RESULTS OF A REFINED D&M MANAGEMENT PROCEDURE APPLIED TO THE SEATTLE 2005 TRIALS

2005 年にシアトルで決定されたトライアルへの改訂版 D&M 管理方式の適用結果

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SUMMARY

The D&M Management Procedure is applied to the trials developed recently in Seattle. Two minor refinements are added to the procedure: TACs may not increase above their immediately previous levels for the first two TAC changes, and the TAC formula incorporates a function directly related to the recent CPUE level to reduce depletion risk. Best performance is achieved under option b): a three-year TAC-change interval commencing in 2008. The MP takes account of longliner catch length distribution information during initial years, and this improves catch performance (while not compromising recovery performance) if recent recruitment is better than anticipated for the reference set trials. A preferred and an alternative version of this candidate MP are put forward. For the same recovery tuning the alternative involves less depletion risk for the reference set and some robustness trials, but the preferred candidate shows lesser variability in inter-interval TAC changes, and does not underachieve on the median spawning biomass recovery target if recent recruitment is appreciably higher (the triple R scenario) than assumed for the reference set trials.

要約

本年二月に開催されたシアトルでの会合で開発されたトライアルに D&M 管理方式を適用した。 D&M 管理方式に関して今回二点のマイナーな改良を行った。 一点は TAC が変更される始めの二年に関しては、前年の TAC を越えてはならないというルールを加えたこと、そしてもう一点は資源崩壊のリスクを軽減するため、近年観察されている CPUE に応じて TAC を直接調整する関数を加えたことである。 本管理方式の最もよいパフォーマンスは TAC を 2008 年から三年おきに変更する(TAC 変更オプション b))の場合に得られた。本管理方式は、延縄漁業で漁獲される若齢魚の割合に関する情報をTAC変更の初期の段階にて考慮しており、これにより資源の加入量が標準(リファレンスケース)の場合よりもよいと分かった場合には、目標とする親魚資源量の回復レベルを変えることなく漁獲のパフォーマンスを向上させる。 いくつか候補となる D&M 管理方式のバージョンがある中で、我々が最も好む管理方式(D&M_03)とそれ以外のもう一つの管理方式(D&M_02)をここでは推奨する。 もう一つの管理方式(D&M_02)は同じ親魚資源量回復レベルにおいて、我々が最も好む管理方式(D&M_03)よりリファレンスケースやいくつかの頑健性をテストしたケースにおいて資源崩壊のリスクが軽減されている点で好ましい。 一方、我々が最も好む管理方式(D&M_03)は年度間の TAC の変動幅がそれよりも小さくかつ、もし近年の加入量が標準(リファレンスケース)の場合よりもかなりよいと分かった場合(triple R ケース)には、目標とする親魚資源量の回復レベルの中央値を変えることなく漁獲のパフォーマンスを向上させている点で好ましい。

INTRODUCTION

Variants of the D&M management procedure (Butterworth and Mori 2003, 2004a, b), with some added features, are used to assess the comparative performance of these candidate MPs for the various operating models (OMs) defined at the CCSBT meeting in Seattle in February 2005.

METHODS

The D&M management procedure is based on fitting a discrete age-aggregated Fox dynamic production model to past catch and CPUE data. The details of how the model is fit are set out in Butterworth and Mori (2004a) and will not be repeated here. Estimates of the parameter values from this model fit are used to compute future TACs as follows.

TAC change intervals b) and c): every three years and every five years starting from 2008

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

where

$\hat{B}_{MSY,y}$ is the maximum sustainable yield level (*MSYL*) as estimated in year *y*,

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 $M\hat{S}Y_y / MSYL_y$ ($\hat{r}_y / \ln \hat{K}_y$ for the Fox model – note that all 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 each time the TAC is calculated,

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

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

α is a control parameter which is varied to obtain the desired median B_{2022}/B_{2004} tuning level, and

$h(CPUE_y^{rat})$ is a function which adjusts the TAC depending on the ratio of the immediate CPUE compared to that over the period immediately preceding application of the MP.

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

$$g(\hat{r}_y) = \begin{cases} 0 & \text{for } 0 \le \hat{r}_y \le r_1 \\ \frac{1}{r_2 - r_1}(\hat{r}_y - r_1) & \text{for } r_1 < \hat{r}_y < r_2 \\ 1 & \text{for } r_2 \le \hat{r}_y \end{cases} . \tag{2}$$

with parameter values fixed at r_1=0.4, r_2=1.0 as is in Butterworth and Mori (2003).

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.

The function $f\left(LL_y\right)$, which modifies the TAC depending on the proportion of lower ages in longline catch, is calculated as follows:

1) For the first TAC change year (i.e. 2008)

$$LL_{2008} = \left(\frac{\sum_{a=4}^{5} LLC_{2004}}{\sum_{a=4}^{30} LLC_{2004}} + \frac{\sum_{a=4}^{5} LLC_{2005}}{\sum_{a=4}^{30} LLC_{2005}} \right) \Big/ 2 \qquad (3)$$

where

$$f\left(LL_{2008}\right) = 1 \qquad \text{if} \quad LL_{2008} \le 0.13$$

$$f\left(LL_{2008}\right) = \left(1 + \left(LL_{2008} - 0.13\right) \cdot \phi_1\right) \qquad \text{if} \quad 0.13 < LL_{2008} < 0.20$$

$$f\left(LL_{2008}\right) = \left(1 + 0.07 \cdot \phi_1\right) = \theta_1 \qquad \text{if} \quad LL_{2008} \ge 0.20$$

2) For the second TAC change year

For option b):

$$LL_{2011} = \left(\frac{\sum_{a=4}^{6} LLC_{2006}}{\sum_{a=4}^{30} LLC_{2006}} + \frac{\sum_{a=5}^{7} LLC_{2007}}{\sum_{a=4}^{30} LLC_{2007}} + \frac{\sum_{a=6}^{8} LLC_{2008}}{\sum_{a=4}^{30} LLC_{2008}} \right) \Big/ 3 \qquad (4)$$

where

$$f\left(LL_{2011}\right) = 1 \qquad \text{if} \quad LL_{2011} \le 0.16$$

$$f\left(LL_{2011}\right) = \left(1 + \left(LL_{2011} - 0.16\right) \cdot \phi_2\right) \qquad \text{if} \quad 0.16 < LL_{2011} < 0.30$$

$$f\left(LL_{2011}\right) = \left(1 + 0.14 \cdot \phi_2\right) = \theta_2 \qquad \text{if} \quad LL_{2011} \ge 0.30$$

The distributions of LL_{2008} and LL_{2011} for the Cfull2, Cfull2_noAC and Cfull2_noAC_tripleR case trials are shown in Figures 1 and 2 respectively. The means of Cfull2 and Cfull2_noAC_tripleR case relate to the choices of the values of 0.13 and 0.20 in equation (3), and 0.16 and 0.30 in equation (4) above. The idea of introducing this function is to give flexibility to the MP, to be able to vary the TAC depending on good or poor recruitment in recent years as reflected by the proportion of lower ages in the longline catch.

No change in the function in equation 4 above made for option c), except that $f\left(LL_{2011}\right)$ is now changed to $f\left(LL_{2013}\right)$.

The function $h\left(CPUE_y^{rat}\right)$ which controls the TAC depending on the ratio of immediate CPUE value compared to that when the MP was first put into effect is:

$$CPUE_y^{rat} = \left(\frac{\frac{1}{3} \sum_{y'=y-4}^{y-2} CPUE_{y'}}{\frac{1}{5} \sum_{y=1998}^{2002} CPUE_y} \right) \tag{5}$$

where

$$h\left(CPUE_y^{rat}\right) = 0 \qquad \text{if } 0 < CPUE_y^{rat} \le 0.5$$

$$h\left(CPUE_y^{rat}\right) = \frac{1}{0.9-0.5}\left(CPUE_y^{rat} - 0.5\right) \qquad \text{if } 0.5 < CPUE_y^{rat} < 0.9$$

$$h\left(CPUE_y^{rat}\right) = 1 \qquad \text{if } CPUE_y^{rat} \le 0.9$$

Prior to the introduction of the *h* factor, MPs reflected lower 10% probability intervals for *B*(2022)/*B*(2004) which dropped to very low levels over time. The reason is that there needs to be a number of years further data for the model fit to be able to establish whether it is dealing with an instance of low productivity and hence reduce *r*, but by the time this becomes evident already too much catch has been taken and the resource is appreciably further depleted.

Figure 3 shows the distribution of $CPUE_{2011}^{rat}$ and the corresponding value of *B*(2022)/*B*(2004) for the 2000 samples of the Cfull2 case of an MP without the *h* function (specifically the MP referred to as D&M_01_2b in the next section). This Figure shows that at this early stage, the CPUE ratio provides a reasonable indicator of the extent of recovery likely; so that the *h* factor was introduced with a view to make use of this information to reduce the TAC at such an early stage in the event of low CPUE. The choices of the values of 0.5 and 0.9 in equation (5) were made on the basis of this Figure. The $CPUE_y^{rat}$ is defined in terms of averages over a number of years to improve the signal:noise ratio in the information input to the *h* function.

Further constraints added were that for the first two years in which the TAC can change, it is not permitted to exceed its immediately previous value. These were added to counter the consequences of an inaccurate initial determination of *r* leading to an increase in the TAC before more information indicated that the reverse action was required. Note that these constraints and the *h* factor are the only new features added to the D&M procedure compared to that in Butterworth and Mori (2004b).

TAC change interval a): every three years starting from 2006

The main TAC equation is same as equation (1), and $h\left(CPUE_y^{rat}\right)$ as in equation (5) except that the lower interval of $CPUE_y^{rat}$ is now set to 0.3. Apart from the second and third year TAC change, $f\left(LL_y\right)$ is set to 1. For the third TAC change year (i.e. 2012), $f\left(LL_{2012}\right)$ is set as in equation (4). Moreover, as above for the first two years in which the TAC can change, it is not permitted to exceed its immediately previous value. For the second TAC change year (i.e. 2009):

$$LL_{2009} = \left(\frac{\sum_{a=4}^{5} LLC_{2004}}{\sum_{a=4}^{30} LLC_{2004}} + \frac{\sum_{a=4}^{5} LLC_{2005}}{\sum_{a=4}^{30} LLC_{2005}} + \frac{\sum_{a=4}^{6} LLC_{2006}}{\sum_{a=4}^{30} LLC_{2006}} \right) \Big/ 3 \quad (6)$$

where

$$f(LL_{2009}) = 1 \qquad \text{if } LL_{2009} \le 0.13$$

$$f(LL_{2009}) = (1 + (LL_{2009} - 0.13)\cdot\phi_1) \qquad \text{if } 0.13 < LL_{2009} < 0.23$$

$$f(LL_{2009}) = (1 + 0.1\cdot\phi_1) = \theta_1 \qquad \text{if } LL_{2009} \ge 0.23$$

with the LL_{2009} values at which the function has a derivative discontinuity having been selected in similar manner to those for equations 3 and 4 (see Figure 4).

Candidate Management Procedure

The performance of three candidate MPs was explored for option b) – a TAC change interval every three years starting from year 2008. The names for these MPs and their associated control value settings are listed in Table 1. The first of these, D&M_01, excludes the new *h* function and is shown primarily for comparison purposes. D&M_02 and D&M_03 are the preferred candidates, differing primarily in their values for the TAC-smoothing control parameter *w* (which necessitates changes to some of the other parameters).

For option a) and c) with different years for TAC changes, only variants of the D&M_02/03 candidates (i.e. including the *h* function) are explored.

RESULTS AND DISCUSSION

Figure 5 provides worm plots and 80% probability interval envelopes for the three candidate MPs with a 1.1 tuning for the Cfull2 OM for option b). For the D&M_01 candidate, the spread of future TACs is relatively narrow, with a consequential wide spread in the future spawning biomass trajectories. Indeed this latter spread seems too wide, and the corresponding results listed in Table 2 confirm that even before 2032, the probability that the spawning biomass has dropped to zero already exceeds 10%.

The introduction of the *h* function avoids this undesirable result, and Figure 5 and Table 2 show that for both further candidates put forward (D&M_02 and D&M_03) the lower end of the 80% probability interval for spawning biomass is maintained reasonably above zero, as variability in biomass is reduced by converting this to extra variability in catch. Though this is at the expense of a slightly higher AAV statistic and lesser recovery after 2022, these factors seem outweighed by the absence of a continuing decline in median catch, and the fact that these two MP candidates seem better able to distinguish situations of greater and lesser productivity, thus permitting catches to rise further if appropriate while at the same time reducing the risk of unintended depletion. These features are also evident in Figure 6, which shows medians and probability interval envelopes for these three candidate MPs on the same plot.

The primary difference between the D&M_02 and D&M_03 candidates is the higher value of the control parameter *w* for the latter, which leads (as is its design intention) to a lesser AAV. Our slight preference between these two candidates is for D&M_03. This may appear weakly motivated at the moment, as the fact that the D&M_02 procedure does not (at its lower 10% probability bound) deplete the resource as much would seem to outweigh its greater AAV. Our preference decision is, however, also driven by some robustness test results as explained below.

<u>Different tunings</u>

Figure 6 also shows catch and spawning biomass projection results for all three candidate MPs for 0.9 and 1.3 as well as 1.1 tunings, with results for the preferred D&M_03 candidate listed in Table 3. Figure 7 shows the D&M_03 results for all three tunings overlaid on the same plot to ease comparison.

There are no qualitative surprises in these plots: as the tuning level is increased, biomass trajectories rise and catch trajectories fall as expected, though the lower end of the probability interval envelope for catches is virtually independent of the tuning level.

