Trials of Fox-model based management procedure for southern bluefin tuna.

Fox モデルに基づいたミナミマグロ管理方策（MP）の試行

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Summary

This document describes some trials of the candidate management procedure (CMP) based on the age-aggregated surplus production model (Fox model). This surplus production model is fitted to the longline CPUE (LL1) and Aerial survey index. TACs are decided on the basis of the surplus productions or MSY which were estimated by the model. The detail is as follows; 1) Current TAC is "xx%" of the surplus production (if $B_y < B_{msy}$) or MSY (if $B_y > B_{msy}$) estimated by the Fox model; 2) "xx%" is shifted in proportion to the ratio of B_y to B_{msy},, and the proportion has an upper and lower limit (control parameter); 3) When the model could not converge or estimated unrealistic values, the current TAC is calculated as "zz%" change from the previous TAC; 4) "zz%" is decided in accordance with the trend of current abundance indices.

The results of the tuning of this CMP show that there are trade-off relationship between the larger TAC increase in the long term and lower TAC reduction in the short term. The difference of the maximum TAC changes value (5000t vs 3000t) and/or the time lag for TAC implementation (0 or 1 year) did not have serious effects on the rebuilding of SSB. There are non-convergence issues and unrealistic parameter estimation issues in this CMP, and these issues frequently happen in some extreme pessimistic scenarios (e.g. "STwin", "omega75") and optimistic scenarios (e.g. "troll", "Laslett") of the robustness trials.

要約

余剰生産モデル（Fox モデル）を組み入れたミナミマグロの管理方式候補（CMP）を試作した。この CMP では、CPUE と航空目視調査データを資源指数として入力した Fox モデルにより、推定された余剰生産量と MSY に基づき TAC を決定する。本モデルでの TAC 算出コンセプトは以下の通り；１）TAC は余剰生産の「xx%」である（資源量が B_{msy} を超える場合は、MSY の「xx%」）、２）モデルにより推移される資源量と B_{msy} の比により「xx%」は増減させる。また、その上限・下限はコントロールパラメータとして設定する。３）Fox モデルが収束しない場合は、資源指標のトレンドに基づき、前回 TAC に対し何%増減させるか決定する。

チューニングの結果、TAC の短期的な少ない削減と長期的な大きな増加にはトレードオフの関係があることが示された。また、TAC 変化量の最大値の違い（3000 トンと 5000 トン）や TAC 決定のタイムラグが資源の回復に与える深刻な影響は観察されなかった。この CMP にはモデルが収束しない問題、および推定値が非現実的となる問題がある。これらの問題は、頑健性試験の悲観的・楽観的なシナリオにおける発生が多かった。

Introduction

The redevelopment of management procedure (MP) was required at the commission meeting of CCSBT in 2009 (Anon. 2009). According to the request from the commission, 1) TAC should be changed at triennial intervals, 2) earlier TAC changes are preferred, 3) two options of the rebuilding reference point and the short term checkpoints are targeted: [option 1] the reference point is 20% of SSB0 in 25 years, and the check point is 10% of SSB0 or double the SSB of 2009 in 12 years; [option2] the reference point is 20% of SSB0 in 30 years, and the check point is 10% of SSB0 or double the SSB of 2009 in 15 years (Anon. 2010).

Fox model based MPs were explored during the previous MP development in the early 2000s to calculate the TAC from the MSY and B_{msy} (e.g. Basson et al., 2005, Butterworth and Mori, 2005), and one of them was adopted by the CCSBT at that time (Anon. 2005). A present CMP summarized in this document is also base on the age-aggregated Fox production model. The Fox model is fitted to the longline (LL1) CPUE index, Aerial survey index, and total catch biomass. The key concept of this CMP is “TAC is lower than the surplus production”. This document illustrated the model structure of this CMP and reported the tentative results of the tuning.

Methods

This analysis was conducted using the “sbtprojv118.exe” (distributed on 19 May 2010) and “c1s1l13hsqrt.grid (new reference set)” (distributed on 20 April 2010) for projection. The Fox model based CMP was coded using the AD Model Builder (ver.9.0.0). Robustness tests were conducted using the grid files which were distributed on mid-April 2010. In all projections, we used the “option 2” of catch split between fisheries; Japan 3000t, Australia 5665t, Korea 1140t, Taiwan 1140t, New Zealand 1000t, Indonesia 750t, Philippines 45t, South Africa 40t, and EC 10t.

Fox Model

In this CMP, the population dynamics of SBT are assumed to be represented by the Fox model which was fitted the past catch (1952-current year), LL1 CPUE (1969-current year), and Aerial survey index (1992-1999, 2004-current year).

$$B_{y+1} = \left(B_y + g(B_y) - C_y\right)e^{\varepsilon_y} \quad ,$$

$$g(B_y) = rB_y\left(1 - \frac{\ln(B_y)}{\ln(K)}\right)$$

Where,

B_y is the biomass of SBT present at the start of year y, (input);

C_y is the catch by mass (all fisheries combined) for year y, (input);

$g(B_y)$ is the surplus production of year y;

r is the intrinsic rate of population growth, (estimate);

K is the carrying capacity, (estimate);

ε_y is the extent of process error during year y, $\varepsilon_y \sim N\left(0;\sigma_\varepsilon^2\right)$.

This model is fit to the abundance indices (LL1 CPUE and Aerial survey) by assuming:

$$I_{CPUE,y} = q\left(B_y\right)^\delta e^{\eta_{CPUE,y}} \quad , \quad I_{Aerial,y} = s\left(B_y\right)^\gamma e^{\eta_{Aerial,y}} \quad ,$$

Where,

$I_{CPUE,y}$ is the CPUE index for year y,

$I_{Aerial,y}$ is the Aerial survey index for year y,

q is the catchability coefficient, (estimate)

s is the sighting ability coefficient, (estimate)

δ is a nonlinear parameter that modifies the relationship between CPUE abundance index to a non-linear form (hear fixed to be 1 (liner)),

γ is a nonlinear parameter that modifies the relationship between Aerial survey index to a non-linear form (hear fixed to be 1 (liner)),

$\eta_{CPUE,y}$ is the extent of observation error of CPUE abundance index during year y, $\eta_{CPUE} \sim N\left(0;\sigma_{\eta_{CPUE}}^2\right)$;

$\eta_{Aerial,y}$ is the extent of observation error of Aerial survey index during year y, $\eta_{Aerial} \sim N\left(0;\sigma_{\eta_{Aerial}}^2\right)$.

The estimate parameters in this model are obtained by minimizing the following negative log-likelihood function that includes contributions from the abundance indices and the process errors. The parameter vector is r, K, q, s, ε_y, $\eta_{CPUE,y}$, $\eta_{Aerial,y}$

$$\begin{aligned}
&-\ln L \\
&= n\ln\sigma_{\eta_{CPUE}} + \frac{1}{2\sigma_{\sigma\eta_{CPUE}}^2}\sum_y\left(\ln I_{CPUE,y} - \ln\left(q\left(B_y\right)^\delta\right)\right)^2 \\
&+ n\ln\sigma_{\eta_{Aerial}} + \frac{1}{2\sigma_{\sigma\eta_{Aerial}}^2}\sum_y\left(\ln I_{Aerial,y} - \ln\left(s\left(B_y\right)^\gamma\right)\right)^2 \\
&+ n\ln\sigma_\varepsilon + \frac{1}{2\sigma_\varepsilon^2}\sum_y\varepsilon_y^2
\end{aligned}$$

For this model,

$$B_{msy} = Ke^{-1}, \quad msy = \frac{Kr}{e\ln K}$$

TAC Specification

In this CMP, current TAC is calculated based on the surplus production (when $B_y < B_{msy}$) or MSY (when B_y

> B_{msy}) which were estimated by the Fox model. But, in some cases, the Fox model does not converge or the estimated value is unrealistic (e.g. the MSY is estimated at lower than 10,000t or higher than 100,000t). Therefore, this CMP has an alternative approach when the surplus production and MSY are unavailable; the current TAC is altered by the arbitrary proportion of the previous TAC. The details are as follows:

1) When the FOX model converged and estimated practically

TAC is calculated as "*xx%* of surplus production or MSY." "*xx%*" is changed in accordance with estimated current biomass, and which has the higher and lower limits as the control parameter (Fig. 1).

$$TAC_y = \begin{cases} g(B_y)\left((x_{high} - x_{low})\left(\dfrac{B_y}{B_{msy}}\right) + x_{low}\right) & if \quad B_y < B_{msy} \\ msy \cdot x_{high} & if \quad B_y \geq B_{msy} \end{cases}$$

Where,

x_{low} is the minimum rate for the TAC calculation. (control parameter)

x_{high} is the maximum rate for the TAC calculation. (control parameter)

2) When the FOX model did not converge or estimated impractically

Current TAC is calculated as "*zz%* change from previous TAC." "*zz%*" is changed in accordance with the trend of current abundance indices (CPUE and Aerial survey). When both indices are upward, current TAC will increase by "*zz%*". On the other hands, both abundance indices are downward, current TAC will decrease by "zz%". If these indices have different trends each other, TAC will not be changed ("zz%" is zero). To judge the current trend of abundance index, the average value of recent 3 years and previous 3 years are compared; recent 1-3 years *vs* 4-6 years for aerial index; recent 2-4 years *vs* 5-7 years for longline (Fig. 2):

$$TAC_y = (1+z)TAC_{y-1} \quad if \begin{cases} non-convergence \\ msy < 10{,}000 \quad or \quad msy > 100{,}000 \end{cases}$$

$$z = \begin{cases} z_{high} & if \quad \bar{I}_{CPUE,(y-2,y-3,y-4)} > \bar{I}_{CPUE,(y-5,y-6,y-7)} \quad and \quad \bar{I}_{Aerial,(y-1,y-2,y-3)} > \bar{I}_{Aerial,(y-4,y-5,y-6)} \\ 0 & if \begin{cases} \bar{I}_{CPUE,(y-2,y-3,y-4)} > \bar{I}_{CPUE,(y-5,y-6,y-7)} \quad and \quad \bar{I}_{Aerial,(y-1,y-2,y-3)} \leq \bar{I}_{Aerial,(y-4,y-5,y-6)} \\ \bar{I}_{CPUE,(y-2,y-3,y-4)} \leq \bar{I}_{CPUE,(y-5,y-6,y-7)} \quad and \quad \bar{I}_{Aerial,(y-1,y-2,y-3)} > \bar{I}_{Aerial,(y-4,y-5,y-6)} \end{cases} \\ z_{low} & if \quad \bar{I}_{CPUE,(y-2,y-3,y-4)} \leq \bar{I}_{CPUE,(y-5,y-6,y-7)} \quad and \quad \bar{I}_{Aerial,(y-1,y-2,y-3)} \leq \bar{I}_{Aerial,(y-4,y-5,y-6)} \end{cases}$$

Where,

$\bar{I}_{CPUE,(i,j,k)}$ is the average value of CPUE index of year i, j, and k.

$\bar{I}_{Aerial,(i,j,k)}$ is the average value of Aerial Survey index of year i, j, and k.

z_{high} is the higher rate to change the current TAC. (here fixed to be 0.2)

z_{low} is the lower rate to change the current TAC. (here fixed to be -0.2)

The TAC change limitations were recommended by CCSBT strategy and fisheries management working group meeting in 2010. Thus TAC is finally decided as follows:

$$TAC_y = \begin{cases} TAC_{y-1} + max_{up} & if \quad TAC_y - TAC_{y-1} > max_{up} \\ TAC_y & if \quad max_{down} < TAC_y - TAC_{y-1} < max_{up} \\ TAC_{y-1} & if \quad min_{down} < TAC_y - TAC_{y-1} < min_{up} \\ TAC_{y-1} - max_{down} & if \quad TAC_y - TAC_{y-1} < max_{down} \end{cases}$$

Where,

max_{up} and max_{down} are recommended “3000t” or “5000t”;

min_{up} and min_{down} are recommended “100t”

Results and Discussion

Tuning

This CMP was able to provide the estimation of surplus production and MSY reflecting the abundance indices, and TAC was calculated based on them. TAC calculation was controlled by the estimated current biomass, which was able to be tuned using the two control parameters (“x-high” and “x-low”). Fig. 4 shows the relationships between the probability of SSB rebuilding and the combinations of those two control parameters. These figures (Fig.4 a-d) indicate that it is possible to attain at the reference points in various combinations of the two control parameters on each condition of TAC change (Max change; 5000t or 3000t, Time lag; 0-year or 1-year). The tuning which was controlled with higher “x-high” value provided the larger increase of TAC in the long term (Fig. 5). On the other hands, the tuning with higher “x-low” value provided the lower cut down of TAC in the short term. It was difficult to use both the higher “x-high” value and the higher “x-low” value to reach the SSB rebuilding reference point: there were trade-off relationships between the higher increase and lower reduction of TAC in this CMP. In terms of the short term check points, the larger TAC reduction in early times of evaluation period was better for the attainment to rebuild 10% SSB_0 or doubling of current SSB (Table 1). The difference of the maximum TAC changes (5000t or 3000t) and/or the time lag for TAC implementation (0 or 1 year) did not have serious effects on the rebuilding of SSB. The projected average TAC was slightly higher in the case of “5000t without time-lag” compared with the other cases, however the larger maximum TAC change (5000t) repeatedly provided the larger TAC increase and reduction. In some robustness scenarios, SSB could not attain the rebuilding reference point (”downwearlysize”, “c2s1l1”, “c3s1l1”, ”STwin”, “run6”, “omega75”, “highCPUECV”, and “upq”), of which ”STwin”, “omega75”, and “upq” scenarios especially provided pessimistic results (Table 2).

