FURTHER INVESTIGATIONS OF A FOX-MODEL BASED MANAGEMENT PROCEDURE FOR SOUTHERN BLUEFIN TUNA

ミナミマグロの **Management Procedure** としての **FOX** モデルのさらなる検討

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SUMMARY

The Fox model-based Management Procedure (MP) of Butterworth and Mori (2003) is modified by reducing TACs more sharply in instances where the *r* parameter of the model is estimated to be low. The resultant “Base case” candidate MP shows improved performance in *h*=0.3 scenarios by arresting declines in abundance within the next 20 years, as well as reducing their extent. Performance is, however, poor in instances where CPUE is proportional to the square root of abundance, and attempts to modify the Base case MP for improvements in this respect achieve only marginal success. A further modification to reduce the extent of TAC changes in a direction opposite to that appropriate during the first few years of management achieves some success, but at the expense of greater reduction in abundance for *h*=0.3 scenarios. Results are reported across a range of candidate MPs that reflect different trade-offs between the sizes of future TACs and the extent of abundance recovery.

要約

Butterworth and Mori (2003)にある Fox モデルにおいて，パラメータ *r* の値が低く推定されたモデルについては TAC が急激に減らされるよう，本論文でモデルを改良した．これにより，本論文で提案している”Base Case”と呼ばれる管理方式において，この先 20 年間の資源の減少を食い止めることで，資源の生産性の低い *h*=0.3 のシナリオについて前回よりも優れたパフォーマンスを得ることが出来た．しかし，CPUE は資源の√に比例していると仮定した場合にはこのモデルのふるまいは思わしくなかった．そこで，”Base Case”の改良を試みたが，モデルのふるまいは少ししか改善されなかった．また，管理のはじめ数年に起こる不適切な TAC の変動（一度減少してから上昇する）を改良する試みはある程度成功したが，その代わりに *h*=0.3 のシナリオの資源の回復は”Base Case”と比べて低くなった．本論文では，「将来の TAC」と「資源の回復」との間の様々なトレードオフを考慮した様々な管理方式について報告する．

DATA

The historical catch data and the CPUE abundance index values used in the evaluations are shown in Table 1. The CPUE values are the median of the five CPUE series provided (B-ratio proxy, Geostat proxy, Stwindow, Laslett Core Area, Nominal).

METHODS

In Butterworth and Mori (2003), the behaviour of the SBT stock when setting the TAC based on the application of two production models (the Schaefer and Fox models) was investigated for seven candidate management procedures. Among these, the performance of the Fox model with γ=0.6 (see equation 7 below) appeared reasonable for the initial trials. In this analysis, we investigate this model further, adjusting the TAC calculation method to attempt to obtain better overall performance in the trials. There are 18 reference case trials and 26 robustness case trials (including the MCMC case).

FOX MODEL

The dynamics of the SBT population are assumed to be represented by the discrete equation (Fox model):

$$B_{y+1} = B_y + rB_y\left(1 - \frac{\ln(B_y)}{\ln(K)}\right) - C_y \qquad (1)$$

where B_y is the biomass of SBT present at the start of year y,

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

K is the pre-exploitation biomass (taken to have units of tons in this application), with the associated assumption of a population at pre-exploitation equilibrium when harvests commenced, i.e. $B_{1952} = K$, and

r is the growth rate parameter for the population.

For this model $B_{MSY} = Ke^{-1}$ and $MSY = rK/e\ln K$.

To estimate the parameters r and K, the model is fit to the available index of abundance (CPUE) by assuming:

$$I_y = q\left(\frac{B_y + B_{y+1}}{2}\right)^{\delta} e^{\varepsilon_y} \qquad (2)$$

where I_y is the CPUE index for year y,

q is a nonlinear constant proportionality (the catchability coefficient),

δ is a nonlinear parameter that modifies the relationship between CPUE and the abundance index to a non-linear form (which is linear when δ = 1) , and

ε_y from $N\left(0,\sigma^2\right)$.

Catches and CPUE are input for past years as described above, and the operating model generates values for future years for each projection in a trial.

The associated negative log likelihood minimized in the fitting process is:

$$-\ln L = \sum_y \mu_y \left[\ln\sigma + \frac{\left(\varepsilon_y\right)^2}{2\sigma^2} \right] \tag{3}$$

for which setting partial derivatives to zero ($\frac{\partial(-\ln L)}{\partial q} = 0$, $\frac{\partial(-\ln L)}{\partial \sigma} = 0$) yields closed form solutions for best estimates of q and σ :

$$q = \exp\left[\sum_y \mu_y \left\{ \ln I_y - \ln\left(\frac{B_y + B_{y+1}}{2} \right)^{\delta} \right\} / \sum_y \mu_y \right] \tag{4}$$

$$\sigma = \sqrt{\frac{\sum_y \mu_y \left(\varepsilon_y\right)^2}{\sum_y \mu_y}} \tag{5}$$

The μ_y factor is introduced to allow for less recent data to be down-weighted in the fitting process, so that management recommendations remain reasonably sensitive to the most recent observations. The specific form used is:

$$\mu_y = e^{-\lambda\left(y_{current} - y\right)} \tag{6}$$

where λ is a parameter, which controls the extent of the down-weighting of the older relative to the more recent data. Here we set λ =0.046, which means that the weight accorded to the CPUE value for 1969 to the likelihood is 10% of that of value for 2020.

TAC SPECIFICATION

The TAC for SBT for each future year is calculated from the following equation:

$$TAC_{y+1} = w_y TAC_y + \alpha\left(1-w_y\right)\cdot M\hat{S}YR_y \cdot \hat{B}_{MSY} \cdot \left(\frac{\hat{B}_y}{\hat{B}_{MSY}}\right)^{\gamma} \cdot g\left(\hat{r}_y\right) \qquad (7)$$

where $\hat{B}_{MSY}$ is the estimated maximum sustainable yield level (MSYL),

γ is a control parameter (here fixed to be 0.6),

w_y is a control parameter,

$M\hat{S}YR_y$ is the estimated maximum sustainable yield rate, calculated as $M\hat{S}Y_y / MSYL$ ($\hat{r}_y / \ln \hat{K}_y$ for the Fox model – note that these estimated values change with year y as more data become available),

$\hat{B}_y$ is the estimated biomass for year y, which (together with $\hat{r}_y$ and $\hat{K}_y$) is re-estimated for each projection year, and

$g\left(\hat{r}_y\right)$ is a function which reduces the TAC further if $\hat{r}_y$ is low.

The parameter w_y is set to 0.7 (independent of year y) for all the MP candidates considered here except for "Base case variant 2". For this case, w_y is specified by the following equation:

$$\begin{aligned} w_y &= \left[w_2\left(y-t_1\right)+w_1\left(t_2-y\right)\right]/\left(t_2-t_1\right) && \text{for } 2002 \le y \le 2012 \\ w_y &= w_2 && \text{for } y > 2012 \end{aligned} \qquad (8)$$

We chose w_1=0.95, w_2=0.7, t_1=2002 and t_2=2012.

The TAC reduction factor $g\left(\hat{r}_y\right)$ is set to:

$$g\left(\hat{r}_y\right) = \begin{cases} 0 & \text{for } 0 \le \hat{r}_y \le r_1 \\ \dfrac{1}{r_2 - r_1}\left(\hat{r}_y - r_1\right) & \text{for } r_1 < \hat{r}_y < r_2 \\ 1 & \text{for } r_2 \le \hat{r}_y \end{cases} . \qquad (9)$$

We set r_1=1.0, r_2=1.5 for MP candidates with δ=0.75, and r_1=0.4, r_2=1.0 for candidates with δ=1. The w parameter is introduced to moderate the extent to which the TAC is adjusted from year to year in the interests of industrial stability. The γ parameter's role is to stabilize the TAC trend in the short term: a particular objective in selecting a value for γ is to avoid instances where the TAC outputs show a decrease for the first few years only, followed by a subsequent increase. Setting γ to a value <1 tends to smooth out this undesirable behaviour, which is further diminished by the

Base case variant 2 specification of a time-dependent w_y factor as in equation 8.

RESULTS

The following five candidate management procedures (MPs) were tested:

1. Base case ("Base") (α=1, δ=1) --aims to achieve lesser resource reduction for the h = 0.3 scenarios.
2. Conservative Base case ("C_Base") (α=0.7, δ=1) ---smaller TACs than for the Base case.
3. Aggressive (less Conservative) Base case ("LC_Base") (α=1.3, δ=1) ---larger TACs than for the Base case.
4. Base case variant 1 ("Base_Var1") (α=1, δ=0.75) ---aims to curtail resource depletion for scenarios where CPUE is proportional to the square root of abundance.
5. Base case variant 2 ("Base_Var2") (α=1, δ=0.75, w_1=0.95, w_2=0.7, t_1=2002 and t_2=2012) ---aims to better stabilize the TAC for the first few years.

Figures 1.1 to 1.5 show the results for the comparisons between the above five MPs for the stochastic implementations (hierarchy level 3) of the reference case scenarios. Figure 1.6 shows these for the MCMC trials (hierarchy level 4). The number of replicates for the stochastic scenarios was set to 100 for all these results. Figure 1.1 provides a summary over the five MPs and Figure 1.2 summarises performance of the MPs to the various robustness criteria using the summary plots developed by CSIRO scientists. In the results for individual scenarios, only the three cases *H30M10Q1*, *H55M10Q1* and *H80M10Q1* have been shown (Figures 1.3 to 1.5) as the patterns of results for scenarios with the same value of h are fairly similar. Furthermore, performance hardly differed between *Q0* (autocorrelated variability in CPUE) and *Q1* (autocorrelated variability in CPUE + a steady 1% increase per year in catchability) scenarios (see Figure 1.1), so only the results for the *Q1* scenarios are shown. Median TAC and spawning biomass trajectories for these three cases are shown in Figure 2 for the five MPs. Corresponding sets of individual trajectories, together with medians with 90% probability envelopes are shown in Figure 3.

