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APPLICATION OF VARIANTS OF A FOX-MODEL BASED MP TO THE "CHRISTCHURCH" SBT TRIALS

Christchurch で設定されたトライアルへの応用版 **FOX** モデルに基づく **MP** の適用

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SUMMARY

The Fox-model based MP developed by Butterworth and Mori (2003) is adapted to also make use of longline catch-at-age information in setting initial TAC modifications. This adaptation is intended in particular to avoid an inevitable TAC reduction on the first occasion the TAC is modified, if recent recruitment has been good. Only partial success is achieved, at the expense of greater variance in initial TACs. The procedure developed shows poor robustness for resource recovery target for trials which standardize selectivity over a narrow range of ages.

要約

Butterworth and Mori (2003) によって開発された Fox モデルによる MP をさらに拡張して、延縄漁業による年齢別漁獲尾数の情報を用いて、TAC 変更の初年度の TAC を調整することを試みた。 これはほぼ必然的である TAC の減少を、もし近年の加入の情報が良い場合には防止しようという考えに基づいている。この試みは部分的には成功したが､代わりに TAC 変更初年度の TAC の分散の幅が大きくなった。 また本方法は、漁業の選択性を狭い年齢幅のものに標準化したトライアルにおいて、目標とする資源回復に達する頑健性が低い。

INTRODUCTION

In response to the final set of SBT MP trials selected at the MP workshop held in Christchurch last August (for convenience, we call these trials the "Christchurch trials"), this paper investigates further the application of variants of the Fox model based Management Procedure (MP) developed by Butterworth and Mori (2003) to these trials. In particular, the ability of an adaptation of this MP to adjust the TAC depending on evidence of recent poor or good recruitment is explored by taking account of information on the proportion of lower ages in longline catch.

DATA

The historical catch data and the CPUE abundance index values used in the applications of the candidate MPs considered are shown in Table 1. The CPUE values are the medians of the five CPUE series provided (B-ratio proxy, Geostat proxy, Stwindow, Laslett Core Area, Nominal). Data for future years are as generated from the Christchurch operating models by the testing software provided.

METHODS

The MPs considered first apply a Fox model to estimate values for resource dynamics parameters. These values are then input to a formula for setting the TAC.

FOX MODEL

The dynamics of the SBT population are taken 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:

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

where I_y is the CPUE index for year y,

q is a constant of proportionality (the catchability coefficient when δ=1),

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

ε_y from $N\left(0,\sigma^2\right)$.

Catches and CPUE are input for past years as described above, and the operating models underlying the trials generate 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 ($\frac{\partial\left(-\ln L\right)}{\partial q}=0$, $\frac{\partial\left(-\ln L\right)}{\partial \sigma}=0$) 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:

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

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

Different adjustments are made to the calculated TAC depending on the interval between TAC changes (i.e. a) every year, b) every three years and c) every five years).

TAC change interval b) every three years and c) every five years

The TAC for future years is calculated from the following equation:

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

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 (which can change from year to year, though is kept year-invariant in all the applications considered here),

$M\hat{S}YR_y$ 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,

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

$f(LL)$ is a function which adjusts the TAC depending on the proportion of lower ages in longline catch,

α is a control parameter which is varied to obtain the desired median B2022/B2002 tuning level, and

a is a further control parameter.

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

$$g\left(\hat{r}_y\right)=\begin{cases}0 & \text{for } 0 \le \hat{r}_y \le r_1 \\ \dfrac{1}{r_2-r_1}\left(\hat{r}_y-r_1\right) & \text{for } r_1 < \hat{r}_y < r_2 \\ 1 & \text{for } r_2 \le \hat{r}_y\end{cases} . \tag{8}$$

We set r_1=1.0, r_2=1.5 for all MP candidates as is in Butterworth and Mori (2003).

The function *f(LL)* which controls the TAC depending on the proportion of lower ages in longline catch is calculated as follows:

$$LL = \left(\frac{\sum_{a=4}^{6} LLC_{2003}}{\sum_{a=4}^{30} LLC_{2003}} + \frac{\sum_{a=5}^{7} LLC_{2004}}{\sum_{a=4}^{30} LLC_{2004}} + \frac{\sum_{a=6}^{8} LLC_{2005}}{\sum_{a=4}^{30} LLC_{2005}} \right) \Big/ 3$$

$$\begin{aligned} f(LL) &= 1 && \text{if} \quad LL \le 0.28 \\ f(LL) &= (1 + (LL - 0.28) * \text{tune}) && \text{if} \quad 0.28 < LL < 0.33 \\ f(LL) &= (1 + 0.05 * \text{tune}) = \theta && \text{if} \quad LL \ge 0.33 \end{aligned} \tag{9}$$

where LLC_y is the catch of age *a* of the Japanese longline fishery in year *y*.

The distributions of *LL* for the Reference and No_AC case trials are shown in Figure 1. Their means relate to the choices of the values of 0.28 and 0.33 in equation (9) above. The idea of introducing this function is to give flexibility to the MP, which can vary the TAC depending on good or poor recruitment as reflected by the proportion of lower ages in longline catch. As the Figure shows, the distributions for *LL* overlap substantially for the two cases, so the value of *LL* does not readily discriminate between the two.

f(LL) and the control parameter *a* are introduced only for the first year that the TAC changes, which is year 2008 for TAC change intervals b) every three years and c) every five years. In other years *f(LL)* and *a* are both set to be 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.

TAC change interval a) every year

The TAC for future years is calculated from the following equation:

$$TAC_{y+1} = w_y TAC_y + \alpha\left(1 - w_y\right)\cdot M\hat{S}YR_y \cdot \hat{B}_{MSY} \cdot \left(\frac{\hat{B}_y}{\hat{B}_{MSY}}\right)^{\gamma} \cdot g\left(\hat{r}_y\right)\cdot\left(1 + \theta_y \tilde{f}\left(LL_y\right)\right) \qquad (10)$$

θ_y and $\tilde{f}\left(LL_y\right)$ are as follows:

$$\theta_y = \theta_0 \cdot \exp^{-\beta(y-y_0)} \qquad (11)$$

$$LL_{2006} = \frac{\sum_{a=4}^{6} LLC_{2003}}{\sum_{a=4}^{30} LLC_{2003}}$$

$$LL_{2007} = \left(\frac{\sum_{a=4}^{6} LLC_{2003}}{\sum_{a=4}^{30} LLC_{2003}} + \frac{\sum_{a=5}^{7} LLC_{2004}}{\sum_{a=4}^{30} LLC_{2004}}\right) \Big/ 2$$

$$LL_{2008+} = \left(\frac{\sum_{a=4}^{6} LLC_{2003}}{\sum_{a=4}^{30} LLC_{2003}} + \frac{\sum_{a=5}^{7} LLC_{2004}}{\sum_{a=4}^{30} LLC_{2004}} + \frac{\sum_{a=6}^{8} LLC_{2005}}{\sum_{a=4}^{30} LLC_{2005}}\right) \Big/ 3$$

$$\begin{cases} f(LL_{2006}) = 0 & \text{if} \quad LL \le 0.334 \\ f(LL_{2006}) = \left(LL_{2006} - 0.334\right) / \left(0.411 - 0.334\right) & \text{if} \quad 0.334 < LL < 0.411 \\ f(LL_{2006}) = 1 & \text{if} \quad LL \ge 0.411 \end{cases}$$

$$\begin{cases} f(LL_{2007}) = 0 & \text{if} \quad LL \le 0.304 \\ f(LL_{2007}) = \left(LL_{2007} - 0.304\right) / \left(0.366 - 0.304\right) & \text{if} \quad 0.304 < LL < 0.366 \\ f(LL_{2007}) = 1 & \text{if} \quad LL \ge 0.366 \end{cases}$$

$$\begin{cases} f(LL_{2008+}) = 0 & \text{if} \quad LL \le 0.28 \\ f(LL_{2008+}) = \left(LL_{2008+} - 0.28\right) / \left(0.33 - 0.28\right) & \text{if} \quad 0.28 < LL < 0.33 \\ f(LL_{2008+}) = 1 & \text{if} \quad LL \ge 0.33 \end{cases} \qquad (12)$$

where y_0 is 2006, θ_0 is 2.2 and β is 0.7.