Non-convergence and unrearistic estimation issues

As pointed out by previous MP developments, the Fox model based MP has the non-convergence issues. In addition to that, our CMP also had a problem that unrealistic parameter values were estimated in some cases. When these problems happen, this CMP calculates the TAC using the alternative approach (Fig. 2). The MSY values which were estimated from the Fox model were unrearistically (< 10000t) lower in the early period, and non-convergence issues happened in the late period. The lower MSY estimation by the Fox model would come from lower *r* and higher *K* parameter estimate. Fig. 7 shows the projected SSB and TAC of the robustness trials when the tuning level is “Pr(B2040>B0x0.2)=70%”. The statuses of the Fox model in these projections are presented in Fig. 8. The impractical estimation issues were happen frequently in some pessimistic scenarios (e.g. “STwin”, “omega75”). On the other hands, the non-convergence issues happen frequently in some optimistic scenarios (e.g. “troll”, “Laslett”). These results suggest that the behavior of the Fox model becomes unstable under the extremely lower and higher biomass (and their abundance indices). This Fox model based CMP has these problems.

References

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Table 1 Summary of the results of tuning. Probability values which are shaded in yellow and green show the results of "option 1" and "option 2", respectively.

Max TAC change	Timelag for the TAC implementation	Timeframe reaching the reference point (20% SSB0)	Probability level for tuning	control parameter		Reference points		Check points				[C2009(Median):C2039(Median)]		
				x-high	*x-low*	Pr[B2035 >0.20*B0]	Pr[B2040 >0.20*B0]	Pr[B2022 >0.10*B0]	Pr[B2022 >2*B2009]	Pr[B2025 >0.10*B0]	Pr[B2025 >2*B2009]	Min	Max	Average
5000t	0	25 years	60%	0.57	0.28	0.603	0.821	0.380	0.357	0.630	0.633	7627.7	13195.5	10141.3
				0.69	0.1	0.600	0.813	0.406	0.392	0.662	0.666	6933.6	15737.5	10760.1
				0.46	0.46	0.603	0.815	0.341	0.320	0.594	0.593	7746.8	11810.0	9429.6
			70%	0.47	0.25	0.708	0.900	0.443	0.425	0.698	0.708	6616.2	11810.0	8867.4
				0.57	0.1	0.702	0.893	0.465	0.452	0.722	0.730	5925.3	13221.0	9504.3
				0.39	0.39	0.703	0.895	0.415	0.398	0.669	0.684	7279.4	11810.0	8361.6
			90%	0.21	0.14	0.899	0.982	0.598	0.597	0.859	0.862	3692.6	11810.0	4980.6
		30 years	60%	0.76	0.35	0.379	0.597	0.270	0.244	0.474	0.473	8538.8	16939.4	12061.0
				0.9	0.13	0.398	0.607	0.319	0.294	0.534	0.535	7627.7	19499.8	12424.6
				0.59	0.59	0.377	0.607	0.239	0.191	0.428	0.415	9363.5	13427.9	11329.6
			70%	0.68	0.31	0.473	0.709	0.319	0.292	0.549	0.548	7627.7	15486.0	11256.2
				0.82	0.1	0.479	0.709	0.355	0.332	0.598	0.600	7627.7	18236.8	11828.6
				0.54	0.54	0.465	0.694	0.269	0.245	0.482	0.479	9094.1	12405.9	10686.1
			90%	0.47	0.24	0.711	0.903	0.448	0.432	0.705	0.713	6514.8	11810.0	8831.2
				0.57	0.1	0.702	0.893	0.465	0.452	0.722	0.730	5925.3	13221.0	9504.3
				0.39	0.39	0.703	0.895	0.415	0.398	0.669	0.684	7279.4	11810.0	8361.6
5000t	1	25 years	60%	0.58	0.28	0.594	0.808	0.361	0.343	0.616	0.621	7627.7	13037.9	10073.4
				0.7	0.1	0.596	0.809	0.389	0.371	0.646	0.652	7018.3	15443.3	10625.6
				0.45	0.45	0.609	0.815	0.343	0.318	0.590	0.601	7627.7	11810.0	9211.5
			70%	0.47	0.24	0.699	0.892	0.420	0.402	0.682	0.693	6447.6	11810.0	8731.8
				0.56	0.1	0.702	0.891	0.444	0.422	0.704	0.713	5841.6	12669.5	9230.8
				0.38	0.38	0.702	0.890	0.404	0.389	0.659	0.673	7022.5	11810.0	8173.6
			90%	0.14	0.12	0.901	0.981	0.559	0.555	0.836	0.845	2695.3	11810.0	4083.0
		30 years	60%	0.75	0.39	0.382	0.596	0.268	0.242	0.465	0.461	8889.0	16103.1	11887.2
				0.9	0.18	0.394	0.597	0.296	0.282	0.516	0.514	7627.7	18371.5	12236.8
				0.6	0.6	0.378	0.603	0.246	0.205	0.430	0.414	9363.5	13310.8	11328.4
			70%	0.68	0.32	0.477	0.710	0.312	0.294	0.541	0.545	7711.1	15035.1	11089.0
				0.83	0.1	0.492	0.710	0.351	0.330	0.588	0.592	7627.7	17637.3	11621.5
				0.53	0.53	0.486	0.709	0.287	0.256	0.496	0.498	8925.7	11961.1	10424.2
			90%	0.44	0.23	0.728	0.906	0.436	0.418	0.700	0.712	6149.2	11810.0	8332.1
				0.53	0.1	0.722	0.905	0.453	0.434	0.717	0.723	5590.6	12006.0	8899.7
				0.36	0.36	0.724	0.906	0.420	0.405	0.678	0.692	6656.1	11810.0	7829.8

Table 1 (cont'd)

Max TAC change	Timelag for the TAC implementation	Timeframe reaching the reference point (20% SSB0)	Probability level for tuning	control parameter		Reference points		Check points				[C2009(Median):C2039(Median)]		
				x-high	*x-low*	Pr[B2035 >0.20*B0]	Pr[B2040 >0.20*B0]	Pr[B2022 >0.10*B0]	Pr[B2022 >2*B2009]	Pr[B2025 >0.10*B0]	Pr[B2025 >2*B2009]	Min	Max	Average
3000t	0	25 years	60%	0.57	0.28	0.600	0.822	0.359	0.339	0.613	0.620	7627.7	13076.1	9894.2
				0.7	0.1	0.603	0.814	0.376	0.357	0.632	0.639	7018.3	15547.9	10357.2
				0.45	0.45	0.607	0.818	0.342	0.316	0.588	0.595	7627.7	11810.0	9187.3
			70%	0.47	0.24	0.697	0.892	0.411	0.392	0.670	0.683	6626.2	11810.0	8663.5
				0.56	0.1	0.691	0.888	0.425	0.404	0.685	0.696	6534.6	12919.7	9142.9
				0.38	0.38	0.701	0.890	0.396	0.385	0.649	0.668	7224.1	11810.0	8146.9
			90%	0.1	0.1	0.900	0.983	0.543	0.539	0.827	0.831	2149.0	11810.0	3584.2
		30 years	60%	0.75	0.39	0.397	0.607	0.270	0.240	0.474	0.467	8889.0	16476.5	11733.9
				0.9	0.22	0.400	0.607	0.289	0.261	0.500	0.495	8046.6	18455.9	12009.7
				0.6	0.6	0.387	0.603	0.246	0.201	0.433	0.420	9363.5	13586.0	11277.2
			70%	0.7	0.32	0.471	0.703	0.303	0.285	0.531	0.534	7839.9	15622.6	11111.1
				0.87	0.1	0.489	0.704	0.328	0.309	0.563	0.567	7627.7	18122.0	11457.0
				0.54	0.54	0.467	0.695	0.277	0.246	0.486	0.482	9094.1	12360.3	10548.0
			90%	0.47	0.24	0.697	0.892	0.411	0.392	0.670	0.683	6626.2	11810.0	8663.5
				0.53	0.1	0.716	0.900	0.436	0.414	0.696	0.709	6534.6	12238.6	8887.0
				0.37	0.37	0.711	0.899	0.407	0.391	0.664	0.676	7027.8	11810.0	7975.9
3000t	1	25 years	60%	0.57	0.27	0.603	0.821	0.349	0.329	0.602	0.611	7627.7	12622.9	9712.1
				0.7	0.1	0.604	0.814	0.363	0.341	0.617	0.625	7018.3	14883.1	10115.0
				0.44	0.44	0.614	0.823	0.336	0.313	0.584	0.594	7627.7	11810.0	8993.6
			70%	0.44	0.23	0.702	0.897	0.399	0.382	0.661	0.677	6534.6	11810.0	8239.5
				0.53	0.1	0.703	0.894	0.405	0.387	0.669	0.684	6534.6	11843.7	8757.6
				0.36	0.36	0.703	0.894	0.391	0.375	0.645	0.662	6800.9	11810.0	7795.3
			90%	0.05	0.05	0.893	0.980	0.494	0.478	0.788	0.789	1097.7	11810.0	3062.7
		30 years	60%	0.76	0.43	0.389	0.593	0.267	0.231	0.460	0.452	9362.9	15842.3	11745.8
				0.9	0.26	0.399	0.600	0.281	0.253	0.487	0.481	8459.2	17198.4	11879.9
				0.62	0.6	0.387	0.603	0.253	0.209	0.438	0.424	9363.5	13626.9	11311.5
			70%	0.71	0.31	0.486	0.707	0.305	0.281	0.530	0.535	7795.5	15209.8	10954.9
				0.9	0.1	0.484	0.698	0.319	0.295	0.551	0.552	7627.7	17078.2	11355.3
				0.54	0.54	0.477	0.697	0.282	0.246	0.491	0.484	9094.1	12083.9	10451.9
			90%	0.42	0.22	0.718	0.906	0.405	0.390	0.669	0.685	6534.6	11810.0	8039.4
				0.5	0.1	0.717	0.902	0.413	0.397	0.679	0.693	6534.6	11810.0	8527.3
				0.34	0.34	0.722	0.906	0.402	0.388	0.661	0.677	6534.6	11810.0	7458.2

Table 2 Summary of the results of robustness trials.

