Behaviors of CPUE-based management procedures examined through the CCSBT final trial specifications

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CCSBT の最終的なテスト仕様を用いて検討した CPUE ベースの管理方式の挙動

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Abstract

Results of exploration of CPUE-based management procedures based on the final trial specifications were presented. Four candidate MPs (HK5, HST, STL, and KH8) were tuned to the moderate tuning level 0.9, as well as the three agreed tuning levels (0.7, 1.1 and 1.5). And behaviors of catch and biomass, performance statistics, and results of robustness tests were examined by the trajectories of catch and biomass and the summary plot of performance statistics.

要旨

最終的なテスト仕様を用いた CPUE ベースの管理方式の検討結果を示す。HK5、HST、STL、KH8 の 4 種類の MP 候補が、合意された 3 種類のチューニングレベル（0.7、1.1、1.5）に加えて、より中庸なチューニングレベル 0.9 にチューニングされた。そして、漁獲量や資源量の挙動、パフォーマンス統計量、ロバストネステストの結果等が、漁獲量や資源量の軌跡、統計量をまとめたプロットなどによって検討された。

Introduction

The final trial specifications for testing the candidate management procedures were agreed at the 4th Meeting of the CCSBT SAG (Anon 2003a) and some modifications were made at the 10th Meeting of CCSBT (Anon 2003b) and also by e-mail correspondence. This paper presents the results of testing the CPUE-based MPs based on the agreed approach. All candidate MPs were tuned to agreed levels of the ratio B2022/B2002 and performance statistics and results of robustness tests were examined.

Specification of trials

We conducted simulation trials under the following specifications.

- OM scenarios: reference set, robustness set (Low1_A12, Med1_A12, Med1_cc, Low1_up20, Med1_up20, Low1_down20, Med1_down20, Low1_CU, Med1_CU), additional robustness set (No_AC, Reduced_rec(=low_R))
- Tuning level (TL=median B2022/B2002): 0.7, 1.1, 1.5, 0.9
- Projection time horizon: 30years, 50years
- The number of simulations: 2000 for reference set and additional robustness set
  200 for robustness set
- Frequency of TAC changes, year of first new TAC, and the maximum changes in TAC :
  - Option-a: every year, 2006, 3000t
  - Option-b: every 3 years, 2008, 5000t
  - Option-c: every 5 years, 2008, 8000t
- The minimum changes in TAC: 100t

In addition to the agreed trials, we conducted additional trials (indicated by underlines). Tuning level 0.9 was introduced as a moderate tuning level, because MPs tuned to 0.7 or 1.5 tend to just increase or decrease TAC independent of the stock status. 50 years projection was introduced because the differences in performance of MP sometimes appear after 30 years projection period. This paper presents results of following trials.

	TL=0.7	TL=0.9	TL=1.1	TL=1.5
Option-a	-	-	Reference	-
Option-b	Reference	Reference Robustness Add. Robust	Reference Robustness Add. Robust	Reference
Option-c	-	-	Reference	-

Candidate MPs explored

Based on the results of the second exploration on candidate MPs (Tsuji et.al. 2003), we further explored following candidate MPs.

1. CON (constant catch, for comparative purpose)

2. HK5 (TAC is set as a minimum of TAC value specified using age 4 CPUE level or 4+ CPUE slope)
3. HST (adjust TAC based on both CPUE slope and distance to the target CPUE)
4. STL (similar to HK5, but use age 4+ CPUE level)
5. KH8 (asymmetric TAC response to 4+ CPUE slope)

Names of MPs are followed by the agreed naming conventions (Anon. 2003a). For example, HK5_01_1b means MP is HK5, tuning level is 0.7, and frequency of TAC change option is Option-b (every 3 years). We indicate tuning level 0.9 as "4". Detail specifications of candidate MPs are shown in Appendices.

Results

Results of tuning and the trajectories of catch and biomass (median, 10th percentile, 90th percentile, and wormplot) for each tuned MPs and scenarios are shown in Appendices. HK5 and STL have alternate combination of parameter values indicated by HK5_02, HK5_03, and STL_02. HK5 also has alternate model structure indicated by HK5_04. Projection time horizon of simulations presented in Appendices is 50 years.

The comparison of performance of candidate MPs are conducted between CON, HK5, HST, and STL. KH8 was excluded from this comparison because of poor performance. Figures 1 and 2 show performance statistics for Reference, No_AC, and Reduced_rec(=low_R) scenarios at tuning level 1.1 or 0.9. Figures 3 to 6 show performance statistics for Reference scenario at tuning levels 0.7, 1.1 and 1.5, and with three TAC changes options. Figures 7 and 8 show performance statistics for robustness test. We present only results of Low1_A12 here because performance is relatively robust for other scenarios as shown in Appendices. Figures 9 to 16 indicate tradeoff in catch and biomass. All Figures are produced by the graphical software provided by the CSIRO scientists and modified by us. For the calculation of performance statistics, projection time horizon of simulations presented in Figures is set to be 30 years. There are some differences in tuning parameters between 30 years simulation and 50 years simulation.

Detailed discussion and comparison of performance among candidate MPs are presented in the companion paper (Tsuji et al. 2004).

References

Anonymous. 2003a. Report of the fourth meeting of the stock assessment group, 25-29 August 2003, Christchurch, New Zealand.

Anonymous. 2003b. Report of the extended commission of the tenth annual meeting of the commission, 7-10 October 2003, Christchurch, New Zealand.

Tsuji,S., Takahashi,N., Shono, H., Kurota,H., Hiramatsu,K. (2003). Further exploration of CPUE-based management procedures. CCSBT-ESC/0309/38.

Tsuji, S., Hiramatsu, K., Kurota,H., Takahashi, N., Shono, H. (2004). Considerations toward choosing appropriate management procedures. CCSBT-MP/0404/10.

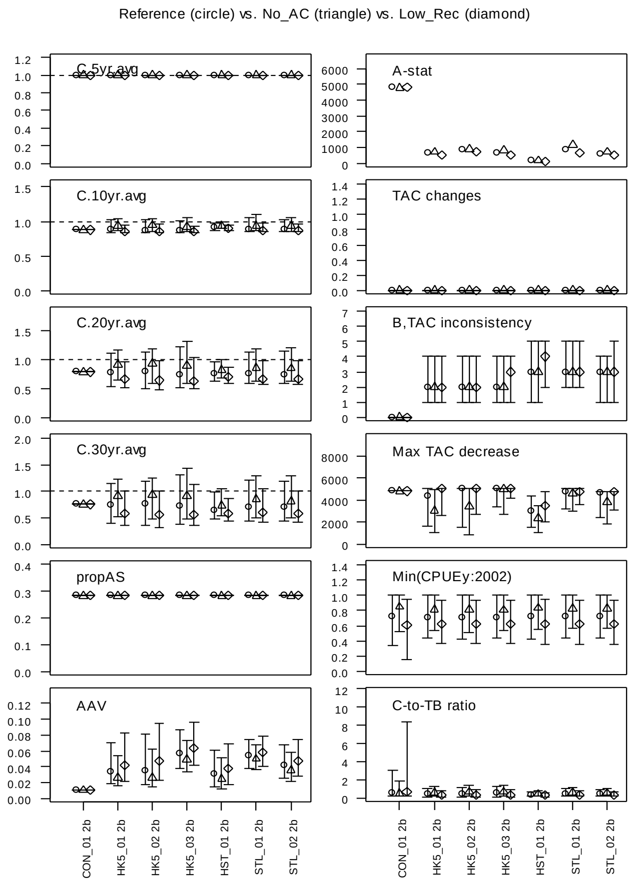
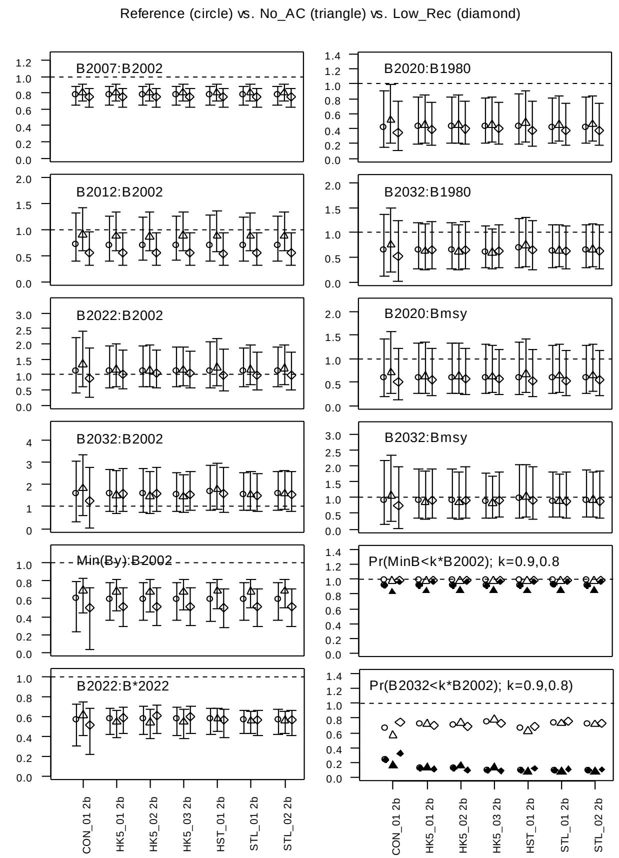