CANDIDATE MANAGEMENT PROCEDURES

The performance of five candidate MPs was explored for option b) – TAC change interval every three years. Convention-based names and their detailed parameter settings are shown in Table 2. Variations of parameters of TAC equation (7) that are not shown in Table 2 were also explored, but found not to provide any obvious improvements in performance statistics for the trials.

RESULTS

Choice of baseline MP

Figure 2a compares the performance between candidate baseline MPs for the Reference and No_AC case trials for median B(2022)/B(2002) tuning level 1.1 and option b) of an every three year TAC change interval. Figure 2b compares performance for the Reference and Low_Rec case trials. A particular concern for the form of MP considered by Butterworth and Mori (2003), which takes no account of catch-at-size information (i.e. D&M_02_2b, with *f*(*LL*)=1), is that the 95% probability interval (PI) for the TAC in 2008 falls completely below the current TAC *even in the relatively good recruitment* (No_AC) *case*. In other words, a TAC reduction is inevitable even though perhaps unnecessary because recruitment is better than expected. The MP does upwardly adjust TACs in the No_AC case later (compared to TACs for the Reference case), as the effect of the better recruitment becomes evident in the CPUE series, but not before perhaps unnecessary TAC reductions have taken place (see Figure 2c), which shows the median TAC trajectory and 95% probability envelope if this MP was tuned to 1.1 for the No_AC rather than for the Reference case trial).

The motivation for including the *f*(*LL*) factor in equation (7) is to attempt to avoid (or at least reduce) such undesirable behaviour, and the other candidate MPs adjust the TAC for 2008 by making use of information on the proportion of younger ages in the longline catch through this factor, with the extent of the adjustment differing between the candidates. Note that the tuning parameter α has to be adjusted as the parameters of *f*(*LL*) are varied, to ensure that the tuning target level of 1.1 for median B2022/B2002 remains achieved (see Table 2). Ideally, the *f*(*LL*) factor would be such that for the No_AC (or Low_Rec) trials, the same median recovery (B2022/B2002=1.1) is attained, with TAC's being adjusted up (or down) compared to Reference case to achieve this.

For all candidate MPs where we include the *f*(*LL*) factor, better performance for B(2022)/B(2002) results for both the No_AC and Low_Rec trials through median projections getting closer to the 1.1 tuning level. For example (see Figure 2a), without the *f*(*LL*) factor, candidate MP (D&M_02_2b) achieves a median B2022/B2002 of 1.28 for the No_AC trial, but this drops to 1.23 with the factor included for candidate MP D&M_01_2b. This means that the candidate MPs including the *f*(*LL*) factor have some capability to adjust the TAC appropriately by increasing it when the proportion of lower ages in the longline catch is high (i.e. relatively good recent recruitment), and reducing it when its is low (i.e. relatively poor recent recruitment). However, there are also "costs" associated with achieving these improvements. The variance of the 2008 TAC increases (see Figure 2), and reducing the likelihood of an immediate TAC reduction is in part achieved by sacrificing catch in the longer term for greater catches in the short term.

On balance, the choice of control parameters associated with the D&M_01_2b candidate MP was judged to reflect the best trade-off between these competing positive and negative effects, and hence was adopted as the baseline MP. Figure 3 shows the various performance statistics for baseline MP for Reference case trial.

Performance of baseline MP for robustness trials

Figure 4a shows the various performance statistics for base line MP for the Reference case trial and the 11 robustness trials (note that the latter are run for 200 rather than 2000 replicates). Performance is relatively robust for most of these trials, with the exception of the Low1_A12 and Med1_A12 trials (reflecting CPUE with selectivity standardized to a narrower age range of the longline catch). For these cases the baseline MP does not reduce the TAC sufficiently rapidly to avoid possible undue resource depletion. Figure 4b compares the various performance statistics between the Low1_A12 trial and the corresponding scenario that contributes to the Reference case model for the baseline MP ("D&M_01_2b"). Figure 4c provides a similar comparison for the Med1_A12 trial. These last two figures show that it is for the lowest steepness cases (the Low1_A12 trial) that the lack of robustness is the most serious.

Changing the interval between TAC changes

Figure 5a shows the median spawning biomass and catch trajectories for the baseline MP for TAC change intervals of a) every year; b) every three years and c) every five years. Figure 5b shows the corresponding wormplots for the spawning biomass and catches. Larger intervals mean bigger initial TAC reductions, and also lower TACs at the end of the projection period.

Alternative tunings for recovery level

Figure 6a shows the median spawning biomass and catch trajectories for the baseline MP for median B2022/B2002 target levels of a) 0.7; b) 1.1; c) 1.5 and d) 0.9. Figure 6b shows the corresponding wormplots for the spawning biomass and catches, and Figure 6c shows the corresponding performance statistics. For the highest recovery target (1.5 tuning), the TAC is reduced by maximal amounts on the first two occasions for change, and thereafter stays at very low levels of a few thousand tons (note that the *w* control parameter had to be reduced from 0.7 to 0.05 to allow this recovery target to be achieved). Only for the 0.7 tuning is it more likely than not that TACs will increase in the short to medium term.

DISCUSSION AND FURTHER DEVELOPMENTS

Advances on Butterworth and Mori (2003) reported in this paper have concentrated on utilizing age information as well as CPUE to see whether immediate TAC reductions, likely otherwise inevitable, can be avoided in cases of relatively good recent recruitment when the need for them in terms of reaching a 1.1 recovery target for median B2022/B2002 becomes less likely.

These efforts are only partially successful. Because the age information is itself noisy, it has only limited ability to discriminate between different levels of recent recruitment and hence to adjust TACs accordingly. Furthermore, allowing the possibility of the first TAC change being other than necessarily downward also has negative implications in terms of less certainty (more variance) in immediate TAC levels.

More specific issues perhaps warranting further work are:

i) the procedure described here for taking account of age data if the TAC is to change annually (option a)) is rather *ad hoc*, and would merit further development if this option is to be pursued further; and

ii) the adjustment factor (*f*(*LL*)) to take account of catch-at-age information in the 2008 TAC (for 3- or 5- yearly TAC changes – option b) and c)) has been somewhat tailored to the existing few specific tests of alternative levels of forthcoming recruitment, so that it should be subjected to a greater range of tests for alternative possible future recruitment patterns.

ACKNOWLEDGEMENTS

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REFERENCES

Butterworth, D. S. and Mori, M. (2003) Further investigations of a Fox-model based management procedure for southern bluefin tuna. Document CCSBT-ESC/0309/37. 24pp

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

	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	

Table 2 Five candidate management procedures and their detailed parameter values. The tuning for median B2022/B2002 is 1.1 unless otherwise specified in parenthesis after the MP name.