Amongst the various robustness trials, performance for the *H30M10Q1_q1Omega* trial was accorded particular importance, since the largest (negative) change in resource depletion compared to the reference case scenario was obtained for this trial. Results were similarly sensitive to some other robustness trials, such as *H30M10Q0_Omega*, *H55M10Q0_Omega* and *H55M10Q1_q1Omega*, but to a lesser extent. This is evident from Figures 4.1 and 4.2 which shows robustness test results for the Basecase MP for h=0.3 and h=0.55 scenario respectively. A summary of the performance of the

MPs to the various robustness trials is shown in Figure 5. Figures 5.1 and 5.2 shows how the results of *H30M10Q1_q1Omega* and *H55M10Q1_q1Omega* differ from the corresponding reference case scenarios *H30M10Q1* and *H55M10Q1*, respectively. For *H30M10Q1_q1Omega*, we also show the result for the deterministic case in Figure 5.3.

Primary differences between the MP candidates

Comparisons between the Base case and its more and less conservative versions (1, 2 and 3)

In general, compared to the Base case, when we lower α (candidate 2: "C_Base"), the TACs are lower and the stock recovers more. On the other hand, when we raise α (candidate 3: "LC_Base"), the TACs are higher so that the extent of stock recovery (if any) is less than for the Base case (Figures 1.3-1.6). The trend in median spawning biomass shows an increase before 2020 for all the MPs except for the Aggressive Base case ("LC_Base") (Figure 2).

Comparisons between Base case and the two variants (1, 4 and 5)

Figure 5.3 shows results over the 5 MPs for the deterministic implementation of reference case trial (*H30M10Q1*) and robustness trial (*H30M10Q1_q1Omega*). When the control parameter δ of the TAC formula (equations 2 and 7) is reduced (candidate 4: "Base_Var1"), depletion is not as severe compared to the Base case (candidate 1: "Base") in the robustness trial for which CPUE is proportional to the square root of abundance. However, for the stochastic implementation this improvement is not as appreciable; although median recovery levels are marginally larger, probability intervals also increase (Figures 5.2). For the *H55M10Q1* scenario, even though recovery is less than for the corresponding *H55M10Q1_q1Omega* robustness trial (Figure 5.1), the status of the stock is not as much an issue, so that we concentrate our discussion on scenarios with *h*=0.3.

When in addition w_y is made time dependent (candidate 5: "Base_Var2"), any decrease of the TAC in the first few years is not as large as for the Base case, leading to more satisfactory resource management in cases where the TAC subsequently increases (Figure 2). However, because the TAC is not reduced as much in the first few years, the stock is reduced further for the h = 0.3 scenarios than for the Base case MP (Figure 1.3 and Figure 2).

DISCUSSION AND FURTHER DEVELOPMENTS

Improving stock status for the stochastic implementation of robustness trial H30M10Q1_q1Omega

The weakest aspect of the Base case MP (candidate 1) is the appreciably greater abundance reduction that eventuates if CPUE is proportional to the square root of abundance, rather than to abundance itself. (see, e.g., Figure 5.1). The introduction of the δ parameter in equation 2, which is set to 0.75 rather than to 1 in "Base-Var1", was intended to compensate for this. Though it does not lead to any noticeable deterioration in performance for other trials, it leads to only a marginal improvement for the *Omega* trials. This aspect of the MPs of this paper warrants more attention.

Include some measure of magnitude in the A statistics

Performance in terms of the A statistic, which reflects multiple changes in direction of the TAC trajectories in the early years, is not included in the graphical output software developed by the CSIRO scientists. We consider that this statistic is particularly important to discriminate between the performance of different candidate MPs; industrial stability considerations are not well served by a TAC which decreases for a few years, and then increases again, or *vice versa*. As detailed in the Results section, candidate MP 5 ("Base_Var2") was introduced to better stabilize the TAC for the first few years, and in particular to avoid such inappropriate trends in short-term TAC changes, which are especially evident for the *h*=0.8 trials. Performance of the five MPs in terms of the "A statistics" for *Q1* scenarios are shown in Figure 6. However, the "A statistic" as defined at present does not include any information of magnitude of such changes in the TAC, and thus does not reflect the improvement introduced by "Base_Var2" compared to the "Base case" MP, as is evident in Figure 2. Modification of this statistic to be able also to reflect the magnitude of such TAC changes in the first few years seems warranted. Even if immediate changes in the TAC are in what eventually turns out to be the wrong direction, it is clearly important to the industry that the magnitude of such changes should be as small as possible.

Trade offs between various MPs

Perhaps the two Figures which best summarise the performance of the MP candidates considered here, and their trade-offs, are Figures 1.6 and 5.2.

Figure 5.2 shows first that our attempts to improve recovery performance (relative to that for our Base case procedure) in cases where CPUE is proportional to the square root of abundance (see B2022:B2002 for Base_Var1 compared to Base) have not been particularly successful. Such improvement as is obtained is sacrificed when more importance (Base_Var2) is placed on reducing the extent of TAC changes in the "wrong" direction in the short term.

Figure 1.6 summarises the trade-offs between MP candidates that focus on either better recovery or larger catches than for the Base case procedure. Only for the Aggressive variant (LC_Base) are catches likely to be maintained, on average over time, at their present levels. However, unlike Base and C_Base, this variant reflects appreciable probability that current abundance will decline, and furthermore manifest virtually no chance that MSYL will be reached by 2020.

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We thank Dr. H. Kurota for advice while conducting these computations. We are also appreciative of graphical software developed by CSIRO scientists. Support from Nakajima Foundation is acknowledged.

Table 1. Estimates of total catch (tons) for 1952-2001 and CPUE values for 1969-2000 input to the management procedure.

	Catch	CPUE
1952	90	-
1953	2643	-
1954	3441	-
1955	2193	-
1956	3837	-
1957	20380	-
1958	16208	-
1959	39505	-
1960	63112	-
1961	85211	-
1962	57464	-
1963	55488	-
1964	51040	-
1965	49084	-
1966	44088	-
1967	54766	-
1968	61835	-
1969	54752	2.4883
1970	44784	2.0917
1971	41970	1.8920
1972	45265	1.9679
1973	41195	1.5681
1974	40576	1.7207
1975	31704	1.2603
1976	42825	1.5825
1977	37442	1.4921
1978	32897	1.3433
1979	36950	1.0826
1980	41343	1.1299
1981	39954	1.1385
1982	36967	0.9015
1983	44221	0.9571
1984	35427	0.8455
1985	30609	0.7100
1986	28544	0.4974
1987	24346	0.4720
1988	22216	0.4146
1989	18442	0.4206
1990	13894	0.4200
1991	13590	0.4752
1992	13260	0.5220
1993	14305	0.7138
1994	12221	0.6909
1995	12423	0.7199
1996	15818	0.4729
1997	15964	0.4854
1998	19684	0.5151
1999	18767	0.4730
2000	16397	0.5856
2001	15386	

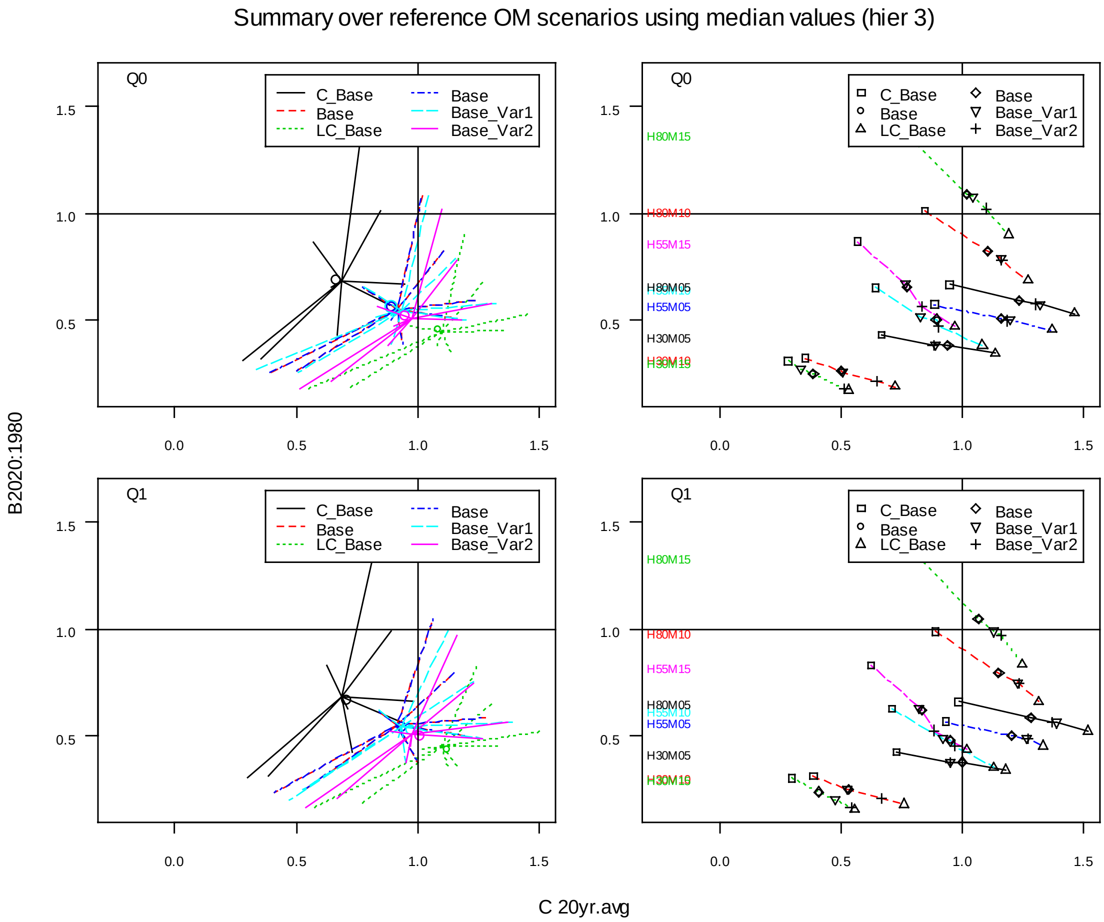

Figure 1.1 Summary performance for the five initial candidate MPs.