Fig.1 Performance statistics for candidate MPs

(Scenario=Reference, No_AC, Reduced_rec, TL=1.1, Option=b)



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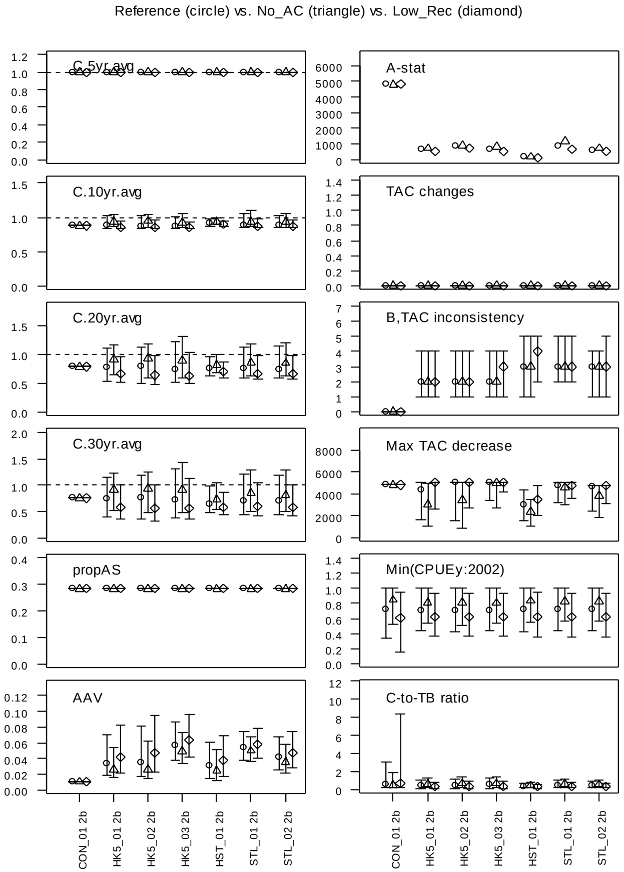


Fig.2 Performance statistics for candidate MPs

(Scenario=Reference, No_AC, Reduced_rec, TL=0.9, Option=b)

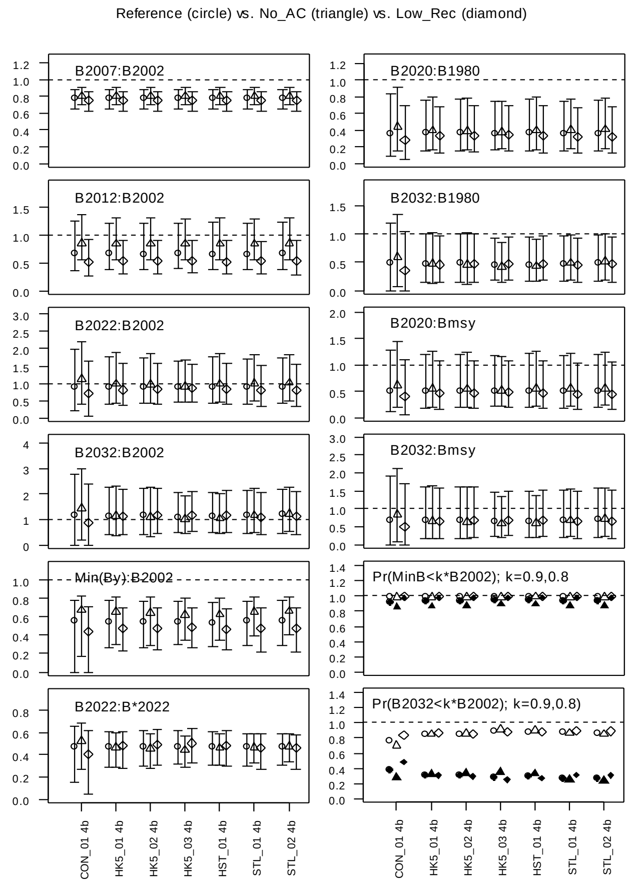


Fig.2 Continued

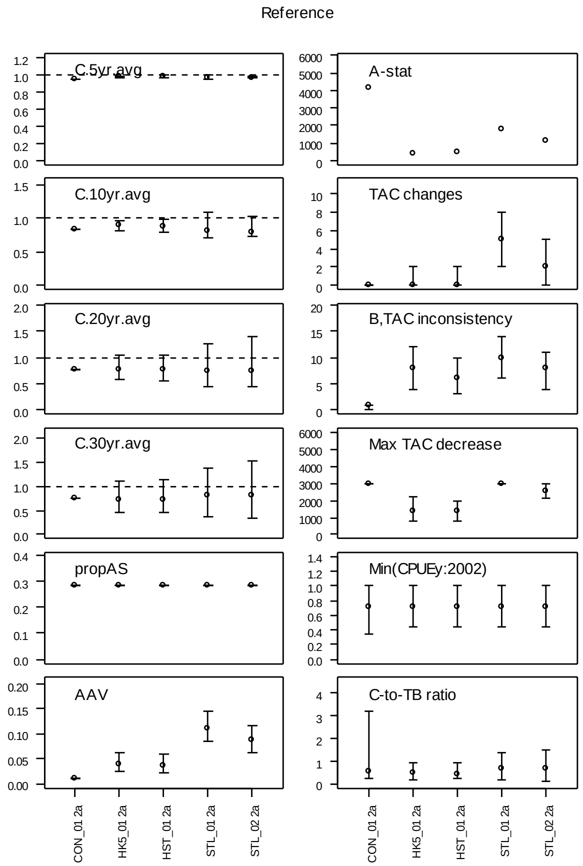


Fig.3 Performance statistics for candidate MPs
(Scenario=Reference, TL=1.1, Option=a)

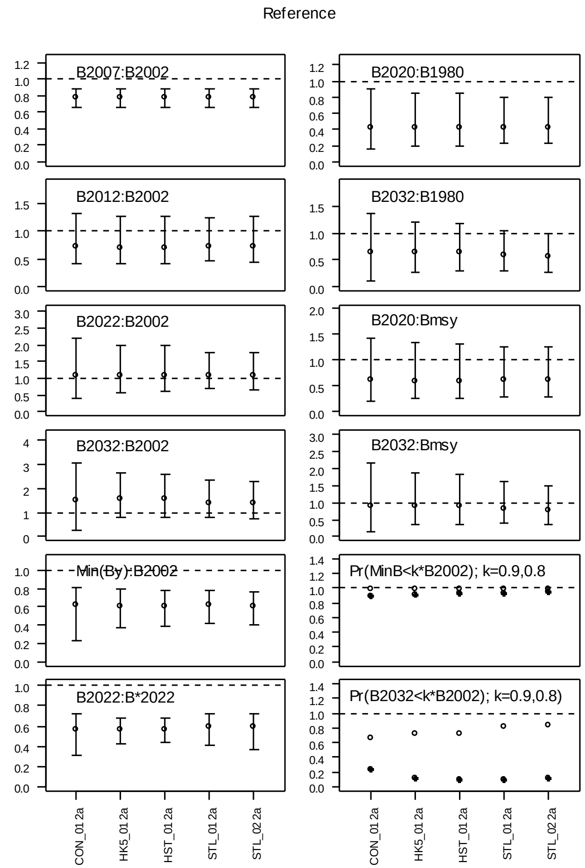


Fig.3 Continued

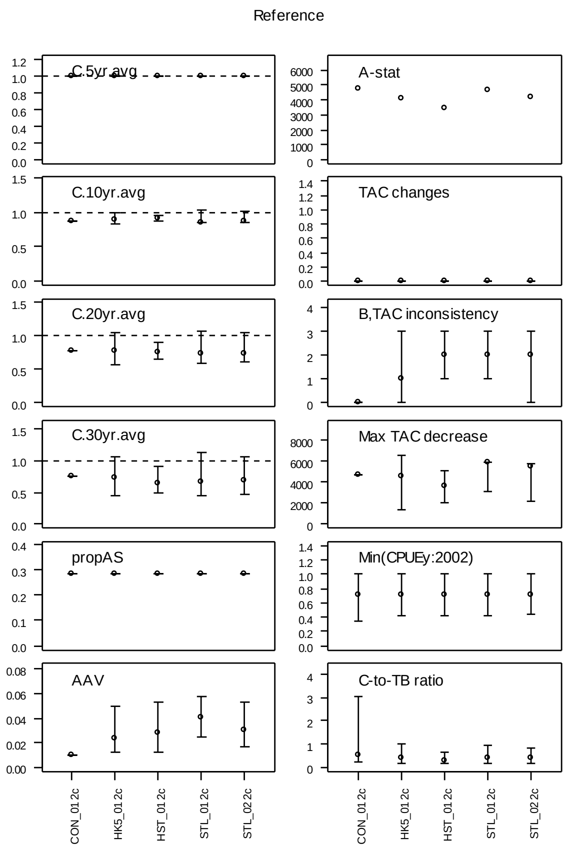


Fig.4 Performance statistics for candidate MPs
(Scenario=Reference, TL=1.1, Option=c)