MP name	Parameter values					
Candidate Mps	δ	*w*	Θ (tune)	α	*a*	*β*
D&M_01_2b	1	0.7	1.4 (8)	0.38	1	
D&M_02_2b	1	0.7	1 (0)	0.58	1	
D&M_03_2b	1	0.7	1.2 (4)	0.47	1	
D&M_04_2b	0.75	0.7	1.4 (8)	0.36	1	
D&M_05_2b	1	0.7	1.4 (8)	0.44	0.95	
"D&M_01" different TAC change interval options						
D&M_01_2a	1	0.7	2.2	0.78	-	0.7
D&M_01_2c	1	0.7	1.4 (8)	0.1	1	
"D&M_01" different tuning options (B2022/B2002)						
D&M_01_1b (0.7)	1	0.7	1.4 (8)	1.44	1	
D&M_01_3b (1.5)	1	0.05	1.4 (8)	0.07	1	
D&M_01_4b (0.9)	1	0.7	1.4 (8)	0.84	1	

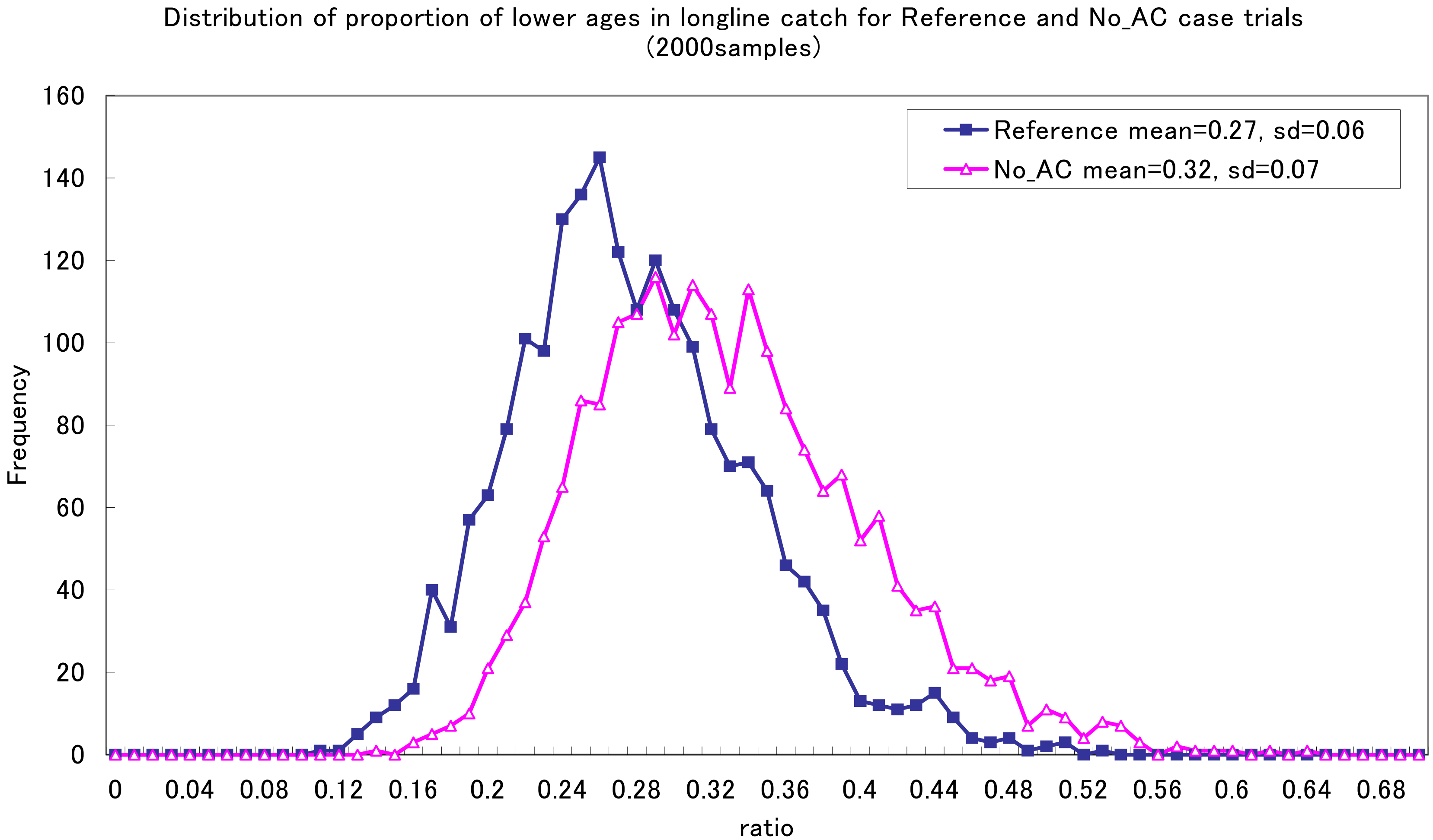


Figure 1. Distribution of proportion of lower ages (*LL* –see equation 9) in the longline catch for the Reference and No_AC cases (2000 samples).

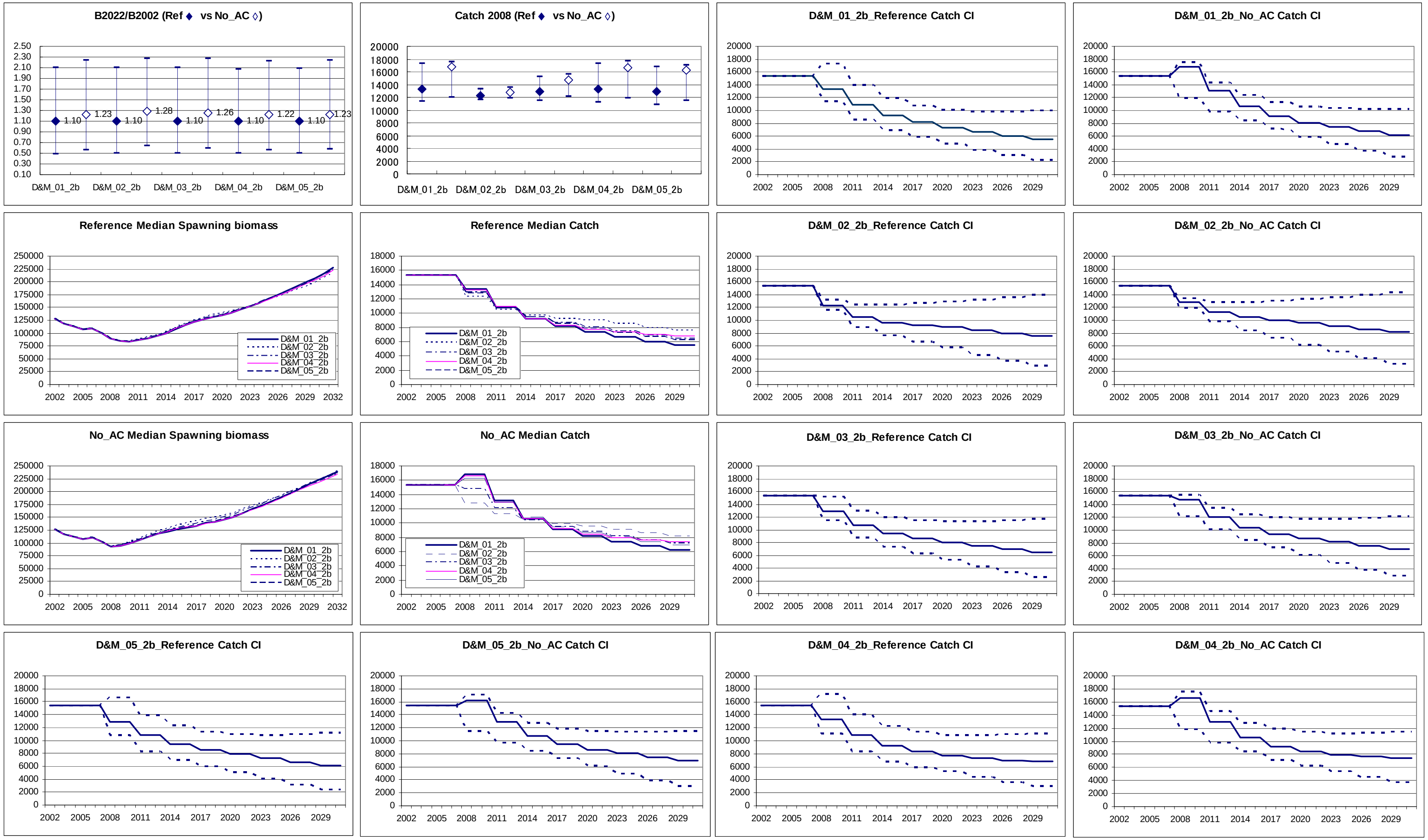


Figure 2a. Comparing performances between candidate options for the baseline MP for the Reference and No_AC case trials.