Timeframe reaching the reference point (20% SSB0)	Probability level for tuning	control parameter		Name of run	Reference points		Check points				[C2009(Median):C2039(Median)]		
		x-high	*x-low*		Pr[B2035 >0.20*B0]	Pr[B2040 >0.20*B0]	Pr[B2022 >0.10*B0]	Pr[B2022 >2*B2009]	Pr[B2025 >0.10*B0]	Pr[B2025 >2*B2009]	Min	Max	Average
25 years	60%	0.57	0.28	**c1s1l1**	**0.603**	0.821	**0.380**	**0.357**	0.630	0.633	7627.7	13195.5	10141.3
				c1s1l2	0.674	0.867	0.449	0.394	0.715	0.681	7627.7	13382.1	10290.6
				troll	1.000	1.000	1.000	1.000	1.000	0.999	9363.5	16575.0	14851.4
				mixtag	0.592	0.820	0.374	0.390	0.637	0.660	7627.7	13241.3	10192.5
				recuncor	0.640	0.838	0.444	0.428	0.666	0.680	7627.7	13342.8	10325.2
				downwearlysize	0.510	0.742	0.333	0.290	0.579	0.543	7627.7	12934.2	9903.6
				regimeshift	0.724	0.881	0.568	0.360	0.770	0.658	7627.7	12965.5	10086.4
				aerdome	0.608	0.813	0.392	0.355	0.629	0.629	7627.7	13187.7	10135.6
				aerflat	0.601	0.819	0.389	0.350	0.639	0.626	7627.7	13164.4	10103.5
				c0s1l1	0.660	0.842	0.505	0.358	0.730	0.623	7627.7	12863.7	9989.7
				c2s1l1	0.573	0.805	0.357	0.295	0.615	0.564	7627.7	13219.7	10168.5
				c3s1l1	0.549	0.782	0.391	0.231	0.619	0.479	7627.7	13181.2	10247.1
				Laslett	0.860	0.961	0.791	0.410	0.931	0.701	8431.4	14249.5	11536.3
				STwin	**0.313**	0.586	**0.108**	**0.199**	0.301	0.421	6732.1	12032.2	8813.9
				run3	0.789	0.925	0.675	0.428	0.863	0.722	7690.4	13811.3	10966.3
				run6	0.576	0.803	0.383	0.321	0.633	0.592	7627.7	13089.8	10095.5
				omega75	**0.185**	0.353	**0.064**	**0.167**	0.165	0.329	6339.4	11810.0	7860.0
				highCPUECV	0.436	0.715	0.208	0.266	0.456	0.532	6403.4	12640.9	9439.8
				highaerialCV	0.628	0.845	0.397	0.380	0.657	0.668	7335.7	13215.7	10097.8
				upq	**0.344**	0.591	**0.176**	**0.243**	0.366	0.483	7627.7	13068.1	9872.7
				downq	0.796	0.934	0.613	0.456	0.832	0.749	7627.7	13125.3	10191.9
				downupq	0.728	0.900	0.554	0.413	0.784	0.704	7627.7	13617.2	10646.9
				truncCPUE	0.760	0.919	0.561	0.399	0.807	0.698	7627.7	13437.6	10473.5
25 years (& 30 years	70% 90%)	0.47	0.25	**c1s1l1**	**0.708**	**0.900**	**0.443**	**0.425**	**0.698**	**0.708**	6616.2	11810.0	8867.4
				c1s1l2	0.762	0.930	0.515	0.461	0.775	0.751	6735.0	11810.0	9006.5
				troll	1.000	1.000	1.000	1.000	1.000	1.000	9363.5	13602.2	12715.1
				mixtag	0.710	0.895	0.449	0.454	0.708	0.732	6557.5	11810.0	8903.9
				recuncor	0.745	0.913	0.509	0.499	0.738	0.755	6814.9	11810.0	9056.4
				downwearlysize	0.620	0.840	0.385	0.345	0.651	0.623	6545.7	11810.0	8709.1
				regimeshift	0.811	0.938	0.627	0.434	0.822	0.740	6664.2	11810.0	8834.0
				aerdome	0.714	0.898	0.450	0.428	0.711	0.710	6610.0	11810.0	8892.5
				aerflat	0.707	0.896	0.445	0.413	0.713	0.704	6591.7	11810.0	8847.2
				c0s1l1	0.747	0.899	0.564	0.412	0.780	0.698	6576.1	11810.0	8734.3
				c2s1l1	0.690	0.895	0.420	0.347	0.691	0.653	6699.2	11810.0	8914.7
				c3s1l1	0.674	0.885	0.450	0.284	0.693	0.552	6727.2	11810.0	8969.8
				Laslett	0.929	0.987	0.831	0.485	0.958	0.775	7248.5	11915.8	9979.2
				STwin	**0.410**	**0.700**	**0.146**	**0.237**	**0.372**	**0.494**	6030.4	11810.0	7848.3
				run3	0.867	0.965	0.730	0.501	0.906	0.785	6930.2	11810.0	9535.5
				run6	0.697	0.891	0.447	0.381	0.703	0.664	6591.3	11810.0	8823.0
				omega75	**0.253**	**0.466**	**0.077**	**0.210**	**0.213**	**0.395**	5589.6	11810.0	7200.4
				highCPUECV	0.575	0.832	0.269	0.348	0.570	0.632	5475.6	11810.0	8281.9
				highaerialCV	0.737	0.916	0.461	0.449	0.730	0.739	6262.2	11810.0	8788.7
				upq	**0.469**	**0.717**	**0.218**	**0.310**	**0.452**	**0.567**	6636.8	11810.0	8757.5
				downq	0.863	0.968	0.658	0.522	0.880	0.812	6624.4	11810.0	8860.9
				downupq	0.823	0.947	0.617	0.480	0.843	0.774	6837.9	11810.0	9285.3
				truncCPUE	0.851	0.965	0.637	0.477	0.873	0.765	6643.1	11810.0	9127.4
25 years	90%	0.21	0.14	**c1s1l1**	**0.899**	0.982	**0.598**	**0.597**	0.859	0.862	3692.6	11810.0	4980.6
				c1s1l2	0.929	0.990	0.655	0.629	0.895	0.874	3750.7	11810.0	5041.6
				troll	1.000	1.000	1.000	1.000	1.000	1.000	5578.3	11810.0	6366.4
				mixtag	0.900	0.984	0.602	0.618	0.850	0.865	3695.3	11810.0	4992.1
				recuncor	0.918	0.988	0.661	0.674	0.886	0.888	3775.4	11810.0	5047.0
				downwearlysize	0.854	0.973	0.546	0.499	0.813	0.798	3660.2	11810.0	4920.2
				regimeshift	0.942	0.990	0.741	0.610	0.922	0.872	3718.6	11810.0	4954.3
				aerdome	0.909	0.982	0.613	0.606	0.870	0.860	3708.1	11810.0	4976.9
				aerflat	0.902	0.981	0.607	0.590	0.864	0.854	3670.0	11810.0	4958.2
				c0s1l1	0.901	0.985	0.684	0.566	0.889	0.846	3648.9	11810.0	4914.3
				c2s1l1	0.907	0.983	0.577	0.525	0.844	0.805	3745.6	11810.0	5012.2
				c3s1l1	0.904	0.986	0.594	0.428	0.831	0.734	3830.5	11810.0	5049.3
				Laslett	0.991	1.000	0.917	0.651	0.987	0.898	4386.7	11810.0	5393.1
				STwin	**0.696**	0.915	**0.257**	**0.389**	0.592	0.674	3181.7	11810.0	4585.5
				run3	0.972	0.999	0.830	0.660	0.965	0.899	4134.4	11810.0	5242.8
				run6	0.895	0.983	0.582	0.544	0.841	0.826	3705.6	11810.0	4966.1
				omega75	**0.487**	0.725	**0.163**	**0.329**	0.361	0.597	2976.6	11810.0	4377.1
				highCPUECV	0.843	0.975	0.468	0.530	0.780	0.824	3329.2	11810.0	4749.0
				highaerialCV	0.904	0.985	0.604	0.610	0.865	0.864	3627.7	11810.0	4934.4
				upq	**0.767**	0.926	**0.376**	**0.492**	0.665	0.757	3673.0	11810.0	5012.1
				downq	0.966	0.997	0.771	0.664	0.946	0.907	3701.2	11810.0	4924.6
				downupq	0.955	0.994	0.753	0.646	0.934	0.890	3924.0	11810.0	5137.4
				truncCPUE	0.967	0.997	0.763	0.639	0.945	0.887	3827.9	11810.0	5067.4

Table 2 (cont'd)

Timeframe reaching the reference point (20% SSB0)	Probability level for tuning	control parameter		Name of run	Reference points		Check points				[C2009(Median):C2039(Median)]		
		x-high	*x-low*		Pr[B2035 >0.20*B0]	Pr[B2040 >0.20*B0]	Pr[B2022 >0.10*B0]	Pr[B2022 >2*B2009]	Pr[B2025 >0.10*B0]	Pr[B2025 >2*B2009]	Min	Max	Average
30 years	60%	0.21	0.14	**c1s1l1**	0.379	**0.597**	0.270	0.244	**0.474**	**0.473**	8538.8	16939.4	12061.0
				c1s1l2	0.460	0.672	0.334	0.281	0.555	0.526	8637.9	17310.8	12332.5
				troll	0.998	0.999	1.000	0.999	1.000	0.997	9363.5	22205.0	18129.3
				mixtag	0.394	0.604	0.283	0.266	0.489	0.509	8686.7	17051.9	12170.3
				recuncor	0.410	0.620	0.322	0.302	0.516	0.511	9363.5	17207.0	12397.1
				downwearlysize	0.309	0.517	0.233	0.192	0.425	0.398	8417.5	16530.9	11710.4
				regimeshift	0.521	0.706	0.450	0.233	0.637	0.482	8647.5	16690.5	12037.4
				aerdome	0.379	0.593	0.282	0.242	0.483	0.474	8983.3	16861.9	12106.9
				aerflat	0.379	0.593	0.287	0.241	0.476	0.467	8700.8	16882.8	12049.8
				c0s1l1	0.475	0.661	0.396	0.239	0.604	0.489	8371.2	16618.4	11894.4
				c2s1l1	0.330	0.554	0.259	0.190	0.460	0.414	8452.2	16890.2	12050.1
				c3s1l1	0.315	0.518	0.290	0.147	0.476	0.330	8596.9	16823.2	12102.8
				Laslett	0.677	0.835	0.694	0.295	0.855	0.539	9363.5	18555.4	14017.9
				STwin	0.152	**0.327**	0.068	0.123	**0.189**	**0.296**	7627.7	14635.1	10000.0
				run3	0.598	0.776	0.561	0.310	0.756	0.563	9363.5	17793.9	13257.3
				run6	0.362	0.580	0.283	0.224	0.485	0.447	8399.2	16760.5	11986.3
				omega75	0.083	**0.185**	0.036	0.096	**0.105**	**0.208**	7611.4	11810.0	8661.2
				highCPUECV	0.180	0.393	0.111	0.117	0.264	0.321	7627.7	16063.9	11077.9
				highaerialCV	0.390	0.631	0.280	0.259	0.503	0.500	7931.1	17092.1	12018.6
				upq	0.147	**0.312**	0.103	0.136	**0.221**	**0.320**	9205.3	16052.7	11451.5
				downq	0.616	0.812	0.502	0.347	0.732	0.616	7737.3	17140.1	12214.9
				downupq	0.525	0.723	0.441	0.297	0.665	0.555	8759.1	17653.6	12800.1
				truncCPUE	0.549	0.749	0.439	0.279	0.668	0.546	8831.1	17332.3	12618.1
30 years	70%	0.21	0.14	**c1s1l1**	0.473	**0.709**	0.319	0.292	**0.549**	**0.548**	7627.7	15486.0	11256.2
				c1s1l2	0.562	0.764	0.383	0.329	0.637	0.601	7694.8	15735.0	11499.1
				troll	1.000	1.000	1.000	1.000	1.000	0.998	9363.5	19839.6	16815.7
				mixtag	0.488	0.710	0.323	0.323	0.555	0.582	7739.8	15577.2	11344.0
				recuncor	0.507	0.734	0.377	0.361	0.585	0.590	8384.0	15672.5	11595.4
				downwearlysize	0.392	0.619	0.273	0.235	0.493	0.465	7627.7	15192.9	10972.5
				regimeshift	0.613	0.800	0.503	0.287	0.700	0.559	7703.9	15184.8	11235.7
				aerdome	0.474	0.697	0.329	0.294	0.541	0.545	8003.7	15533.4	11311.1
				aerflat	0.478	0.705	0.327	0.290	0.547	0.544	7751.5	15414.8	11236.5
				c0s1l1	0.569	0.739	0.447	0.295	0.668	0.552	7627.7	15129.2	11076.9
				c2s1l1	0.430	0.679	0.299	0.234	0.530	0.484	7627.7	15503.6	11291.3
				c3s1l1	0.404	0.640	0.329	0.185	0.545	0.399	7658.8	15422.3	11334.6
				Laslett	0.769	0.906	0.742	0.341	0.894	0.622	9363.5	16784.3	13028.9
				STwin	0.218	**0.439**	0.087	0.156	**0.230**	**0.350**	7627.7	13883.2	9575.5
				run3	0.694	0.850	0.620	0.356	0.800	0.634	8914.3	16238.7	12365.8
				run6	0.460	0.691	0.324	0.264	0.548	0.512	7627.7	15388.9	11201.8
				omega75	0.119	**0.258**	0.048	0.125	**0.127**	**0.261**	7070.3	11810.0	8427.8
				highCPUECV	0.285	0.547	0.150	0.180	0.350	0.412	7397.1	14784.0	10488.0
				highaerialCV	0.493	0.740	0.332	0.311	0.586	0.587	7627.7	15541.4	11254.0
				upq	0.231	**0.437**	0.128	0.180	**0.283**	**0.393**	8204.3	15060.8	10839.3
				downq	0.701	0.876	0.554	0.392	0.784	0.686	7627.7	15480.6	11386.8
				downupq	0.622	0.804	0.493	0.347	0.727	0.625	7803.7	16079.6	11897.2
				truncCPUE	0.650	0.844	0.494	0.332	0.733	0.609	7867.7	15792.0	11721.9

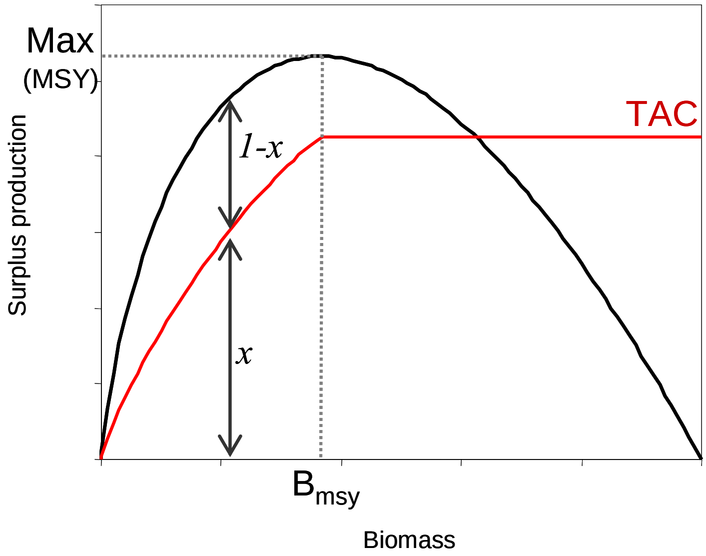


Fig. 1. The catch control rule for the CMP (red line) based on the MSY which is calculated by the Fox model. TAC is determined as the "*xx% of the surplus production (or MSY)*", where "*xx%* (x-value)" is controlled by the current biomass and control parameters (see Fig. 2).