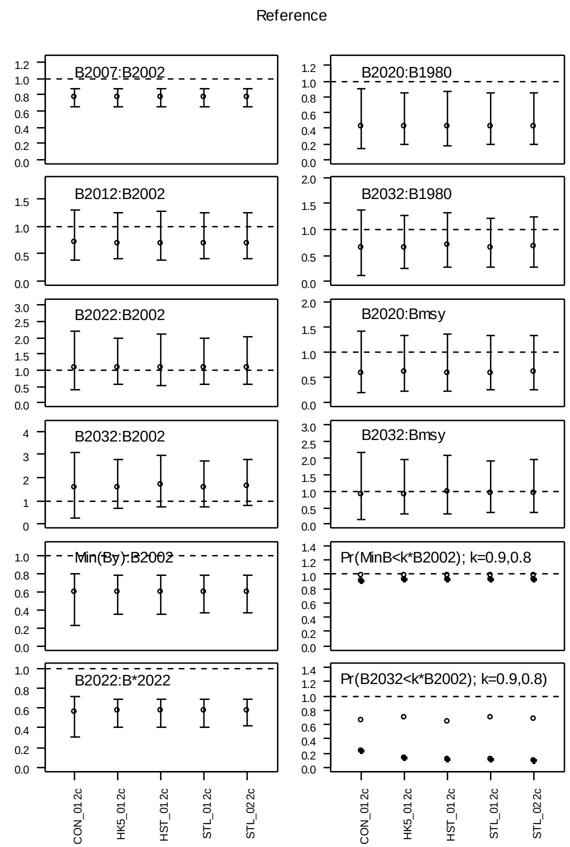


Fig.4 Continued

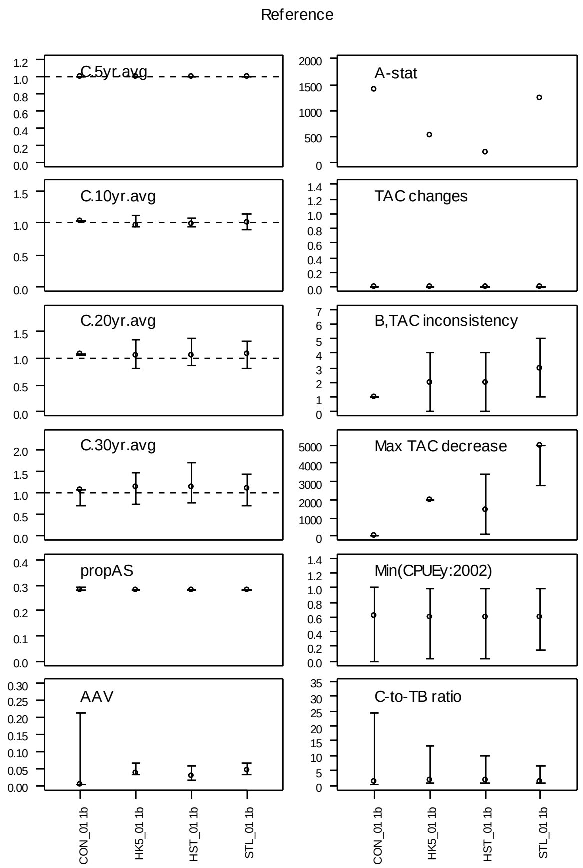


Fig.5 Performance statistics for candidate MPs
(Scenario=Reference, TL=0.7, Option=b)

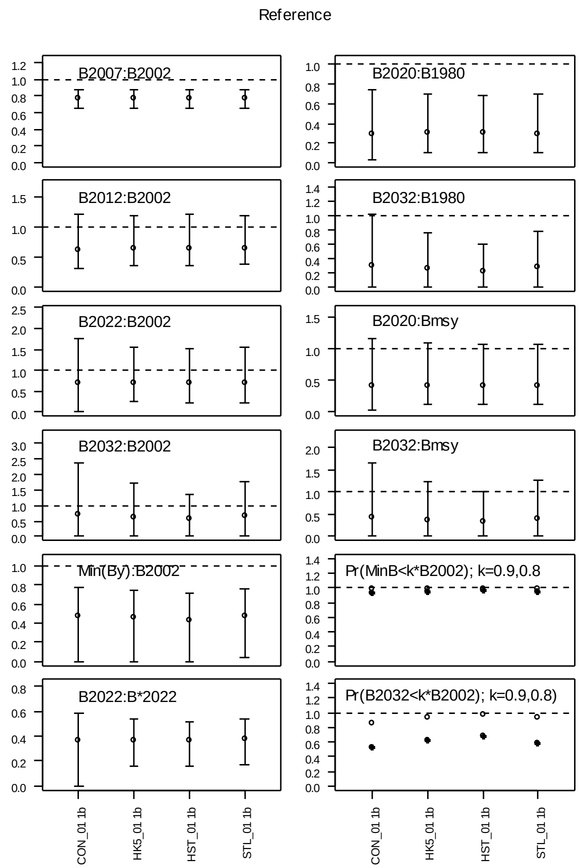


Fig.5 Continued

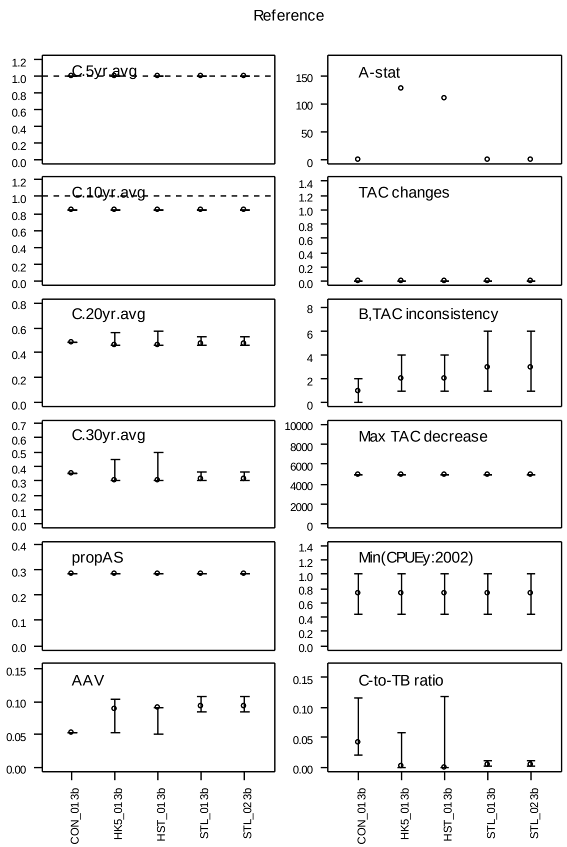


Fig.6 Performance statistics for candidate MPs
(Scenario=Reference, TL=1.5, Option=b)