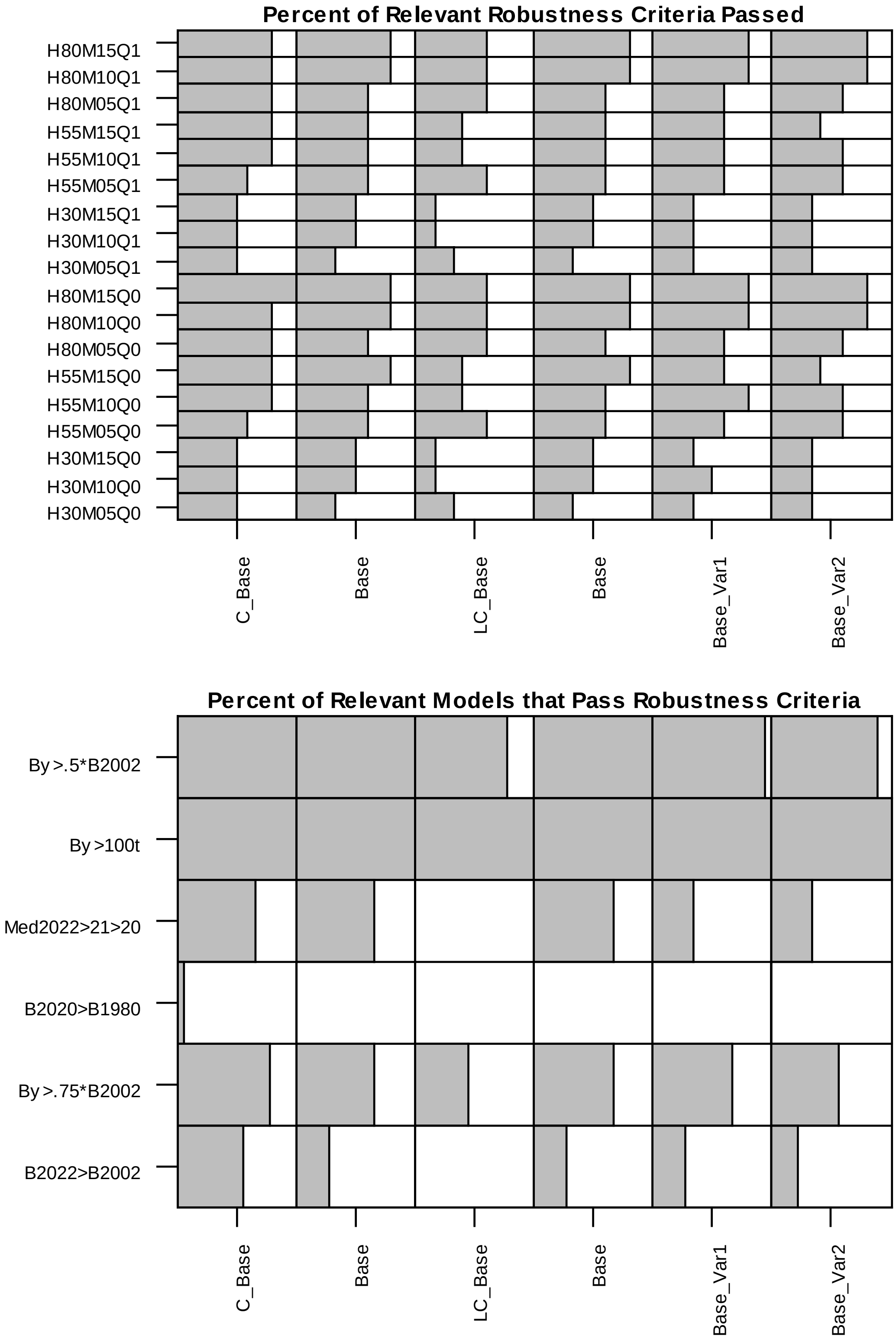

Figure 1.2 Summary performance for the five initial candidate MPs to various robustness criteria.

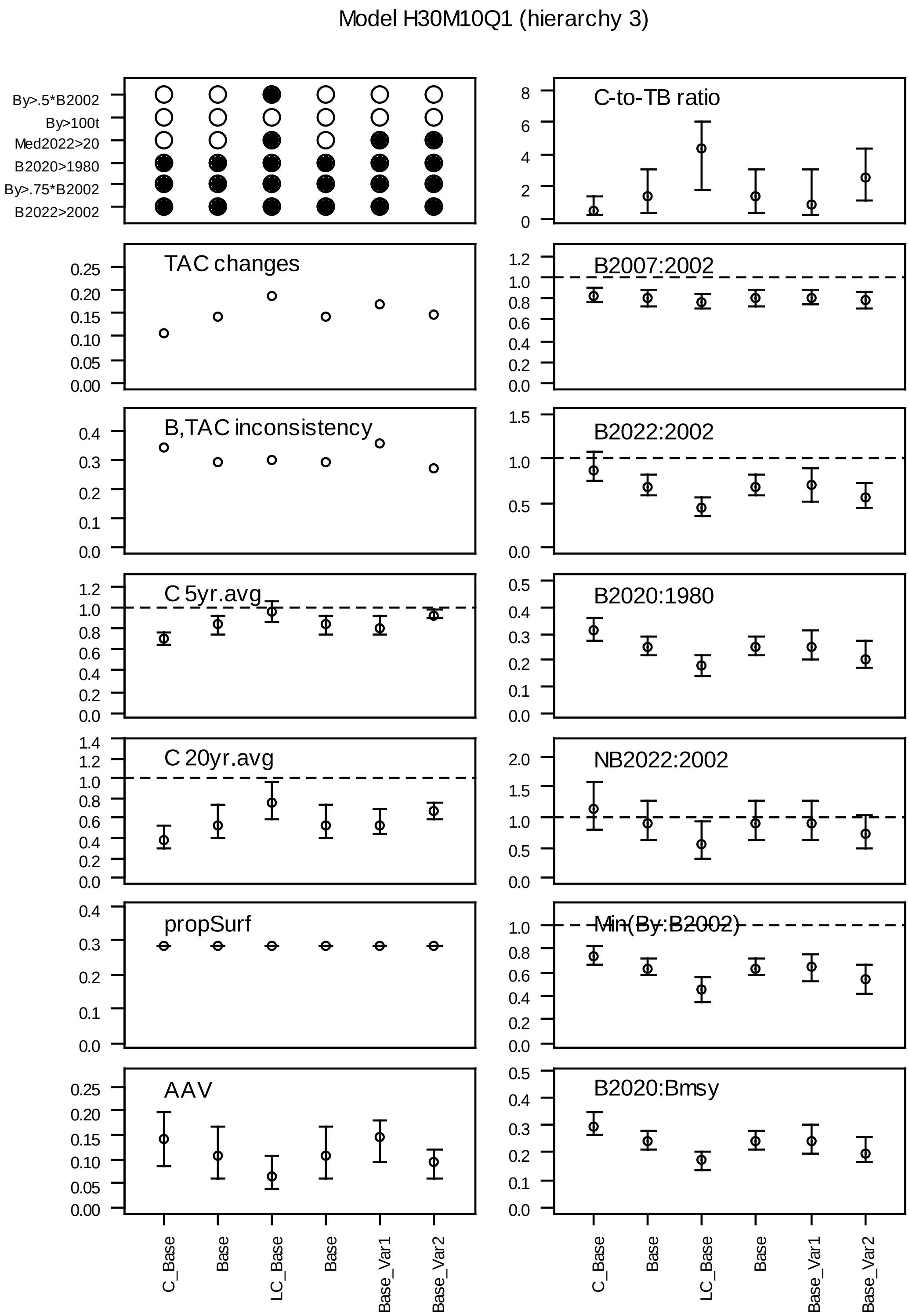

Figure 1.3 Performance statistics for five candidate MPs for scenario *H30M10Q1*. The top left plot shows whether the MP either passed or failed the 6 robustness criteria (○=passed, ●=failed).

