	94	120
1974	39327	1646	2	13	8	8	9	26	22	25	13	14	14	29	24	36	29	44	31	52	78	88	91
1975	39185	1640	11	72	951	1097	407	999	228	202	80	77	42	31	28	60	73	91	53	87	117	82	67
1976	39293	1645	6	36	66	106	29	49	28	34	20	26	32	34	19	21	35	116	153	195	252	168	204
1977	122251	14043	2	62	80	355	66	80	54	49	17	43	98	124	155	128	119	269	363	436	251	352	544
1978	102821	11606	44	5902	6303	3470	947	1427	684	1787	835	580	251	91	66	74	101	150	152	191	294	463	1104
1979	29621	1160	6	96	188	851	944	1149	890	1448	785	235	226	318	802	515	645	433	512	443	448	703	1536
1980	36353	854	2033	15607	3917	5477	1588	1911	612	585	653	1189	960	627	537	284	319	178	187	166	134	97	118
1981	6214	0	1382	21952	7487	7414	2258	2046	1396	435	500	92	96	123	249	250	181	207	293	330	159	117	116
1982	83125	8032	1343	10506	4820	3448	1573	1343	839	239	193	97	87	118	112	140	140	168	215	249	230	249	404
1983	226640	106617	40671	188731	9138	8926	1859	1332	408	391	279	107	92	139	204	136	183	520	356	329	232	192	60
1984	1638	310	13374	33705	19455	37527	11850	2575	3100	1352	1573	544	453	323	330	467	652	966	1063	1113	926	701	743
1985	9187	16855	6433	10595	10554	13263	10991	15134	4675	2066	1002	899	1132	715	938	1141	1388	1520	2097	1929	1418	1604	1142
1986	20718	12931	29570	126968	16245	10464	6009	2541	4503	1853	508	990	600	631	551	645	1239	1550	1607	2410	2296	2309	1069
1987	83027	25633	10699	31922	14467	21290	3583	3205	2858	2321	1473	2395	1688	2935	3096	1432	872	1484	1493	1418	787	695	838
1988	27855	4081	71561	112611	22198	7800	8587	5410	2791	1291	1200	758	2095	3614	3329	1263	1261	1517	1662	2562	1101	666	810
1989	17029	1547	63118	80361	38199	33531	3179	6864	4444	1315	1599	861	939	1725	1817	1029	816	1189	1090	1915	1924	597	1379
1990	33841	35563	14727	57764	10724	12003	5959	2591	1325	1385	2281	1860	1261	947	1005	1420	1652	1473	1727	1393	626	321	610
1991	34622	75604	5314	25324	10979	8391	1281	1841	1646	950	1070	578	528	399	318	643	1817	1535	2563	1130	386	67	194
1992	35183	14342	52263	65952	7106	25371	9740	2132	1898	1148	969	320	631	779	788	1654	2087	3627	2244	1074	254	443	259
1993	11208	6126	27173	47400	30475	58166	11387	10004	5372	2451	1784	2432	2145	1298	1001	605	1128	944	1784	1543	588	465	897
1994	10841	13227	11224	39672	17131	12240	14488	12456	4813	2845	2844	2910	2131	2693	2898	3934	3504	3189	3013	2498	1253	988	1467
1995	30057	29177	15465	103578	10468	11448	14914	4482	3082	3404	4790	5457	6170	3589	1898	2436	1963	2310	1486	1754	791	784	1050
1996	26950	25008	39116	29808	23464	13882	6680	6360	4483	3703	3181	2518	2455	1958	885	903	1225	1244	1717	1135	967	833	793
1997	556	4515	38508	29760	9039	17819	11211	5676	3515	2926	4518	4566	3621	1641	1610	1276	1723	1853	1447	905	743	480	615
1998	0	1878	34342	42496	10185	23127	24712	6734	5062	2017	655	3502	4473	973	1024	2630	3003	1830	686	363	219	217	176
1999	351	1648	5854	43401	25118	36145	3662	10743	5392	2785	4301	2415	1989	1382	1190	1316	5352	3165	1202	641	270	213	1379
2000	0	1559	22131	27542	25787	15476	9188	4556	3881	5593	6045	6579	3613	1303	1191	1282	1570	1089	1108	807	561	256	413
2001	0	0	1393	1274	27980	31838	10875	11919	5255	2651	1866	1692	1673	1665	876	1798	1403	1839	1523	354	182	105	206
2002	0	147	2152	10684	14018	31970	21573	10110	3824	2584	1629	1656	1638	1679	1084	1395	1598	1388	1512	640	551	298	308
2003	672	16	724	2713	35391	21438	14368	6705	2565	2066	1863	3513	2175	1967	1448	1442	1574	2817	4543	2108	674	328	167
2004	7952	2570	11469	15694	16741	18275	6469	4381	3015	1605	1176	634	1572	1862	1445	688	976	1429	2315	734	484	351	562
2005	459	2496	5718	48716	71889	28998	22402	6145	3231	730	862	1424	678	98	77	46	17	137	222	75	62	35	60
2006	243	1298	2475	12155	62554	20174	26017	2550	3523	748	473	753	980	799	291	93	47	192	303	143	94	73	123
2007	0	59	61	188	366	2790	902	1451	3561	1808	1325	924	1201	1478	682	718	969	556	1084	369	65	42	27
2008	0	0	3	143	1215	1914	582	722	1049	1850	1691	1376	1800	1371	818	1418	516	544	371	228	387	86	193
2009	0	0	13	162	61	853	703	468	795	1561	731	583	1333	1564	543	844	366	188	400	51	32	23	11
2010	0	1	36	0	142	127	867	563	1724	2919	2133	1738	1467	769	470	476	354	107	70	78	29	19	0
2011	0	0	0	0	265	84	278	2256	4372	1215	756	503	290	389	106	118	143	160	135	70	51	33	30
2012	0	0	2	4	22	66	80	103	1123	583	192	257	137	142	106	77	263	240	166	93	71	40	26
2013	0	43	11	0	25	35	91	305	751	933	252	104	133	98	102	99	194	334	234	116	85	153	233