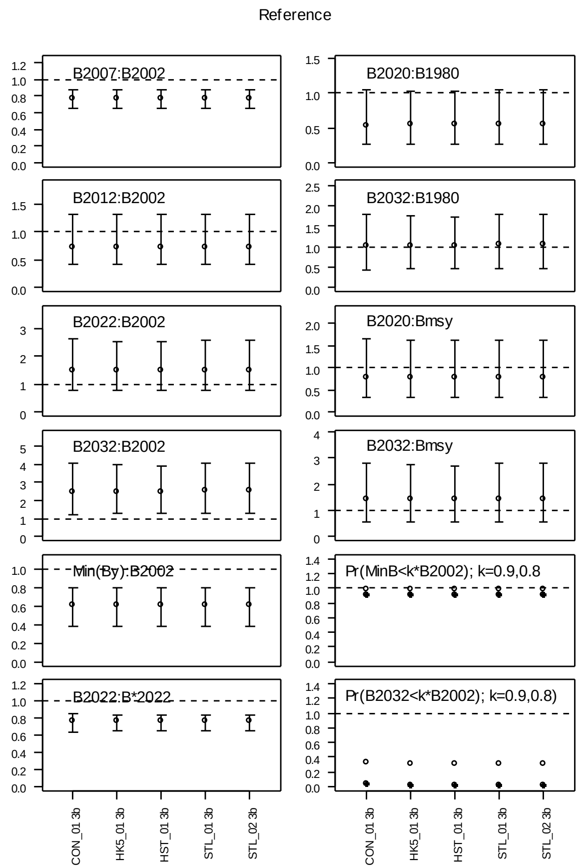


Fig.6 Continued

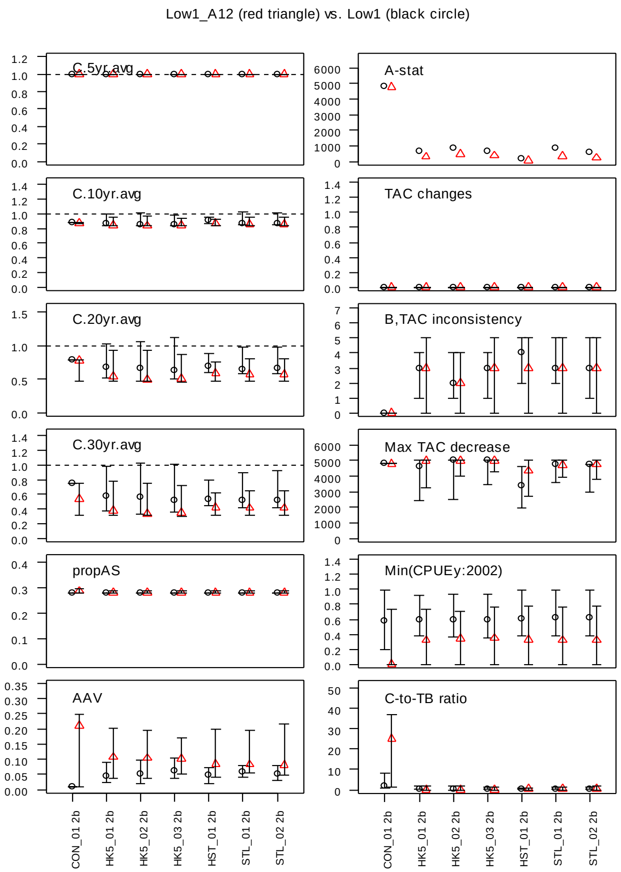


Fig.7 Performance statistics for candidate MPs (Scenario=Low1_A12, Low1, TL=1.1, Option=b)

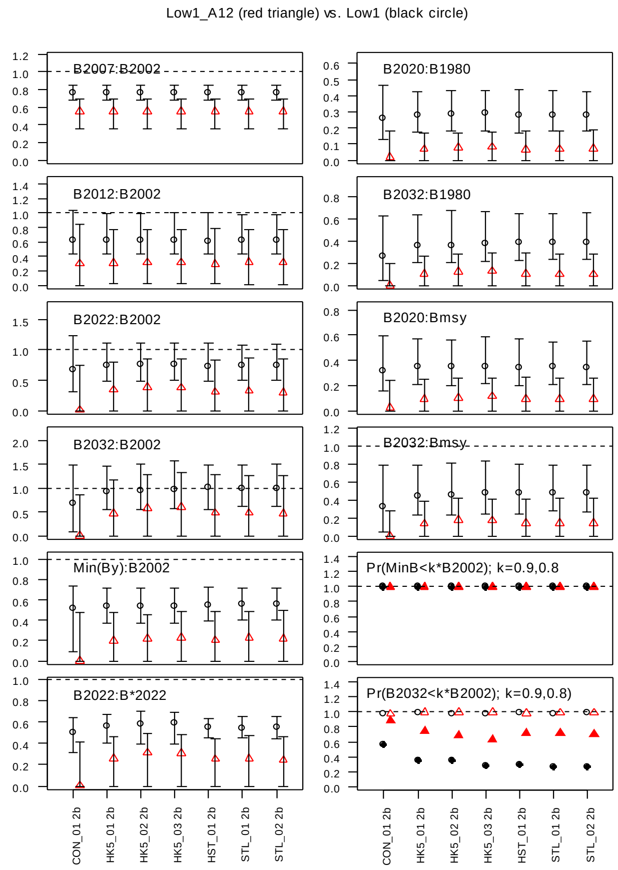


Fig.7 Continued

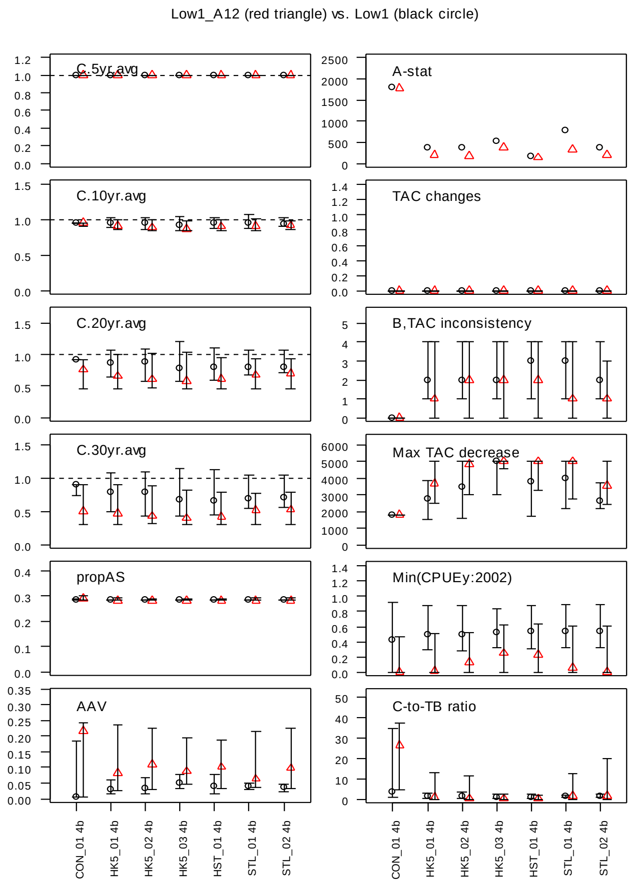


Fig.8 Performance statistics for candidate MPs

(Scenario=Low1_A12, Low1, TL=0.9, Option=b)

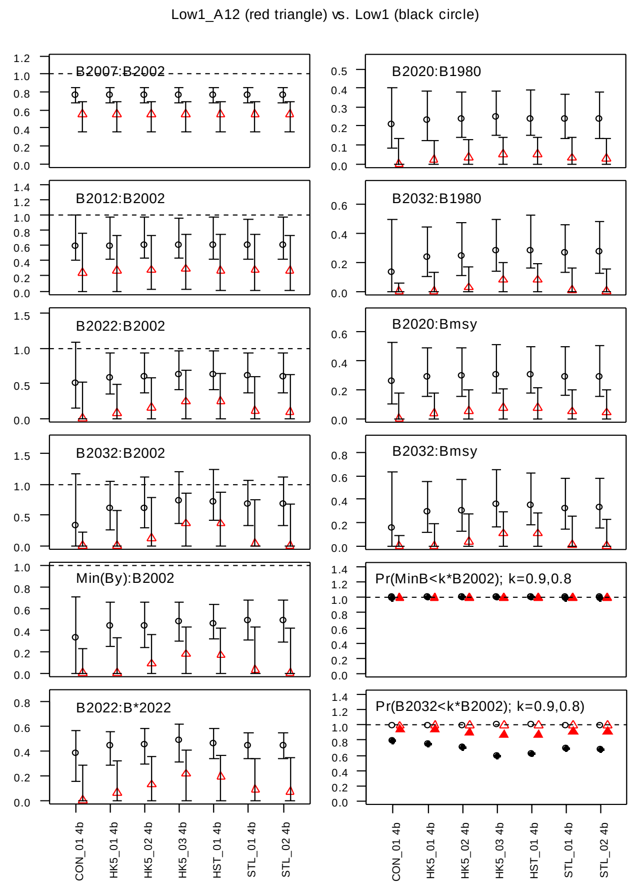


Fig.8 Continued

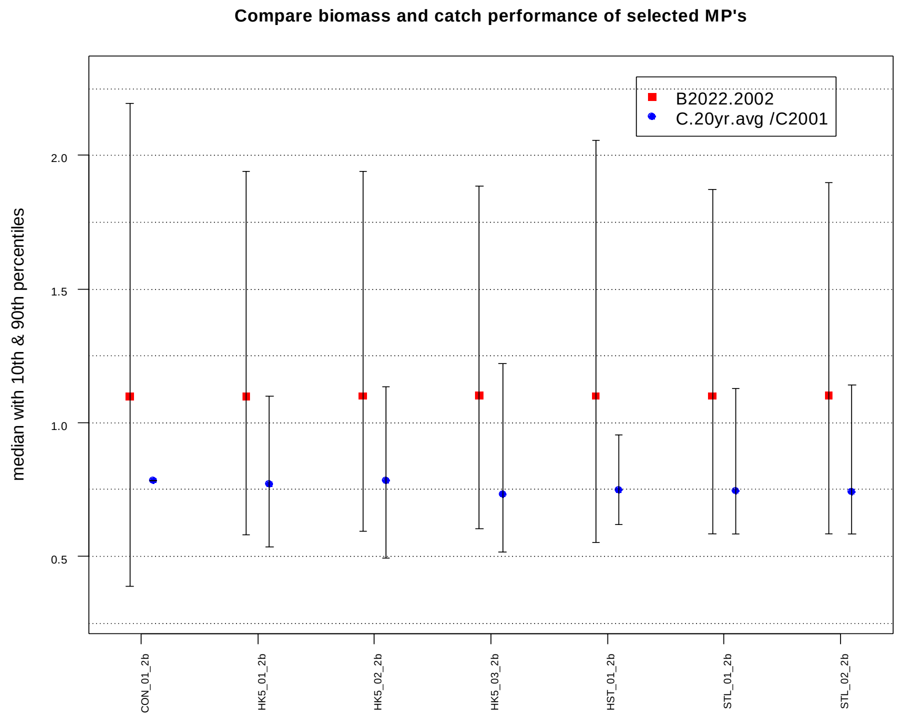


Fig.9 Comparison of B2022 and C20years (Scenario=Reference, TL=1.1, Option=b)