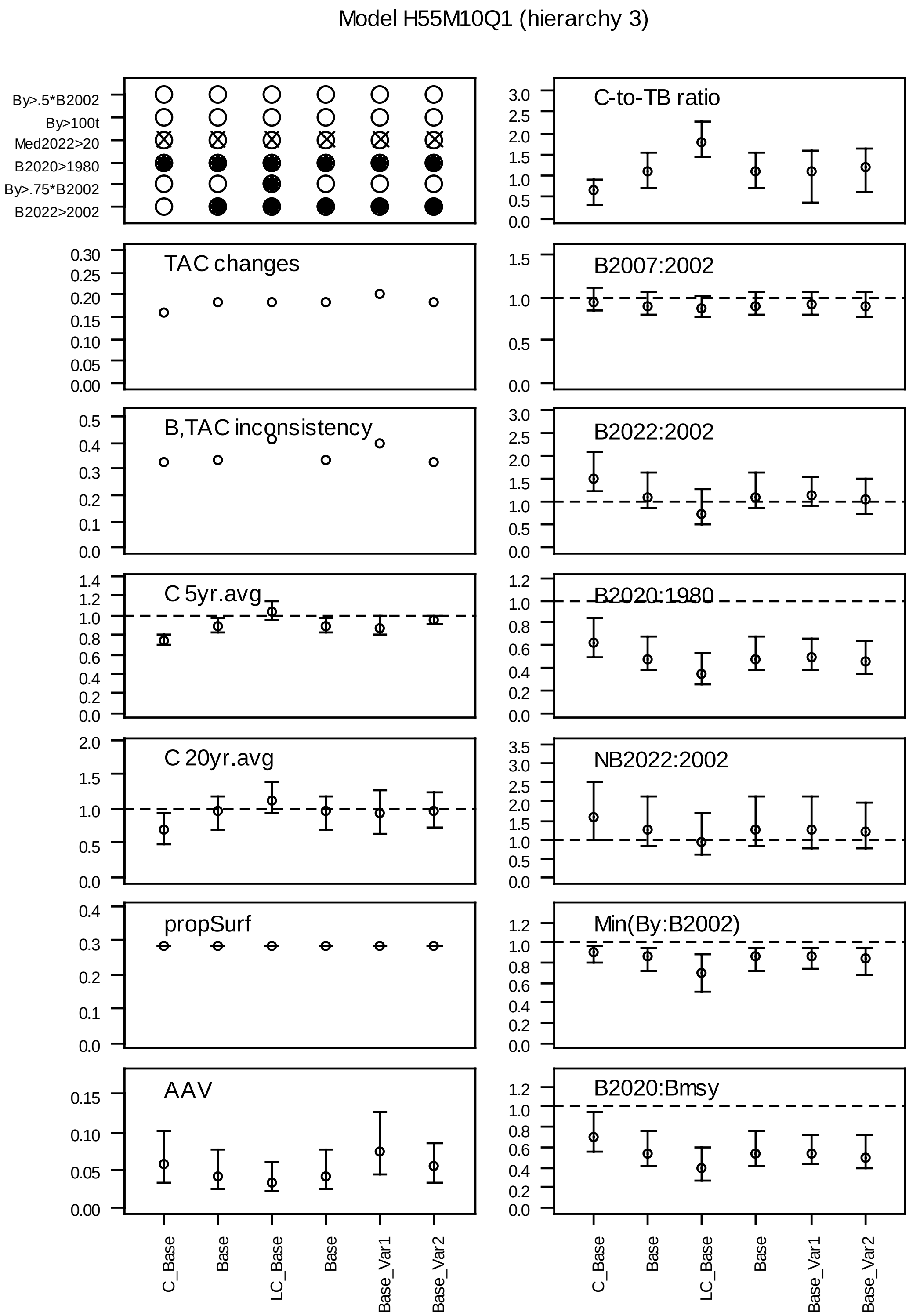

Figure 1.4 Performance statistics for five candidate MPs for scenario *H55M10Q1*. The top left plot shows whether the MP either passed or failed the 6 robustness criteria (○=passed, ●=failed), ⊗ shows that the criteria is not applied for this steepness scenario.

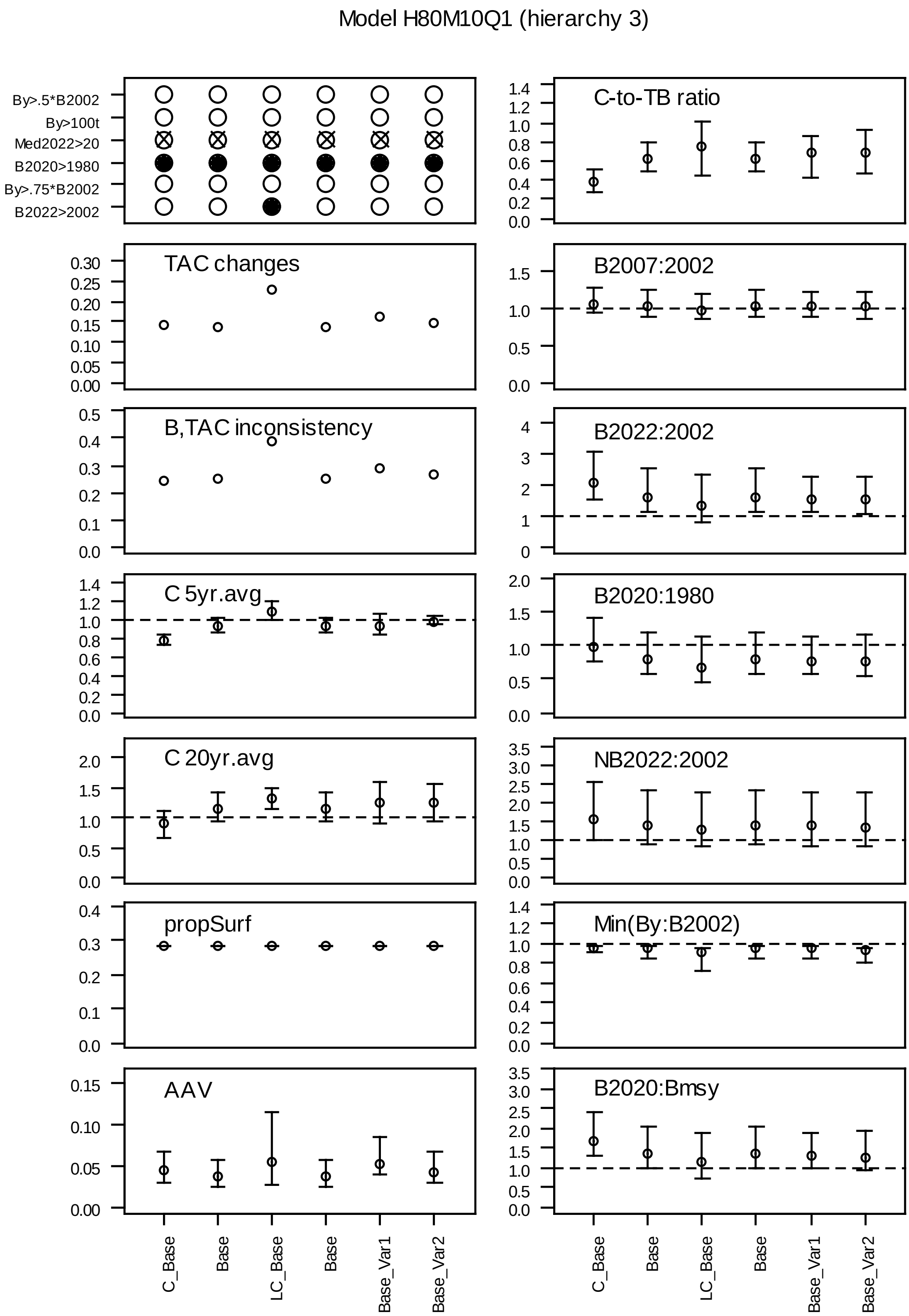

Figure 1.5. Performance statistics for five candidate MPs for scenario *H80M10Q1*. The top left plot shows whether the MP either passed or failed the 6 robustness criteria (○=passed, ●=failed), ⊗ shows that the criteria is not applied for this steepness scenario.