Table A3: Index series used – values followed by associated standard errors (where available) are given.

	Mor&Sp_Trap		SpBB1		SpBB2		SpBB3		JPLL_EastMed		NorPS		JPLL_NEA1		Larval index	
Units	numbers		biomass		biomass		biomass		numbers		biomass		numbers		biomass	
1952	-	-	179.22	0.43	-	-	-	-	-	-	-	-	-	-	-	-
1953	-	-	184.74	0.53	-	-	-	-	-	-	-	-	-	-	-	-
1954	-	-	226.46	0.41	-	-	-	-	-	-	-	-	-	-	-	-
1955	-	-	187.01	0.42	-	-	-	-	-	-	36.20	-	-	-	-	-
1956	-	-	470.53	0.43	-	-	-	-	-	-	21.25	-	-	-	-	-
1957	-	-	315.05	0.41	-	-	-	-	-	-	28.61	-	-	-	-	-
1958	-	-	252.25	0.41	-	-	-	-	-	-	24.13	-	-	-	-	-
1959	-	-	506.79	0.41	-	-	-	-	-	-	32.41	-	-	-	-	-
1960	-	-	485.16	0.43	-	-	-	-	-	-	46.83	-	-	-	-	-
1961	-	-	327.29	0.41	-	-	-	-	-	-	51.84	-	-	-	-	-
1962	-	-	180.12	0.46	-	-	-	-	-	-	64.67	-	-	-	-	-
1963	-	-	-	-	312.09	493.00	-	-	-	-	1.67	-	-	-	-	-
1964	-	-	-	-	457.40	415.00	-	-	-	-	33.98	-	-	-	-	-
1965	-	-	-	-	228.91	0.41	-	-	-	-	69.60	-	-	-	-	-
1966	-	-	-	-	349.10	421.00	-	-	-	-	35.70	-	-	-	-	-
1967	-	-	-	-	345.89	414.00	-	-	-	-	61.06	-	-	-	-	-
1968	-	-	-	-	447.00	422.00	-	-	-	-	23.53	-	-	-	-	-
1969	-	-	-	-	610.62	401.00	-	-	-	-	28.06	-	-	-	-	-
1970	-	-	-	-	594.66	431.00	-	-	-	-	42.76	-	-	-	-	-
1971	-	-	-	-	744.71	403.00	-	-	-	-	43.52	-	-	-	-	-
1972	-	-	-	-	525.63	413.00	-	-	-	-	43.05	-	-	-	-	-
1973	-	-	-	-	535.63	396.00	-	-	-	-	42.15	-	-	-	-	-
1974	-	-	-	-	245.39	439.00	-	-	-	-	45.72	-	-	-	-	-
1975	-	-	-	-	484.22	0.41	-	-	1.90	0.15	38.00	-	-	-	-	-
1976	-	-	-	-	483.96	414.00	-	-	2.15	0.12	21.16	-	-	-	-	-
1977	-	-	-	-	547.56	407.00	-	-	3.53	0.14	42.44	-	-	-	-	-
1978	-	-	-	-	705.26	412.00	-	-	1.50	0.15	12.28	-	-	-	-	-
1979	-	-	-	-	623.01	409.00	-	-	2.70	0.14	3.75	-	-	-	-	-
1980	-	-	-	-	634.81	446.00	-	-	1.69	0.16	20.14	-	-	-	-	-
1981	768.36	57.19	-	-	510.66	422.00	-	-	1.63	0.17	-	-	-	-	-	-
1982	1038.12	34.63	-	-	503.78	418.00	-	-	3.32	0.13	-	-	-	-	-	-
1983	1092.05	34.63	-	-	625.14	432.00	-	-	2.12	0.13	-	-	-	-	-	-
1984	1200.27	34.63	-	-	331.71	449.00	-	-	1.62	0.12	-	-	-	-	-	-