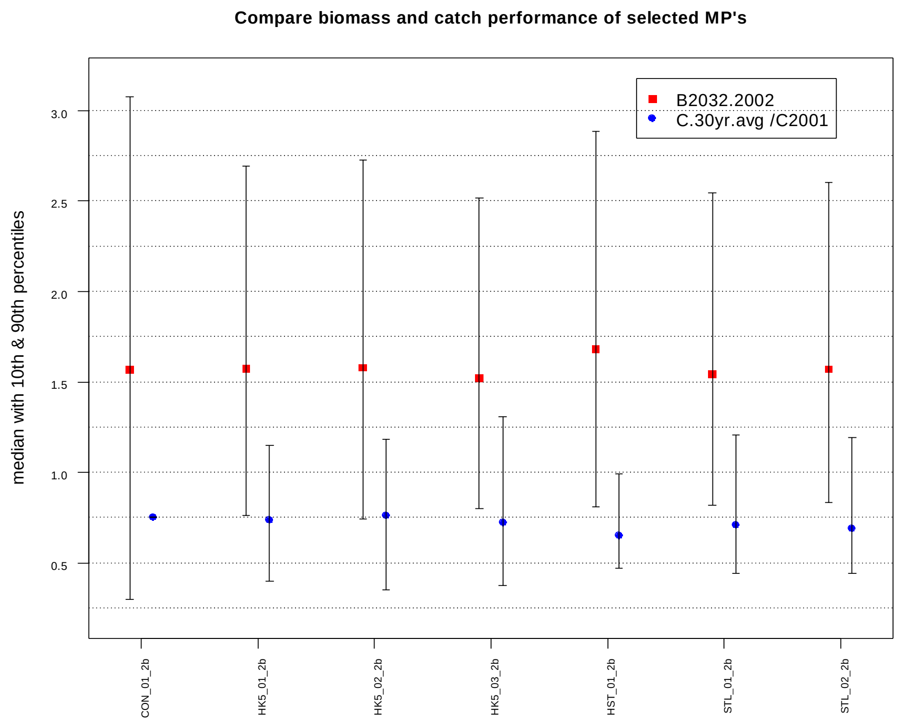


Fig.10 Comparison of B2032 and C30years (Scenario=Reference, TL=1.1, Option=b)

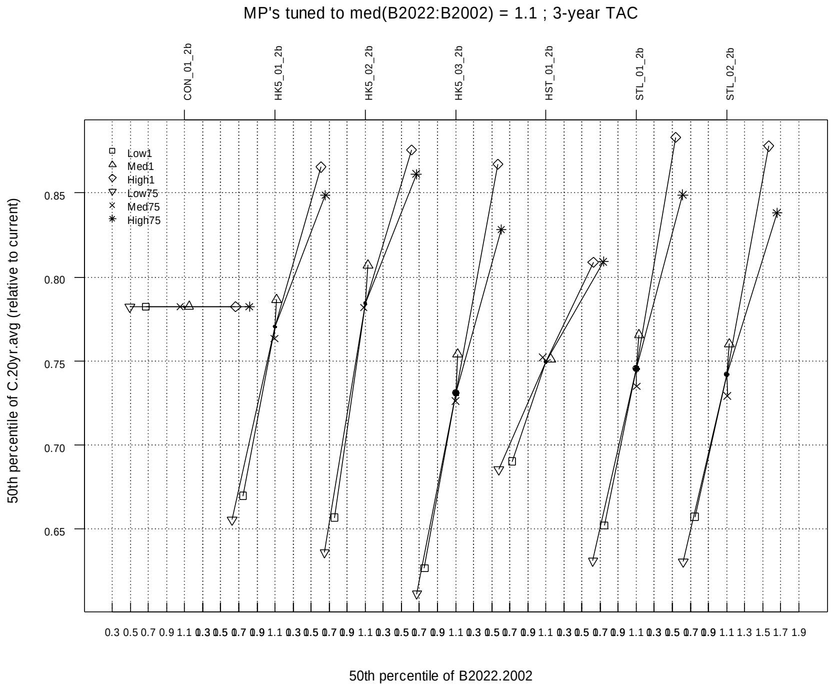


Fig.11 Comparison of B2022 and C20years (Scenario=six individual reference sets, TL=1.1, Option=b)

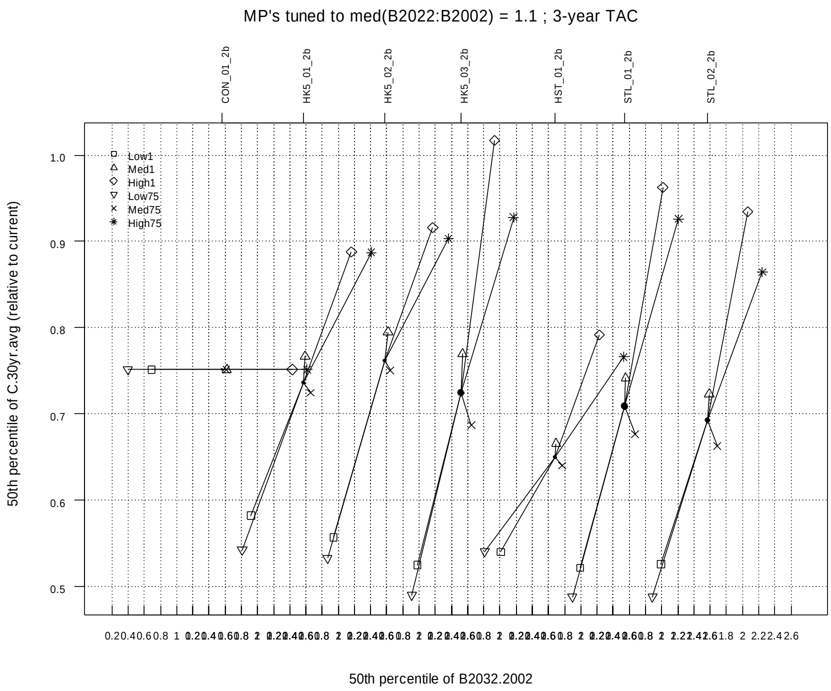


Fig.12 Comparison of B2032 and C30years (Scenario=six individual reference sets, TL=1.1, Option=b)

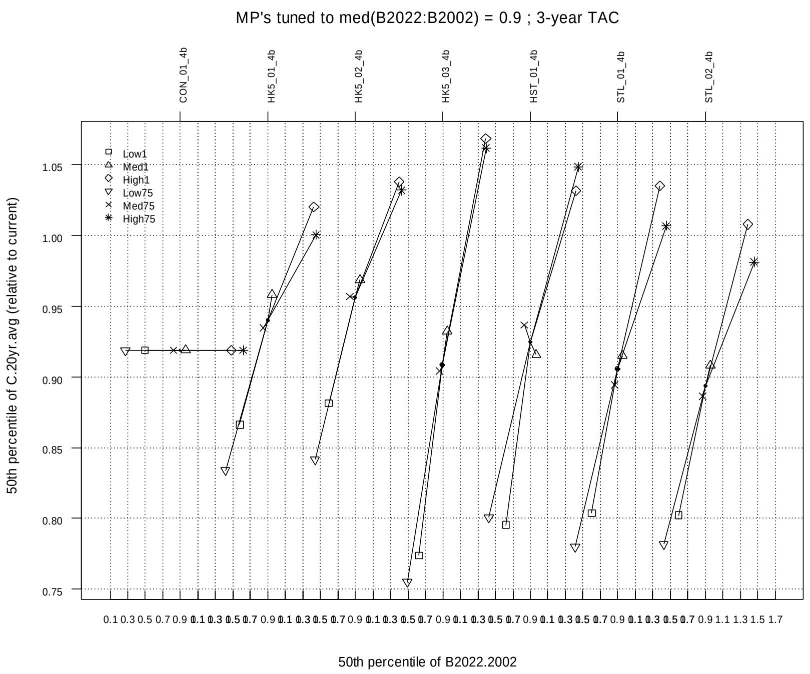


Fig.13 Comparison of B2022 and C20years (Scenario=six individual reference sets, TL=0.9, Option=b)