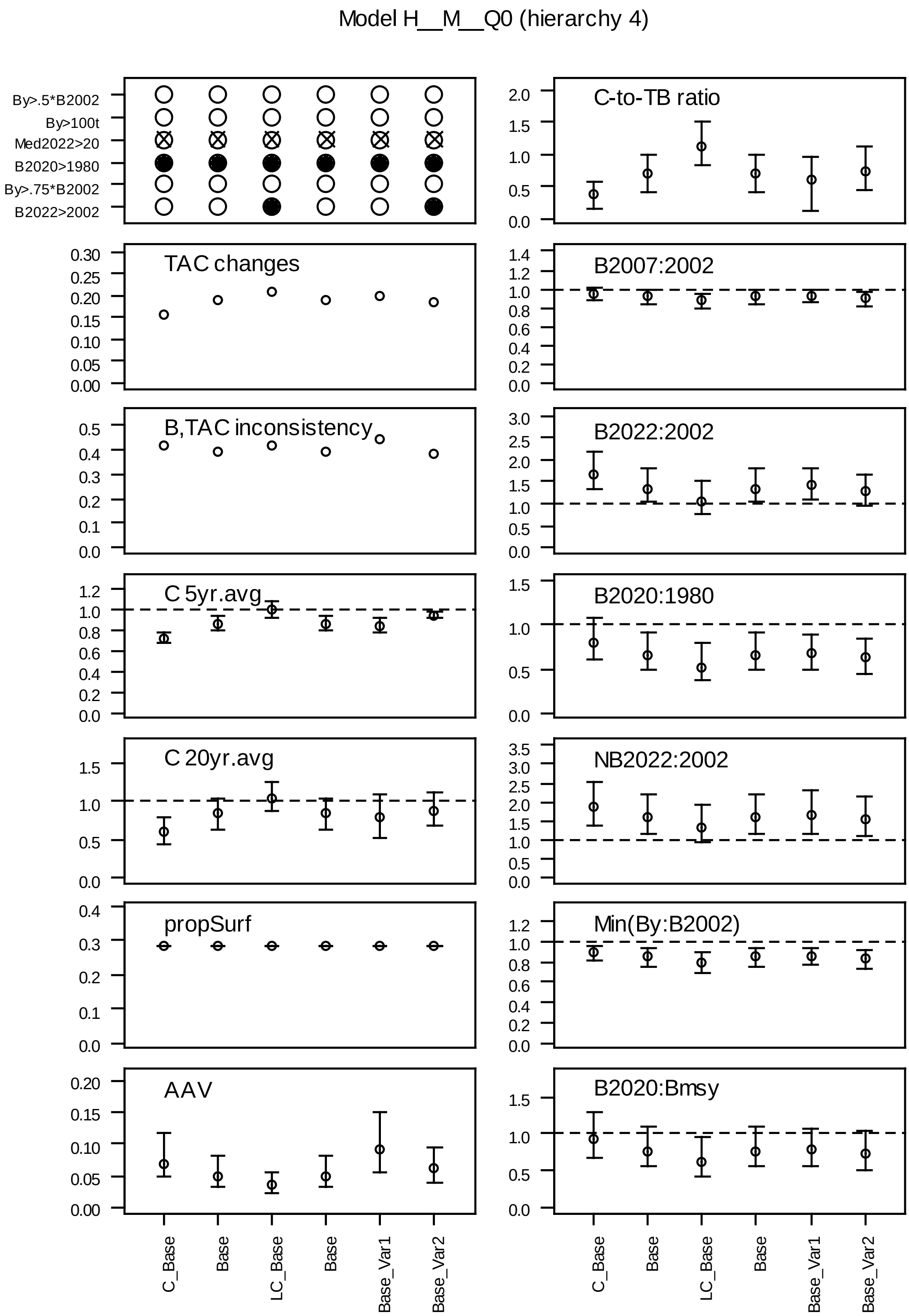

Figure 1.6. Performance statistics for five candidate MPs for scenario *H__M__Q0*. The top left plot shows whether the MP either passed or failed the 6 robustness criteria (○=passed, ●=failed), ⊗ shows that the criteria is not applied for this steepness scenario.

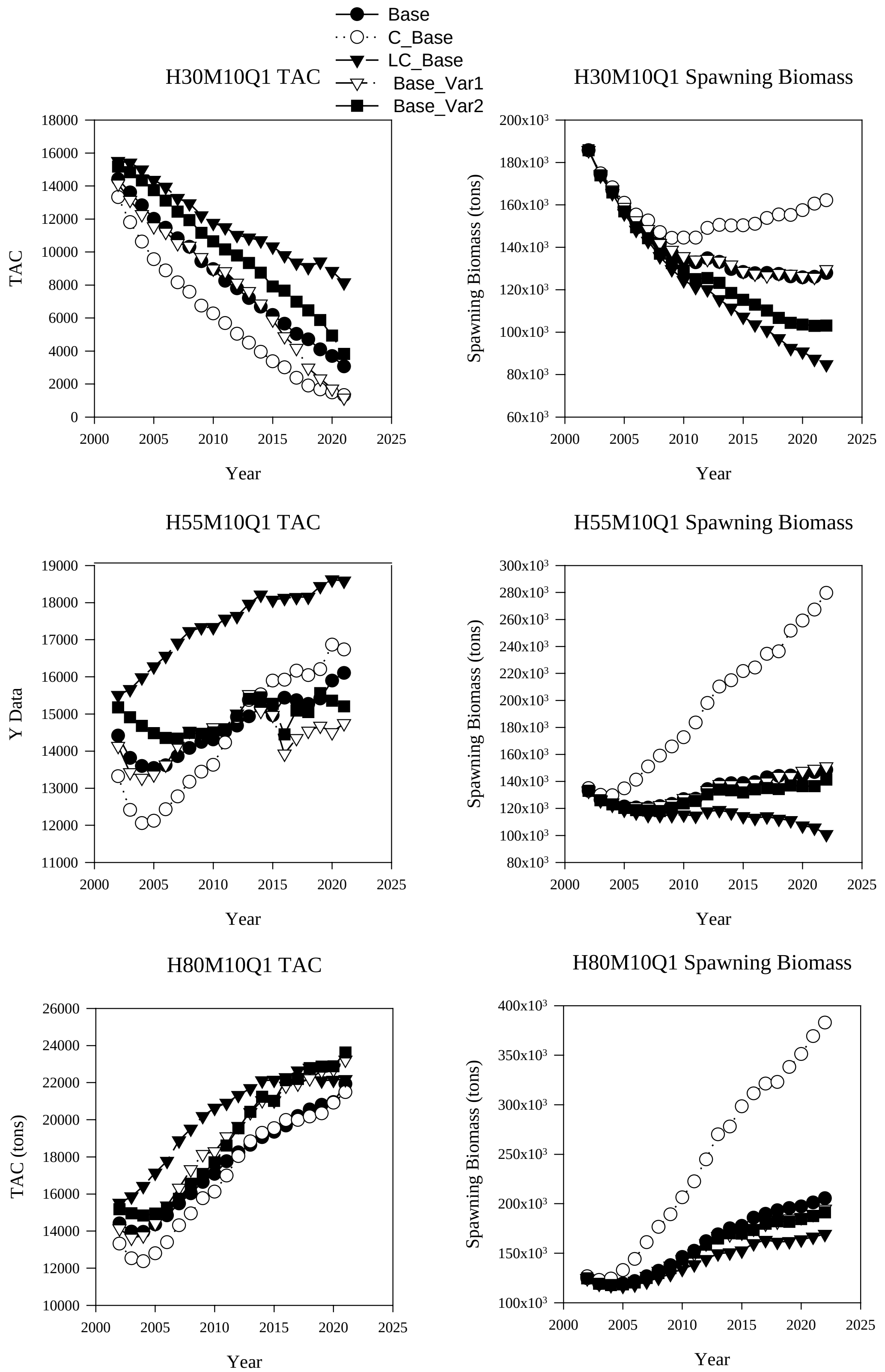

Figure 2. Median TAC and spawning biomass for five candidate MPs for the *H30M10Q1*, *H55M10Q1* and *H80M10Q1* scenarios.

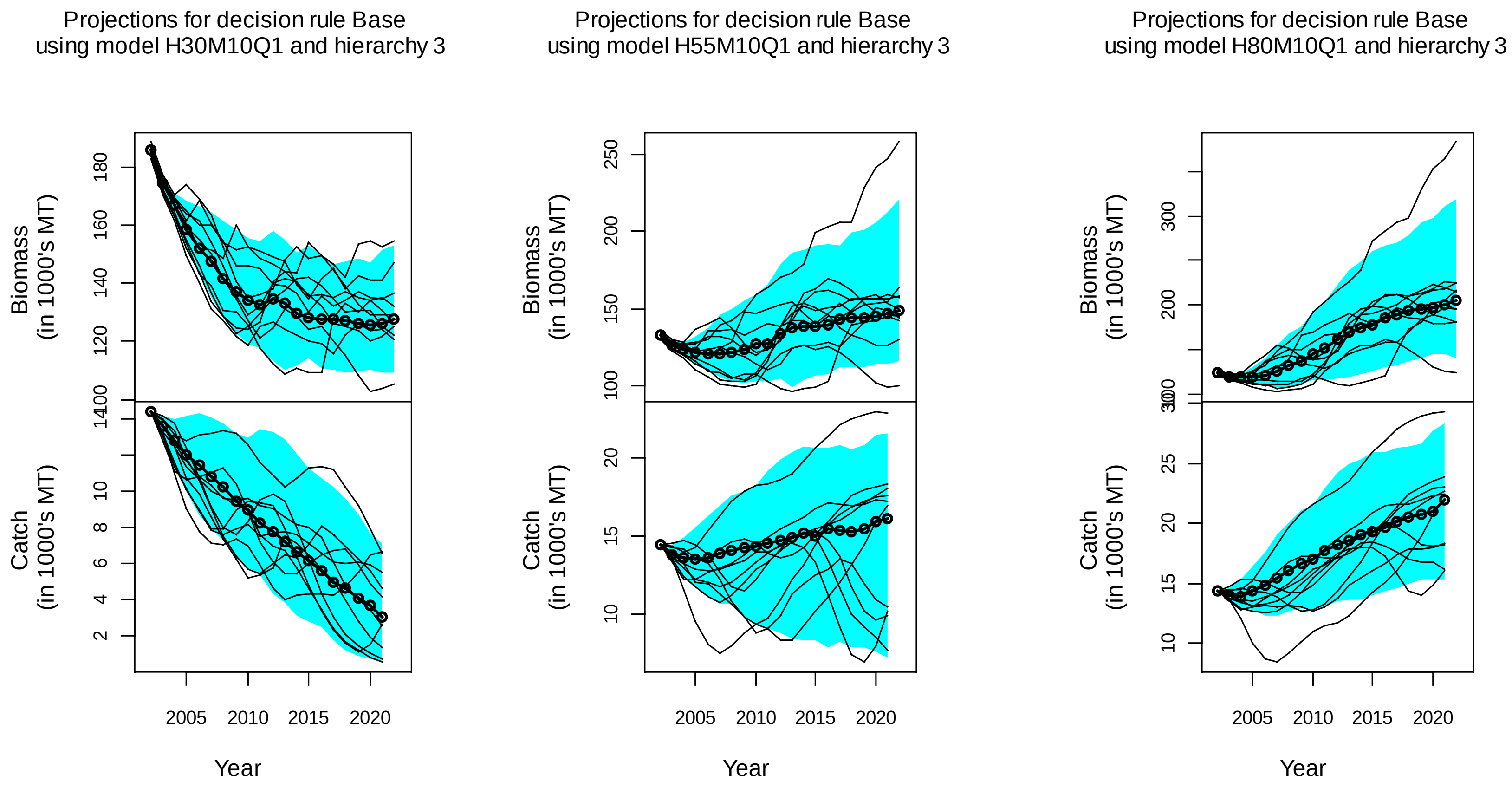

Figure 3. Individual trajectories and median with 90% probability envelopes of TAC and spawning biomass for scenarios *H30M10Q1*, *H55M10Q1* and *H80M10Q1*. The MP is "Base case".