1985	814.46	34.64	-	-	1125.74	407.00	-	-	1.75	0.15	-	-	-	-	-	-
1986	394.33	28.05	-	-	751.21	419.00	-	-	1.32	0.14	-	-	-	-	-	-
1987	433.53	28.05	-	-	1008.43	415.00	-	-	2.16	0.13	-	-	-	-	-	-
1988	1014.56	28.03	-	-	1394.68	419.00	-	-	1.35	0.14	-	-	-	-	-	-
1989	531.45	26.09	-	-	1285.60	0.40	-	-	1.05	0.16	-	-	-	-	-	-
1990	614.37	22.60	-	-	986.51	407.00	-	-	1.41	0.14	-	-	0.08	0.32	-	-
1991	727.86	22.59	-	-	901.20	422.00	-	-	1.21	0.13	-	-	0.10	0.27	-	-
1992	313.95	22.63	-	-	695.16	427.00	-	-	1.03	0.14	-	-	0.22	0.16	-	-
1993	325.36	22.62	-	-	2093.55	403.00	-	-	1.04	0.14	-	-	0.23	0.14	-	-
1994	341.90	22.62	-	-	1007.03	419.00	-	-	1.12	0.16	-	-	0.26	0.16	-	-
1995	223.43	22.65	-	-	1235.91	405.00	-	-	1.42	0.15	-	-	0.29	0.13	-	-
1996	375.22	24.62	-	-	1739.29	398.00	-	-	0.50	0.22	-	-	0.77	0.13	-	-
1997	992.41	24.59	-	-	2246.41	404.00	-	-	0.53	0.21	-	-	0.50	0.13	-	-
1998	925.14	24.59	-	-	879.51	409.00	-	-	0.71	0.17	-	-	0.24	0.16	-	-
1999	1137.45	24.59	-	-	339.77	436.00	-	-	0.64	0.22	-	-	0.35	0.15	-	-
2000	739.23	22.59	-	-	960.44	402.00	-	-	0.74	0.20	-	-	0.38	0.12	-	-
2001	1284.62	22.58	-	-	704.49	447.00	-	-	0.96	0.17	-	-	0.45	0.12	0.39	0.40
2002	1130.42	22.58	-	-	687.42	423.00	-	-	2.05	0.15	-	-	0.34	0.13	0.61	0.49
2003	662.66	23.68	-	-	444.91	482.00	-	-	1.70	0.13	-	-	0.34	0.14	1.07	0.45
2004	332.36	22.62	-	-	1210.46	417.00	-	-	0.82	0.18	-	-	0.32	0.12	0.11	0.29
2005	677.39	22.59	-	-	2383.57	0.40	-	-	0.88	0.15	-	-	0.23	0.11	0.14	0.24
2006	633.94	22.60	-	-	850.09	0.48	-	-	1.91	0.15	-	-	0.28	0.11	-	-
2007	1000.60	22.59	-	-	-	-	1177.62	419.00	0.94	0.19	-	-	0.28	0.11	-	-
2008	634.18	22.60	-	-	-	-	2144.54	304.00	1.22	0.17	-	-	0.33	0.11	-	-
2009	876.71	22.59	-	-	-	-	955.29	305.00	1.04	0.24	-	-	0.48	0.11	-	-
2010	1042.24	23.66	-	-	-	-	2109.08	309.00	-	-	-	-	2.04	0.05	-	-
2011	674.97	22.59	-	-	-	-	2762.62	306.00	-	-	-	-	2.87	0.06	-	-
2012	1187.75	23.66	-	-	-	-	2216.18	390.00	-	-	-	-	4.81	0.07	2.96	0.22
2013	4285.56	33.12	-	-	-	-	1571.64	445.00	-	-	-	-	4.46	0.06	1.71	0.25