<u>Robustness tests</u>

Performance statistics are plotted for the complete set of robustness tests for all three candidate MPs for the 1.1 tuning under option b). Results are reported in the form of comparisons with the corresponding reference set OM, either in Figures 8-10 for tests relative to the complete reference set (Cfull2), or in Figures 11-13 where tests consider changes for only some elements of the reference set.

For the first set of comparisons (Figures 8-10), only one feature stands out: given two or four more years of low recruitment, performance in meeting recovery targets is impacted appreciably. In terms of the lower ends of probability intervals, the D&M_01 MP fails for not only the "low R4" but also the "low R2" test. The D&M_02 and D&M_03 MPs behave appreciably better given their introduction of the *h* function, with the former slightly better as regards depletion risk, but both of these candidate MPs do still encounter difficulties with the "low R4" test.

Two features are evident from the comparisons for certain reference set elements only in Figures 11-13. First, recovery towards B_{msy} is much enhanced for the test involving a reduction in carrying capacity (essentially because the current B_{msy} is lower for this scenario). Secondly, depletion risk is appreciably altered only in one case, that of the alternative formulation of selectivity for the Indonesian fishery. In this case there is a high probability of substantial decline in spawning biomass under the D&M_01 MP, and although this is greatly improved for the other two candidate MPs, particularly for D&M_02, performance remains substantially worse compared to the corresponding reference set trial

<u>Performance under more optimistic recruitment scenarios</u>

Figure 14 contrasts the performances of the three candidate MPs for more optimistic immediate recruitment scenarios ("no AC" and "triple R"), with corresponding results listed in Table 2. Particular emphasis was placed in the design of the D&M MP on attempting, though the *f*(*LL*) functions which utilize information on the length structure of the Japanese longliner catch, to allow enhanced catches in both the short and larger term if such data indicated better recruitment than envisaged under the reference set, provided recovery objectives were not compromised. Thus in terms of the performance statistics, one seeks candidate MPs for which it is the catch, more than the biomass that increases for better recruitment relative to the reference case.

The results reported are indicative of some success towards this end. For example, under the "triple R" scenario the D&M_03 MP median recovery by 2022 is not compromised (still being 2% greater than for the reference case), but achieves a 20-year average catch increase of some 26% (were it not for the inclusion of the *f*(*LL*) functions, this increase would be some 3% less; furthermore it is the introduction of these functions that excludes (for the 1.1 tuning) the inevitability of a TAC decrease the first time the MP is implemented in 2008). One negative feature here, however, is that for the "triple R" scenario, the D&M_02 MP "over-corrects", achieving only 5% rather than the 10% recovery target increase for 1.1 tuning. It is for this reason that we marginally prefer the D&M_03 over the D&M_02 candidate MP.

Figure 15 and Table 3 show core performance statistics results for our preferred D&M_03 MP under the three different tuning levels. Again there are no qualitative surprises, with trends as the tuning is changed in the expected directions. The lower end of the probability interval for spawning biomass for the reference set for 0.9 tuning does appear undesirably low.

Alternative TAC change intervals

Figure 16 shows worm plots for the preferred candidate MP for each of the three intervals under consideration. Performance for the five-year interval option c) is clearly worse than b); with a continually decreasing lower probability interval over time for spawning biomass, so that only one candidate is reported for this option.

Surprisingly, however, option a) which first adjusts the TAC in 2006 also performs worse than option b): a large immediate TAC reduction is inevitable, and the lower end of the probability interval for spawning biomass drops compared to b). The first of these features may be on account of the first change having to take place before the *f*(*LL*) function with its information on recruitment can be taken into account. However, the authors had limited time to explore the control parameter space for this option, so that there may be other variants of the MP which perform better in these respects under option a).

Figure 17 compares catch and spawning biomass median and probability interval envelopes for the different options for their corresponding preferred candidate MPs, while Figure 18 does this for the preferred and another variant for option a). Figure 19 compares performances under different feature recruitment scenarios, with these results also listed in Table 4. There are no obvious surprises in these results, with the c) option showing the greatest variability in spawning biomass recovery.

CONCLUDING REMARKS

Our preferred candidate MP is D&M_03 for a three year TAC change interval commencing in 2008 (option b). This outperforms the corresponding candidates which we have been able (in the time available) to develop for the alternative TAC change options.

Important aspects of the preferred candidate are a reduction in the risk of depletion to a low spawning biomass level through introduction of the $h\left(CPUE_y^{rat}\right)$ function, and improved short and longer term catch performance for scenarios with better recruitment in the immediate future by taking account of the distributions of catch at length for the Japanese longliner.

A second candidate is also offered for option b) (D&M_02). This shows better performance in terms of lower probability interval levels for future spawning biomass for both the reference set and some robustness tests, but evidences higher inter-TAC-change TAC variability, and underperforms in achieving median recovery targets if recent recruitment is appreciably better (the triple R scenario) than anticipated under the reference set.

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Table 1. Candidate management procedures and their associated control parameter values.

- **1.1** tuning for TAC change interval three years starting with year 2008

MPname	$\theta_1\,(\phi_1)$	$\theta_2\,(\phi_2)$	w	$h\left(CPUE_y^{rat}\right)$	α
D&M_01_2b	1.6 (8.57)	1.2 (1.43)	0.5	-	0.742
D&M_02_2b	1.1 (1.43)	1.2 (1.43)	0.5	Yes	1.927
D&M_03_2b	1.2 (2.86)	1.2 (1.43)	0.65	Yes	1.402

- **0.9** tuning for TAC change interval three years starting with year 2008

MPname	$\theta_1\,(\phi_1)$	$\theta_2\,(\phi_2)$	w	$h\left(CPUE_y^{rat}\right)$	α
D&M_01_1b	1.6 (8.57)	1.2 (1.43)	0.5	-	0.894
D&M_02_1b	1.1 (1.43)	1.2 (1.43)	0.5	Yes	3.134
D&M_03_1b	1.2 (2.86)	1.2 (1.43)	0.65	Yes	2.239

- **1.3** tuning for TAC change interval three years starting with year 2008

MPname	$\theta_1\,(\phi_1)$	$\theta_2\,(\phi_2)$	w	$h\left(CPUE_y^{rat}\right)$	α
D&M_01_3b	1.6 (8.57)	1.2 (1.43)	0.5	-	0.595
D&M_02_3b	1.1 (1.43)	1.2 (1.43)	0.5	Yes	1.252
D&M_03_3b	1.2 (2.86)	1.2 (1.43)	0.65	Yes	0.878

- 1.1 tuning for TAC change interval three years **starting with year 2006**

MPname	$\theta_1\,(\phi_1)$	$\theta_2\,(\phi_2)$	w	$h\left(CPUE_y^{rat}\right)$	α
D&M_02_2a	1.2 (2.00)	1.2 (1.43)	0.65	Yes	3.006
D&M_03_2a	1.2 (2.00)	1.2 (1.43)	0.75	Yes	1.581

- 1.1 tuning for TAC change interval **five years** starting with year 2008

MPname	$\theta_1\,(\phi_1)$	$\theta_2\,(\phi_2)$	w	$h\left(CPUE_y^{rat}\right)$	α
D&M_03_2c	1.1 (1.43)	1.2 (1.43)	0.5	Yes	1.463

Table 2. Some selected performance statistics for the three candidate MPs for the Cfull2, Cfull2_noAC and Cfull2_noAC_tripleR trials.

		Cfull2			Cfull2_noAC			Cfull2_noAC_tripleR		
		D&M_01_2b	D&M02_2b	D&M03_2b	D&M_01_2b	D&M02_2b	D&M03_2b	D&M_01_2b	D&M02_2b	D&M03_2b
mean(cat[y:y+19])	10%	7955	6176	7020	8245	6666	7384	8684	7506	8172
	median	9567	9779	9880	10150	11596	11115	11190	13327	12454
	90%	12403	16663	15003	13621	18622	16661	14587	19900	17744
mean(cat[y:2031])	10%	5835	4605	5293	6139	5095	5644	6553	5746	6266
	median	8183	9855	9225	8798	11302	10529	9727	12578	11798
	90%	13194	19852	17300	14565	21894	19205	15385	23068	20271
B(2022)/B(2004)	10%	0.056	0.381	0.240	0.215	0.418	0.345	0.225	0.343	0.310
	median	1.097	1.098	1.103	1.242	1.093	1.138	1.279	1.049	1.120
	90%	2.500	2.155	2.238	2.806	2.262	2.455	2.867	2.342	2.499
B(2032)/B(2004)	10%	0.000	0.353	0.236	0.077	0.328	0.395	0.054	0.137	0.275
	median	1.770	1.261	1.435	2.025	1.176	1.459	2.029	1.014	1.325
	90%	4.166	2.754	3.098	4.485	2.656	3.165	4.470	2.530	3.040
AAV	10%	0.039	0.055	0.041	0.026	0.045	0.033	0.019	0.040	0.026
	median	0.075	0.124	0.088	0.067	0.098	0.070	0.056	0.081	0.057
	90%	0.260	0.212	0.130	0.130	0.185	0.111	0.127	0.172	0.107

Table 3. Some selected performance statistics for the preferred candidate MP (D&M_03) for the 0.9, 1.1 and 1.3 tuning for the Cfull2, Cfull2_noAC and Cfull2_noAC_tripleR trials.

		Cfull2			Cfull2_noAC			Cfull2_noAC_tripleR		
		D&M_03_1b (0.9)	D&M_03_2b (1.1)	D&M_03_3b (1.3)	D&M_03_1b (0.9)	D&M_03_2b (1.1)	D&M_03_3b (1.3)	D&M_03_1b (0.9)	D&M_03_2b (1.1)	D&M_03_3b (1.3)
mean(cat[y:y+19])	10%	6441	7020	6939	7660	7384	7190	8553	8172	7784
	median	10705	9880	8865	12485	11115	9813	13931	12454	10981
	90%	17595	15003	12555	19242	16661	13890	20234	17744	14955
mean(cat[y:2031])	10%	5362	5293	5212	5830	5644	5447	6560	6266	5985
	median	10356	9225	7977	11887	10529	8910	13044	11798	9940
	90%	20617	17300	13492	22814	19205	15048	24016	20271	16094
B(2022)/B(2004)	10%	0.121	0.240	0.326	0.163	0.345	0.482	0.108	0.310	0.458
	median	0.898	1.103	1.299	0.892	1.138	1.380	0.850	1.120	1.383
	90%	1.955	2.238	2.596	2.121	2.455	2.894	2.196	2.499	2.911
B(2032)/B(2004)	10%	0.000	0.236	0.419	0.000	0.395	0.668	0.000	0.275	0.599
	median	0.866	1.435	2.041	0.767	1.459	2.194	0.627	1.325	2.124
	90%	2.195	3.098	4.233	2.129	3.165	4.504	1.931	3.040	4.433
AAV	10%	0.046	0.041	0.038	0.041	0.033	0.029	0.038	0.026	0.019
	median	0.091	0.088	0.082	0.077	0.070	0.065	0.068	0.057	0.052
	90%	0.215	0.130	0.111	0.175	0.111	0.108	0.262	0.107	0.101

Table 4. Some selected performance statistics for the preferred candidate MP (D&M_03) for three TAC change interval a) every three years starting from 2006, b) every three years starting from 2008 and c) every five years starting from 2008 for the Cfull2, Cfull2_noAC and Cfull2_noAC_tripleR trials.

		Cfull2			Cfull2_noAC			Cfull2_noAC_tripleR		
		D&M_03_2a	D&M_03_2b	D&M_03_2c	D&M_03_2a	D&M_03_2b	D&M_03_2c	D&M_03_2a	D&M_03_2b	D&M_03_2c
mean(cat[y:y+19])	10%	8274	7020	7392	8536	7384	7537	9031	8562	8037
	median	10211	9880	9899	11647	11115	10733	12871	13403	11940
	90%	14822	15003	13738	16766	16661	14928	17403	17896	16320
mean(cat[y:2031])	10%	6415	5293	5546	6791	5644	5707	7209	6758	6209
	median	9779	9225	9148	11275	10529	10377	12576	13505	11576
	90%	17427	17300	15546	19626	19205	16843	20542	20327	18388
B(2022)/B(2004)	10%	0.172	0.240	0.127	0.258	0.345	0.284	0.281	0.547	0.291
	median	1.100	1.103	1.097	1.112	1.138	1.213	1.162	1.330	1.251
	90%	2.370	2.238	2.433	2.492	2.455	2.750	2.651	2.639	2.842
B(2032)/B(2004)	10%	0.000	0.236	0.042	0.068	0.395	0.259	0.021	0.540	0.210
	median	1.354	1.435	1.519	1.264	1.459	1.608	1.233	1.533	1.587
	90%	3.184	3.098	3.519	3.077	3.165	3.859	3.036	3.247	3.824
AAV	10%	0.031	0.041	0.038	0.029	0.033	0.031	0.030	0.025	0.025
	median	0.053	0.088	0.076	0.047	0.070	0.060	0.046	0.051	0.052
	90%	0.129	0.130	0.146	0.080	0.111	0.099	0.077	0.099	0.093