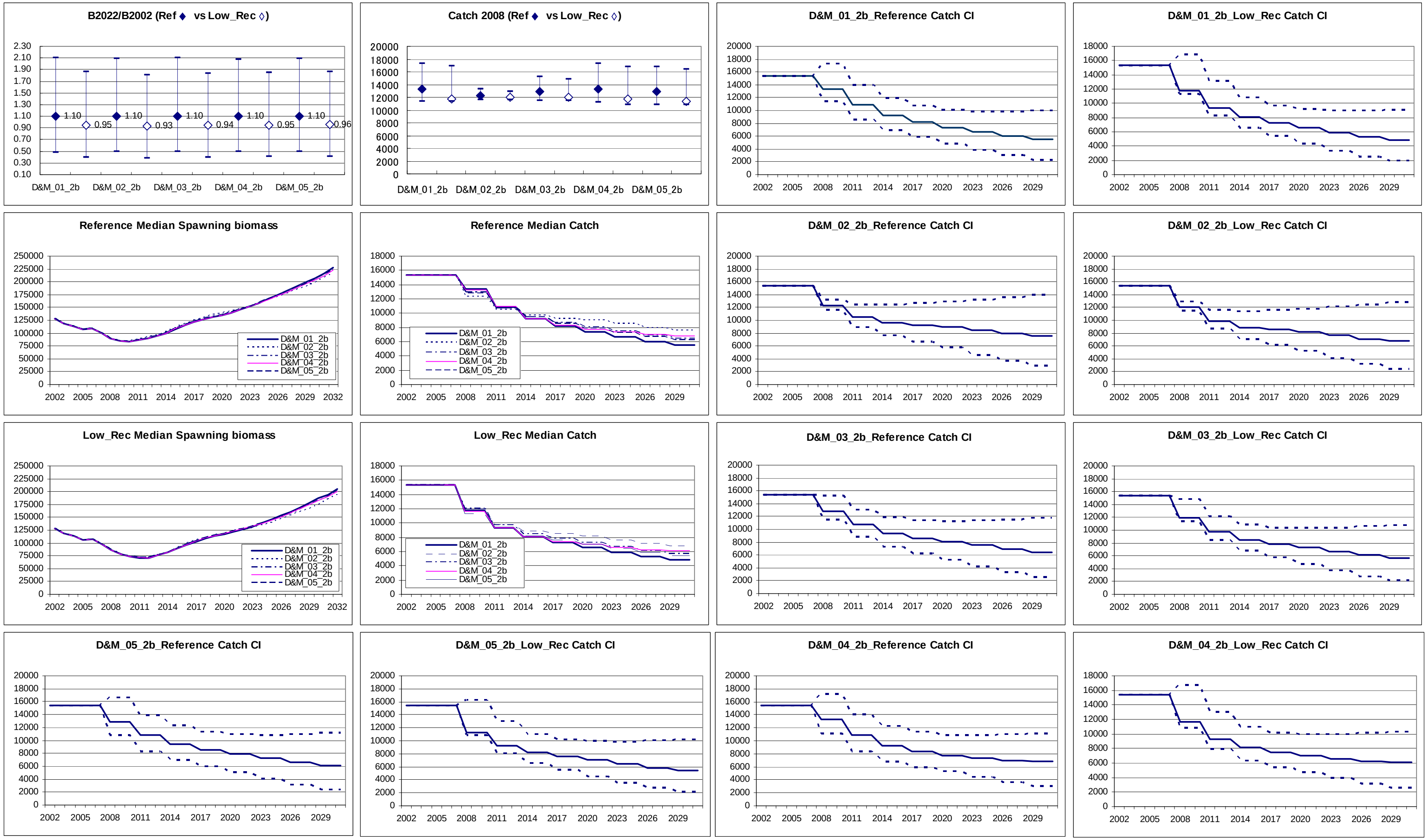


Figure 2b. Comparing performances between candidate options for the baseline MP for the Reference and Low_Rec case trials.

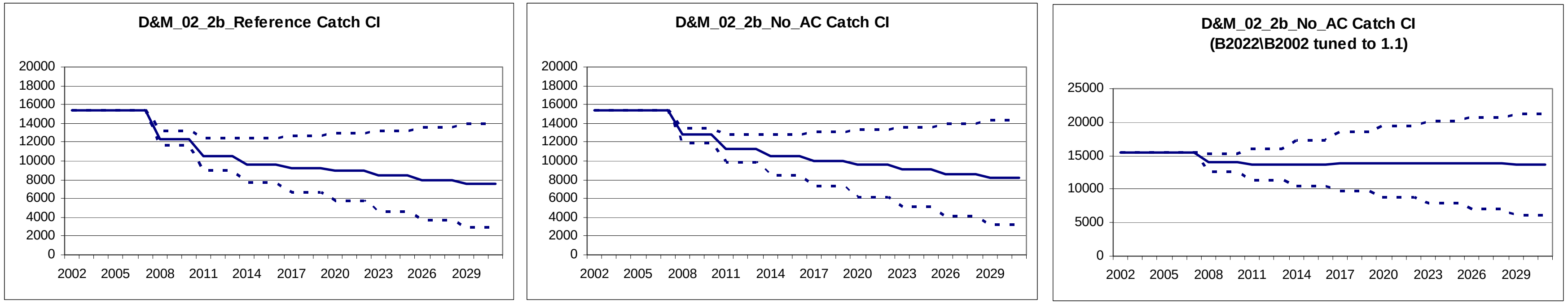


Figure 2c. Comparing TAC performances of the D&M_02_2b MP for the Reference case and No_AC case trial with that for the No_AC's Base trial with the MP retuned to achieve a median B2022/B2002 of 1.1.