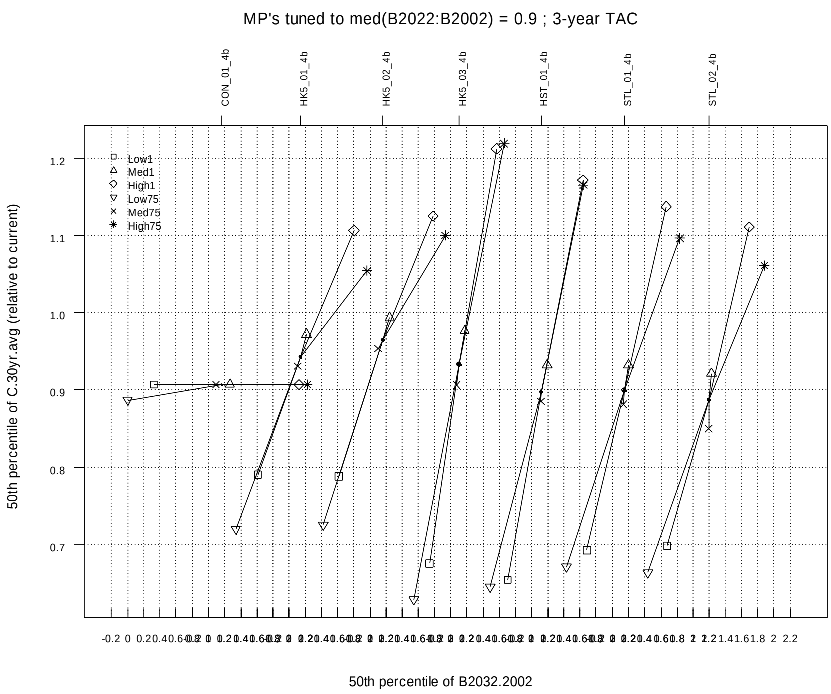


Fig.14 Comparison of B2032 and C30years (Scenario=six individual reference sets, TL=0.9, Option=b)

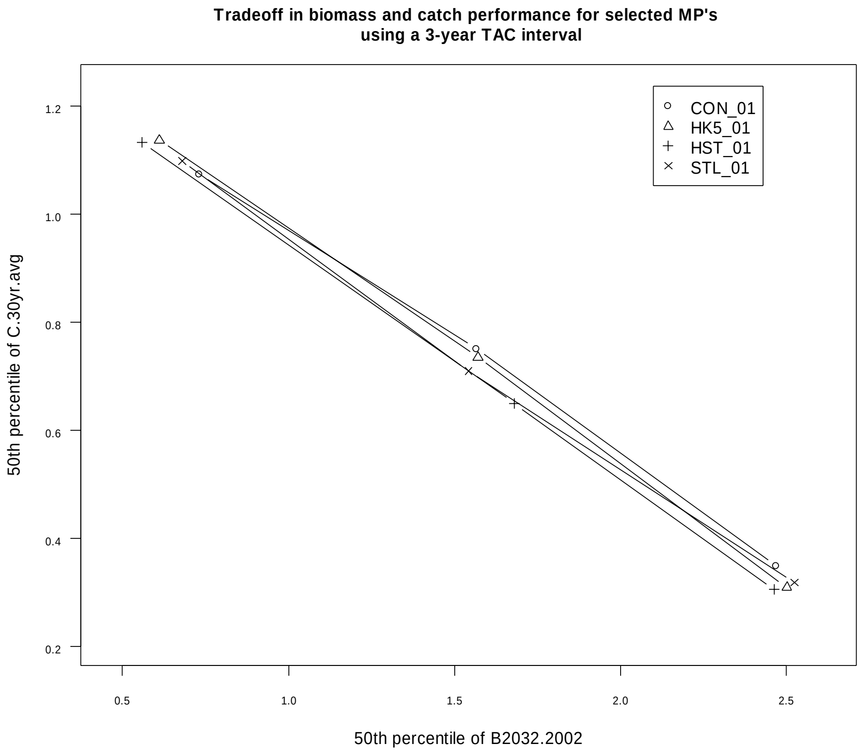


Fig.15 Tradeoff in B2022 and C20years (Scenario=Reference, TL=1.1, Option=b)

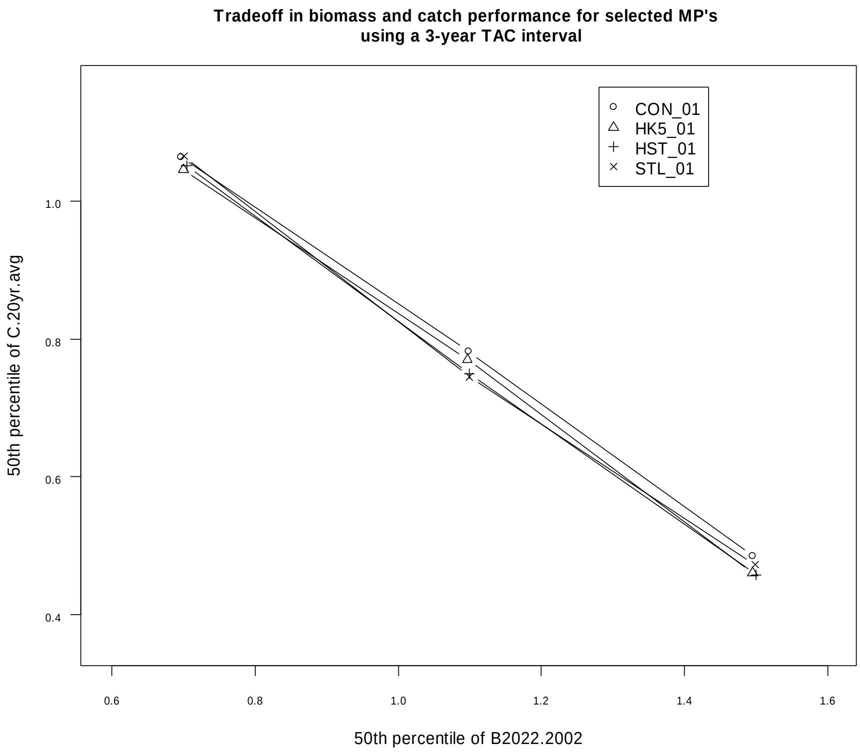


Fig.16 Tradeoff in B2032 and C30years (Scenario=Reference, TL=1.1, Option=b)

Appendix 1."CON" - constant catch strategy

1. Basic idea

Constant catch strategy might be helpful to managers and industry, because they can make future plans easily. TACs are changed to a target level only once in 2005 (option A) and 2008 (option B, C), if TAC change is within the limit at each option. Current catch and zero catch rules are calculated for reference.

2. Notes

Target constant levels are determined as follows:

	target level		B_{2022}/B_{2002}	ave C_{20yrs}
CON_01_1b	16800		0.697	16375.7
CON _01_2a	11200		1.100	12037.1
CON _01_2b	10400		1.103	11895.7
CON _01_2c	10400		1.103	11895.7
CON _01_3b	1200		1.499	7461.4
CON _01_4b	13600		0.898	14135.7
CON _02_b	0		1.532	7039.3
CON _03_b	15385.7		0.785	15385.7

- Average catch over 20 years is unexpectedly high, especially at the tuning level 1.1 (CON_01_2b).
- Performance for robustness trials is not acceptable. Extinction is often observed in low productive scenarios (Fig. A1-2), and catch level does not change according to alternative recruitment assumptions (Fig. A1-1).

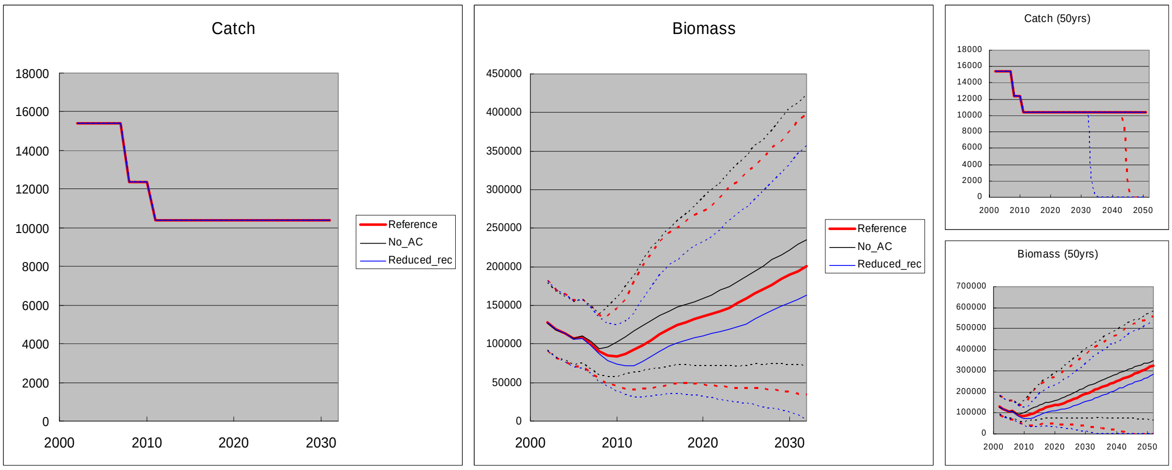


Fig.A1-1 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is CON_01_2b (TL=1.1, Option-b).