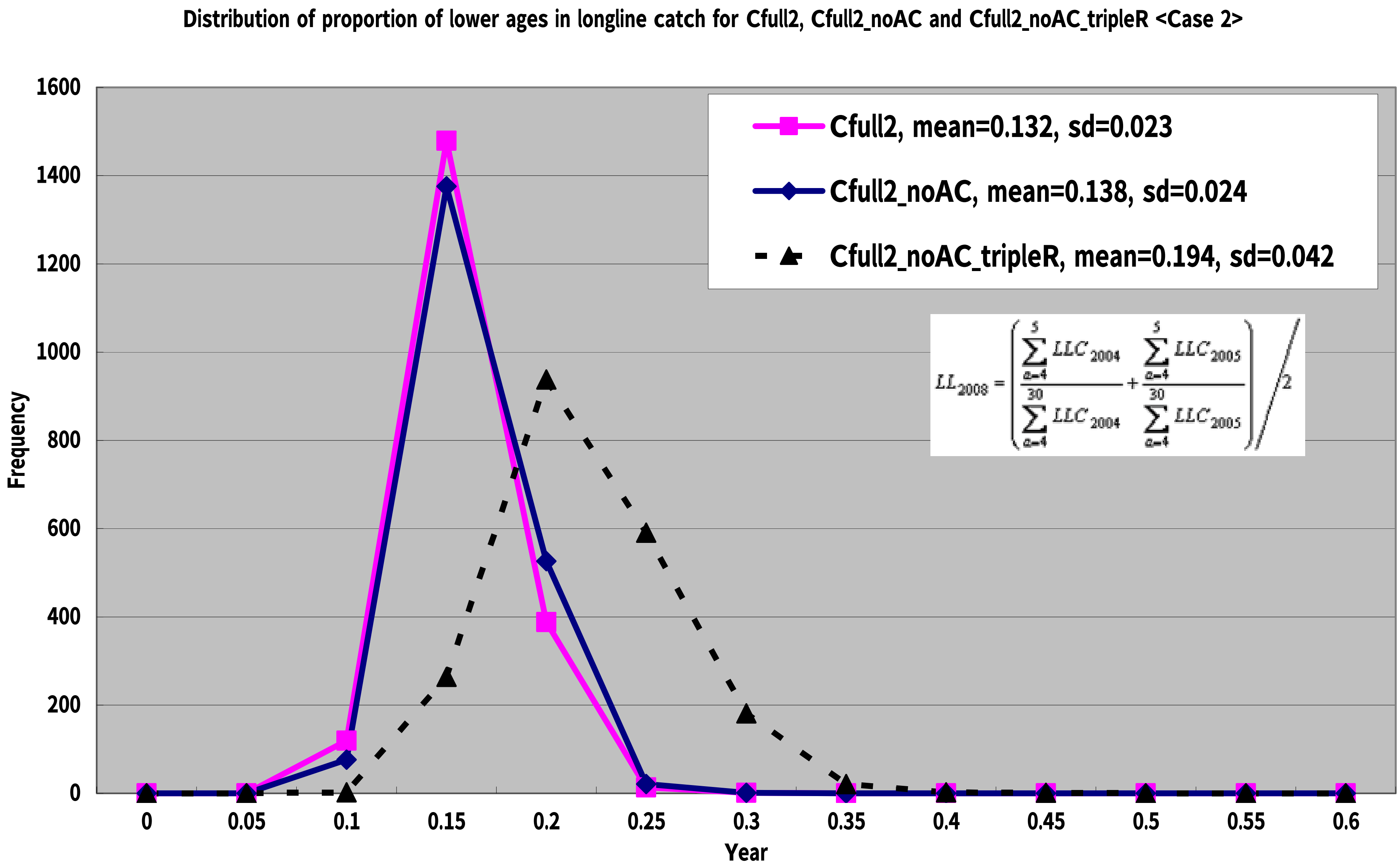


Figure 1. Distribution of proportion of lower ages (LL_{2008} – see equation 3) in the longline catch for the Cfull2, Cfull2_noAC and Cfull2_noAC_tripleR cases (2000samples).

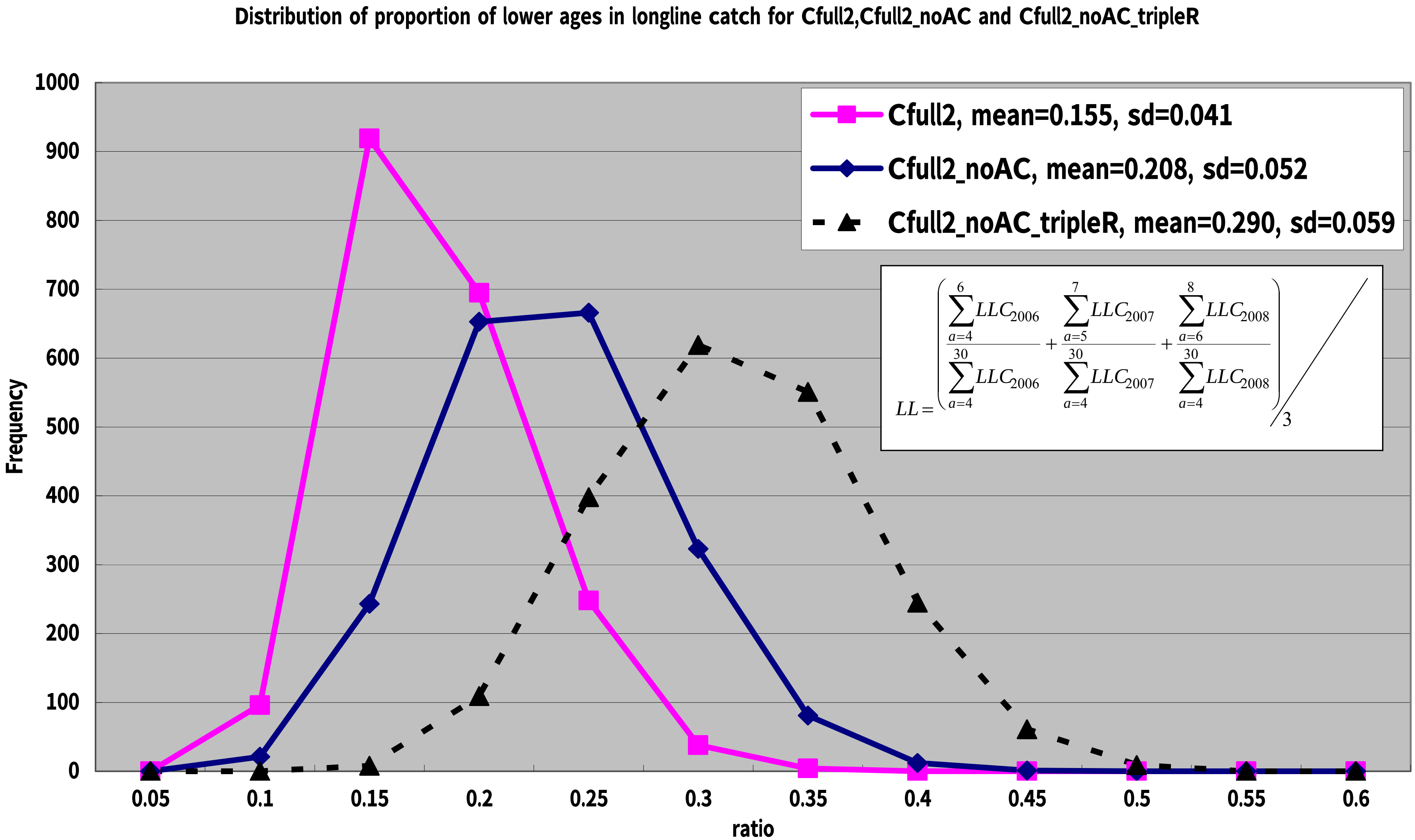


Figure 2. Distribution of proportion of lower ages (LL_{2011} – see equation 4) in the longline catch for the Cfull2, Cfull2_noAC and Cfull2_noAC_tripleR cases (2000samples).

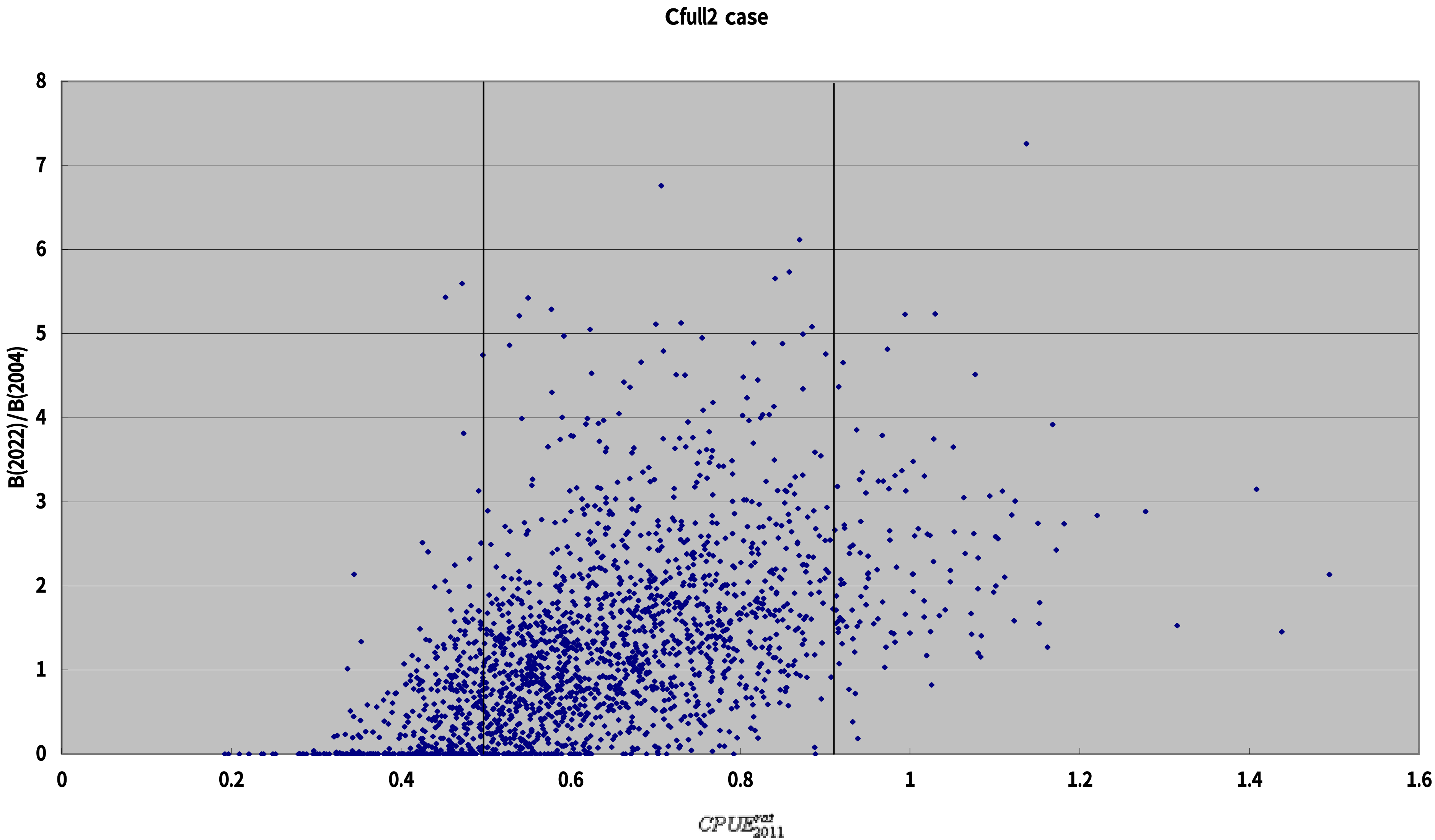
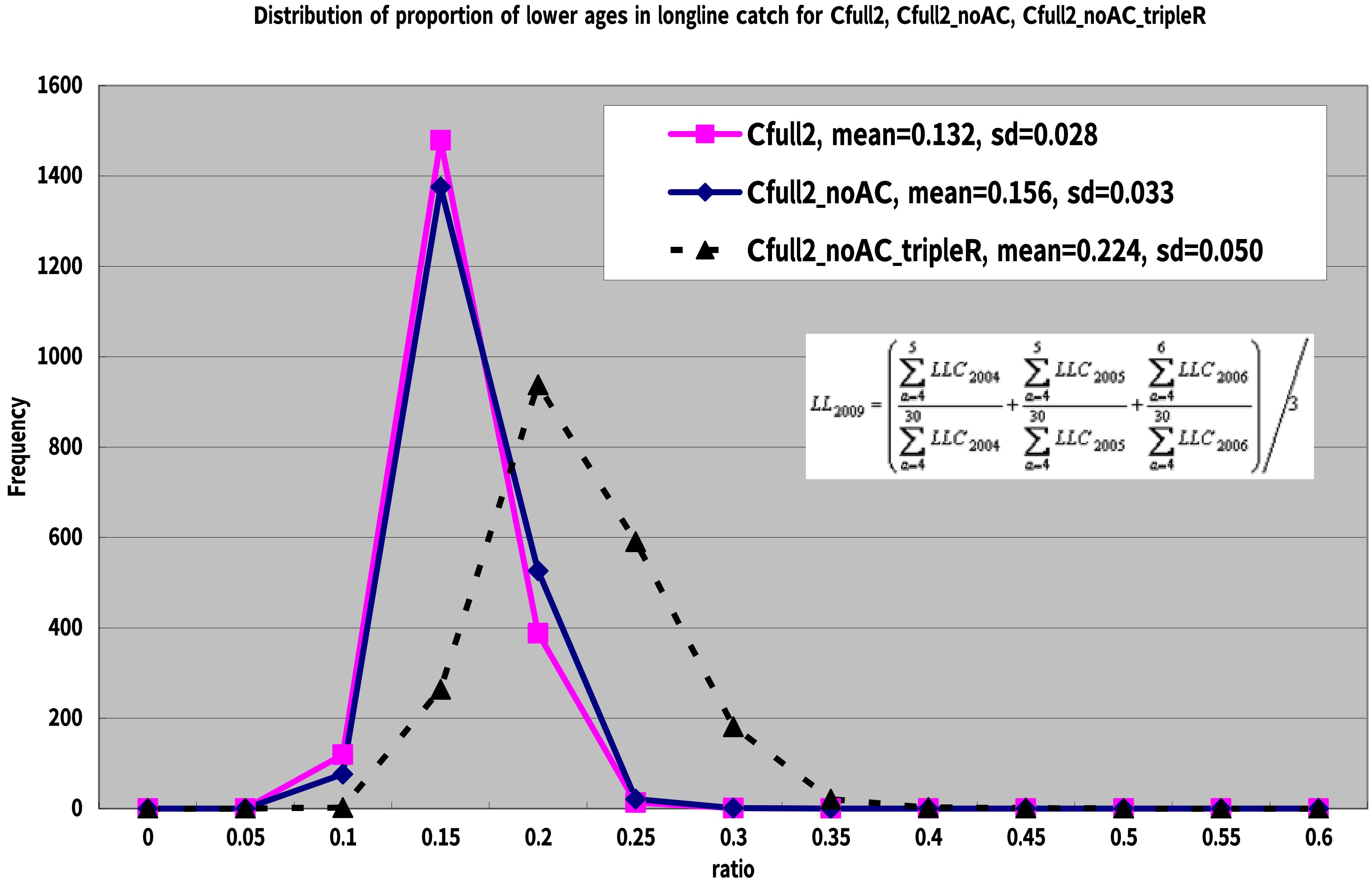