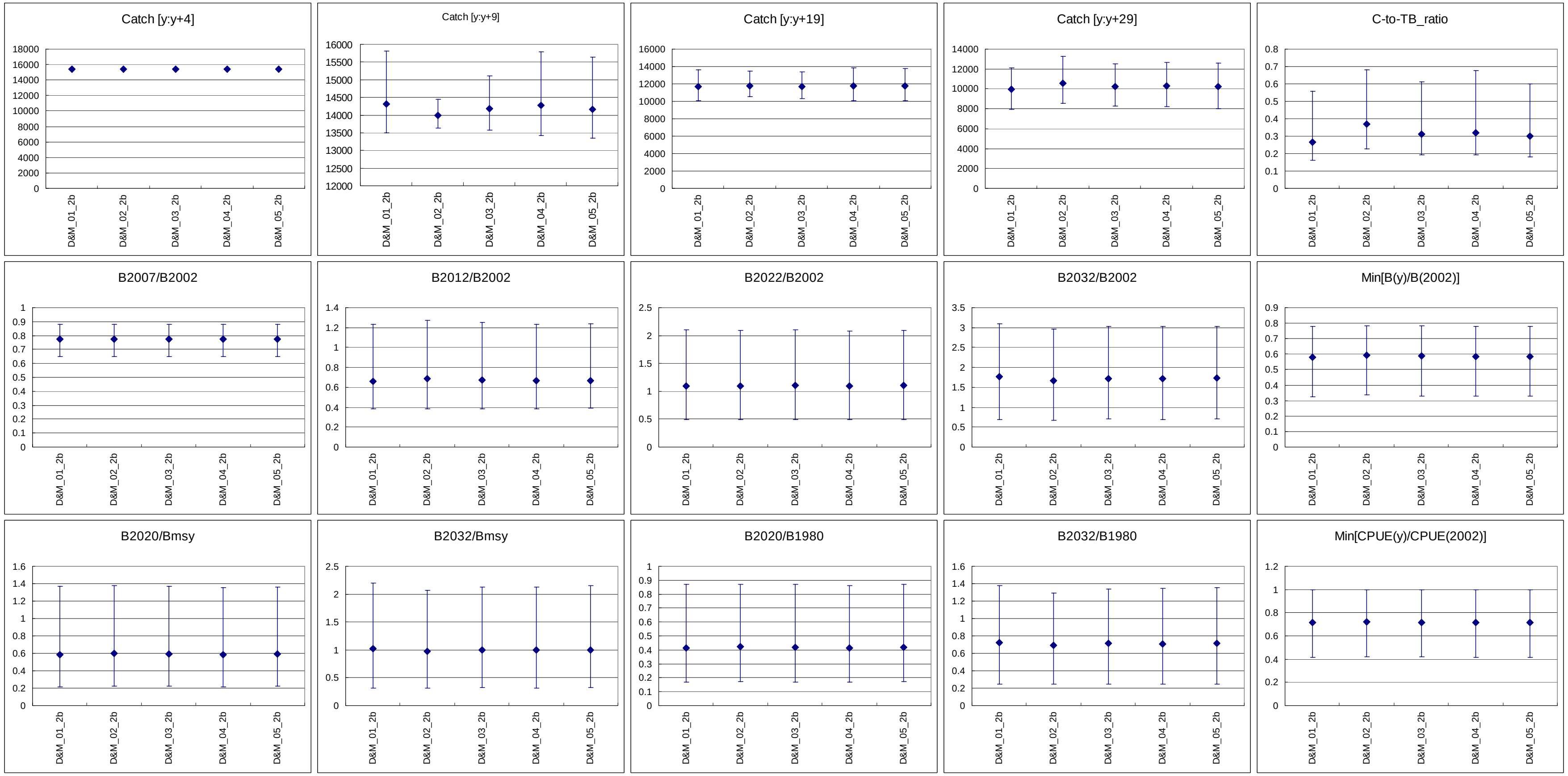


Figure 3. Performance statistics for candidate options for the baseline MP for the Reference case trial.

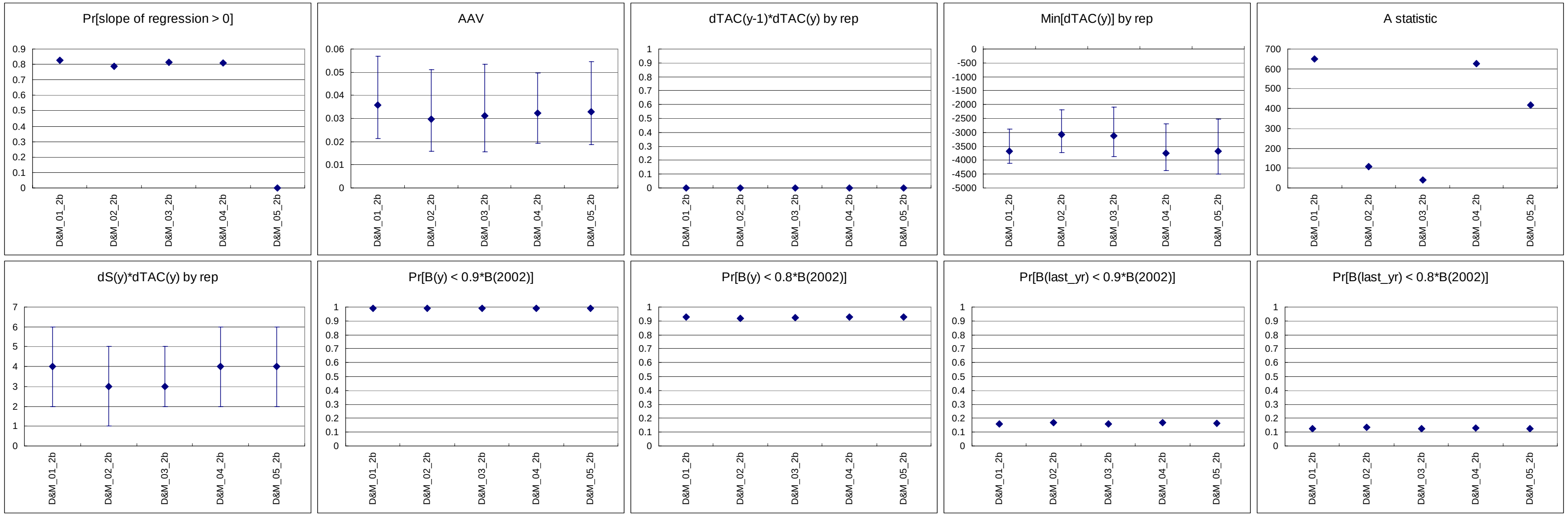


Figure 3 (continued). Performance statistics for candidate options for the baseline MP for the Reference case trial.

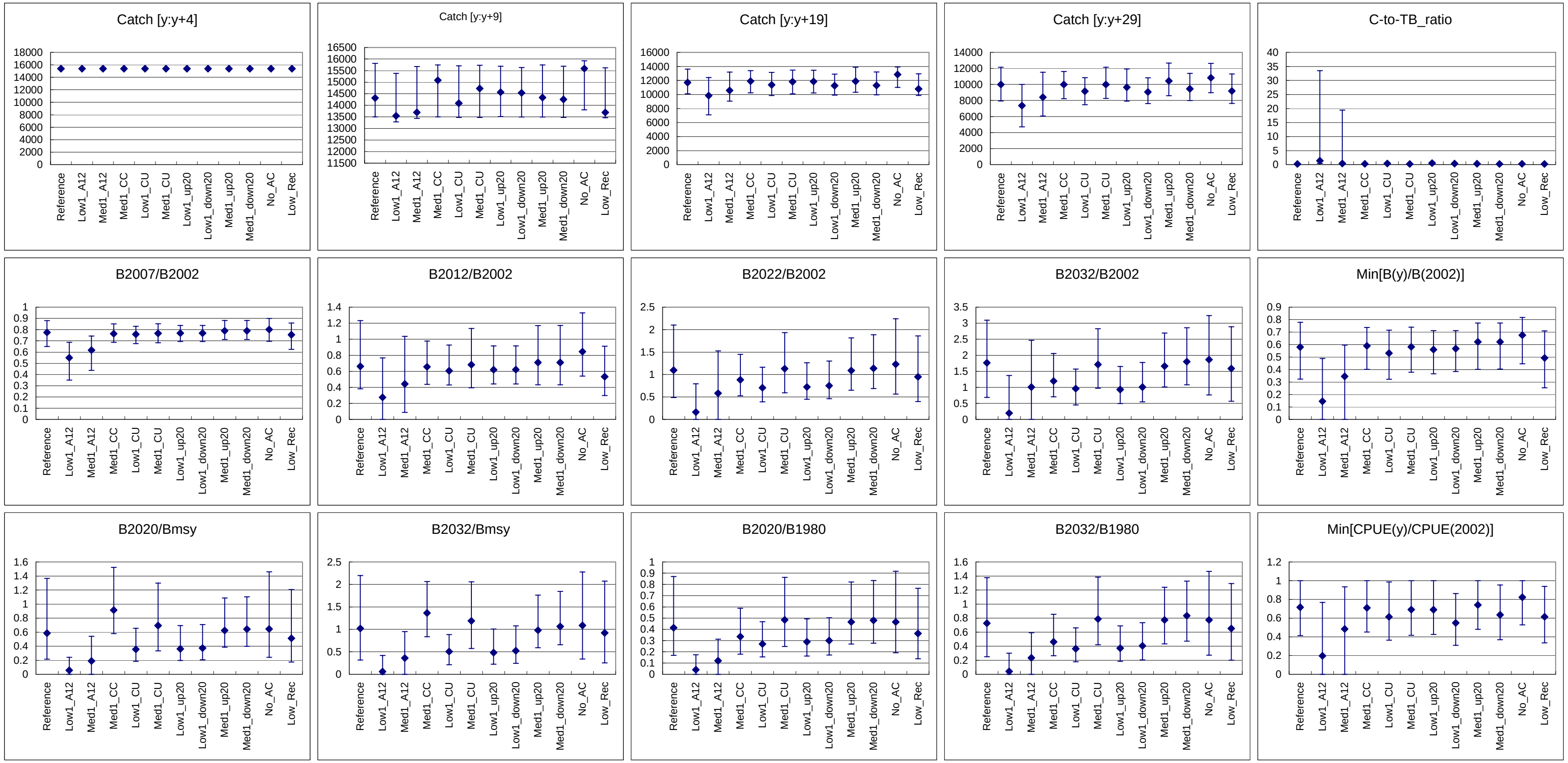


Figure 4a. Performance statistics for the Reference case trial and 11 robustness trials for the baseline MP ("D&M_01_2b").