Appendix B - The Statistical Catch-at-Length Model

The text following sets out the equations and other general specifications of the Statistical Catch at Length (SCAL) assessment model applied to develop Operating Models (OMs) for the simulation testing, followed by details of the contributions to the (penalised) log-likelihood function from the different sources of data available and assumptions concerning the stock-recruitment relationship. Quasi-Newton minimization is then applied to minimize the total negative log-likelihood function to estimate parameter values (the package AD Model Builder™ (Fournier *et al*. 2011) is used for this purpose). The description below includes more options than used in this paper, but these have been included here for completeness as they may be used in later extensions.

B.1. Population dynamics

B.1.1 Numbers-at-age

The resource dynamics are modelled by the following set of population dynamics equations:

$$N_{y+1,1} = R_{y+1} \qquad \text{(B1)}$$

$$N_{y+1,a+1} = N_{y,a}e^{-Z_{y,a}} \qquad \text{for } 1 \le a \le m-2 \qquad \text{(B2)}$$

$$N_{y+1,m} = N_{y,m-1}e^{-Z_{y,m-1}} + N_{y,m}e^{-Z_{y,m}} \qquad \text{(B3)}$$

where

$N_{y,a}$ is the number of fish of age *a* at the start of year *y* (which refers to a calendar year),

m is the maximum age considered (taken to be a plus-group),

R_y is the recruitment (number of 1-year-old fish) at the start of year *y*,

M_a denotes the natural mortality rate for fish of age *a*,

$Z_{y,a} = \sum_f F_y^f S_{y,a}^f + M_a$ is the total mortality in year *y* on fish of age *a*, where

F_y^f is the fishing mortality of a fully selected age class in year *y* for fishery *f*, and

$S_{y,a}^f$ is the commercial selectivity at age *a* for year *y* for fishery *f*.

B.1.2. Recruitment

The number of recruits (i.e. new 1-year olds) at the start of year *y* is assumed to be related to the spawning stock size (i.e. the biomass of mature fish) at the mid-point of the preceding year by a Beverton-Holt stock-recruitment relationship, allowing for annual fluctuation about the deterministic relationship:

$$R_y = \frac{\alpha B_{y-1}^{\text{sp}}}{\beta + B_{y-1}^{\text{sp}}} e^{(\varsigma_y - (\sigma_R)^2/2)} \qquad \text{(B4)}$$

where

α and β are spawning biomass-recruitment relationship parameters,

ς_y reflects fluctuation about the expected recruitment for year *y*, which is assumed to be normally distributed with standard deviation σ_R (which is input in the applications considered here); these residuals are treated as estimable parameters in the model fitting process.

B_y^{sp} is the spawning biomass in year *y*, computed as:

$$B_y^{sp} = \sum_{a=0}^{m} f_{y,a} w_{y,a}^{sp} N_{y,a} e^{-Z_a \frac{T^s}{12}} \quad \text{(B5)}$$

where

spawning for the stocks under consideration is taken to occur T^s months after the start of the year (here $T^s = 6$) and some natural mortality has therefore occurred,

$w_{y,a}^{sp}$ is the mass of fish of age *a* during spawning, and

$f_{y,a}$ is the proportion of fish of age *a* that are mature.