Figure 3. Distribution of $CPUE_{2011}^{rat}$ and the corresponding value of $B(2004)/B(2022)$ for the 2000 samples of the Cfull2 case under the D&M_01_2b MP. The vertical lines show the range over which the h function increases from 0 to 1.



$$LL_{2009} = \left(\frac{\sum_{a=4}^{5} LLC_{2004}}{\sum_{a=4}^{30} LLC_{2004}} + \frac{\sum_{a=4}^{5} LLC_{2005}}{\sum_{a=4}^{30} LLC_{2005}} + \frac{\sum_{a=4}^{6} LLC_{2006}}{\sum_{a=4}^{30} LLC_{2006}} \right) \Big/ 3$$

Figure 4. Distribution of proportion of lower ages (LL_{2009} –see equation 6) in the longline catch for the Cfull2, Cfull2_noAC and Cfull2_noAC_tripleR cases (2000samples).

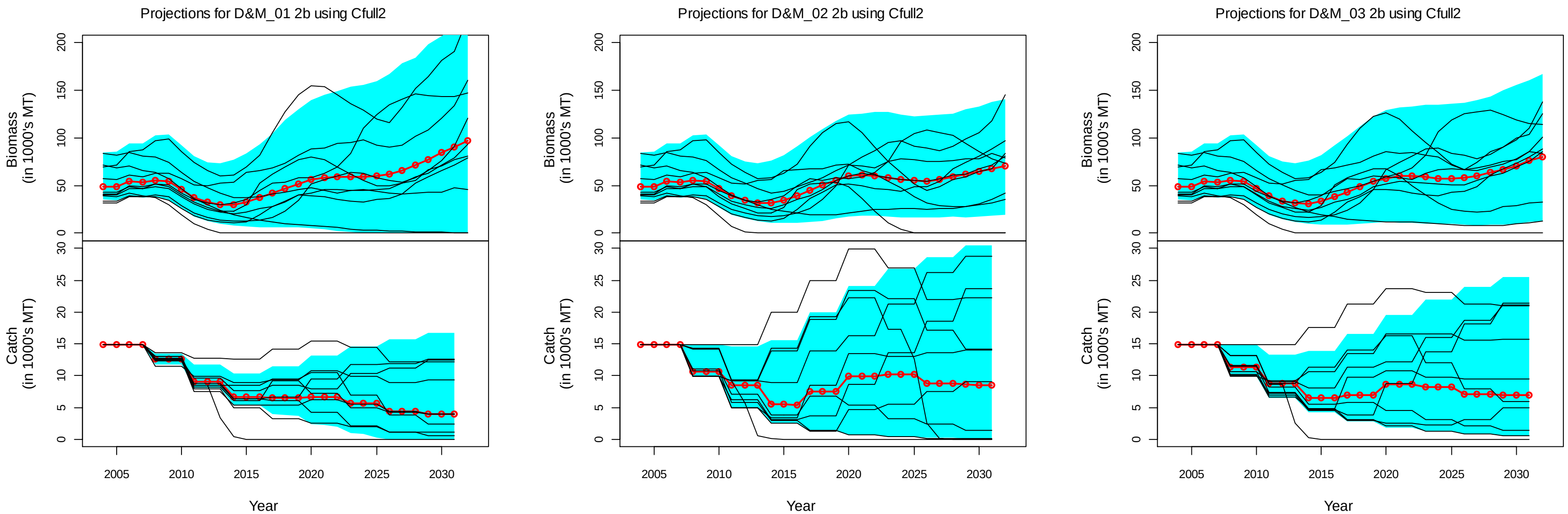


Figure 5. Worm plots for the three candidate MPs for a *B*2022/*B*2004 tuning level of 1.1 for the Cfull2 case.

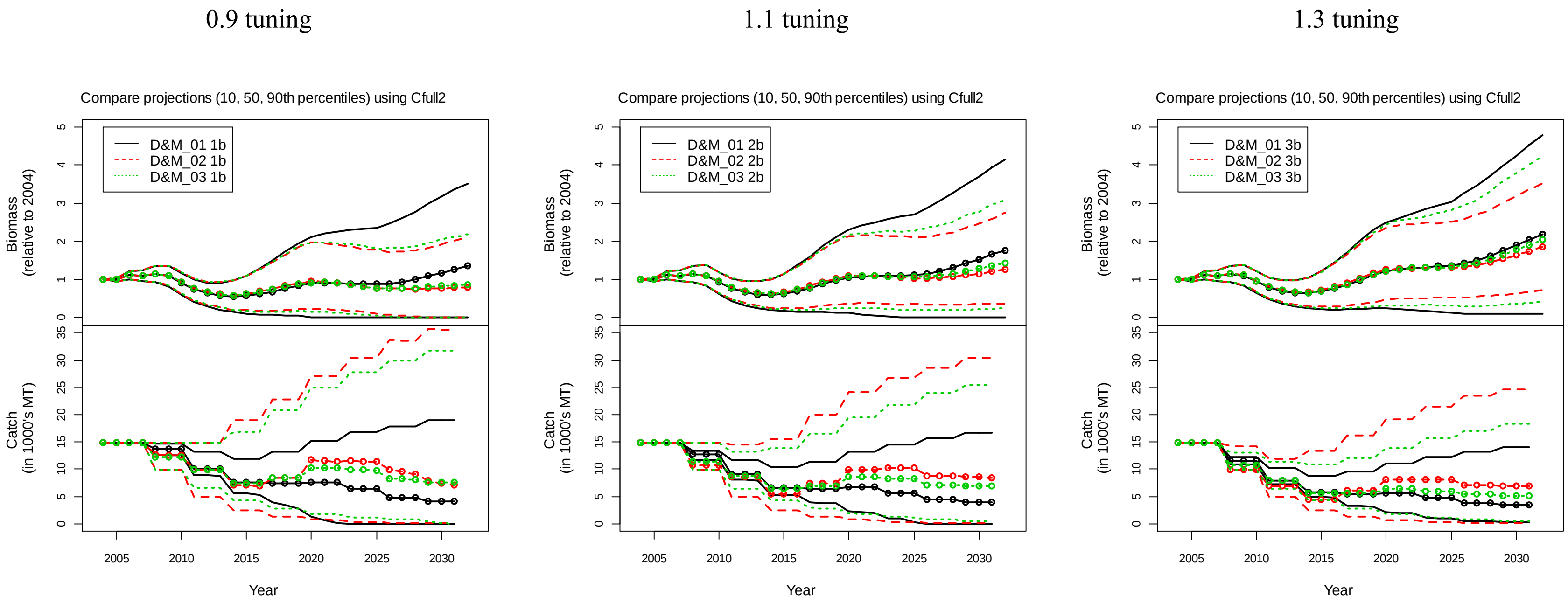


Figure 6. Median and 10th and 90th percentiles for the three candidate MPs for three tuning level of 0.9, 1.1 and 1.3 for the Cfull2 trial.

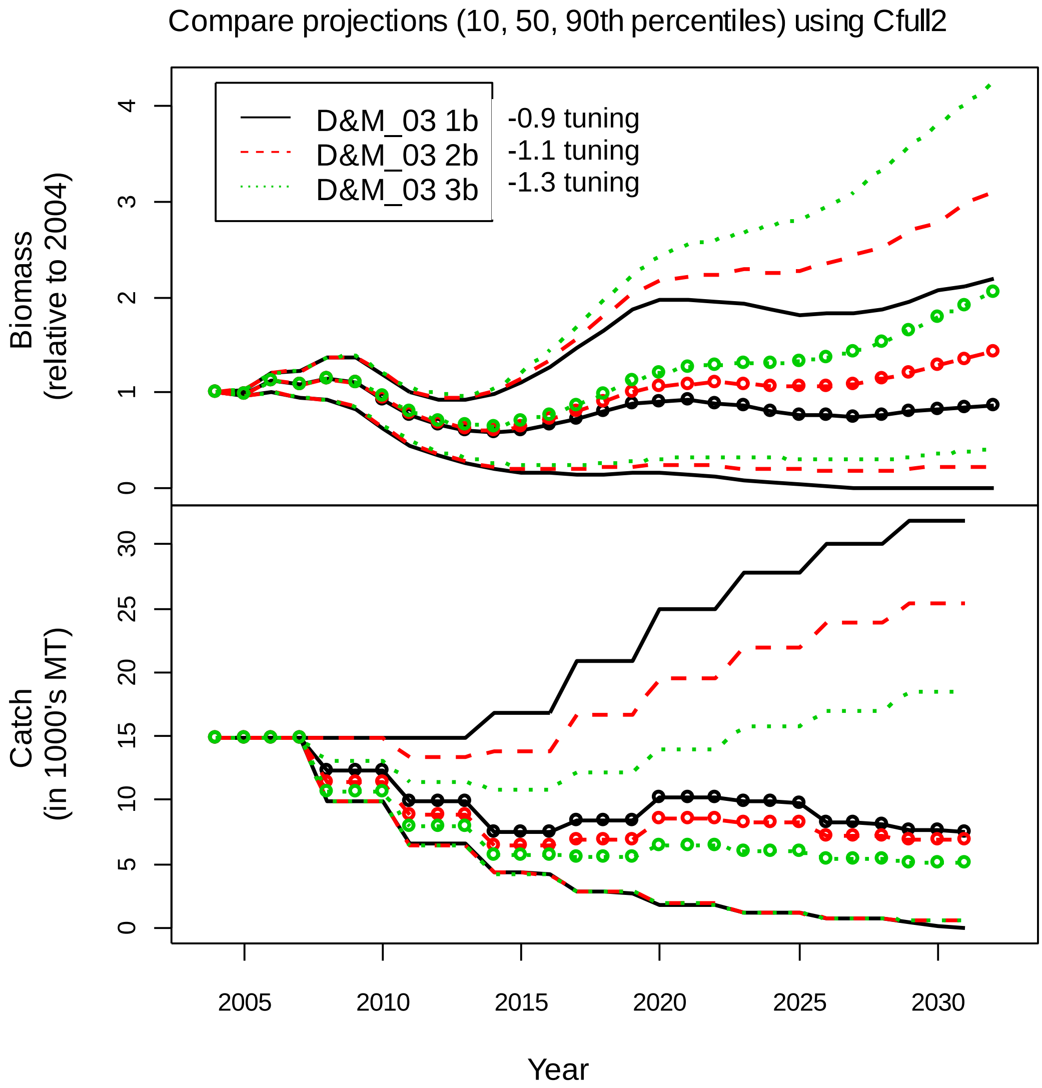


Figure 7. Median and 10th and 90th percentiles for the preferred candidate MP (D&M_03) for three tuning levels of 0.9, 1.1 and 1.3 for the Cfull2 trial.