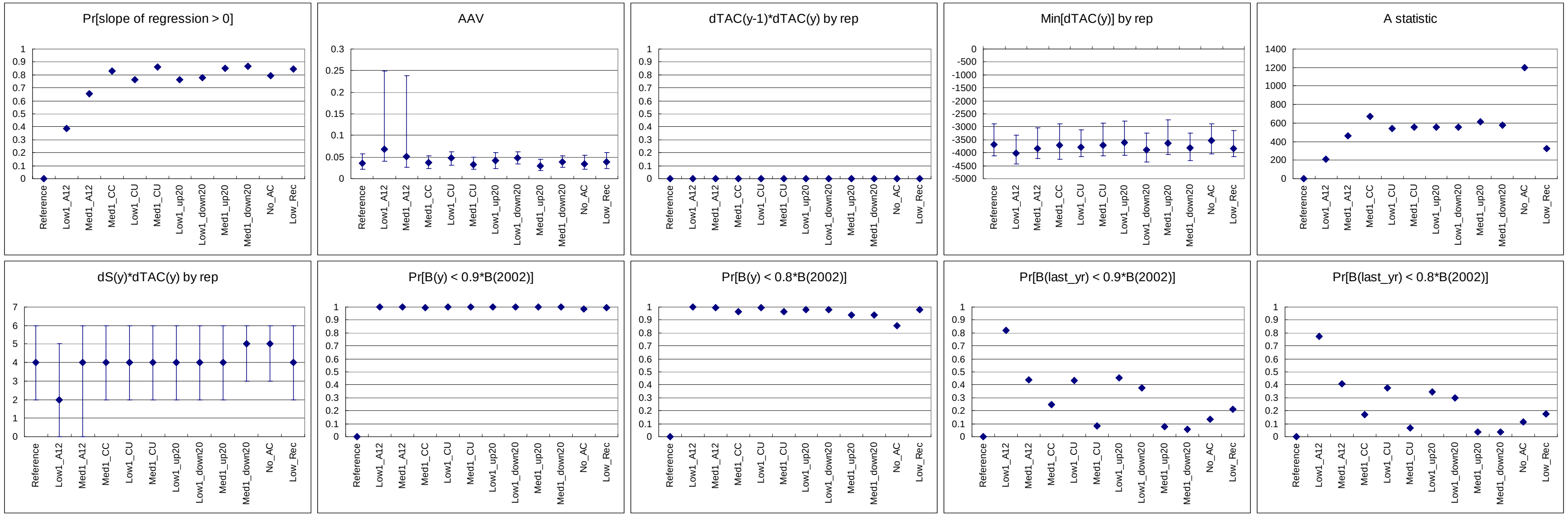
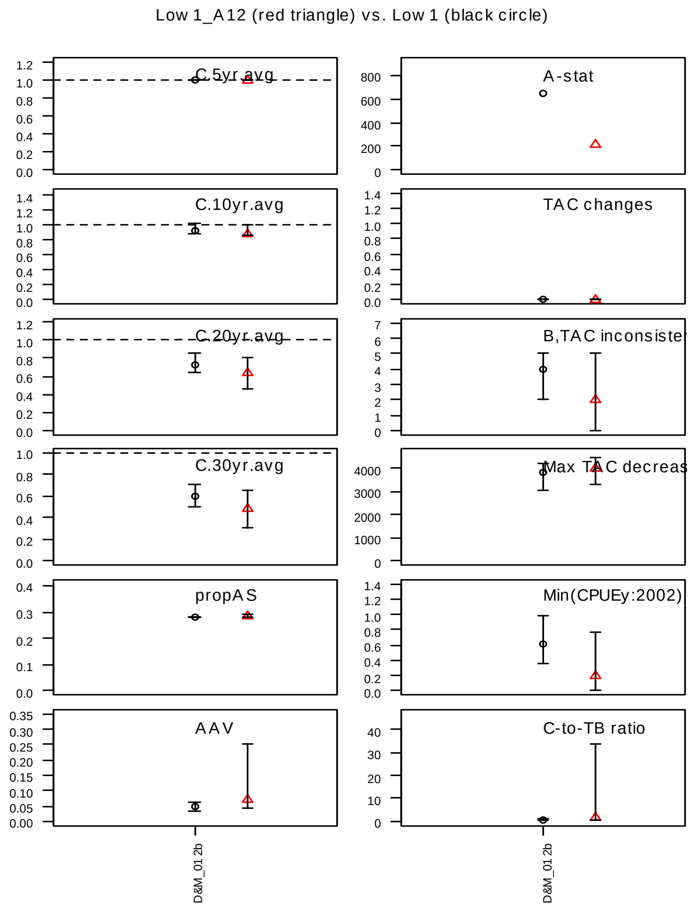


Figure 4a (continued). Performance statistics for the Reference case trial and 11 robustness trials for base line MP ("D&M_01_2b").



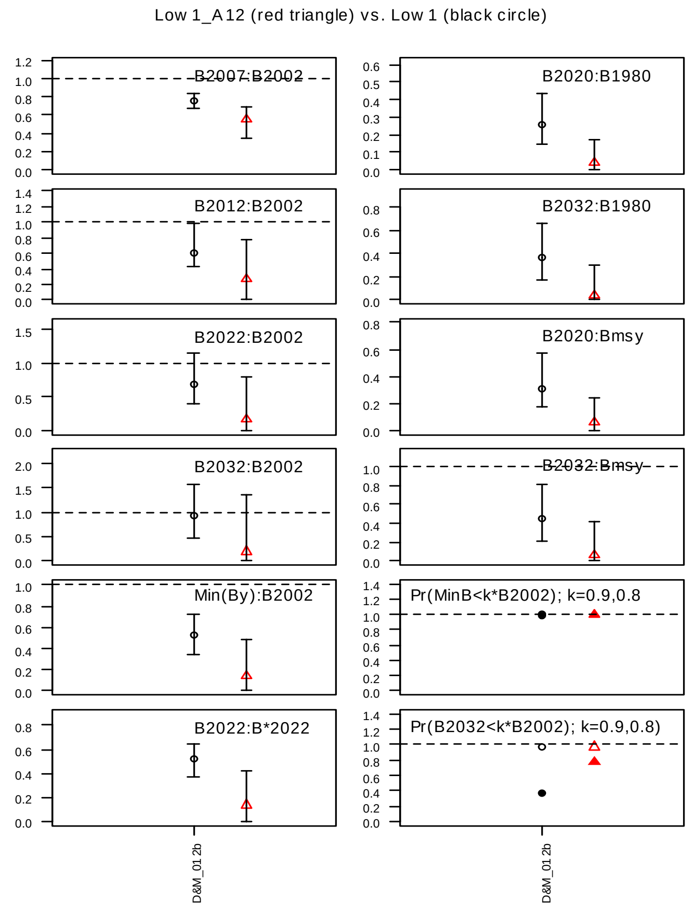


Figure 4b. Comparison of the performance statistics between the Low1_A12 trial and the corresponding scenario that contributes to the Reference case for the baseline MP ("D&M_01_2b").