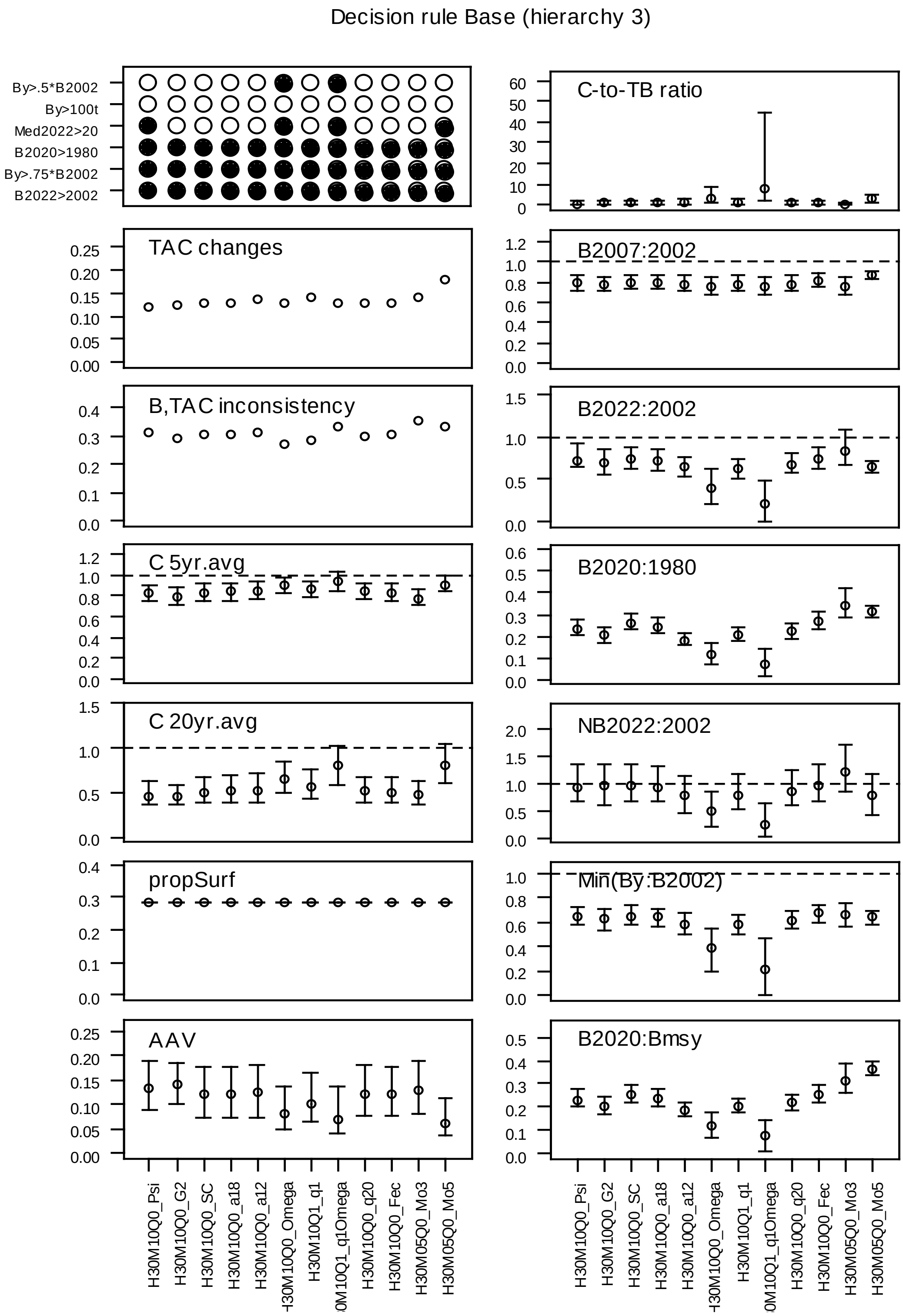

Figure 4.1 Performance statistics for the Base Case MP for robustness trials for *h*=0.3 scenarios. The top left plot shows whether the MP either passed or failed the 6 robustness criteria (○=passed, ●=failed).

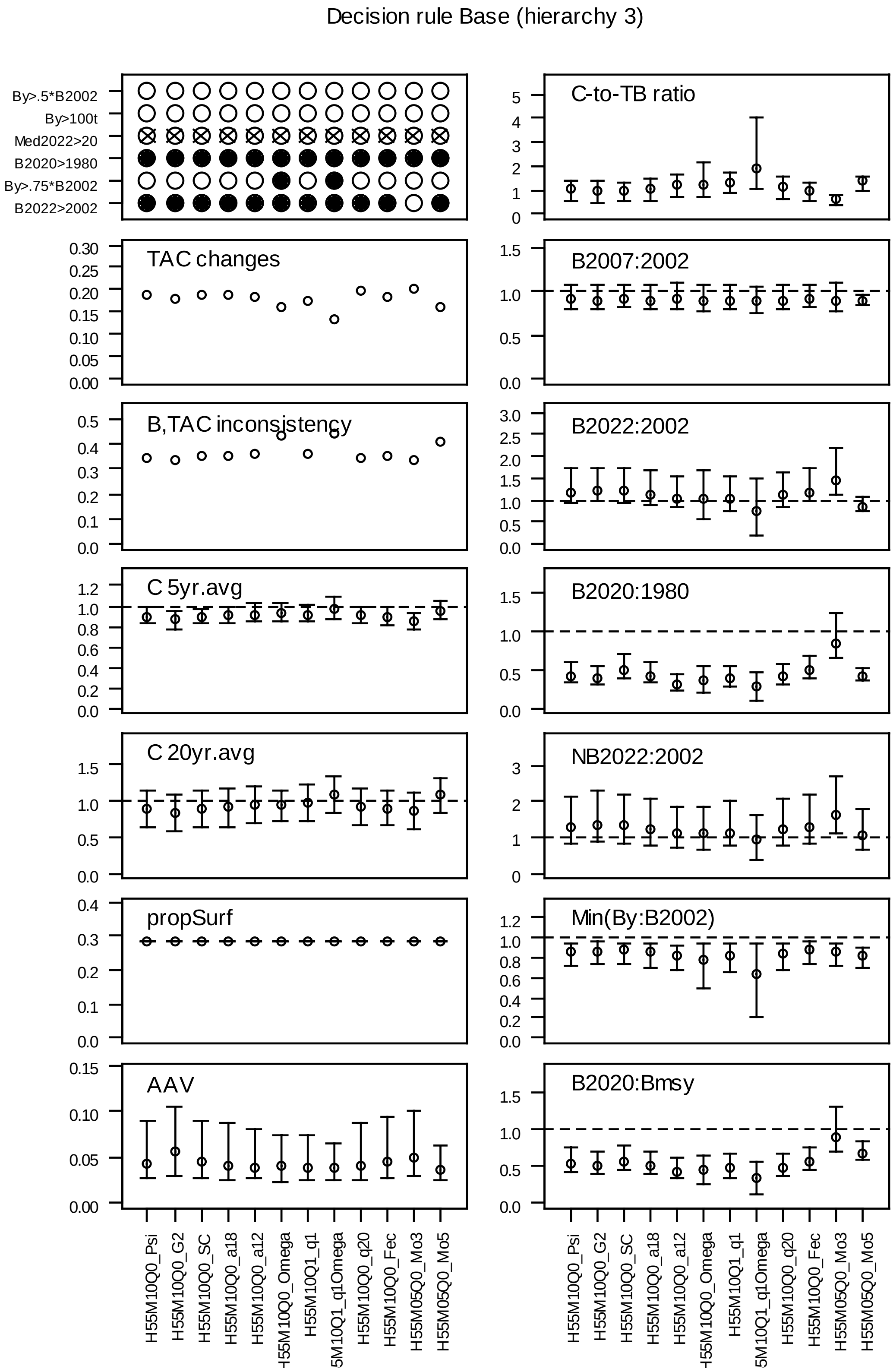

Figure 4.2 Performance statistics for the Base Case MP for robustness trials for *h*=0.55 scenarios. The top left plot shows whether the MP either passed or failed the 6 robustness criteria (○=passed, ●=failed)); ⊗ shows that the criteria is not applied for this steepness scenario.