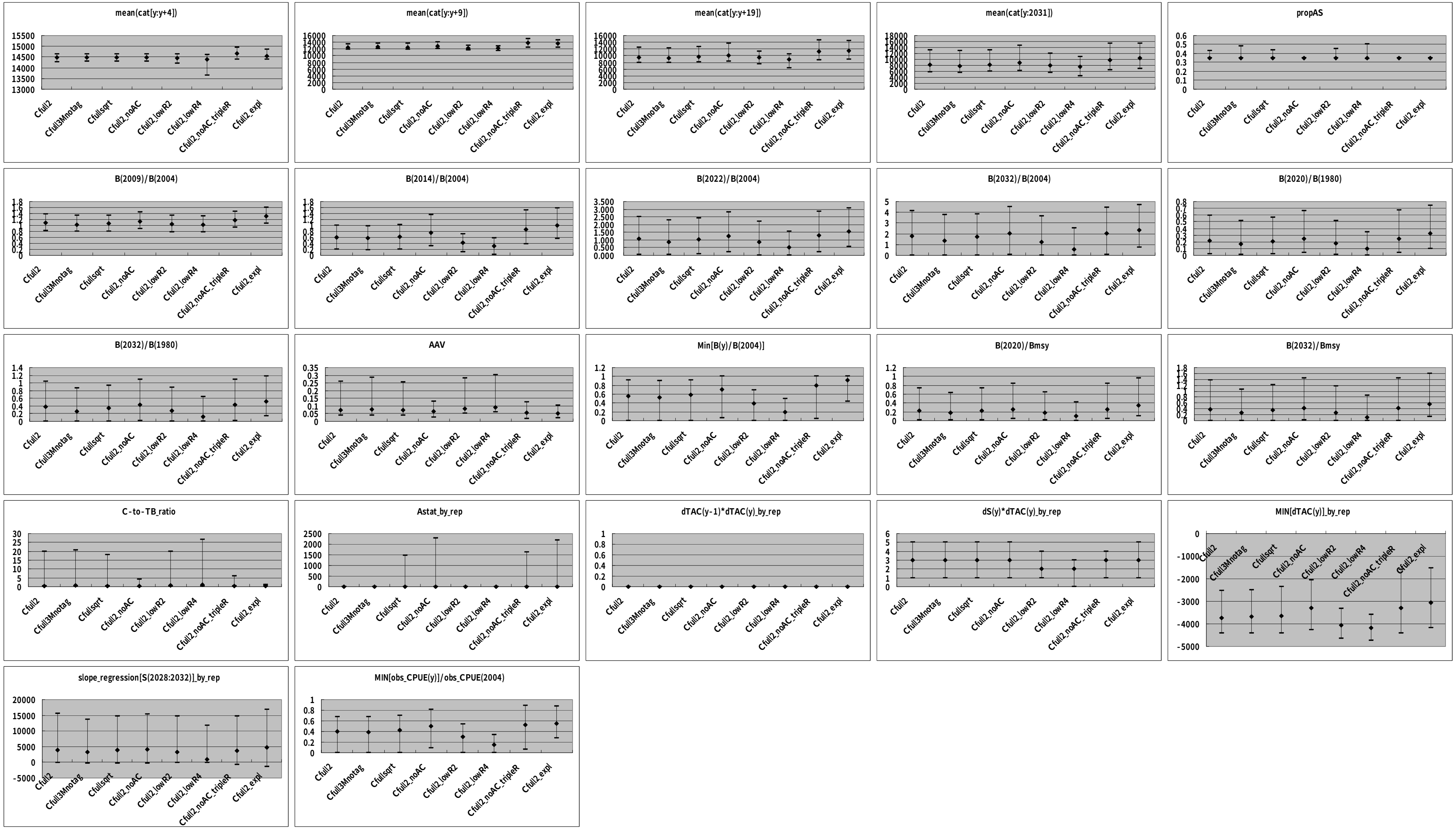


Figure 8. Performance statistics for different robustness trials compared to the Cfull2 case for D&M_01_2b.

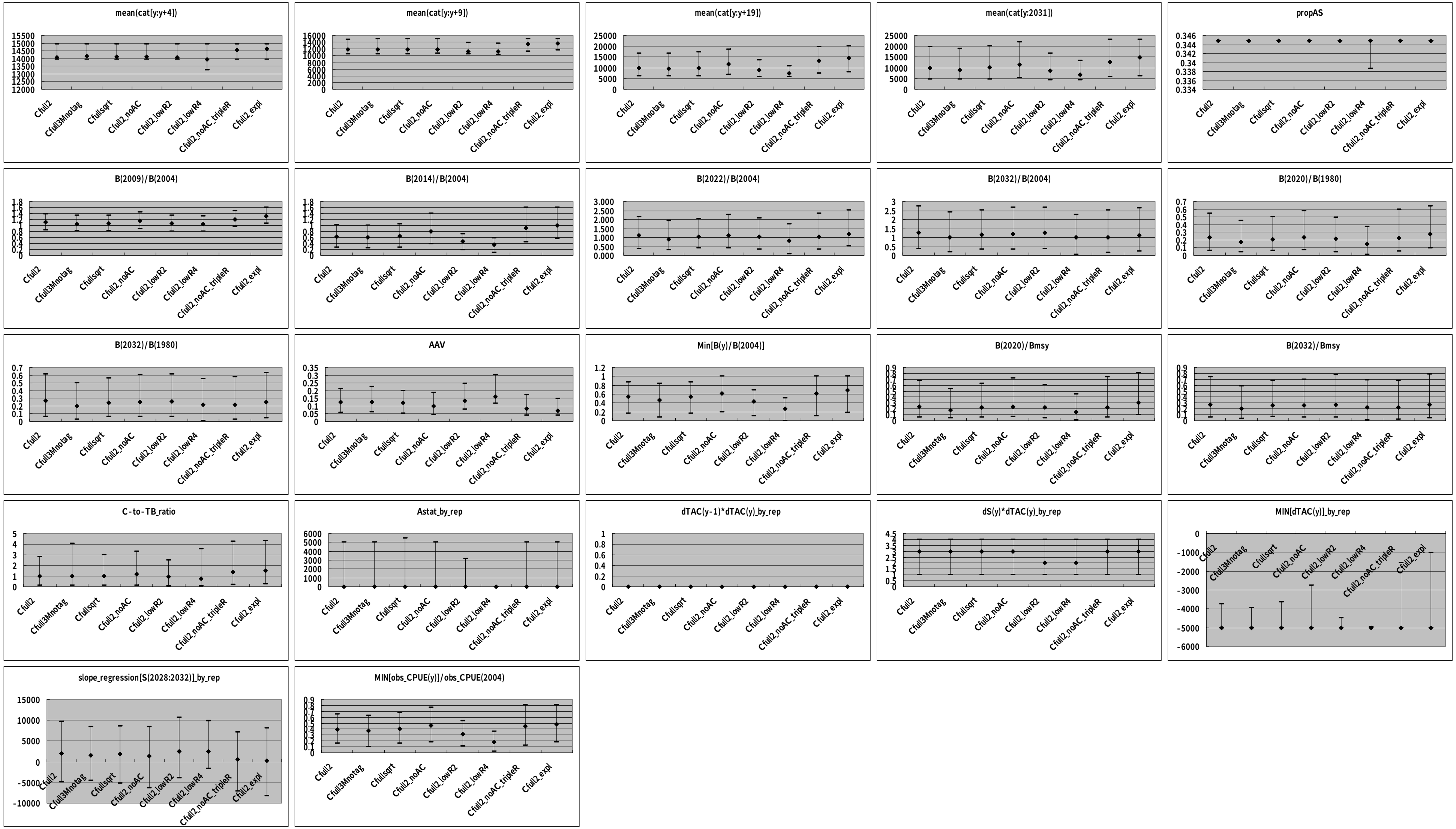


Figure 9. Performance statistics for different robustness trials compared to the Cfull2 case for D&M_02_2b.

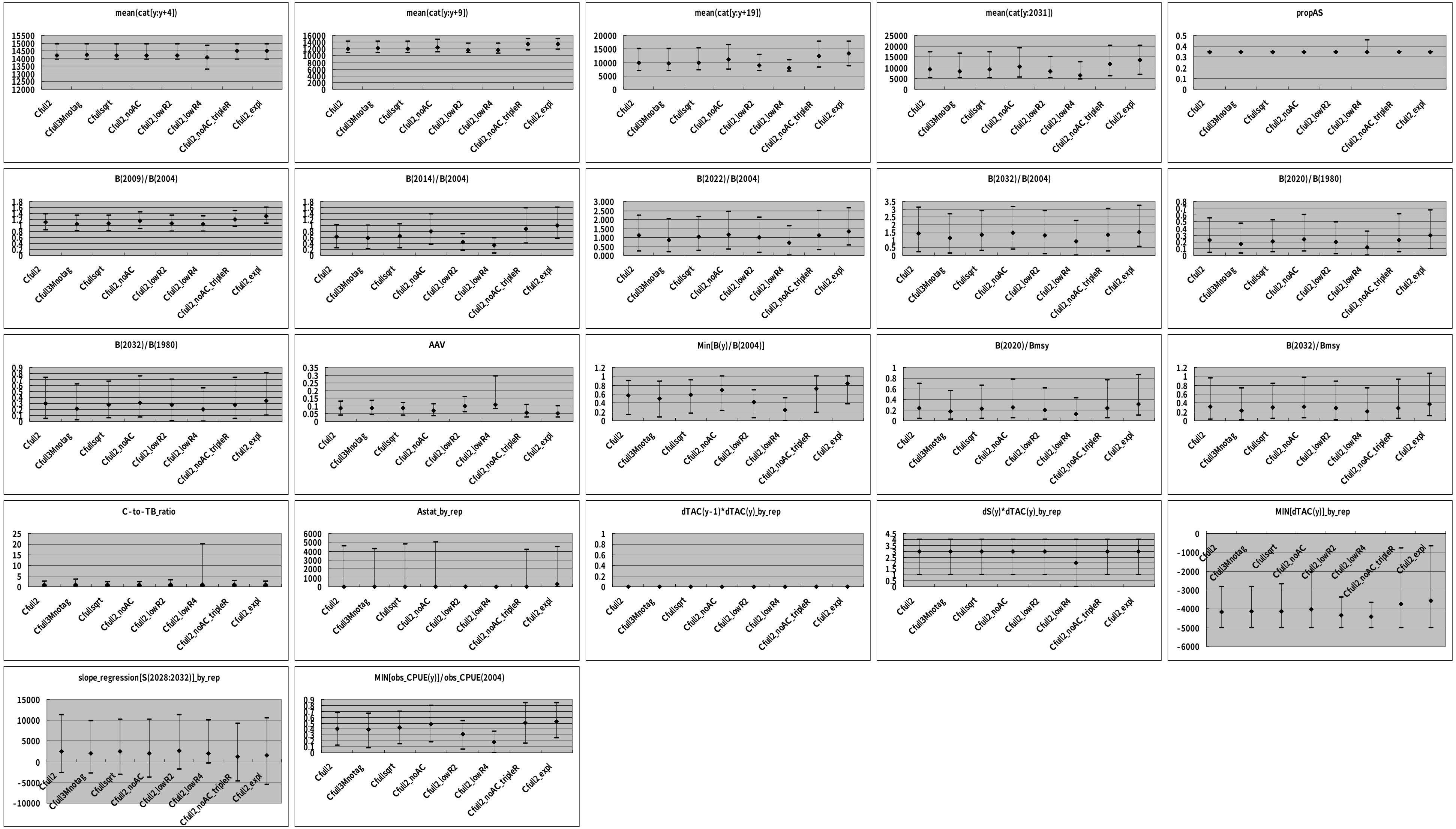


Figure 10. Performance statistics for different robustness trials compared to the Cfull2 case for D&M_03_2b.

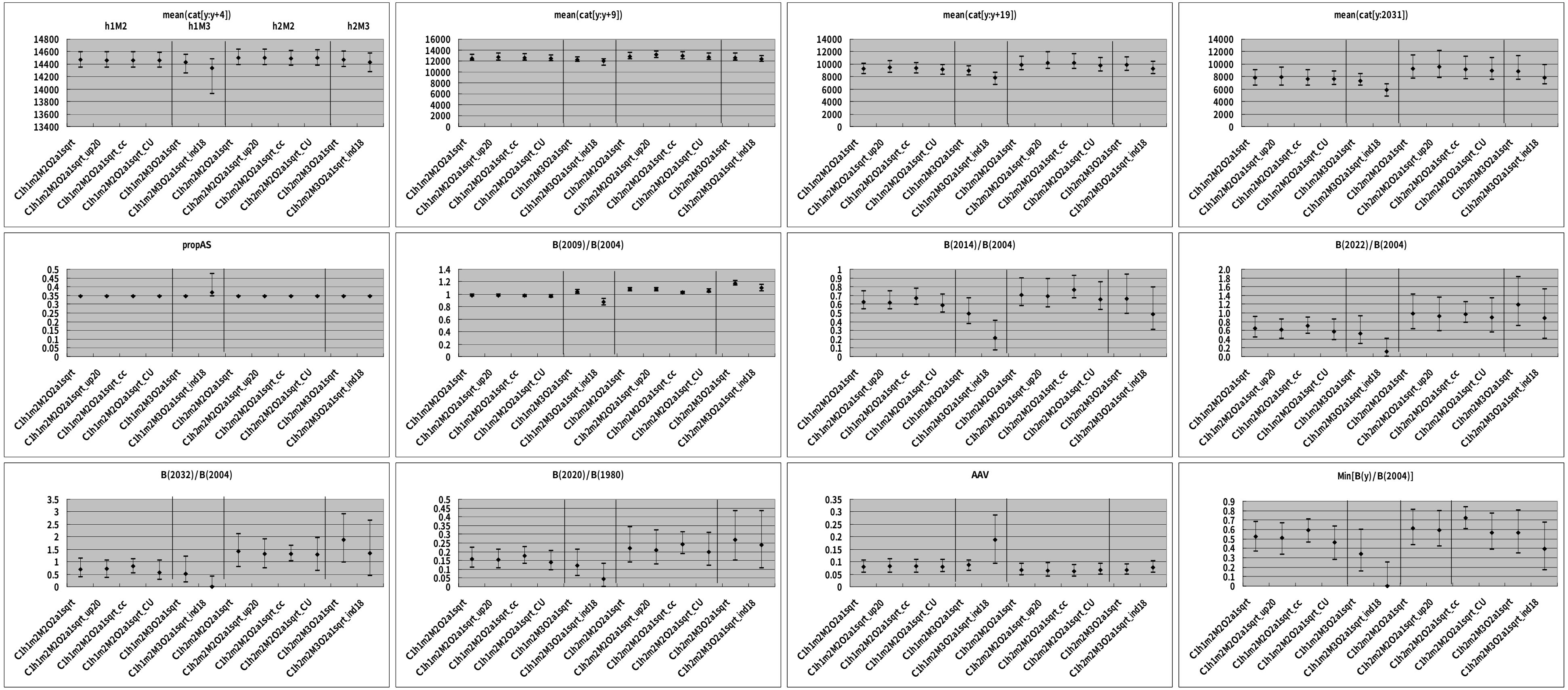


Figure 11a. Performance statistics for different robustness trials compared to elements of the Cfull2 case for D&M_01_2b. Note that within each of the four blocks of results for each statistics, the first statistic shown is for the Cfull2 case element.