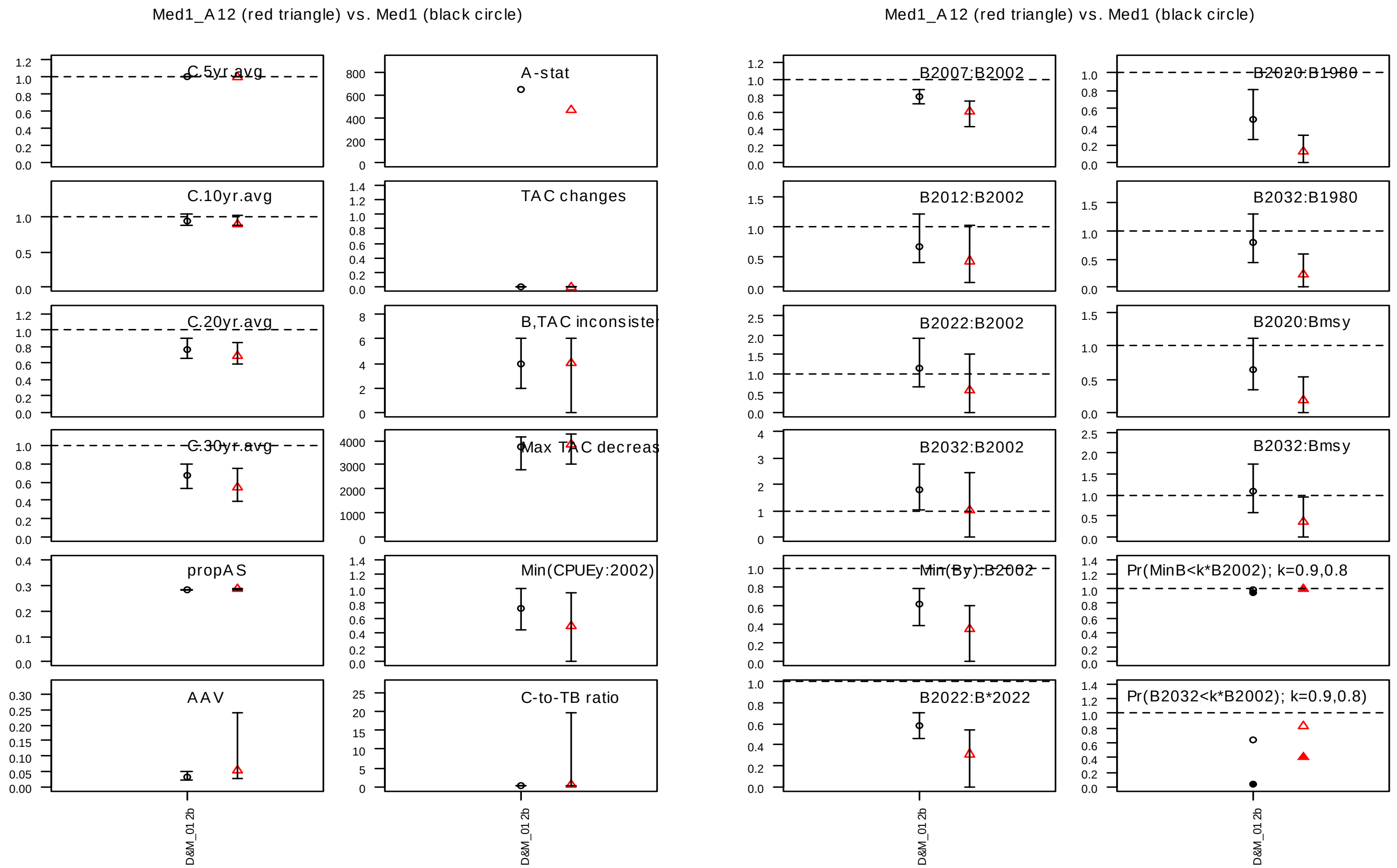


Figure 4c. Comparison of the performance statistics between the Med1_A12 trial and the corresponding scenario that contributes to the Reference case model for the baseline MP ("D&M_01_2b").

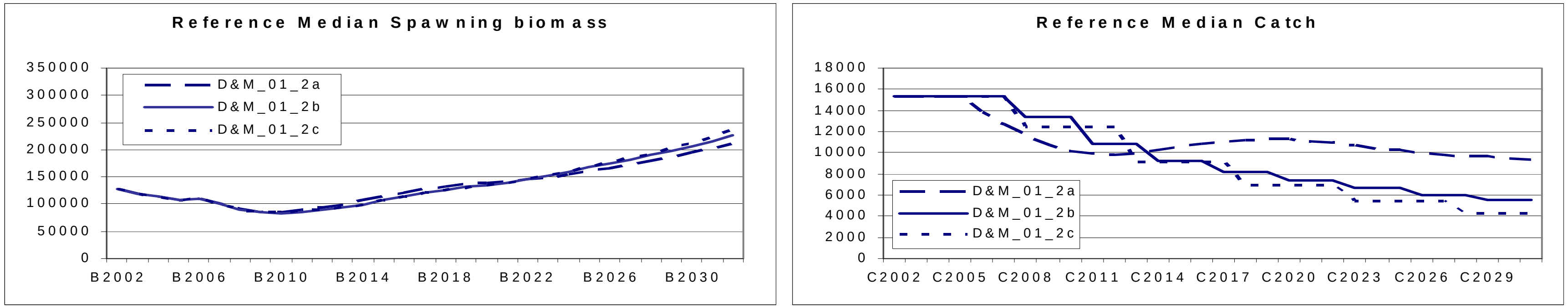


Figure 5a. Median spawning biomass and catch trajectories for the baseline MP (“D&M_01”) for a TAC change interval of a) every year; b) every three years and c) every five years for tuning level 1.1.

1-year TAC change **3-year TAC change** **5-year TAC change**

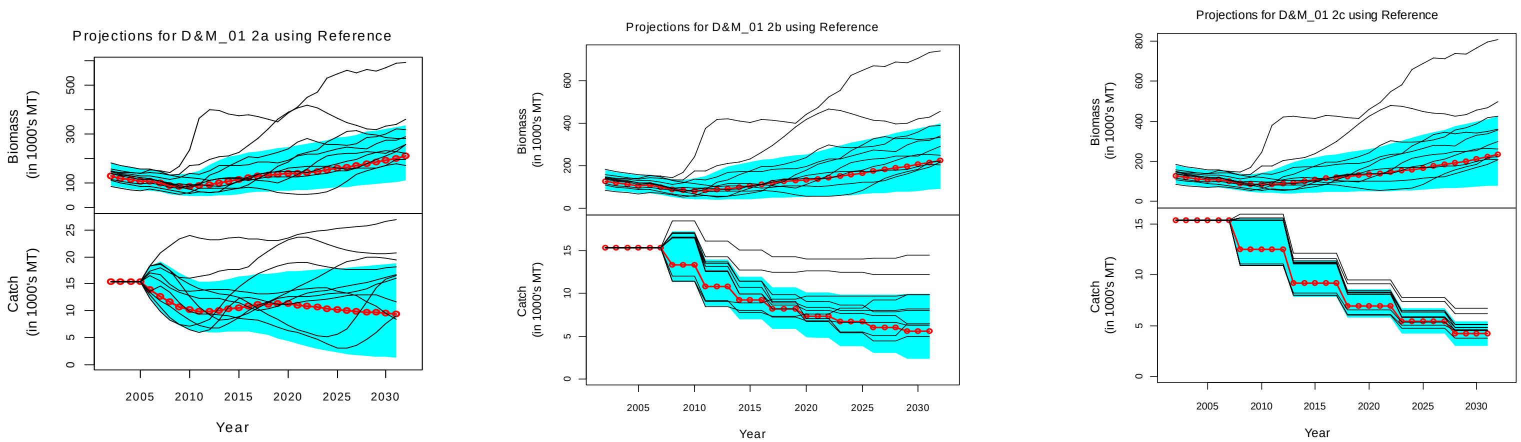


Figure 5b. Wormplots for the baseline MP (“D&M_01”) for different options for the TAC change interval: a) every year, b) every three years and c) every five years for tuning level 1.1.