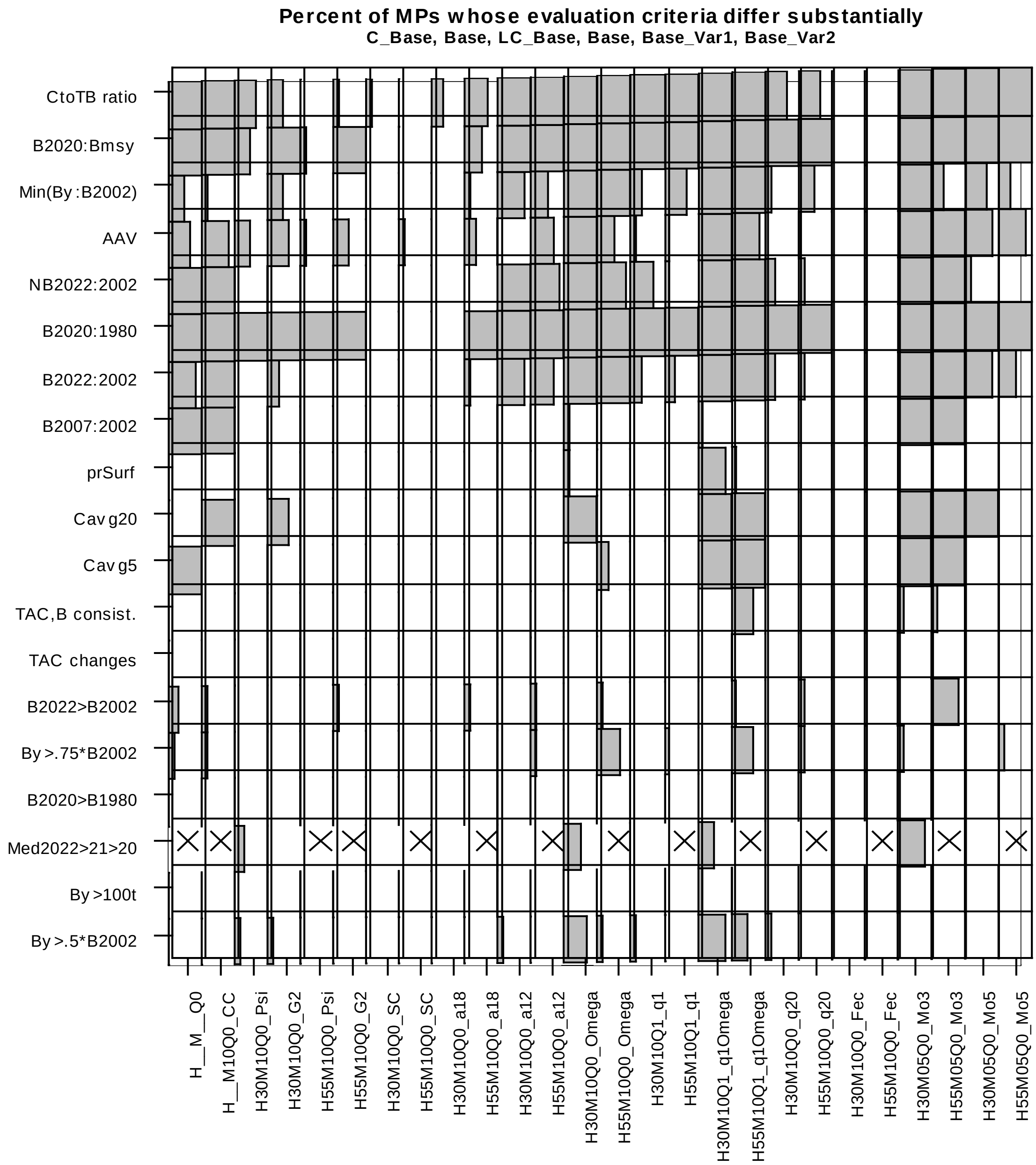

Figure 5. Performance of MPs whose evaluation criteria differ substantially to the reference trials. The percent of the box that is shaded grey represents the percent of MP's whose evaluation measures differ substantially between the robustness model and the reference model. For the 11 catch and biomass performance statistics, a substantial difference is defined as more than a 10% change in the median value relative to the reference case, or more than a 20% change in the range from the 10^{th} to 90^{th} percentile. For the TAC related measures, these are already expressed as percent occurrences, so a substantial difference is defined as an absolute change of more than 10%. For the 6 robustness criteria, a substantial change is simply whether or not the result changes between the robustness model and the reference model. × means that the measure is not relevant to the scenario.

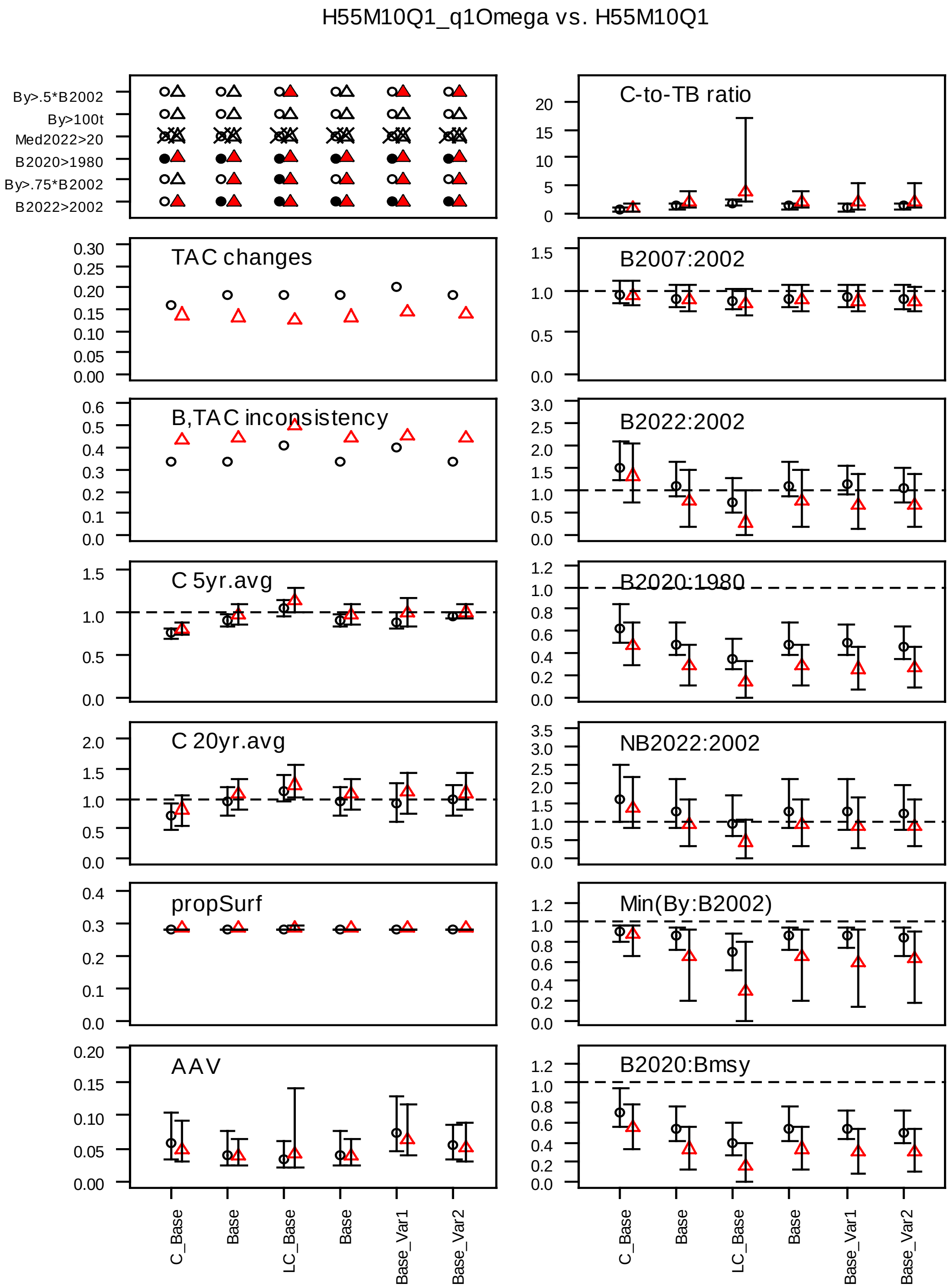

Figure 5.1 Performance statistics for five candidate MPs which compare the reference scenario *H55M10Q1* and its robustness trial *H55M10Q1_q1Omega* for a stochastic case. The top left plot shows whether the MP either passed or failed the 6 robustness criteria (○=passed, ●=failed); ⊗ shows that the criteria is not applied for this steepness scenario. The reference scenario is plotted on the left hand side (○) and the corresponding robustness trial on the right hand side (△).