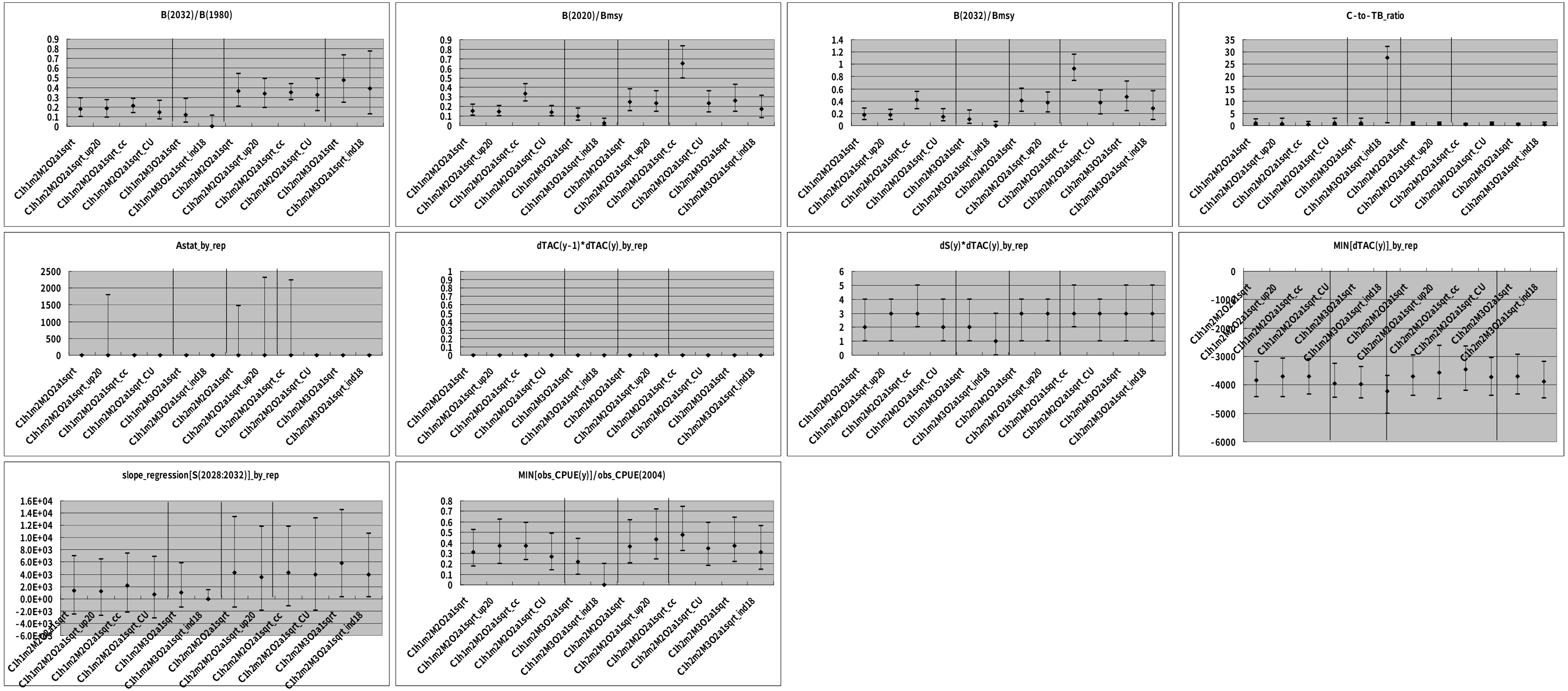


Figure 11b. Performance statistics for different robustness trials compared to elements of the Cfull2 case for D&M_01_2b. Note that within each of the four blocks of results for each statistics, the first statistic shown is for the Cfull2 case element.

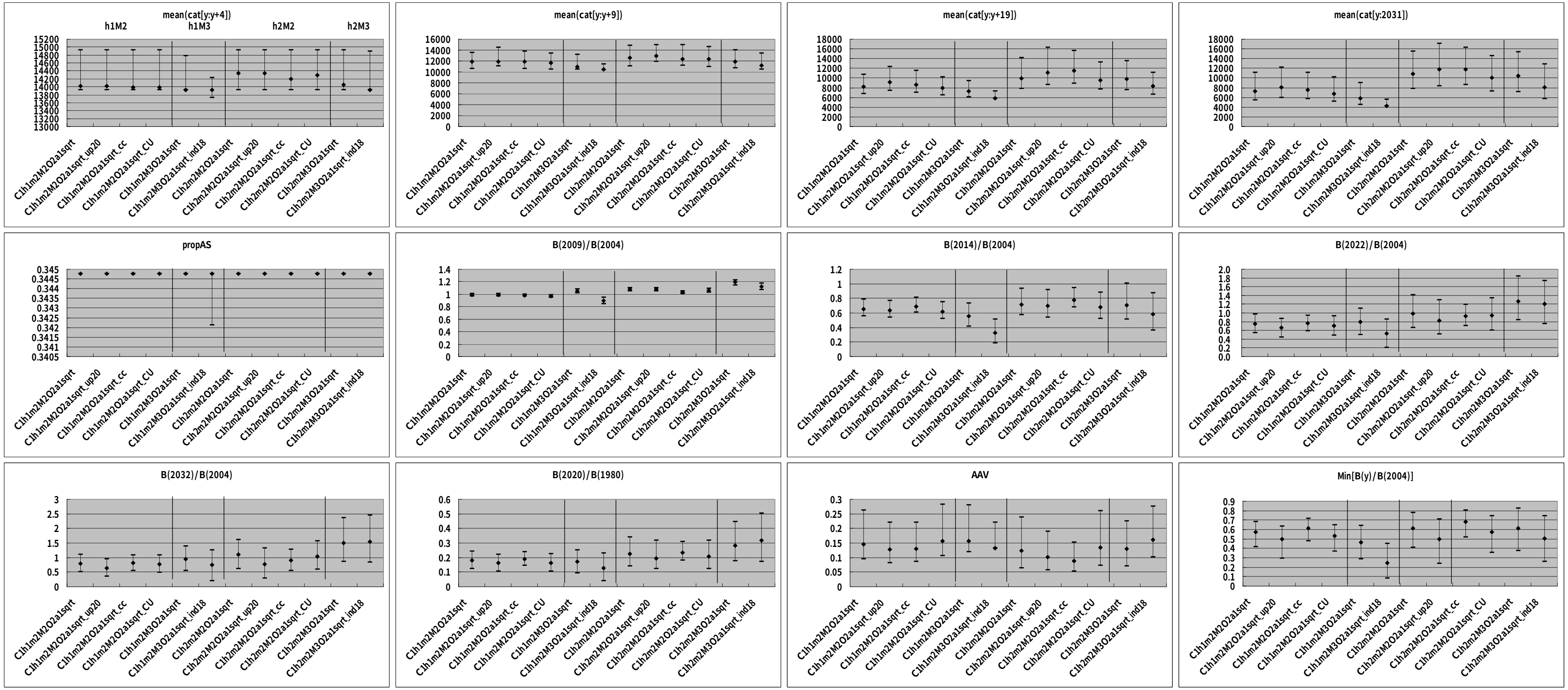


Figure 12a. Performance statistics for different robustness trials compared to elements of the Cfull2 case for D&M_02_2b. Note that within each of the four blocks of results for each statistics, the first statistic shown is for the Cfull2 case element.

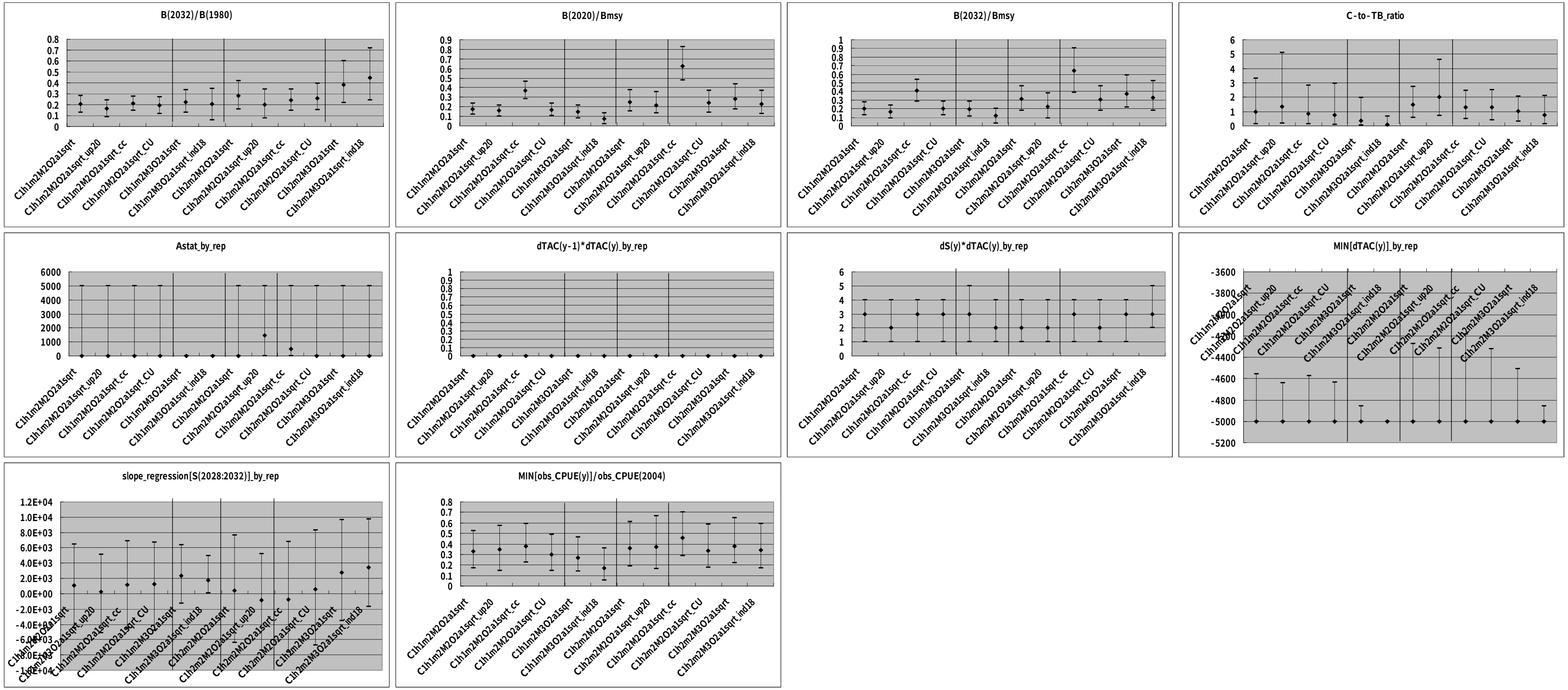


Figure 12b. Performance statistics for different robustness trials compared to elements of the Cfull2 case for D&M_01_2b. Note that within each of the four blocks of results for each statistics, the first statistic shown is for the Cfull2 case element.

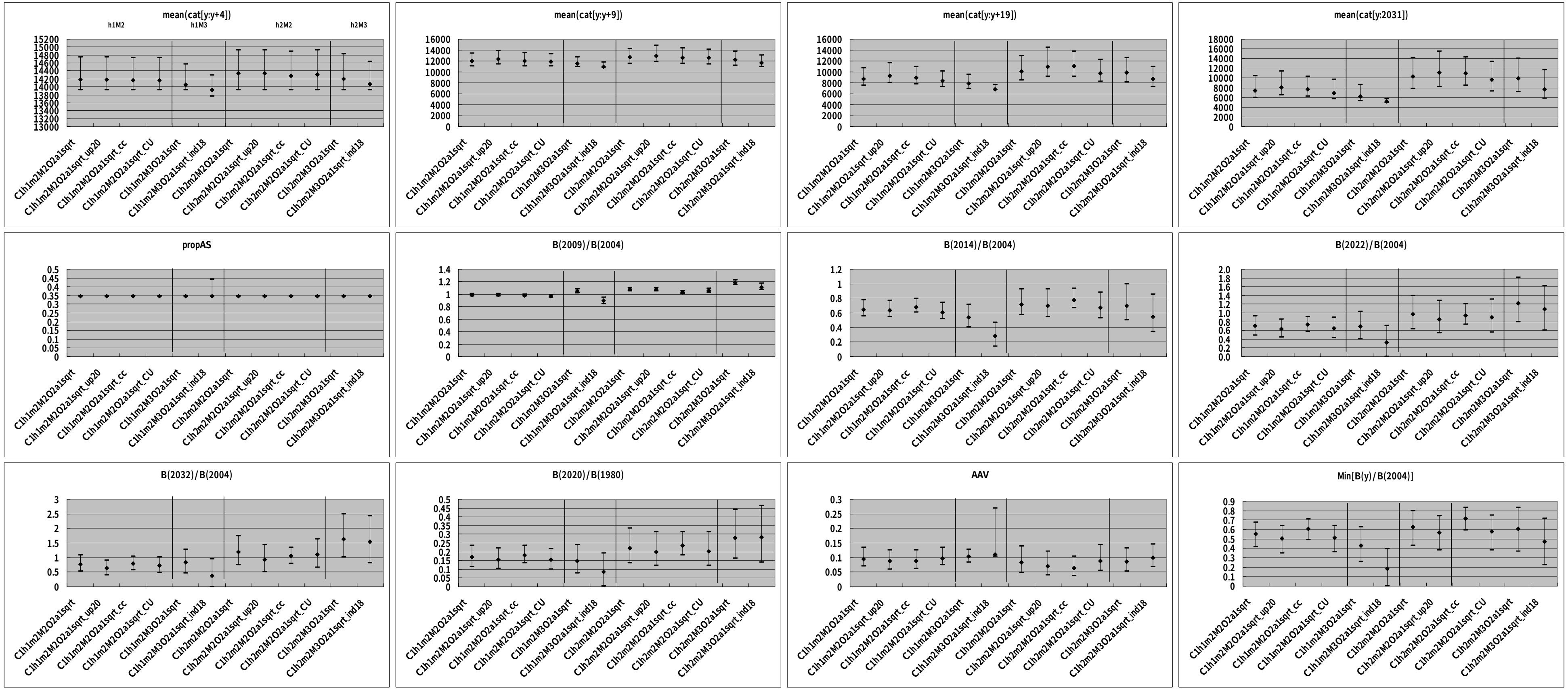


Figure 13a. Performance statistics for different robustness trials compared to elements of the Cfull2 case for D&M_03_2b. Note that within each of the four blocks of results for each statistics, the first statistic shown is for the Cfull2 case element.