B.1.3. Total catch and catches-at-age

The total catch by mass in year *y* is given by:

$$C_y^f = \sum_{a=0}^{m} w_{y,a}^{f} C_{y,a}^f = \sum_{a=0}^{m} w_{y,a}^{f} N_{y,a} S_{y,a}^f F_y^f \left(1 - e^{-Z_{y,a}}\right) \Big/ Z_{y,a} \quad \text{(B6)}$$

where

$C_{y,a}^f$ is the catch-at-age, i.e. the number of fish of age *a*, caught in year *y* by fleet *f*,

$S_{y,a}^f$ is the commercial selectivity of fleet *f* (i.e. combination of availability and vulnerability to fishing gear) at age *a* for year *y*; when $S_{y,a} = 1$, the age-class *a* is said to be fully selected,

F_y^f is the proportion of a fully selected age class that is fished by fleet *f* , and

$w_{y,a}^f$ denotes the selectivity-weighted mid-year weight of fish of age *a* landed in year *y* by fleet *f*, computed as:

$$\tilde{w}_{y,a}^f = \sum_l S_{y,l}^f w_l A_{a,l} \Big/ S_{a,l}^f \quad \text{(B7)}$$

with

w_l is the weight of fish of length *l*; and

$A_{a,l}$ is the proportion of fish of age *a* that fall in the length group *l* (i.e., $\sum_l A_{a,l} = 1$ for all ages).

The matrix $A_{a,l}$ is calculated under the assumption that length-at-age is normally distributed about a mean given by the von Bertalanffy equation, i.e.:

$$L_a \sim N\left[L_\infty\left(1 - e^{-\kappa(a-t_o)}\right); \theta_a^2\right] \quad \text{(B8)}$$

where

θ_a is the standard deviation of length-at-age a, which is modelled to be proportional to the expected length-at-age *a*, i.e.:

$$\theta_a = \beta L_\infty\left(1 - e^{-\kappa(a-t_o)}\right) \quad \text{(B9)}$$

with β fixed here to 0.1 for age 1, 0.2 for age 15 and changing linearly for the intermediate .

Selectivity is estimated as a function of length and then converted to an effective selectivity-at-age:

$$S^f_{y,a} = \sum_l S^f_{y,l} A_{a,l} \qquad \text{(B10)}$$

B.1.4. Initial conditions

For the first year (y_0) considered in the model (here 1950), the numbers-at-age are estimated directly for ages 1 to a^{est}, with a parameter ϕ which mimics recent average fishing mortality for ages above a^{est} (a^{est}=4 here), i.e.:

$$N_{y_0,a} = N_{\text{start},a} \qquad \text{for } 1 \le a \le a^{est} \qquad \text{(B11)}$$

and

$$N_{\text{start},a} = N_{\text{start},a-1} e^{-M_{a-1}} (1-\phi S_{a-1}) \qquad \text{for } a^{est} < a \le m-1 \qquad \text{(B12)}$$

$$N_{\text{start},m} = N_{\text{start},m-1} e^{-M_{m-1}} (1-\phi S_{m-1}) \Big/ (1-e^{-M_m}(1-\phi S_m)) \qquad \text{(B13)}$$

B.2. The (penalised) likelihood function

The model is fitted to CPUE and commercial catch-at-length data to estimate model parameters (which may include residuals about the stock-recruitment function, facilitated through the incorporation of a penalty function described below). Contributions by each of these to the negative of the (penalised) log-likelihood (- ℓnL) are as follows.

B.2.1 Relative abundance data

The likelihood is calculated assuming that the index observed for a particular fishing fleet is log-normally distributed about its expected value:

$$I^i_y = \hat{I}^i_y \exp(\varepsilon^i_y) \quad \text{or} \quad \varepsilon^i_y = \ell n(I^i_y) - \ell n(\hat{I}^i_y) \qquad \text{(B14)}$$

where

I^i_y is the index of biomass or abundance index for year y for gear/flag combination i,

$\hat{I}^i_y = \hat{q}^i \sum^m w^i_{y,a} S^i_{y,a} N_{y,a} e^{-Z_a/2}$ is the corresponding model estimate of biomass or

$\hat{I}^i_y = \hat{q}^i \sum^m S^i_{y,a} N_{y,a} e^{-Z_a/2}$ is the corresponding model estimate of abundance in numbers, or, in the case of the larval index:

$\hat{I}^i_y = \hat{q}^i B^{sp}_y$

$\hat{q}^i$ is the constant of proportionality (catchability) for the index series, and

ε^i_y from $N\left(0,(\sigma^i_y)^2\right)$.