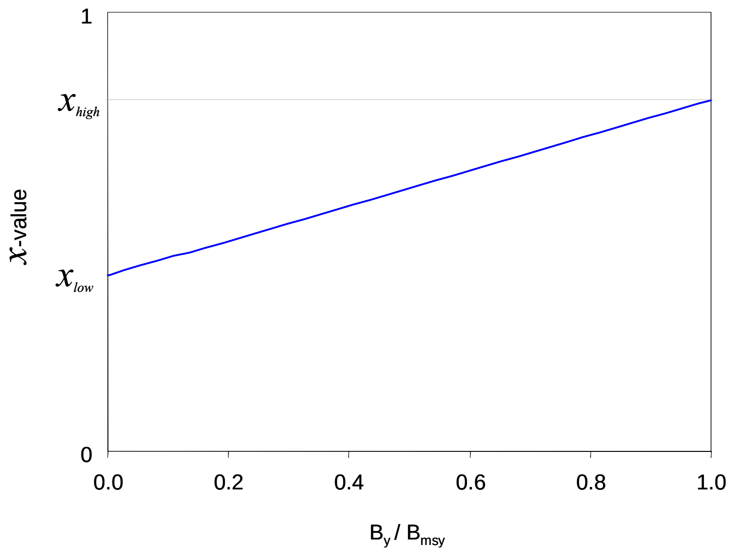


Fig. 2. The relationship between the current biomass and "*xx%* (x-value)" parameter for the CMP. Higher and lower limits of "*xx%* (x-value)" are the "control parameter" to tune the behavior of the CMP.

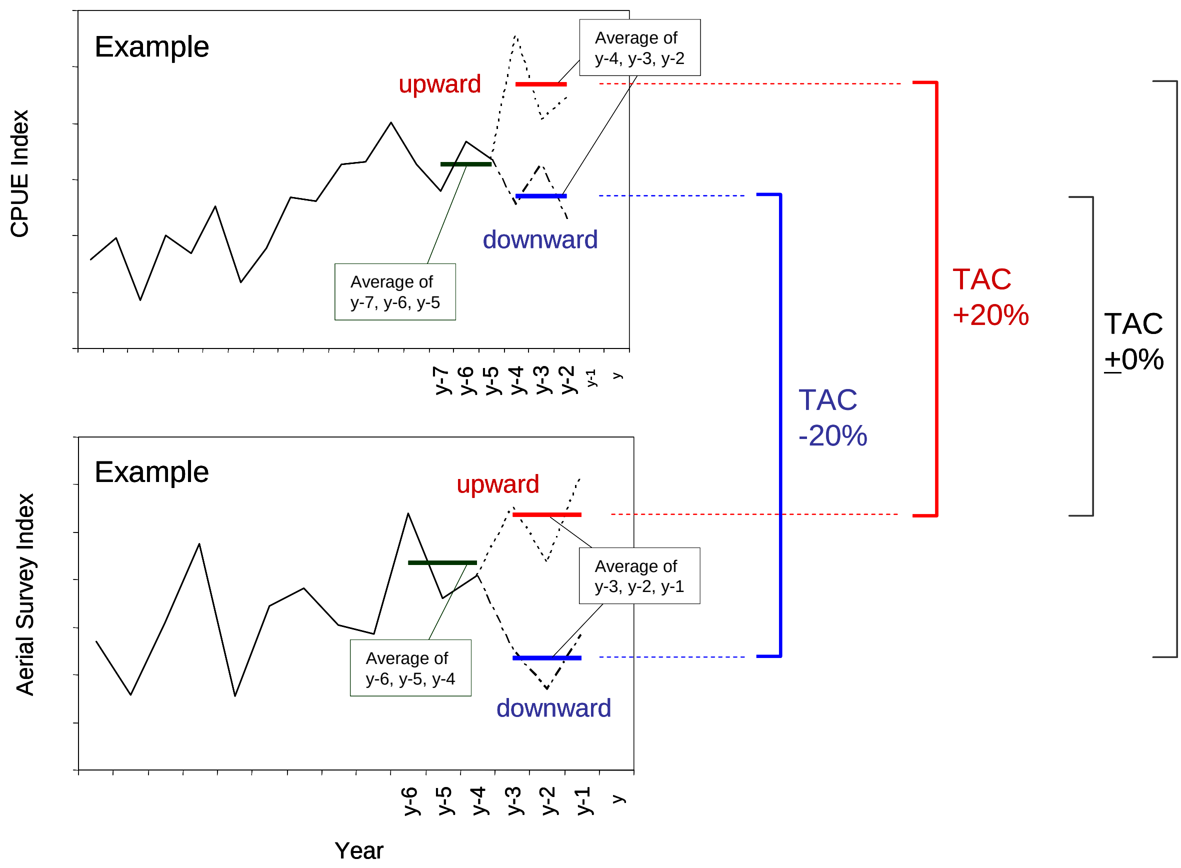


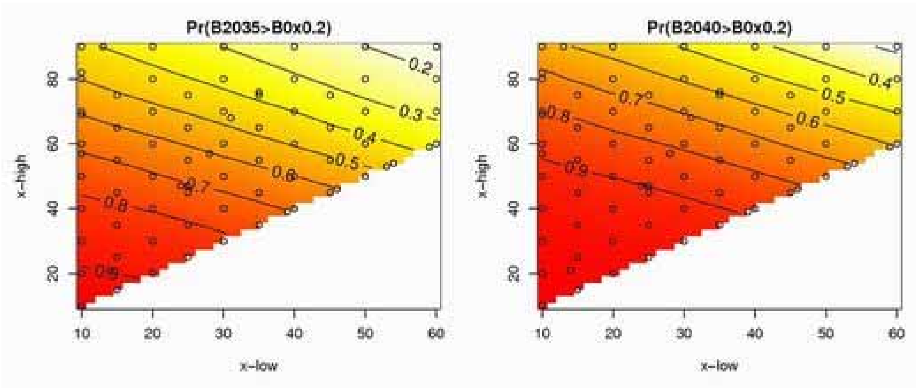
Fig. 3. The alternative catch control rule for the CMP. When the Fox model does not converge or estimates impractically, TAC is determined based on the trend of the abundance indices; current TAC is previous TAC ± zz%. In this MP trial, the rate of TAC change (zz%) is specified “20%”.

a) Max TAC change:

"5000t"

TAC implementation:

"No time-lag"

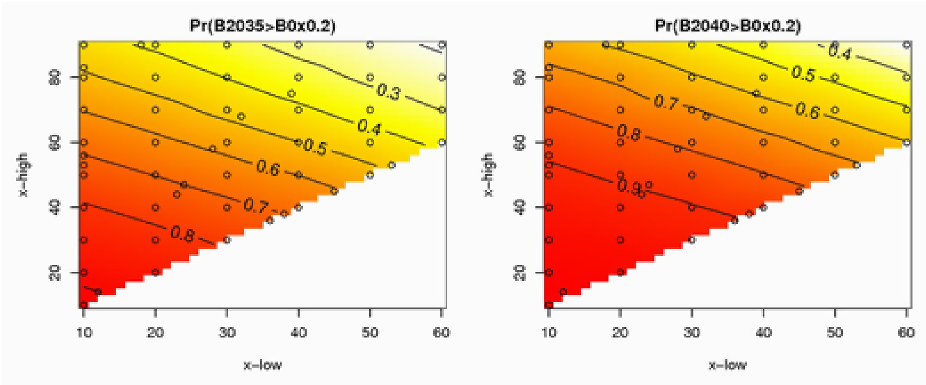


b) Max TAC change:

"5000t"

TAC implementation:

"1year time-lag"

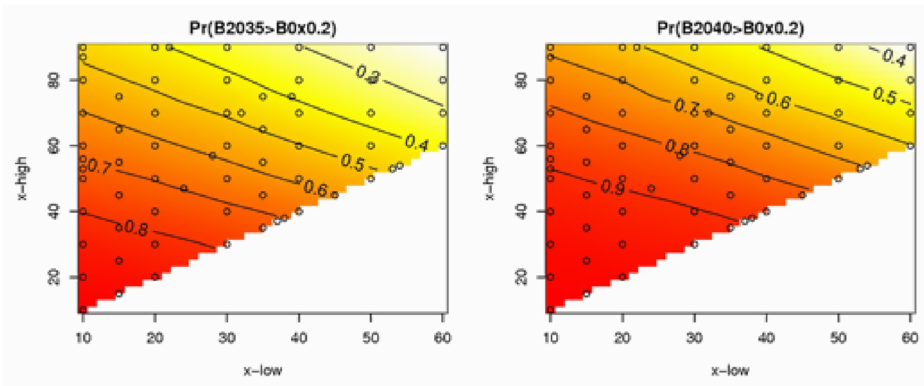


c) Max TAC change:

"3000t"

TAC implementation:

"No time-lag"



d) Max TAC change:

"3000t"

TAC implementation:

"1year time-lag"

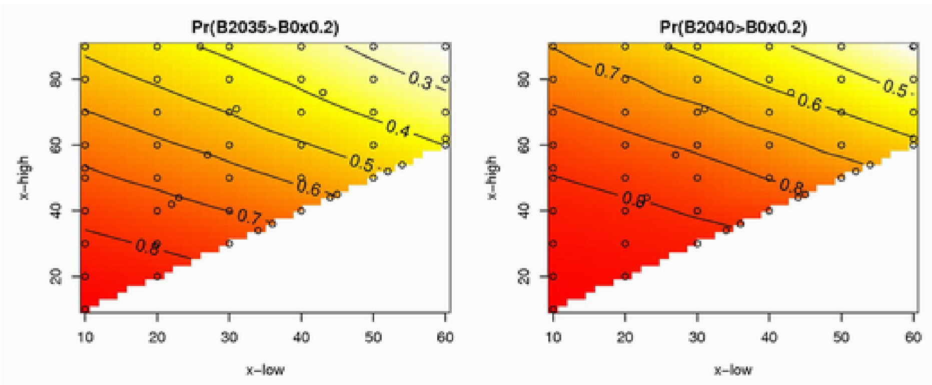


Fig. 4. The relationships between the probability of SSB rebuilding and the combination of the control parameters (x-high and x-low).

a) Max TAC change:

"5000t"

TAC implementation:

"No time-lag"

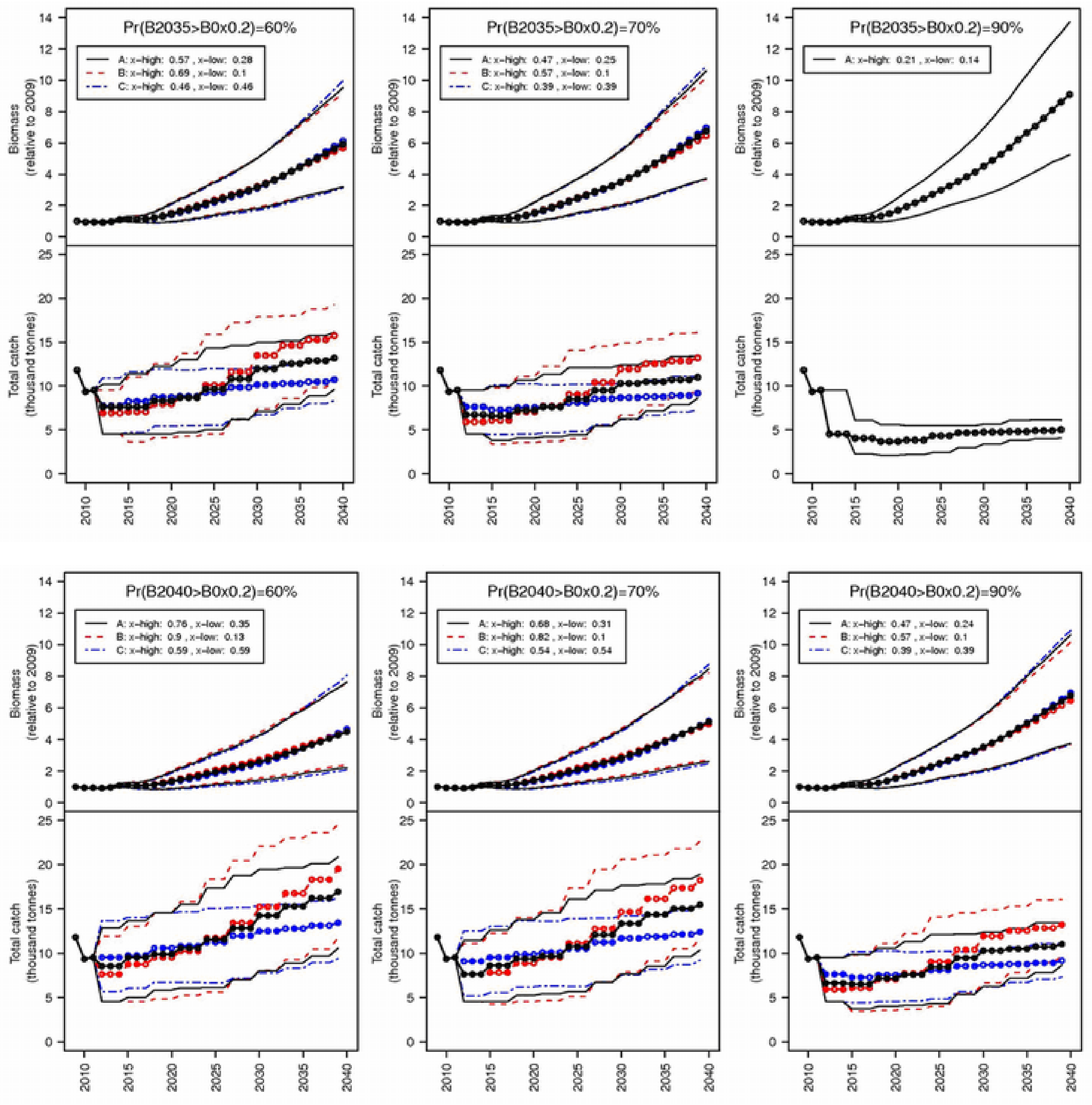


Fig. 5. Examples of the trajectories of SSB and TAC under the tuning for the rebuilding to 20% of SSB_0 in 25 years or 30 years. Lines indicate Median, 10^{th} and 90^{th} percentile of 2000 runs. Red lines indicate the tuning of the larger TAC increase in the long term. Blue lines indicate the tuning of the lower TAC cut down in the short term. Black lines indicate the intermediate case.