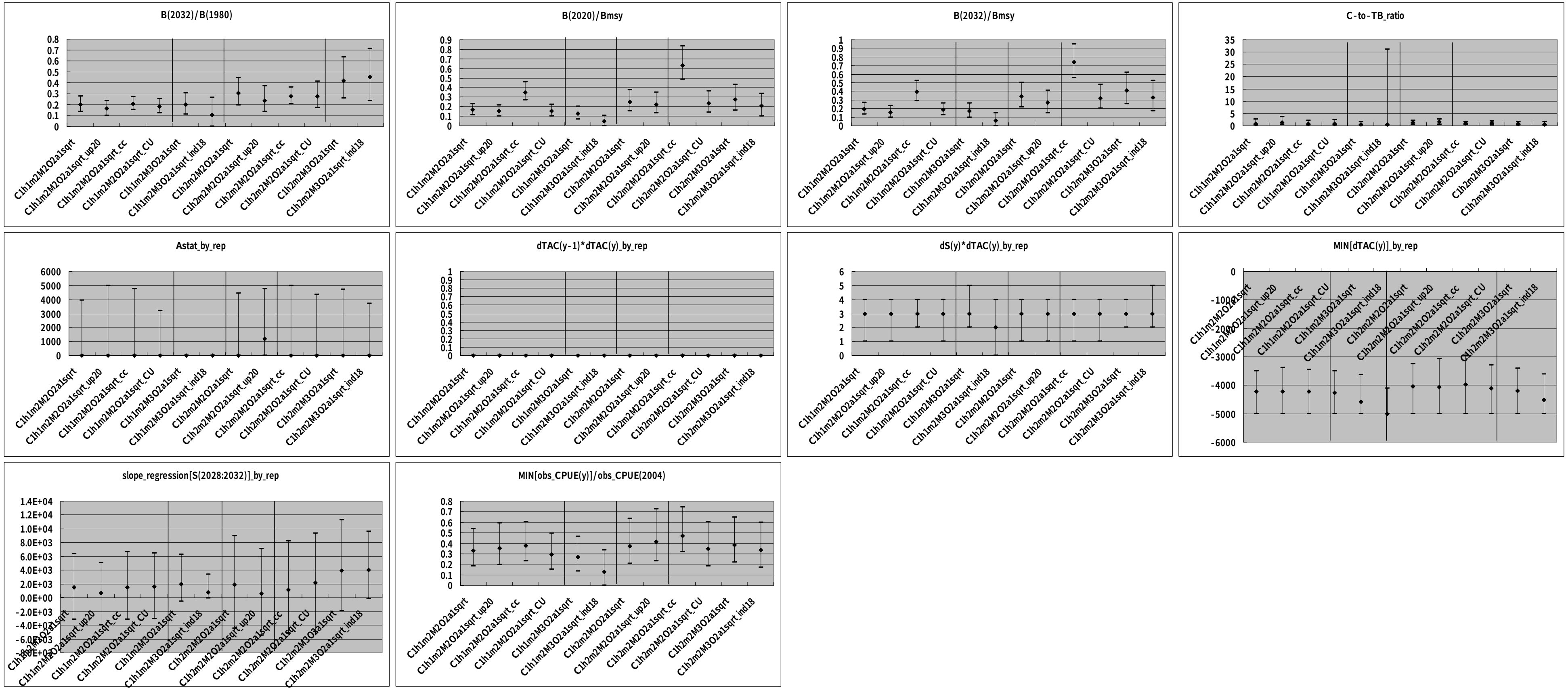


Figure 13b. Performance statistics for different robustness trials compared to element of Cfull2 case for D&M_03_2b. Note that within each of the four blocks of results for each statistics, the first statistic shown is for the Cfull2 case element.

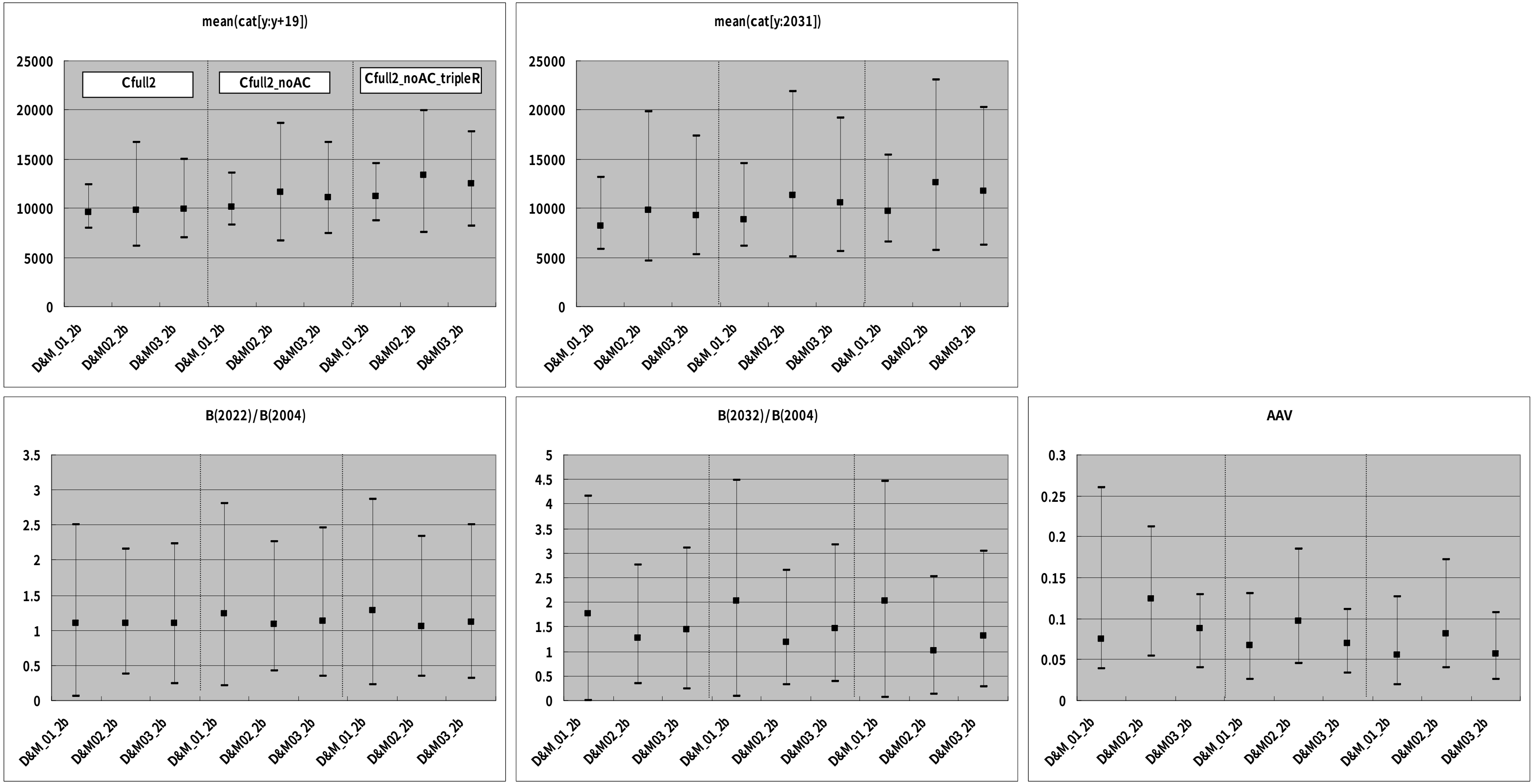


Figure 14. Some selected performance statistics for the three candidate MPs for the Cfull2, Cfull2_noAC and Cfull2_noAC_tripleR trials.

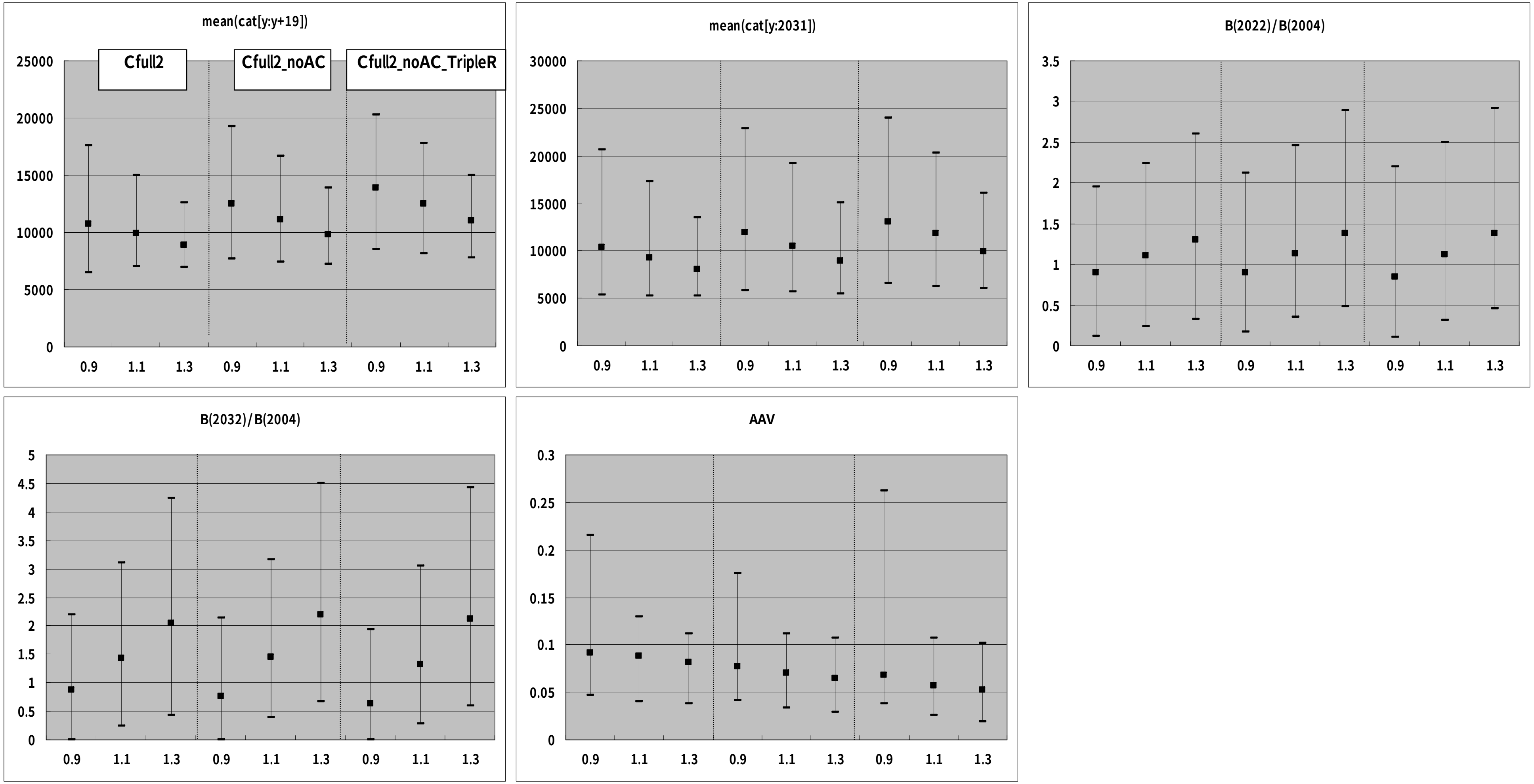


Figure 15. Some selected performance statistics for the preferred candidate MP (D&M_03) for 0.9, 1.1 and 1.3 tunings for the Cfull2, Cfull2_noAC and Cfull2_noAC_tripleR trials.

a) Every three year TAC change starting from 2006 b) Every three year TAC change starting from 2008 c) Every five year TAC change starting from 2008

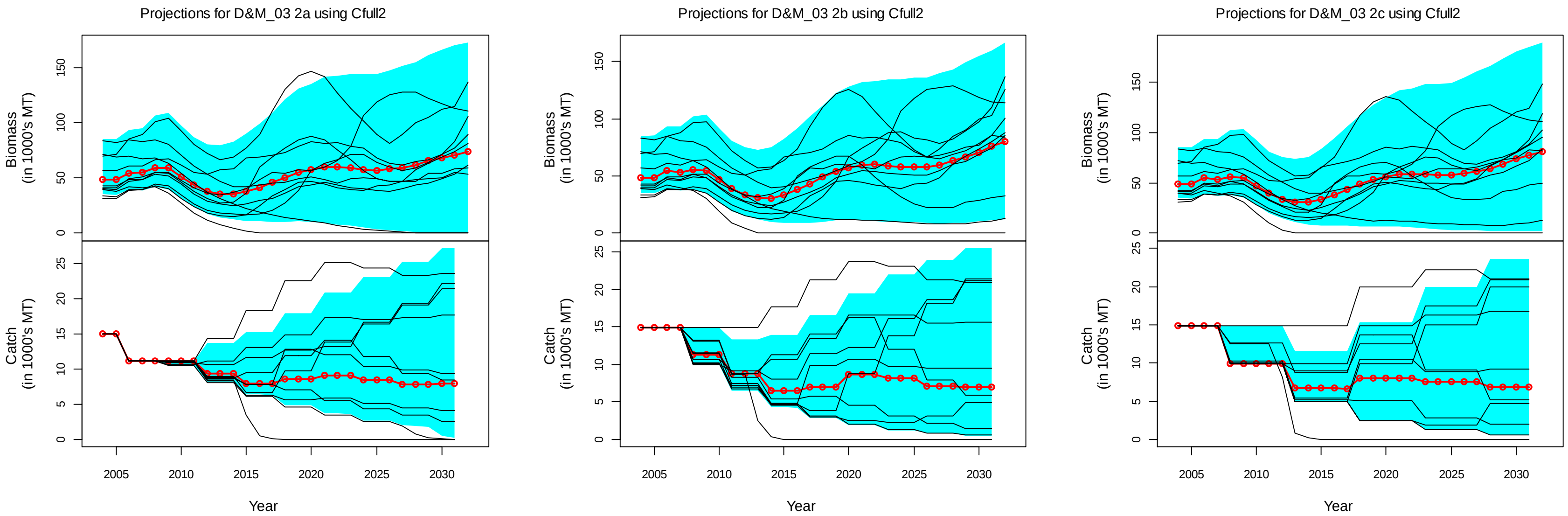


Figure 16. Worm plots for the preferred candidate MP (D&M_03) for a *B*2022/*B*2004 tuning level of 1.1 for the Cfull2 case for TAC change option a) every three year TAC change starting from 2006, b) every three year TAC change starting from 2008, and c) every five year TAC change starting from 2008.