The contribution of the index data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ell n L^{i} = \sum_{y}\left\{\ell n\left(\sqrt{\left(\sigma^{i}\right)^{2}+\left(\sigma^{i}_{Add}\right)^{2}}\right)+\frac{\left(\varepsilon^{i}_{y}\right)^{2}}{2\left[\left(\sigma^{i}\right)^{2}+\left(\sigma^{i}_{Add}\right)^{2}\right]}\right\} \quad \text{(B15)}$$

where

σ^{i} is the standard deviation of the residuals for the logarithm of index *i* in year *y*, estimated by its maximum likelihood value:

$$\hat{\sigma}^{i} = \sqrt{1/n_{i}\sum_{y}\left(\ln\left(I^{i}_{y}\right)-\ln\left(q^{i}I^{i}_{y}\right)\right)^{2}}$$

where n_i is the number of data points for index i, and

σ^{i}_{Add} is the square root of the additional variance for the CPUE series, which can be estimated in the model fitting procedure but has been set to zero in the applications considered here.

The catchability coefficient q^{i} for index *i* is estimated by its maximum likelihood value:

$$\ell n\,\hat{q}^{i} = 1/n_{i}\sum_{y}\left(\ln I^{i}_{y}-\ln\hat{I}_{y}\right) \quad \text{(B16)}$$

The model is fit to the following abundance index series (see **Table A4**):

1) Mor&Sp_Trap: Moroccan and Spanish (combined) trap (1981-2013)
2) SpBB1: Spanish bait boat (1952-1962)
3) SpBB2: Spanish bait boat (1963-2006)
4) SpBB3: Spanish bait boat (2007-2013)
5) NorPS: Norwegian purse seine (1955-1980)
6) JPLL_EastMed: Japanese longline fishery in east Atl. (south of 40N) and Med. (1975-2009)
7) JPLL_NEA1: Japanese longline fishery in the Northeast Atl. (north of 40N) (1990-2013)
8) Larval index: Western Mediterranean sea (2001-2013)

Note that for the applications considered hear, selectivity at age $S^{f}_{y,a}$ is year-invariant over the period for which values of the index are available. More complex formulations are necessary should selectivity-at-age change during such periods.

The indices' selectivities are taken to be the same as for the overall gear type, i.e.:

1) Mor&Sp_Trap: corresponds to trap
2) SpBB1, SpBB2, and SpBB3 correspond to baitboat
3) NorPS: corresponds to purse seine, and
6) JPLL_EastMed, JPLL_NEA1 and JPLL_NEA2 correspond to longline.

B.2.3. Commercial catches-at-length

The contribution of the catch-at-length data to the negative of the log-likelihood function under the assumption of an “adjusted” lognormal error distribution (Punt and Kennedy 1997) is given by:

$$-\ell n L^{\mathrm{CAL}} = w_{len}\sum_{f}\sum_{y}\sum_{l}\left[\ell n\left(\sigma^{f}_{\mathrm{len}}/\sqrt{p^{f}_{y,l}}\right)+p^{f}_{y,l}\left(\ell n\,p^{f}_{y,l}-\ell n\,\hat{p}^{f}_{y,l}\right)^{2}/2\left(\sigma^{f}_{\mathrm{len}}\right)^{2}\right] \quad \text{(B17)}$$

where

$p_{y,l}^{f} = C_{y,l}^{f} / \sum_{l'} C_{y,l'}^{f}$ is the observed proportion of fish caught in year *y* by fleet *f* that are of length *l*,