b) Max TAC change:

"5000t"

TAC implementation:

"1year time-lag"

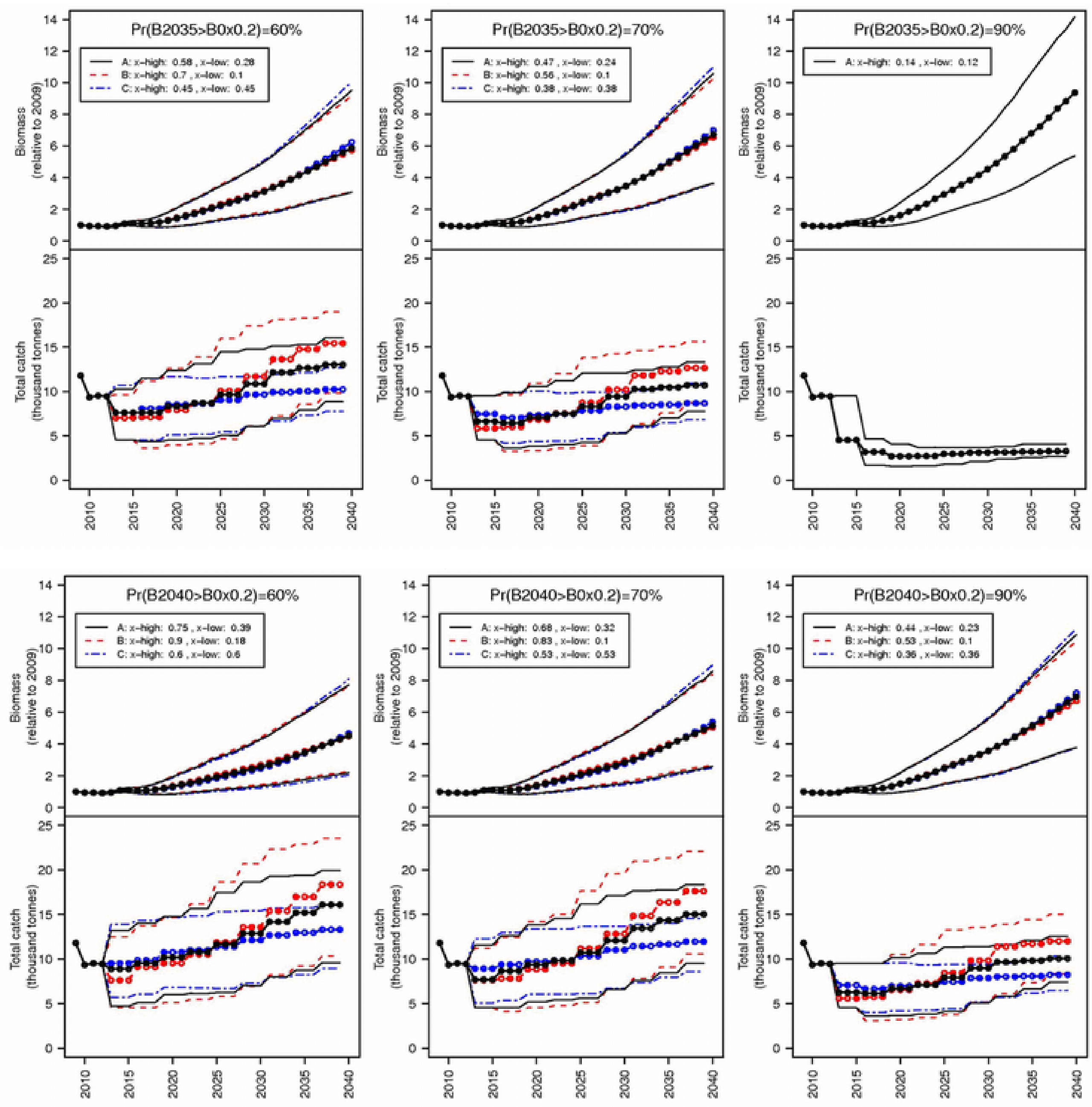


Fig. 5. (cont'd)

c) Max TAC change:

"3000t"

TAC implementation:

"No time-lag"

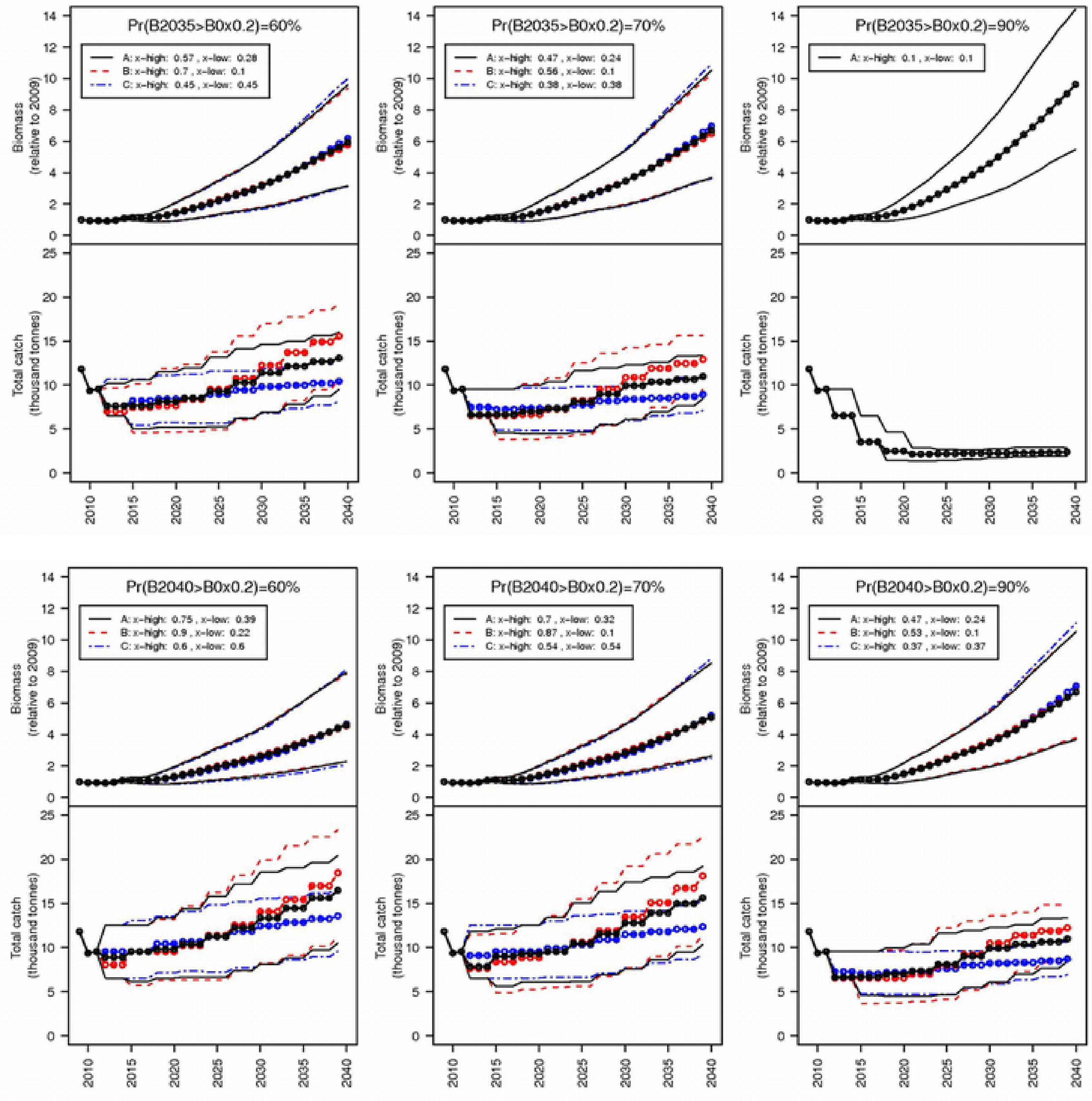


Fig. 5. (cont'd)

d) Max TAC change:

"3000t"

TAC implementation:

"1year time-lag"

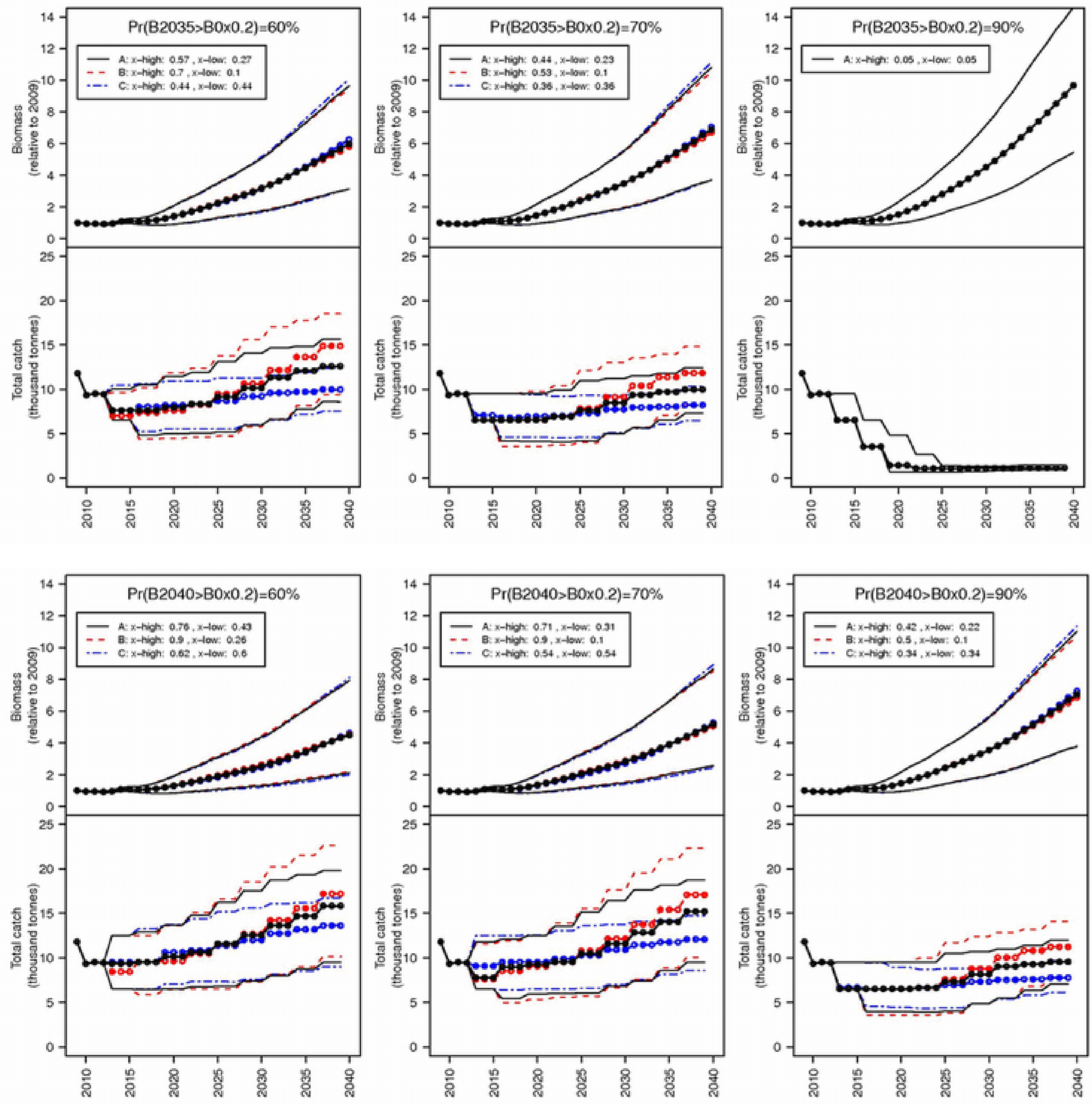


Fig. 5. (cont'd)