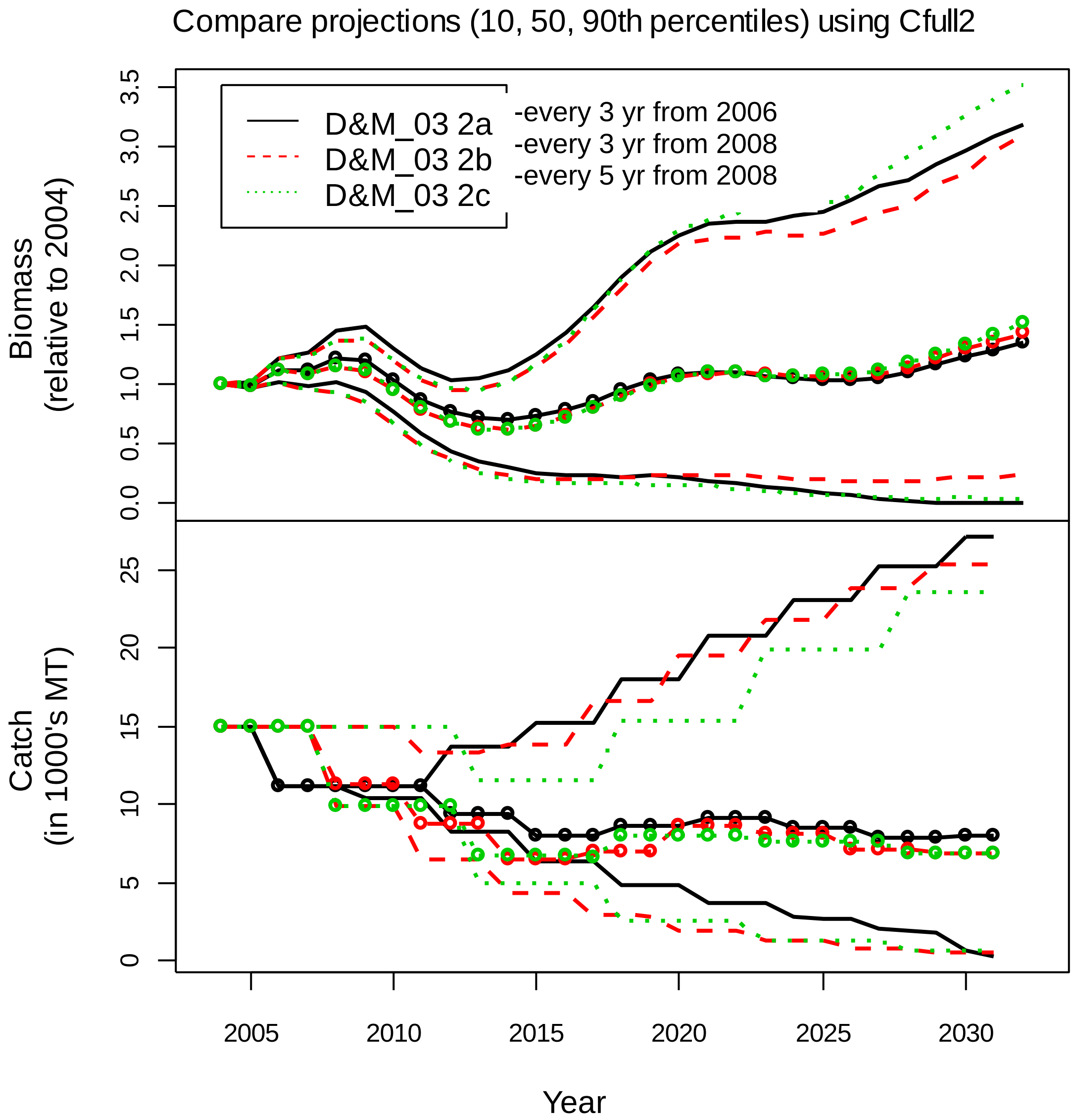


Figure 17. Median and 10th and 90th percentiles for the preferred candidate MP (D&M_03) for three TAC change intervals: a) every 3 years starting from 2006, b) every 3 years starting from 2008, and c) every 5 years starting from 2008 for the Cfull2 trial.

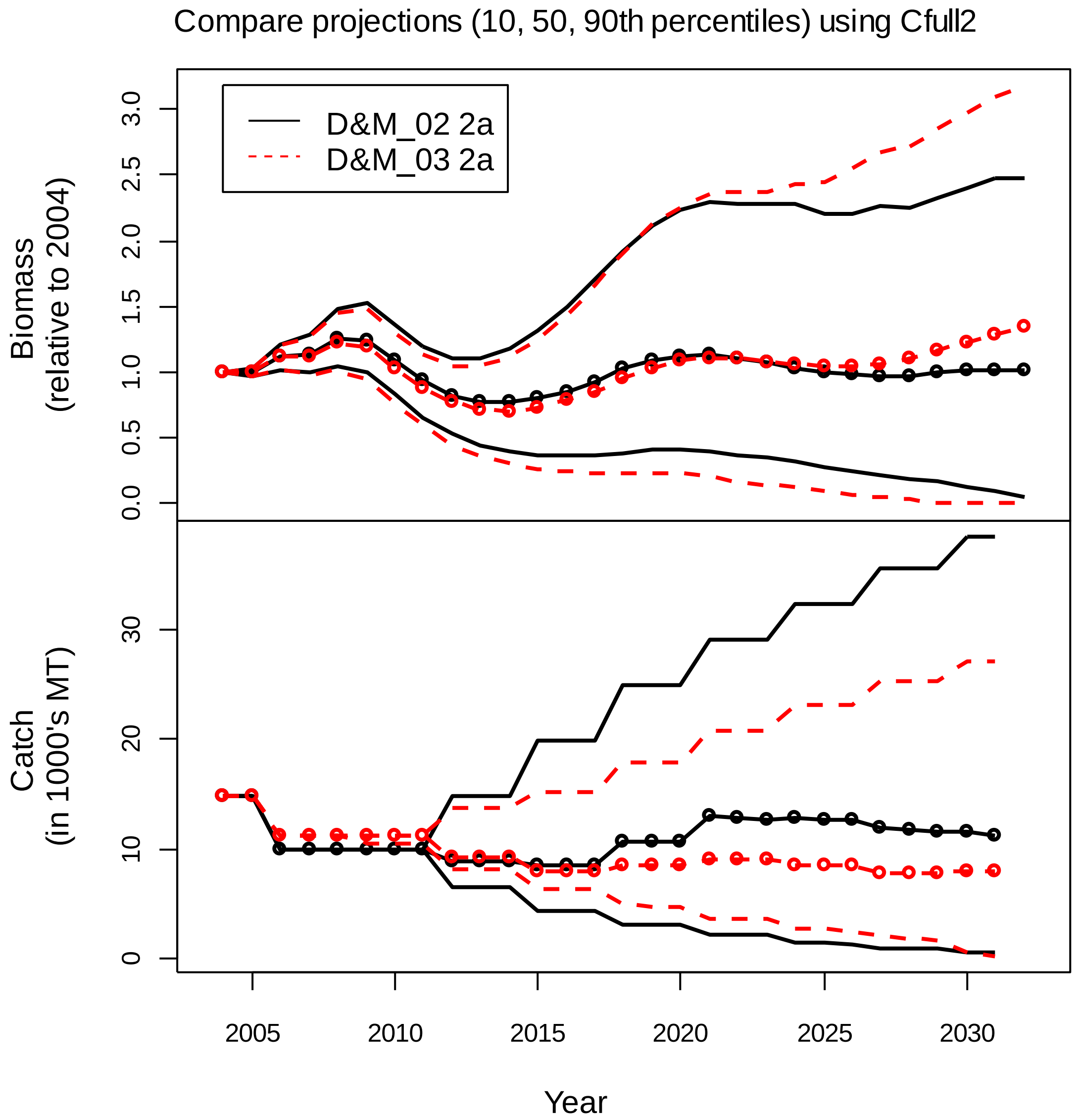


Figure 18. Median and 10th and 90th percentiles for the two candidate MPs (D&M_02 and D&M_03) for TAC change interval: a) every 3 years starting from 2006 for the Cfull2 trial.

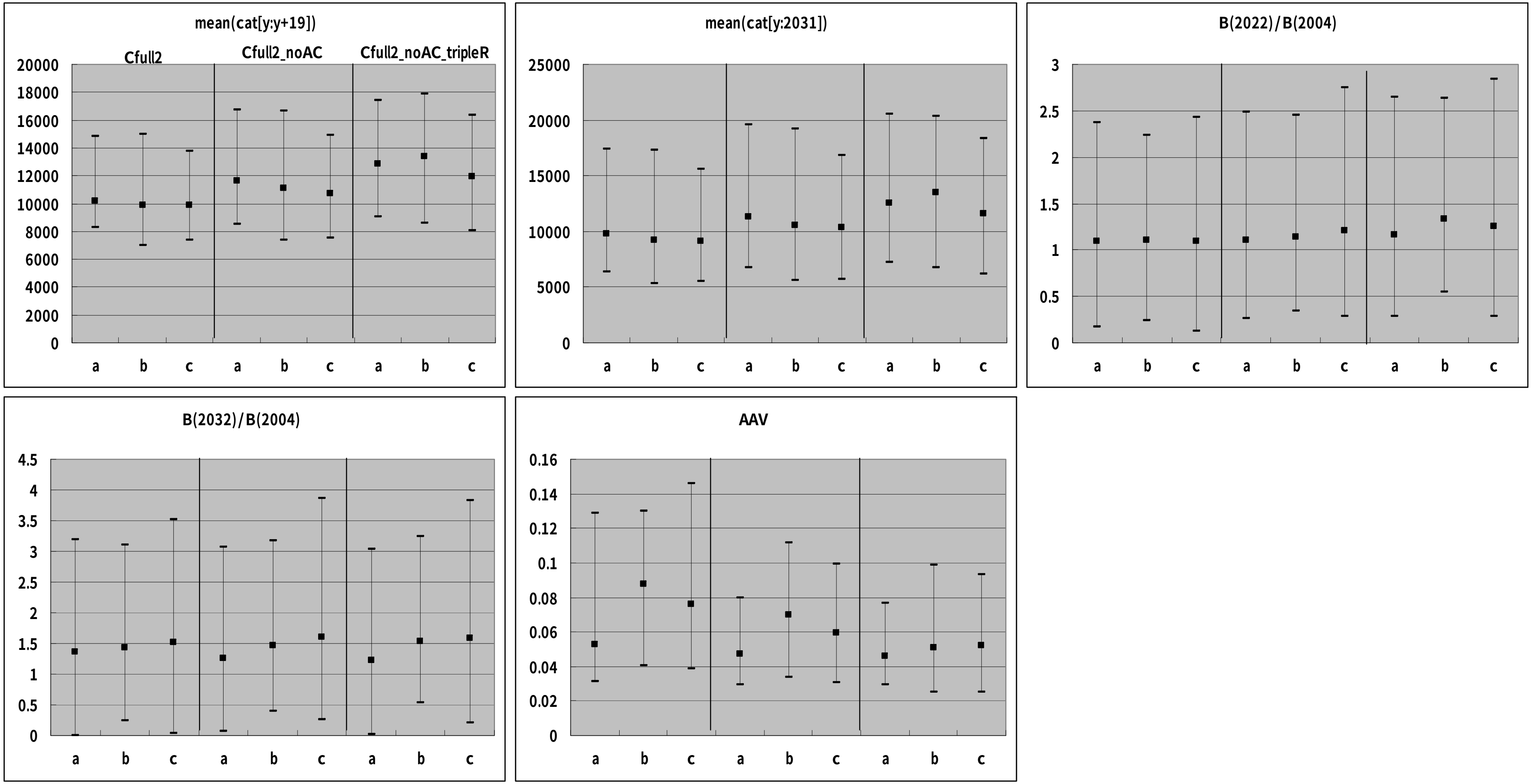


Figure 19. Some selected performance statistics for the preferred candidate MP (D&M_03) for TAC change interval a) every three year starting from 2006, b) every three year starting from 2008, and c) every five year starting from 2008 for the Cfull2, Cfull2_noAC and Cfull2_noAC_tripleR trials.