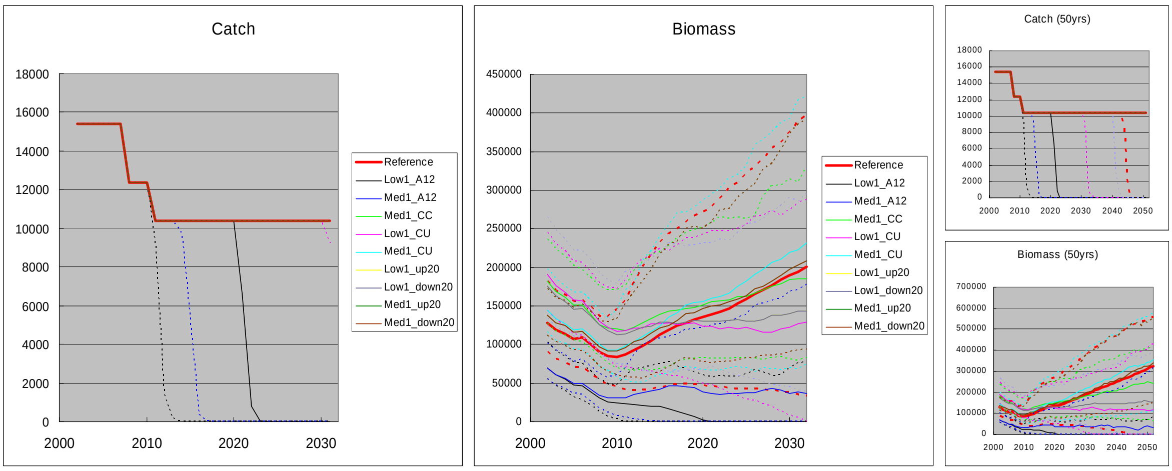


Fig.A1-2 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is CON_01_2b (TL=1.1, Option-b).

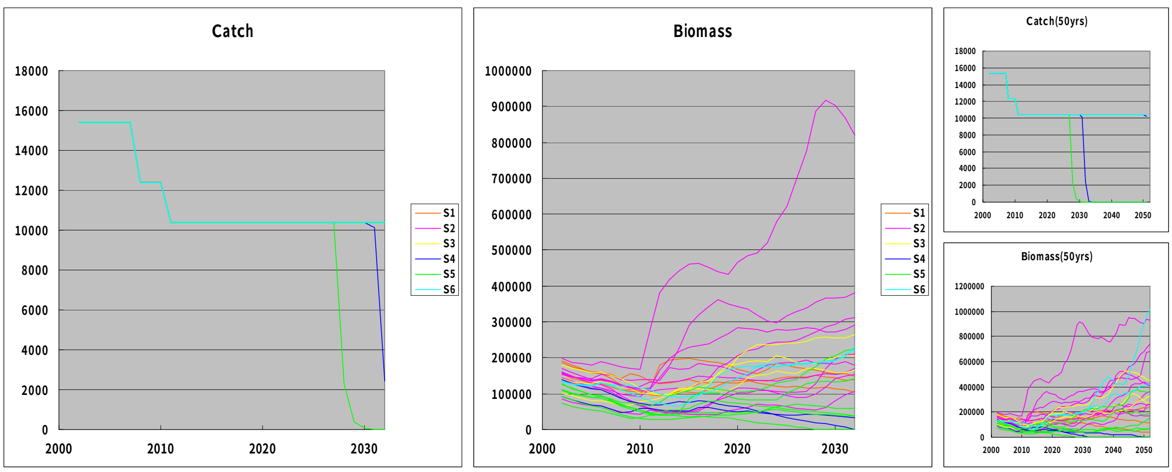


Fig.A1-3 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is CON_01_2b (TL=1.1, Option-b).

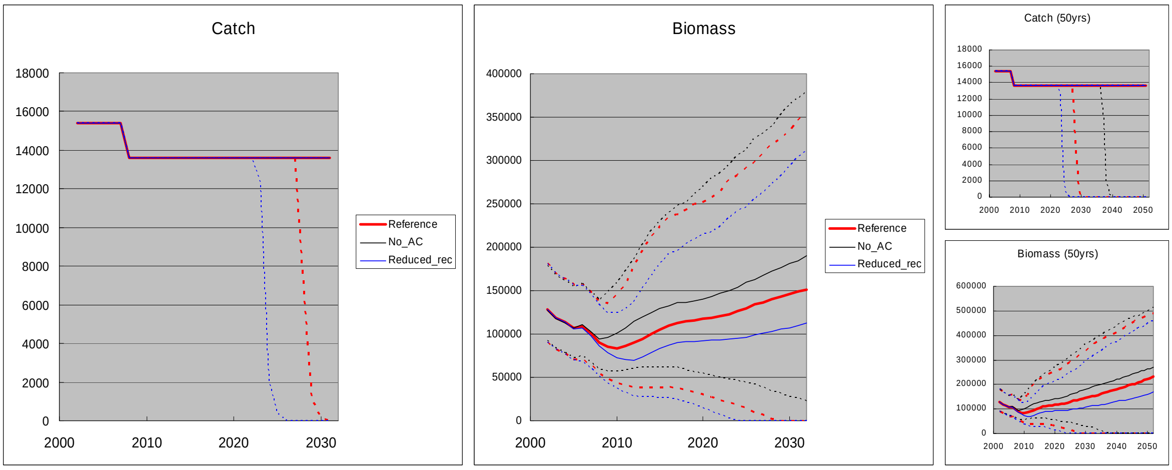


Fig.A1-4 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is CON_01_4b (TL=0.9, Option-b).

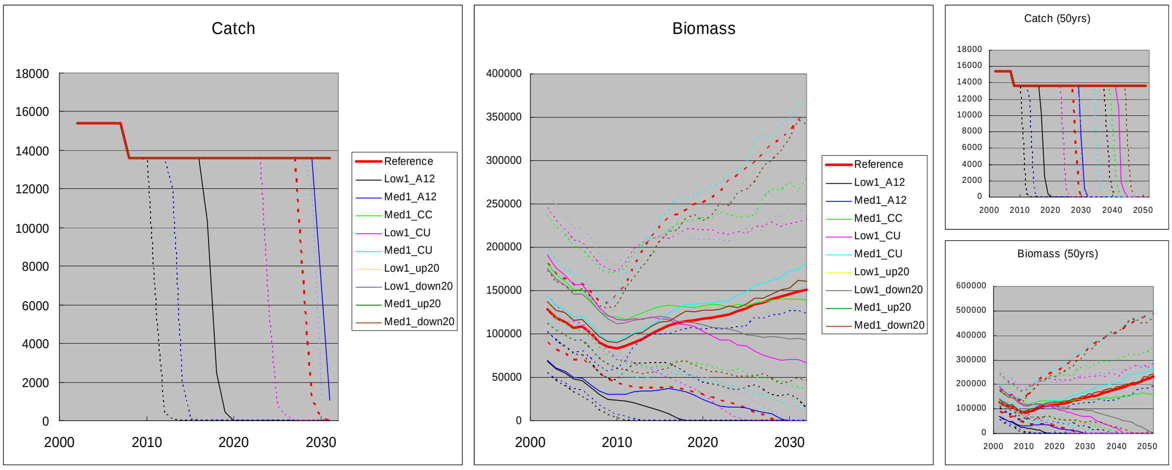


Fig.A1-5 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is CON_01_4b (TL=0.9, Option-b).