Tuning level "1c": Pr(2035>B0x0.2) = 60%

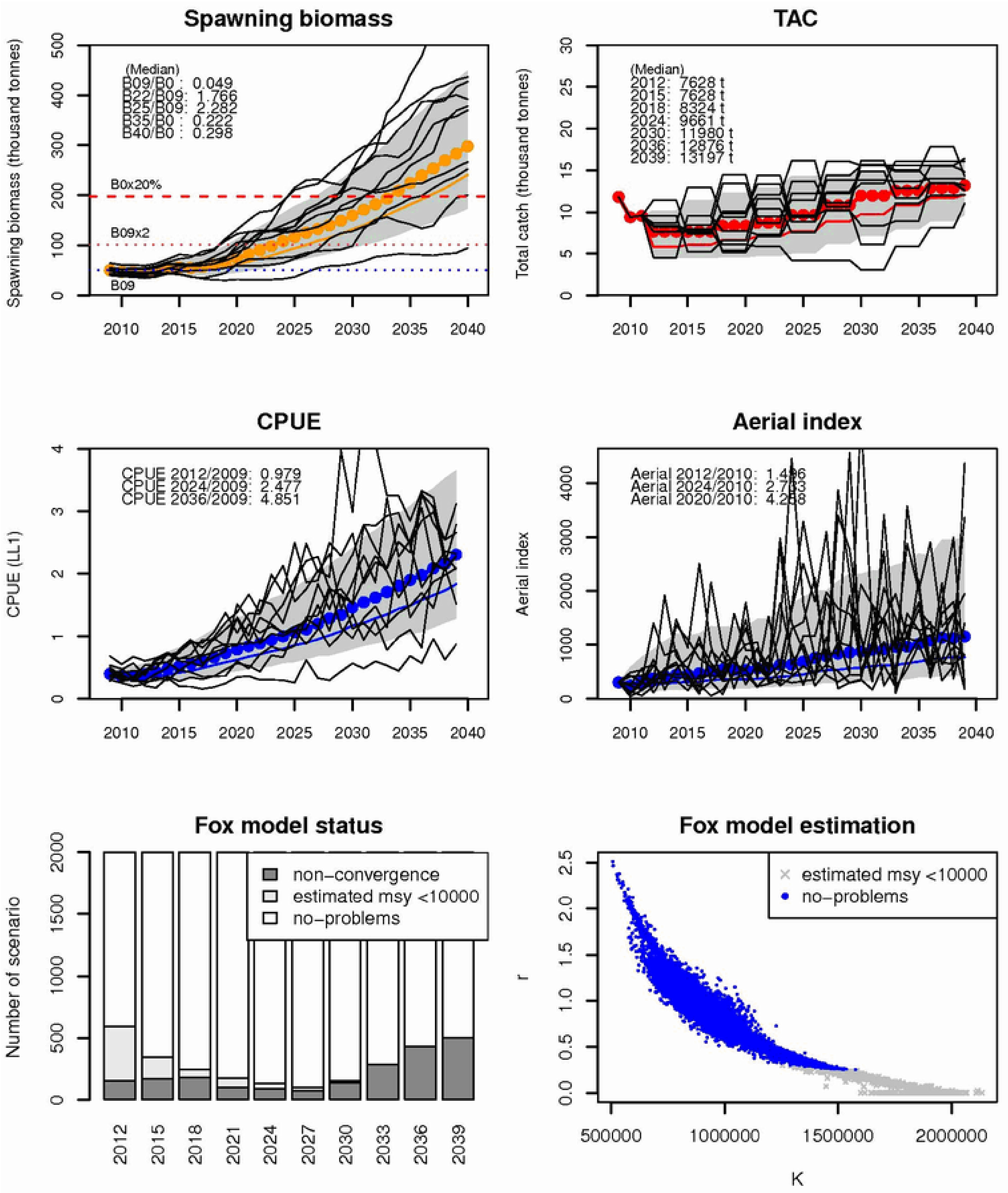


Fig. 6. The worm plots of SSB, TAC, CPUE, Aerial index, and the bar plot of the status of the Fox model convergence and scatter plot of r and K estimation of the Fox model. The maximum TAC changes value and the time lag for TAC implementation is "5000t" and "1 year", respectively.

Tuning level "2c": Pr(2035>B0x0.2) = 70%

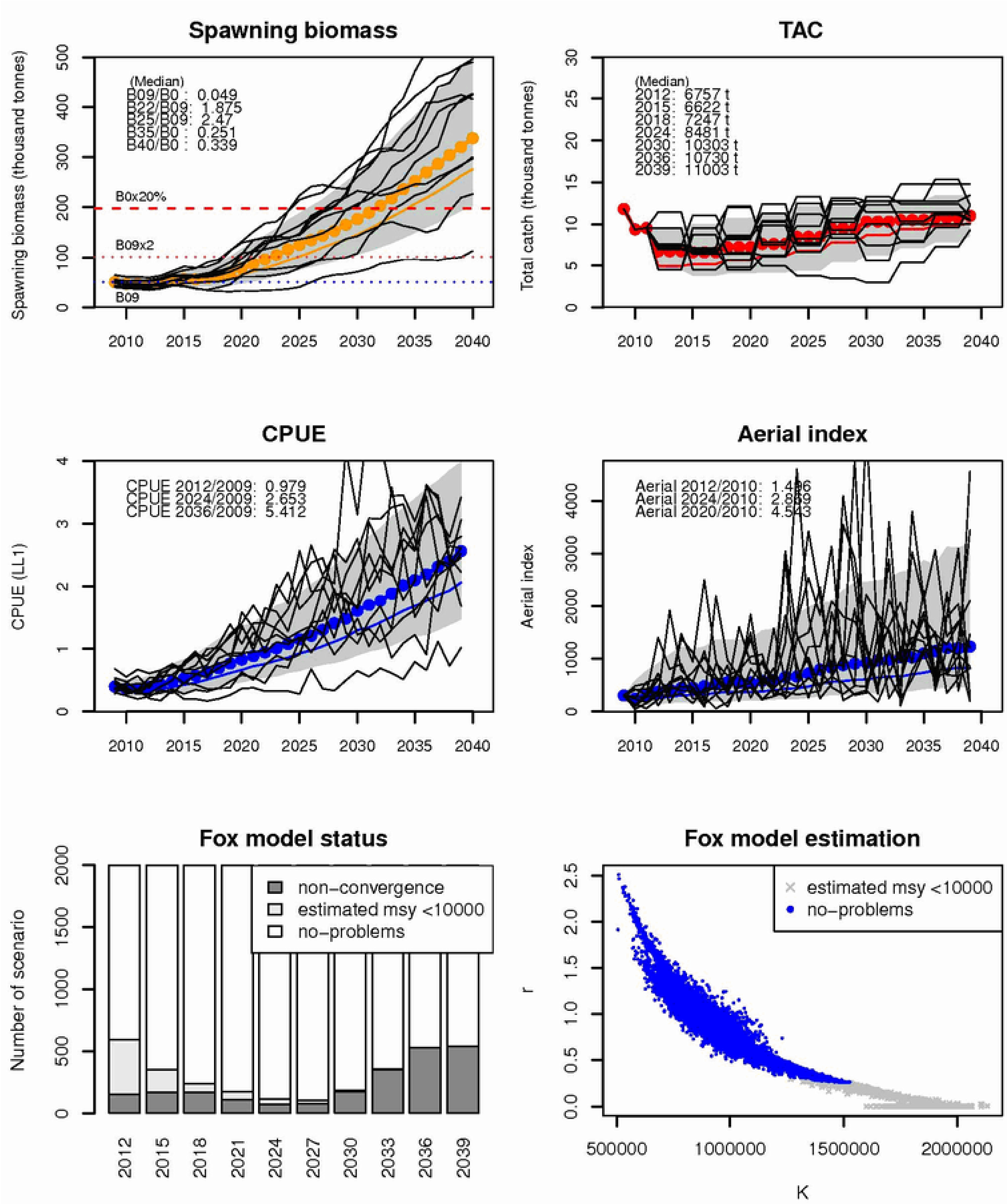


Fig. 6. (cont'd)

Tuning level "3c": Pr(2035>B0x0.2) = 90%

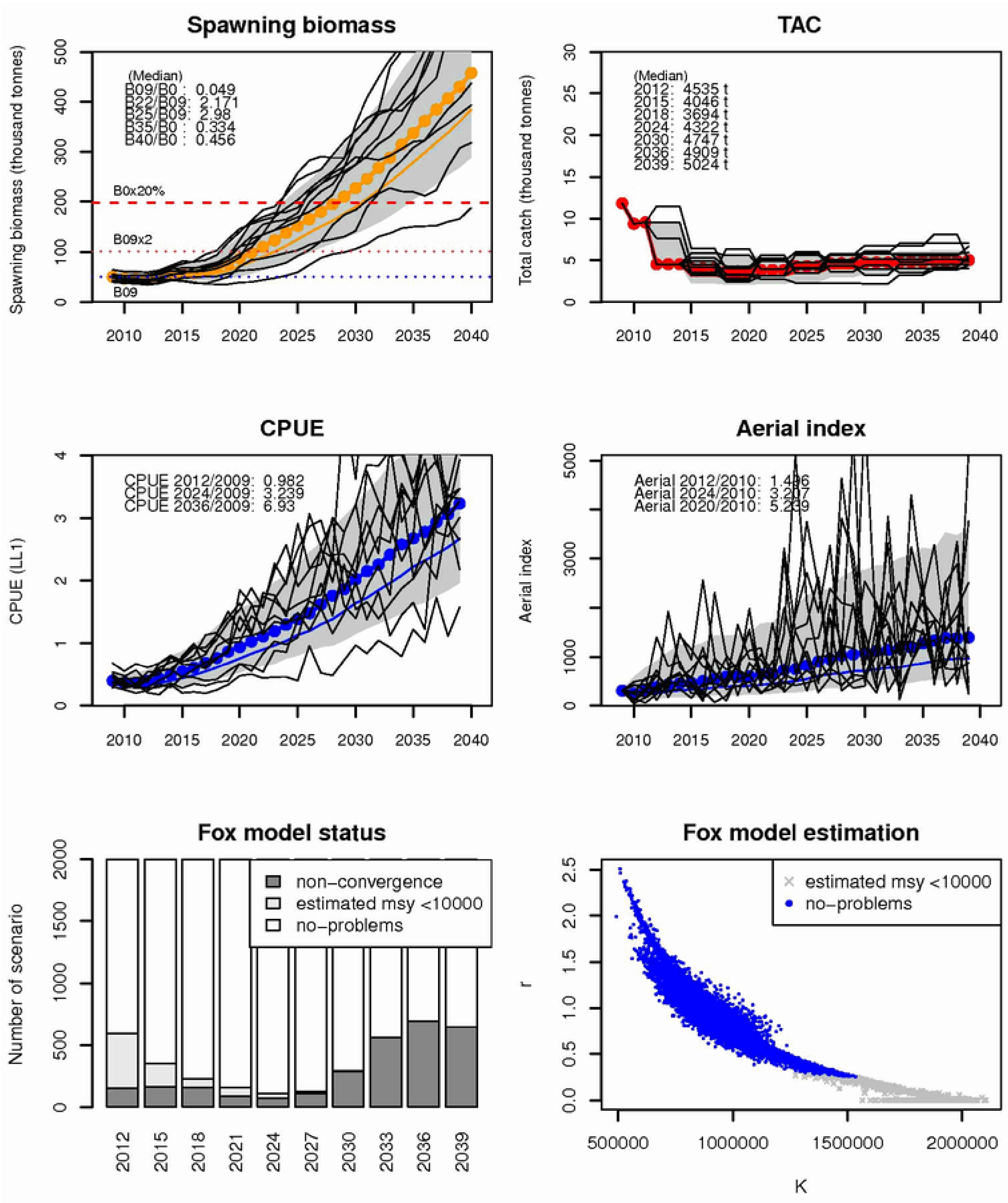


Fig. 6. (cont'd)