$\hat{p}_{y,l}^{f} = \hat{C}_{y,l}^{f} / \sum_{l'} \hat{C}_{y,l'}^{f}$ is the model-predicted proportion of fish caught in year *y* by fleet *f* that are of length *l*,

where

$$\hat{C}_{y,l}^{f} = \sum_{a} N_{y,a} \; A_{a,l} S_{y,l}^{f} \, e^{-Z_{y,a}/2} \tag{B18}$$

and

σ_{com}^{f} is the standard deviation associated with the catch-at-length data, which is estimated in the fitting procedure by:

$$\hat{\sigma}_{\text{com}}^{f} = \sqrt{\sum_{y}\sum_{l} p_{y,a}^{f} \left(\ell n\, p_{y,l}^{f} - \ell n\, \hat{p}_{y,l}^{f}\right)^{2} / \sum_{y}\sum_{l} 1} \tag{B19}$$

Commercial catches-at-length are grouped with the next length class if the proportion is less than 2%.

The w_{len} weighting factor may be set to a value less than 1 to downweight the contribution of the catch-at-length data (which tend to be positively correlated between adjacent length groups) to the overall negative log-likelihood compared to that of the CPUE data. Here $w_{len} = 0.5$.

The model is fit to CAL data for each of the five fleets assumed in the model (baitboat, longline, purse seine, traps, other) (see **Table A3**).

B.2.4. Stock-recruitment function residuals)

The stock-recruitment residuals are assumed to be log-normally distributed. Thus, the contribution of the recruitment residuals to the negative of the (now penalised) log-likelihood function is given by:

$$-\ell n L^{\text{pen}} = \sum_{y=y_1+1}^{y_2} \left[\varsigma_y^2 \big/ 2\sigma_{\text{R}}^2 \right] \tag{B20}$$

where

ς_y is the recruitment residual for year *y*, which is estimated for year y_1 to y_2 (see equation (B4)),

σ_{R} is the standard deviation of the log-residuals, which is input (here σ_{R}=0.5).

B.3. Estimation of precision

Where quoted, 95% probability interval estimates are based on the Hessian.

B.4. Model parameters

The model input parameters are given in **Table** B1 below.

Table **B1**: Input parameters (units are gm, cm and year as appropriate) (length-weight, von Bertalanffy growth, maturity and natural mortality at age to age 15 from ICCAT, 2012).

Model plus group (*m*)	15						
Length-weight	*a*=0.0000295, *b*=2.899 (<=100cm) and *a*=0.0000196, *b*=3.009 (>100cm)						
von Bertalanffy growth	κ=0.093, L_{inf}=319, t_0=-0.97						
Maturity-at-age	50% maturity at age 4, 100% maturity at age 5						
Natural mortality	1	2-5	6	7	8	9	10+
	0.49	0.24	0.20	0.18	0.15	0.13	0.10
Stock-recruitment	Beverton-Holt, *h*=0.98*, σ_R=0.5						

* This high value was specified on input rather than estimated in the fit of the model given the absence of any clear trend in the stock-recruitment plot.

B.4.2. Fishing selectivity

Fishing selectivities-at-length are estimated using a four parameters double-logistic form:

$$S_l = \left(1+e^{-a1(l-b1)}\right)^{-1}\left[1-\left(1+e^{-a2(l-b2)}\right)^{-1}\right] \qquad \text{(B21)}$$

Details of the fishing selectivities used are shown in **Table B2**.

Table B2: Details of the selectivities estimated.

	Number of parameters estimated	Number of selectivity periods
Bait boat	4x3	Three: 1950-1962, 1963-2006, 2007-2013
Longline	4x1	One
Purse seine	4x5	Three: 1950-1980, 1981-1984, 1985-2001, 2002-2006, 2007-2013
Traps	4x2	Two: 1950-1973, 1974-2013
Other	4x3	Three: 1950-1966, 1967-1984, 1985-2013

Appendix C - Projection methodology

Projections into the future under a specific Candidate Management Procedure (CMP) are evaluated using the following steps for the Operating Model (OM) under consideration.

Step 1: Begin-year (2014) numbers-at-age

The components of the numbers-at-age vector for each gender and species at the start of 2014 are obtained from the MLE of an assessment of the resource.