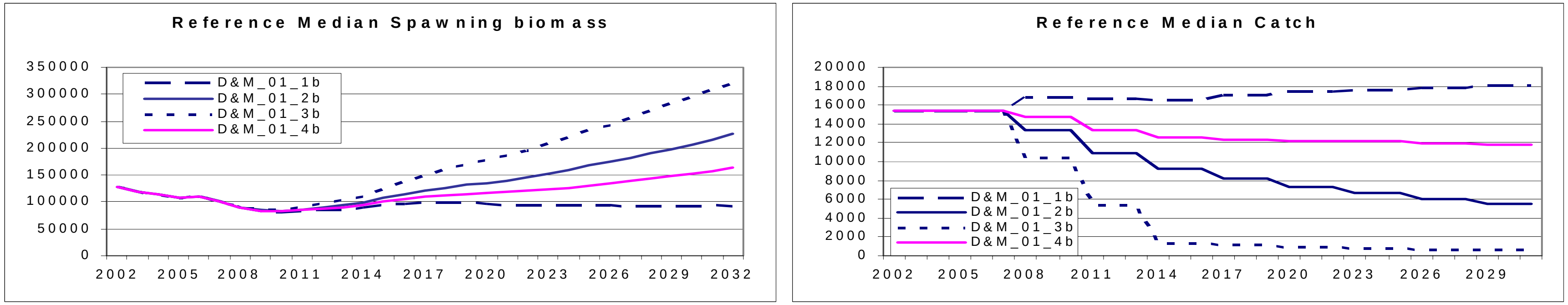


Figure 6a. Median spawning biomass and catch trajectories for the baseline MP ("D&M_01") for B2022/B2002 tuning levels of a) 0.7; b) 1.1; c) 1.5 and d) 0.9.

a) Tuning 0.7 **b) Tuning 1.1** **c) Tuning 1.5** **d) Tuning 0.9**

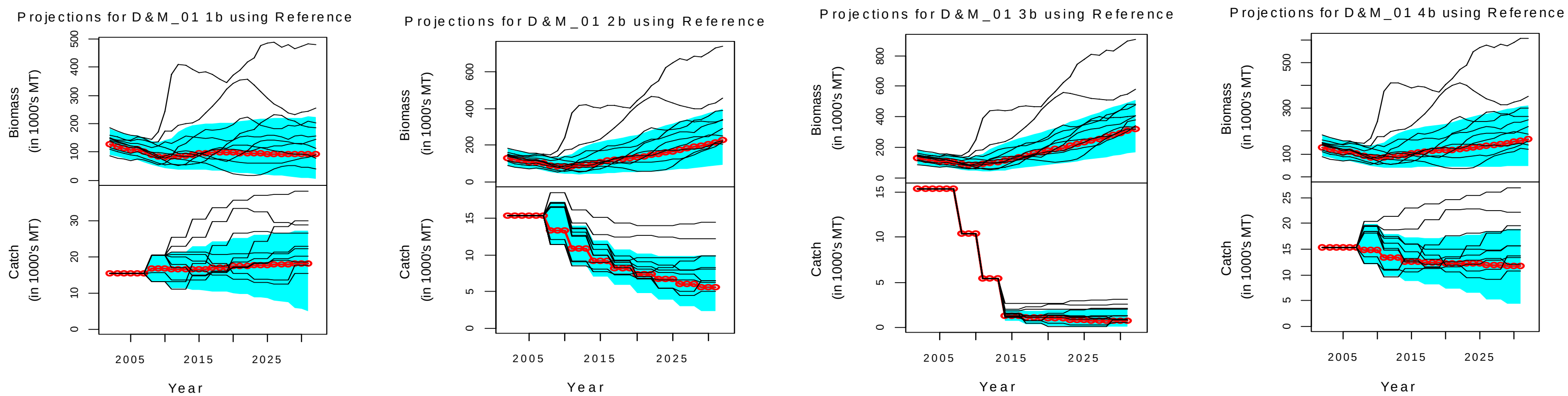


Figure 6b. Worm plots for the baseline MP ("D&M_01") for B2022/B2002 tuning levels of a) 0.7; b) 1.1; c) 1.5 and d) 0.9.

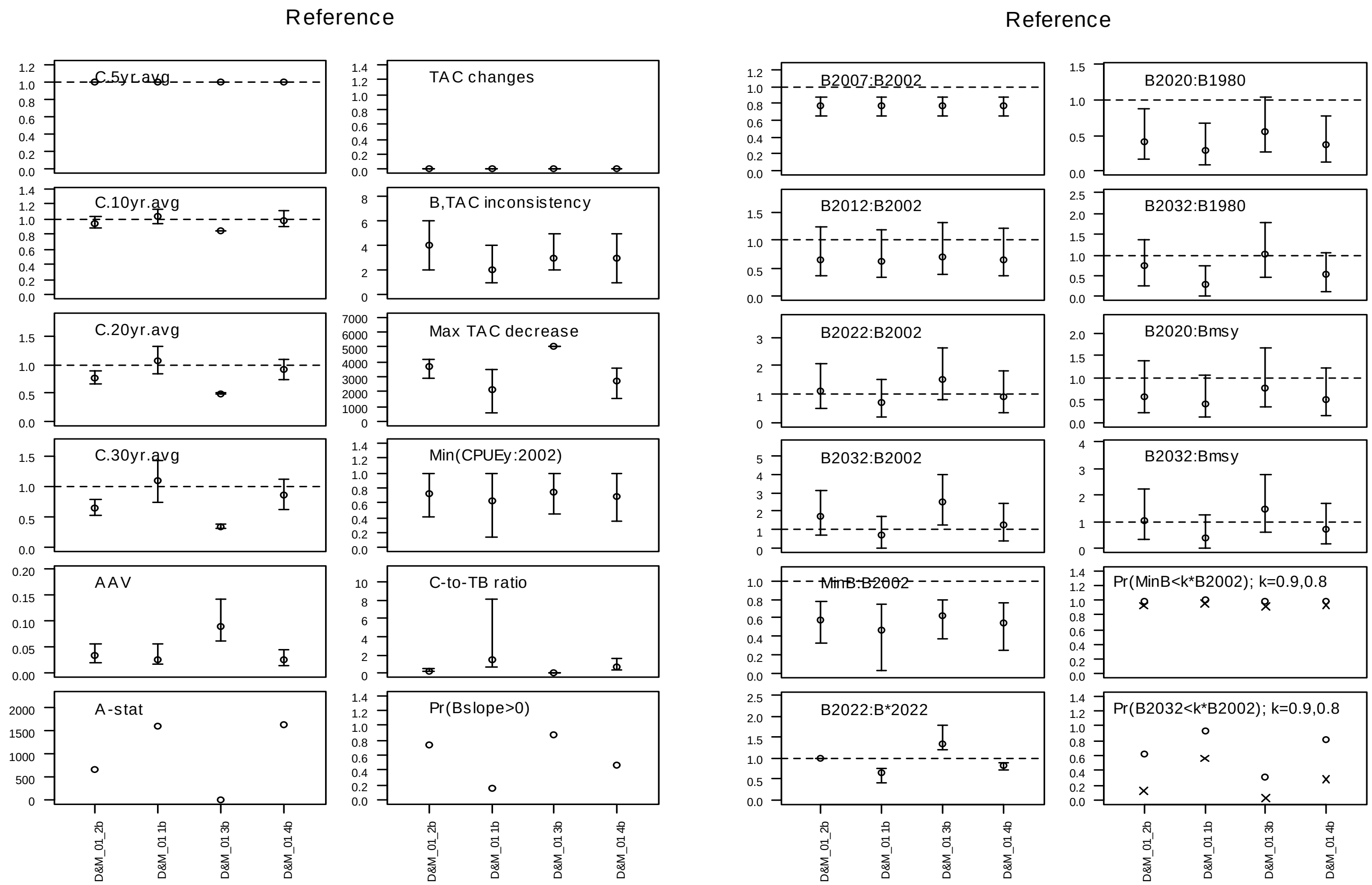


Figure 6c. Performance statistics for the baseline MP “D&M_01” with B2022/B2002 tuning levels of a) 0.7; b) 1.1; c) 1.5 and d) 0.9.