Tuning level ”4c”: Pr(2040>B0x0.2) = 60%

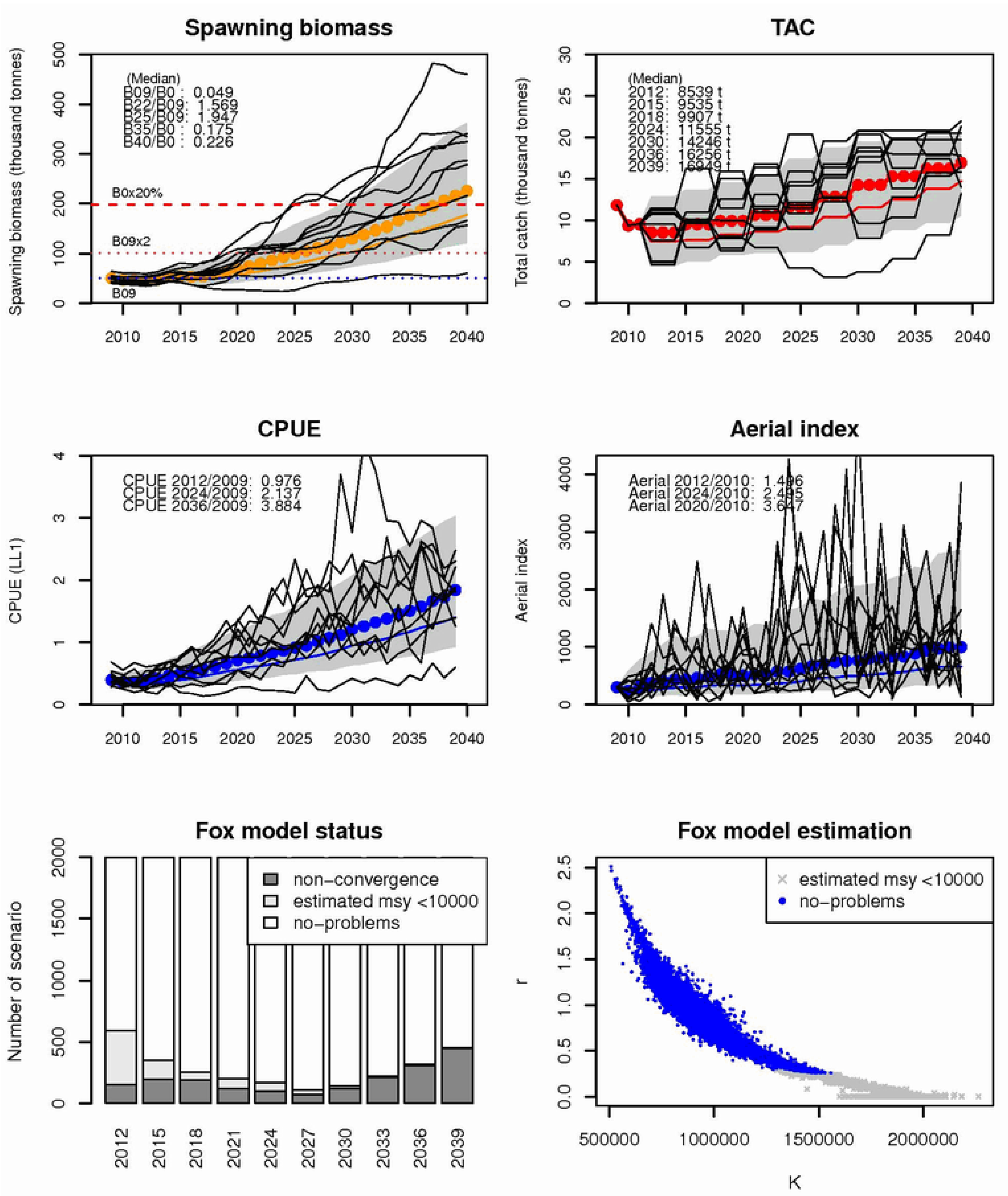


Fig. 6. (cont’d)

Tuning level "5c": Pr(2040>B0x0.2) = 70%

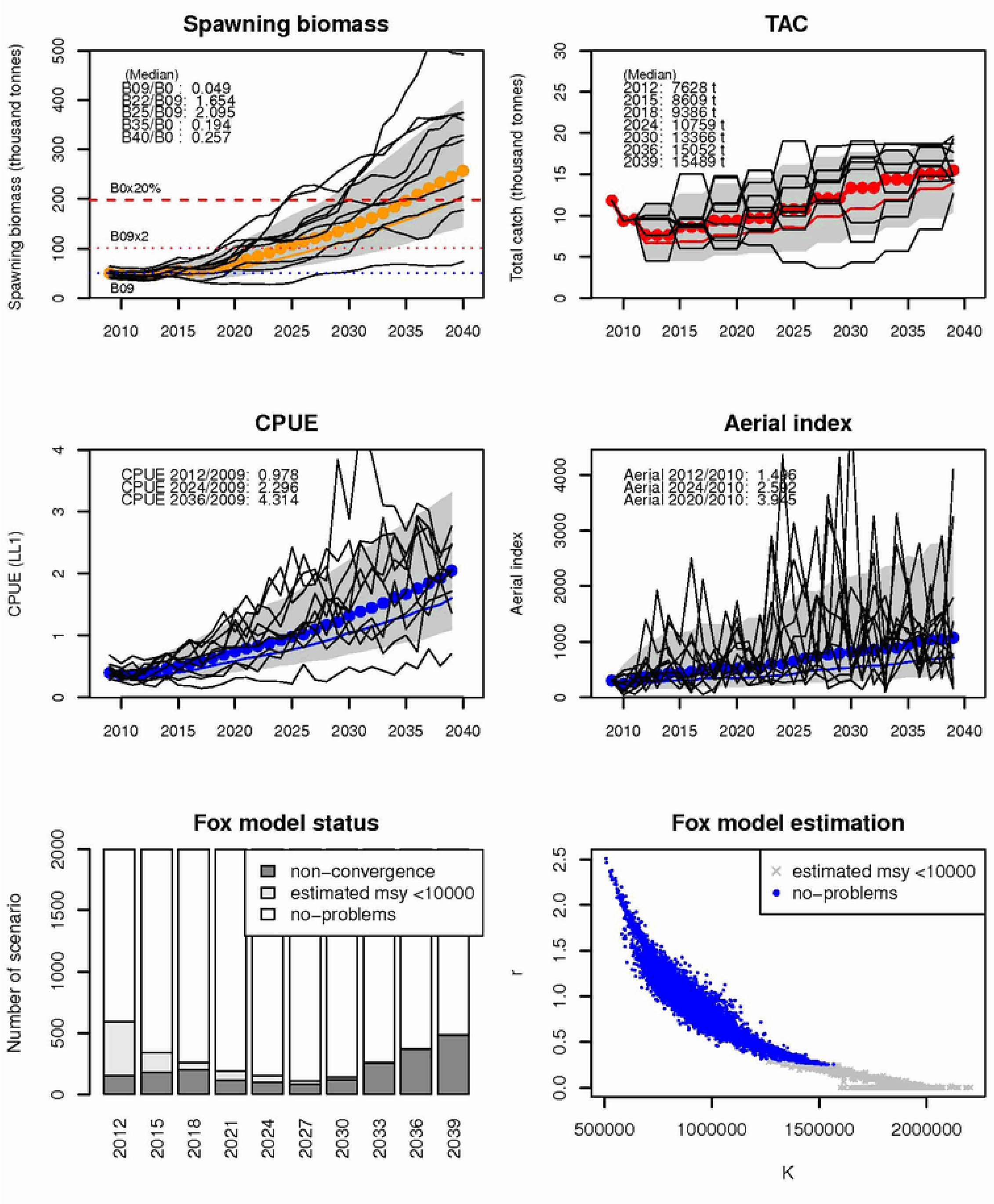


Fig. 6. (cont'd)

Tuning level "6c": Pr(2040>B0x0.2) = 90%

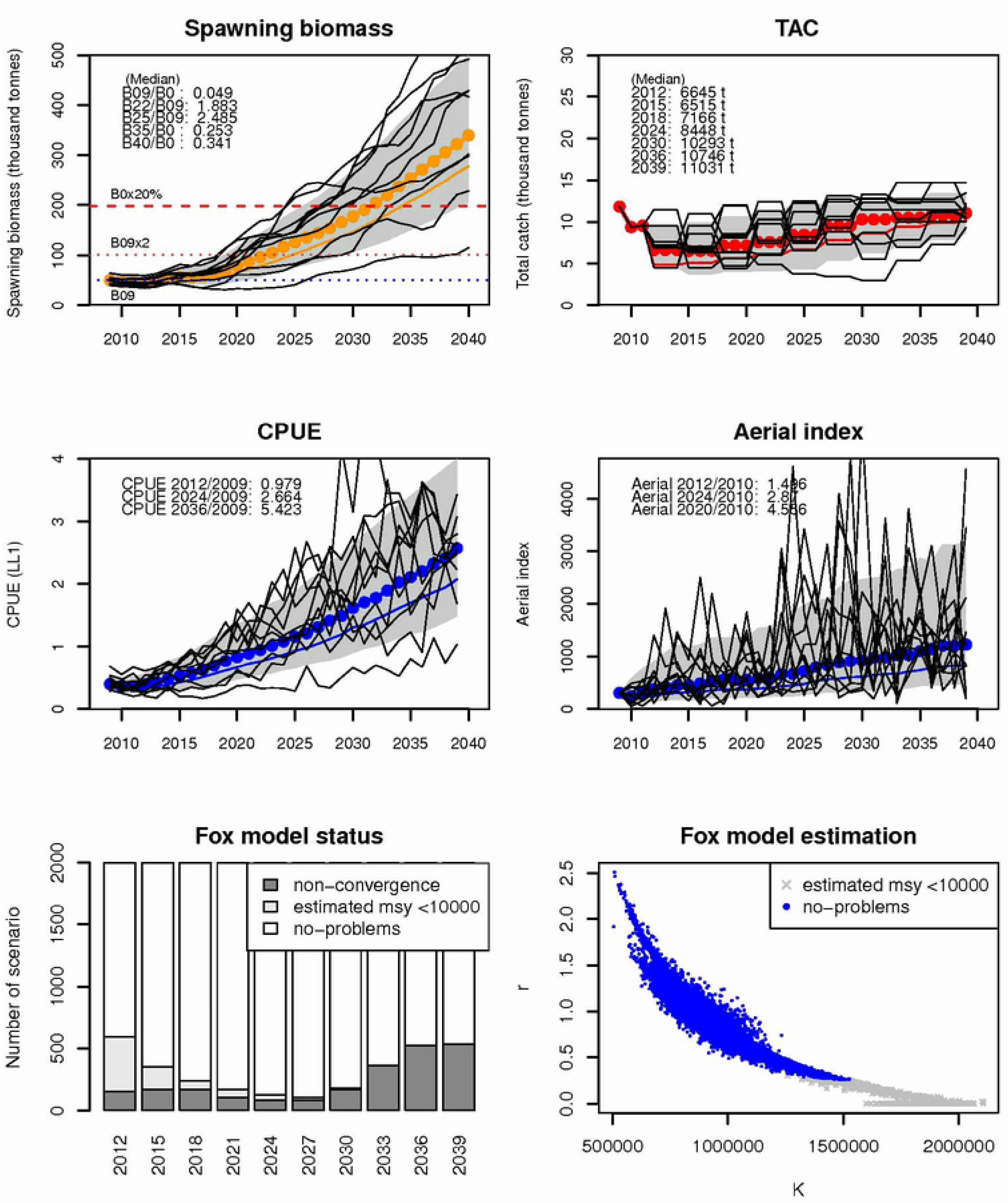


Fig. 6. (cont'd)

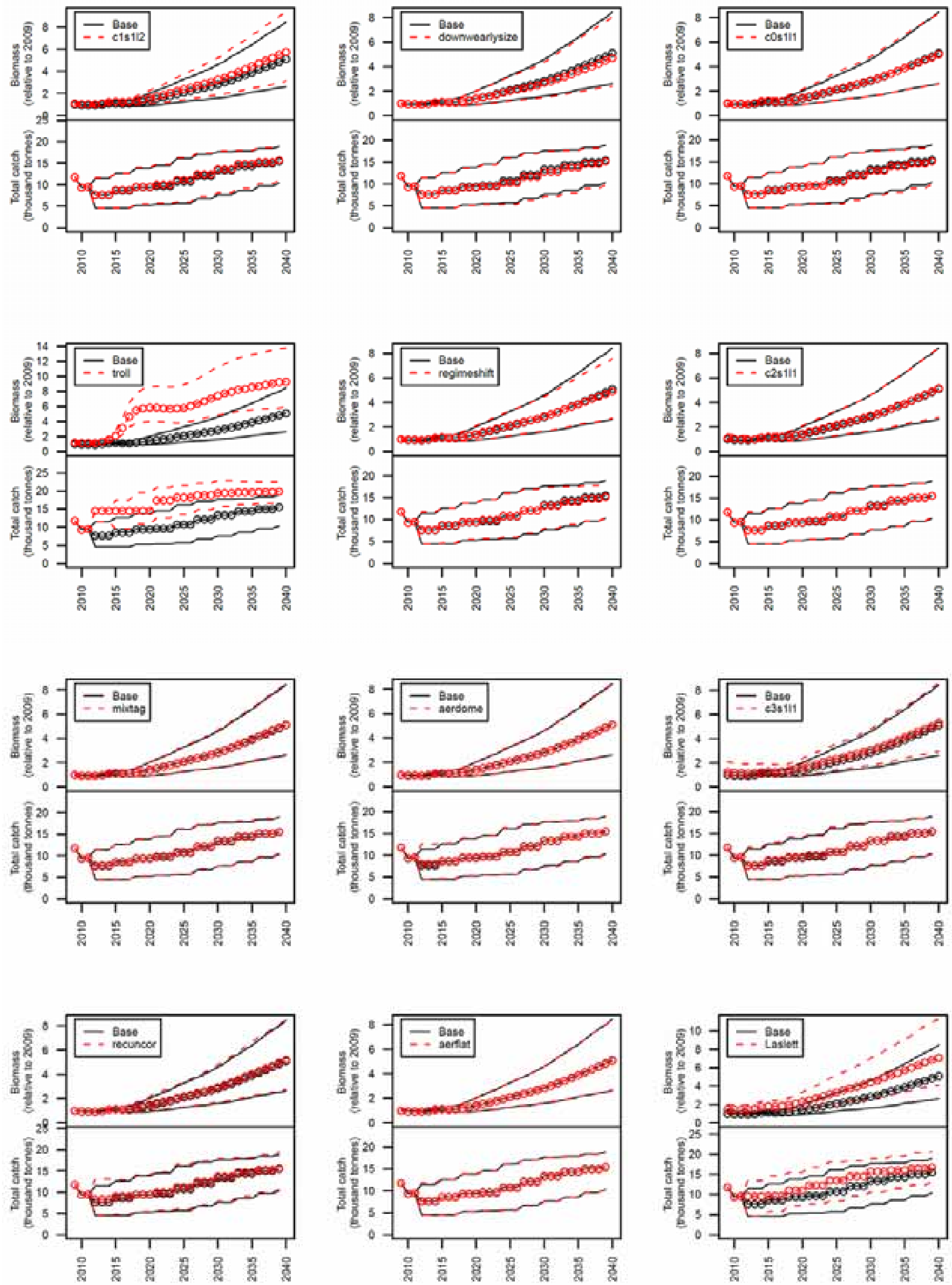


Fig. 7. The projected SSB and TAC of the robustness trials. Tuning level is “Pr(B2040>B0x0.2)=70%”. The maximum TAC changes value and the time lag for TAC implementation is “5000t” and “1 year”, respectively.