Error is included for numbers-at-ages 1 to 3 because these are poorly estimated in the assessment given limited information on these year-classes:, i.e.:

$N_{2014,a} \rightarrow N_{2014,a} e^{\varepsilon_a}$ $\qquad \varepsilon_a$ from $N\left(0,(\sigma_R)^2\right)$

Step 2: Catch

These numbers-at-age are projected one year forward at a time given a catch C_y for the year concerned, where catch is specified by the CMP. This requires specification of how the catch is disaggregated by fleet to obtain C_y^f and how future recruitments are generated.

The total TAC recommended by the CMP is divided in fixed proportions among the various fleet, using the 2013 proportions, i.e.:
Baitboat: 3.0%;
Longline: 7.7%;
Purse seine: 63.2%;
Traps: 22.5%
Other: 3.6%

The commercial selectivity functions are taken to stay constant in the projections (i.e. same as 2013).

The numbers-at-age can then be computed for the beginning of the following year (y+1):

$$N_{y+1,1} = R_{y+1} \qquad \text{(C1)}$$

$$N_{y+1,a+1} = N_{y,a} e^{-Z_{y,a}} \qquad \text{for } 1 \le a \le m-2 \qquad \text{(C2)}$$

$$N_{y+1,m} = N_{y,m-1} e^{-Z_{y,m-1}} + N_{y,m} e^{-Z_{y,m}} \qquad \text{(C3)}$$

Step 3: Recruitment

Future recruitments are provided by the Beverton-Holt stock-recruitment relationship.

$$R_y = \frac{\alpha B_{y-1}^{\mathrm{sp}}}{\beta + B_{y-1}^{\mathrm{sp}}} e^{(\varsigma_y - (\sigma_{\mathrm{R}})^2/2)} \qquad \text{(C4)}$$

Log-normal fluctuations are introduced by generating ς_y factors from $N\left(0,\sigma_R^2\right)$.

Step 4: Generate data

The information obtained in Steps 1 to 3 is used to generate values of the indices of abundance (here, JPLL_NEA and larval index only). The indices are generated from the OM, assuming the same error structures as in the past.

The index series are generated from model estimates for corresponding mid-year exploitable numbers or spawning biomass and catchability coefficients, with multiplicative lognormal errors incorporated:

For JPLL_NEA:

$$I_y^i = \hat{q}^i \left(\sum^m S_{y,a}^i N_{y,a} e^{-Z_a/2} \right) e^{\varepsilon_y^i} \quad \text{(C5)}$$

and for the larval index:

$$I_y^i = \hat{q}^i \left(\sum_{a=0}^m f_{y,a} w_{y,a}^{\text{sp}} N_{y,a} e^{-Z_a \frac{T^s}{12}} \right) e^{\varepsilon_y^i} \quad \text{(C6)}$$

$$\varepsilon_y^i \quad \text{from } N\left(0, \left(\sigma^i\right)^2\right) \quad \text{(C7)}$$

Lognormal error variance includes the index sampling variance with the CV set equal to the average historical value, plus additional variance (the variability that is not accounted for by sampling variability) as estimated within the OM concerned from past data.

$$\sigma^i = \sqrt{\ln(1 + \overline{CV^i}^2) + \sigma_a^2} \quad \text{(C8)}$$

For JPLL_NEA, $\overline{CV^i}$ ranges from 0.72 to 0.78 depending on the OM, with additional variance estimated to be close to 0 for the RC and S1 0.25 for S2. For the larval index, $\overline{CV^i}$ ranges from 0.75 to 0.87 depending on the OM, with additional variance estimated to be close to 0 for all OMs.

Step 5:

Given the new indices of abundance I_{y-1}^i compute TAC_{y+1} using the CMP.

Step 6:

Steps 1-5 are repeated for each future year in turn for as long a period as desired, and at the end of that period the performance of the candidate MP under review is assessed by considering statistics such as the average catch taken over the period and the final spawning biomass of the resource.

Performance Statistics

Performance statistics (median and 95% probability intervals), related to the catch and resource depletion considerations, are computed for the CMPs tested. Projections are conducted over 25 years, though for the year 2014 the catch was specified as the TAC set for that year (13 500t), and for 2015 to 2017 the catches were to the amounts agreed by the Commission (16 142t,19 296t and 23 155t), so that the MP generated TAC comes into effect for the first time for 2018.