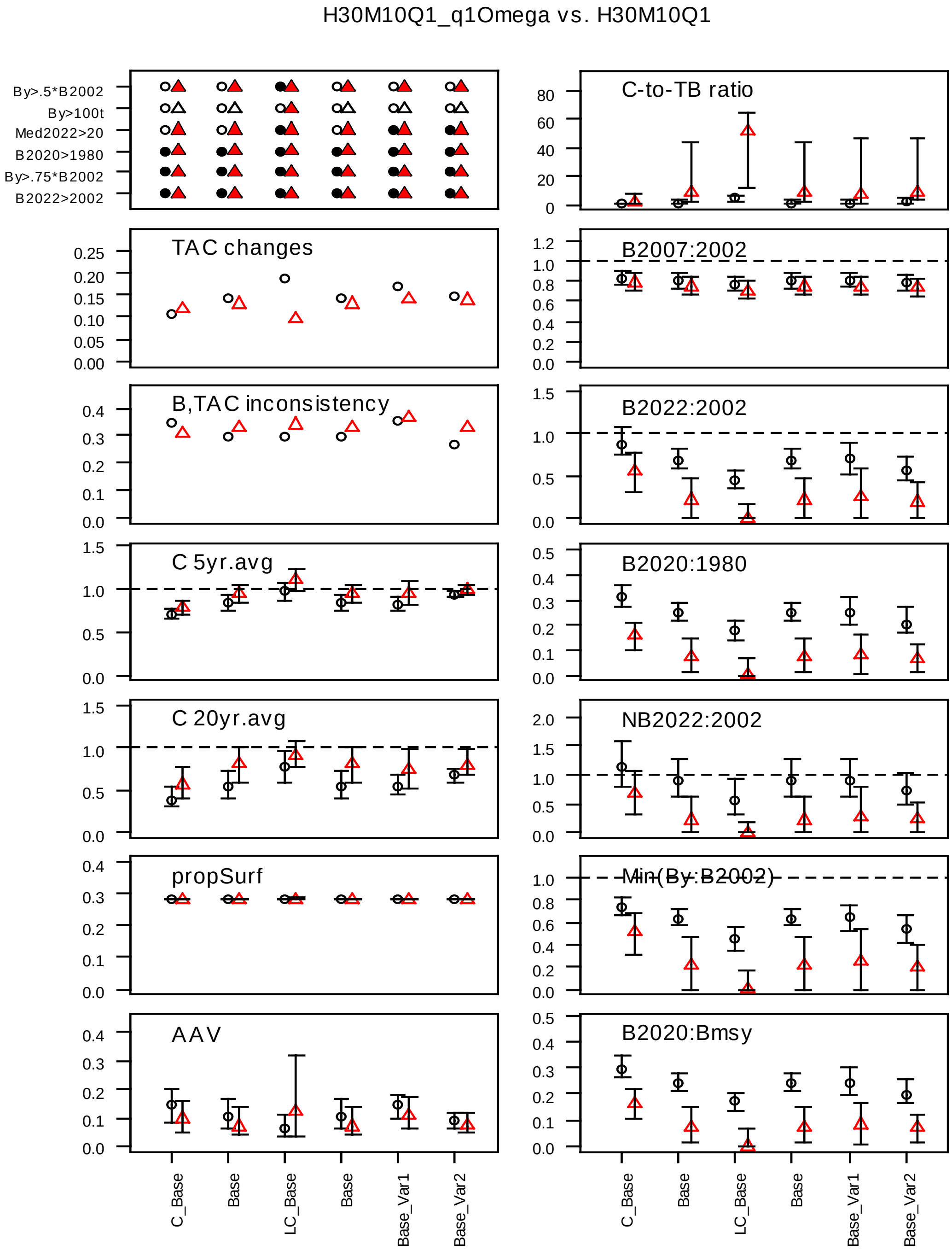

Figure 5.2 Performance statistics for five candidate MPs which compare the reference scenario *H30M10Q1* and its robustness trial *H30M10Q1_q1Omega* for a stochastic case. The top left plot shows whether the MP either passed or failed the 6 robustness criteria (○=passed, ●=failed). The reference scenario is plotted on the left hand side (○) and the corresponding robustness trial on the right hand side (△).

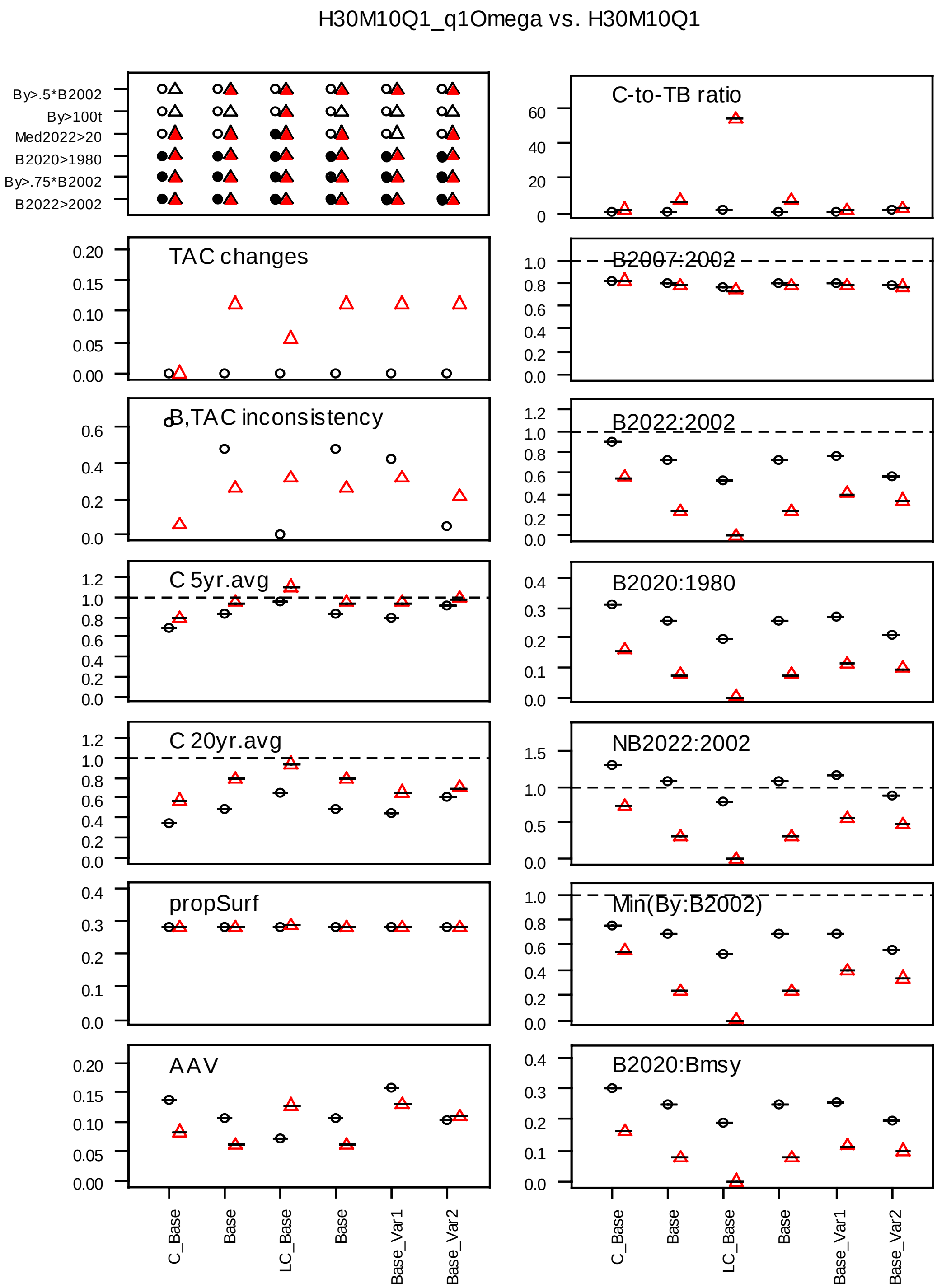

Figure 5.3. Performance statistics for five candidate MPs which compare the reference scenario *H30M10Q1* and its robustness trial *H30M10Q1_q1Omega* for a deterministic case. The top left plot shows whether the MP either passed or failed the 6 robustness criteria (○=passed, ●=failed). The reference scenario is plotted on the left hand side (○) and the corresponding robustness trial on the right hand side (△).

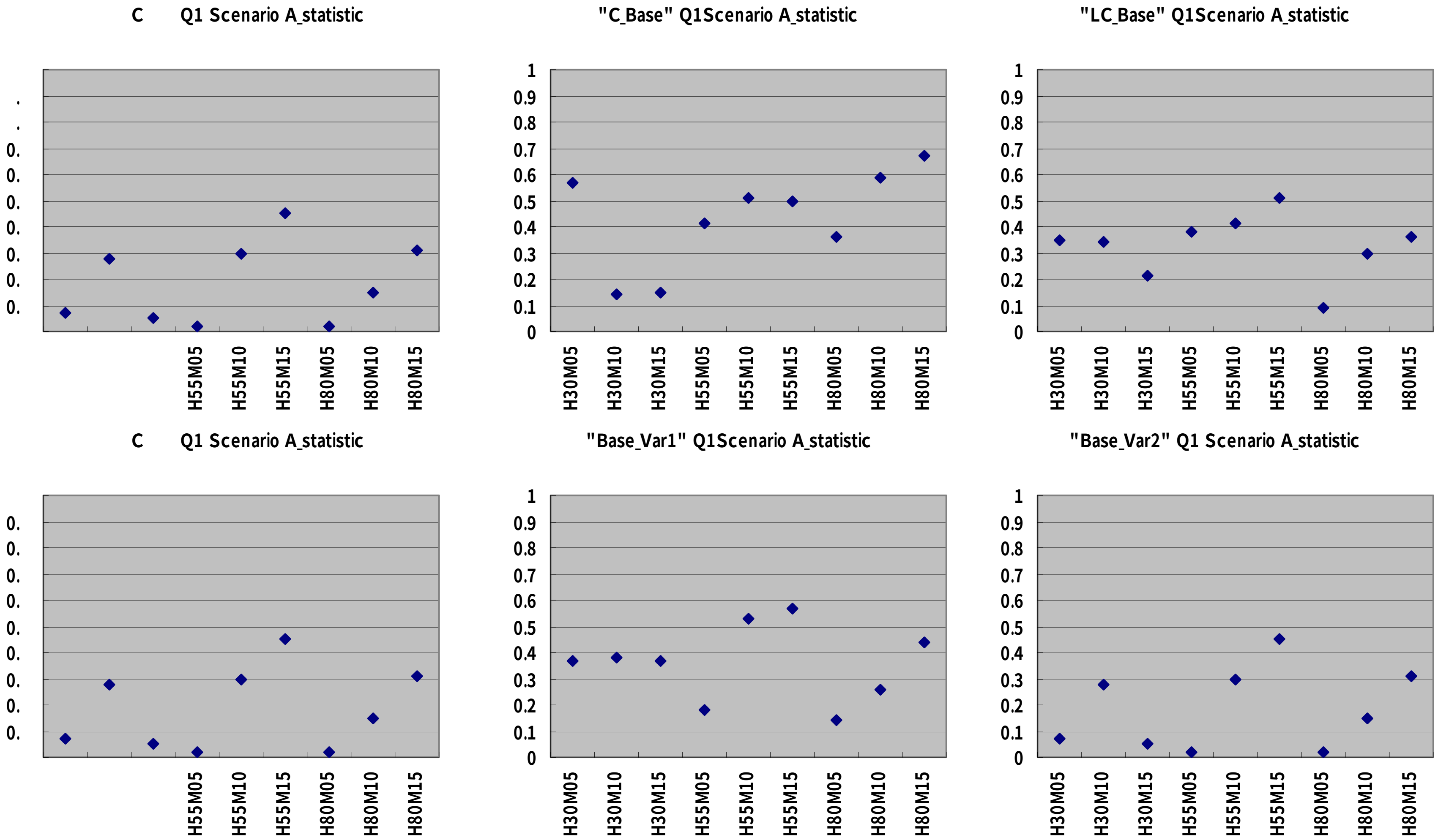

Figure 6 A statistics for the five MPs (Reference scenarios, Q=1).