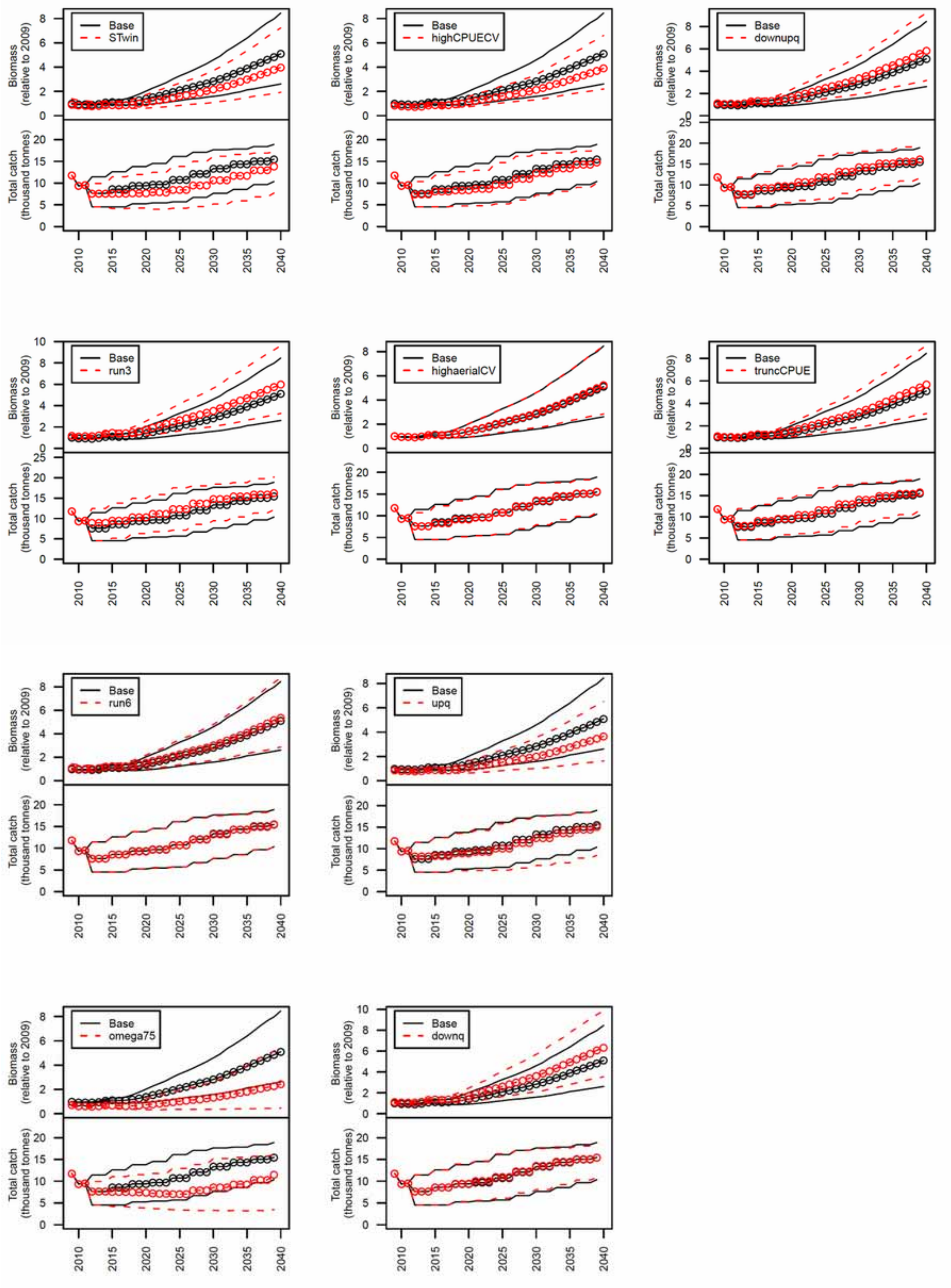

Base
STwin
Base
highCPUECV
Base
downupq
Base
run3
Base
highaerialCV
Base
truncCPUE
Base
run6
Base
upq
Base
omega75
Base
downq
Biomass (relative to 2009)
Total catch (thousand tonnes)

Fig. 7. (cont'd)

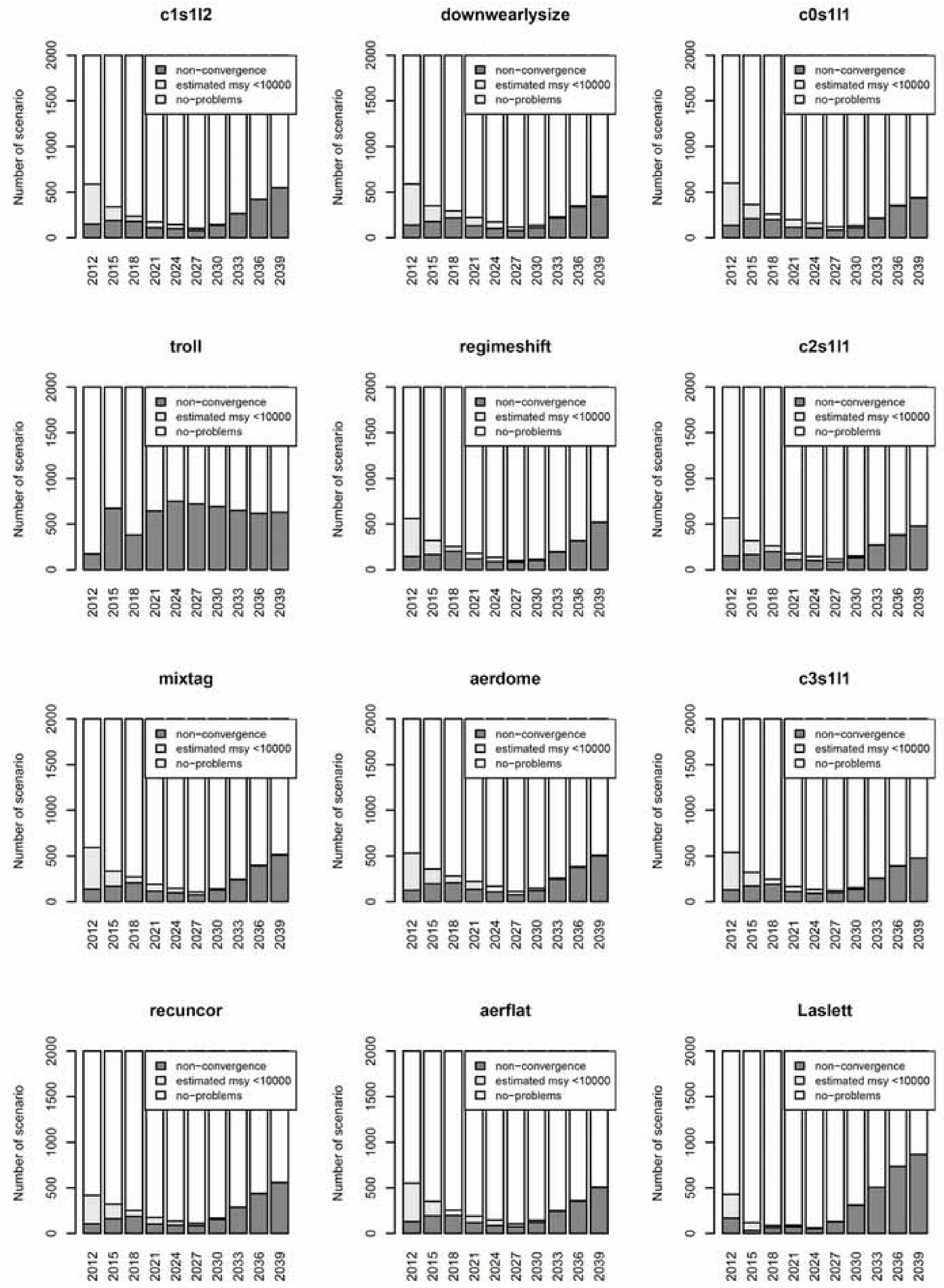


Fig. 8. The statuses of the Fox model under the robustness trials. Tuning level is "Pr(B2040>B0x0.2)=70%". The maximum TAC changes value and the time lag for TAC implementation is "5000t" and "1 year", respectively.

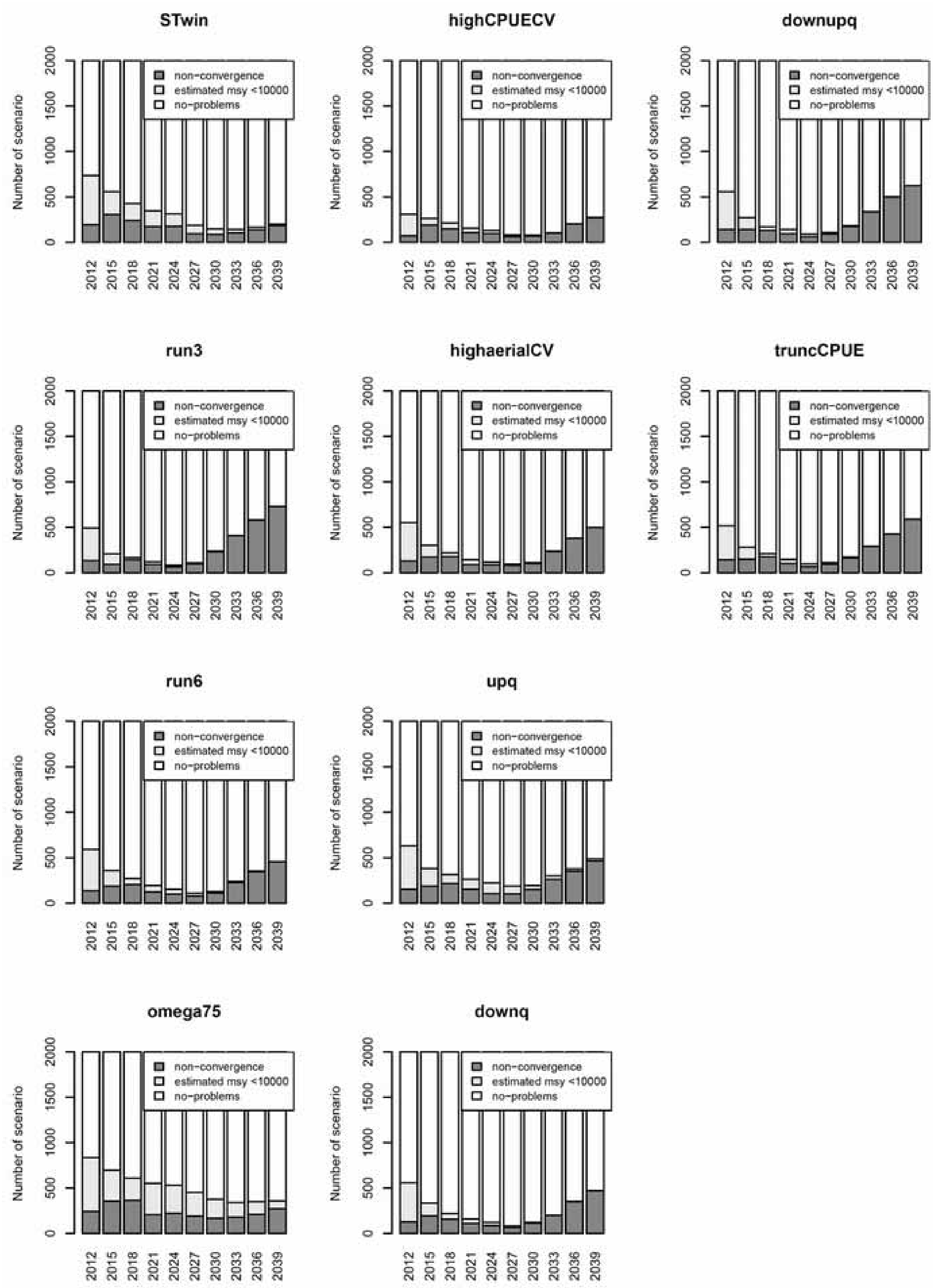

STwin
highCPUECV
downupq
run3
highaerialCV
truncCPUE
run6
upq
omega75
downnq
non−convergence
estimated msy <10000
no−problems
Number of scenario
0
500
1000
1500
2000
2012
2015
2018
2021
2024
2027
2030
2033
2036
2039

Fig. 8. (cont'd)

Appendix： Flow chart of this CMP calculation