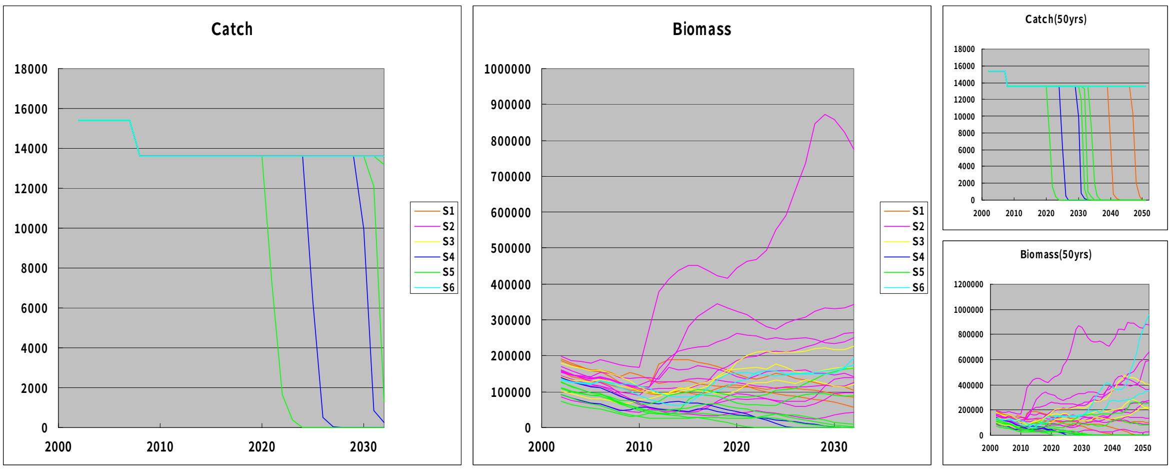


Fig.A1-6 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is CON_01_4b (TL=0.9, Option-b).

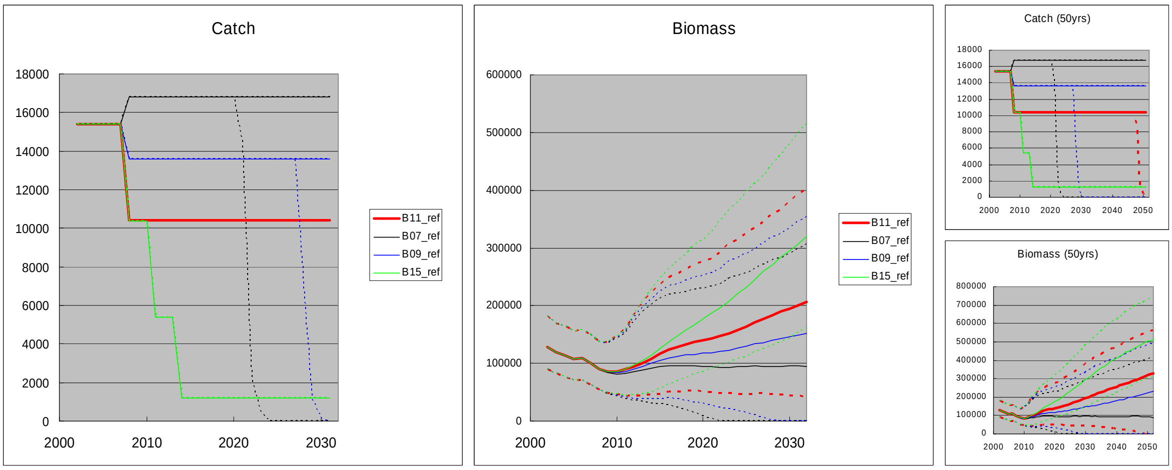


Fig.A1-7 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference scenario at four tuning levels (TL=1.1, 0.7, 0.9, 1.5) with Option-b. The MPs are CON_01.

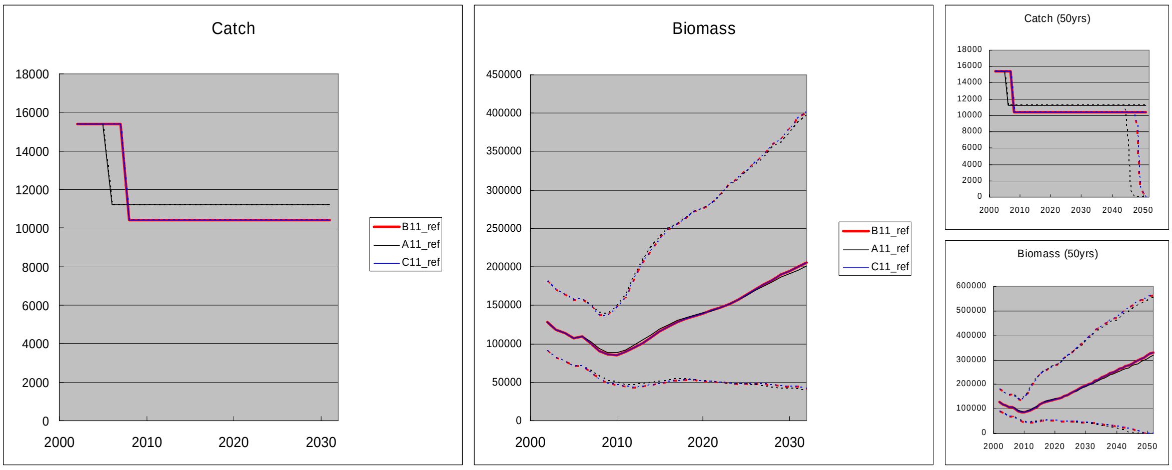


Fig.A1-8 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference scenario with three TAC change options (Option-a, b, and c) at TL=1.1. The MPs are CON_01.

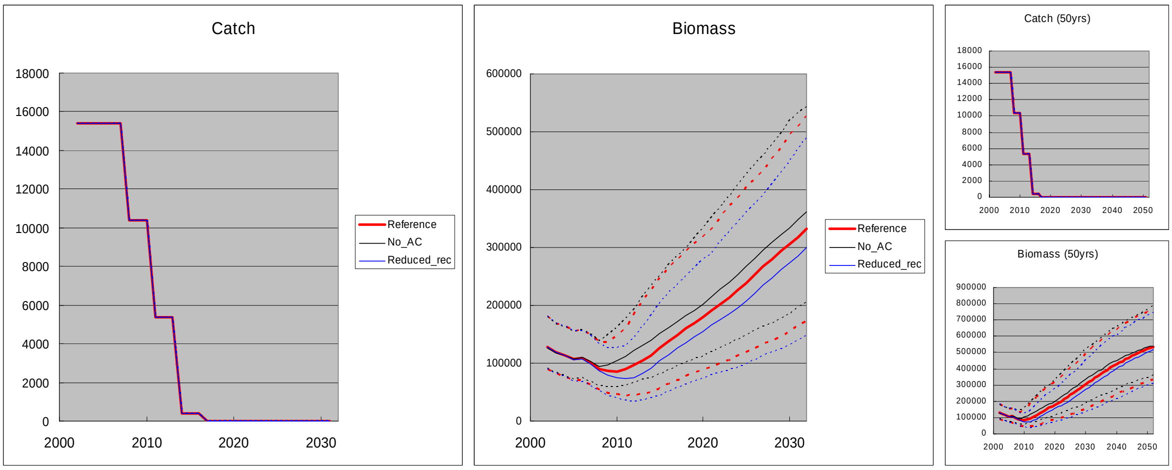


Fig.A1-9 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is CON_02_b (zero catch strategy, Option-b).

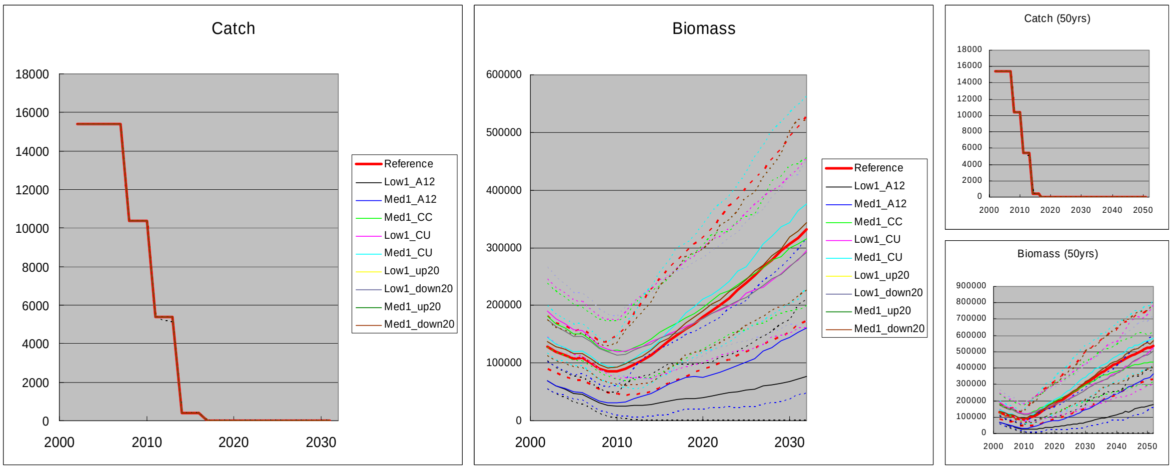


Fig.A1-10 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is CON_02_b (zero catch strategy, Option-b).

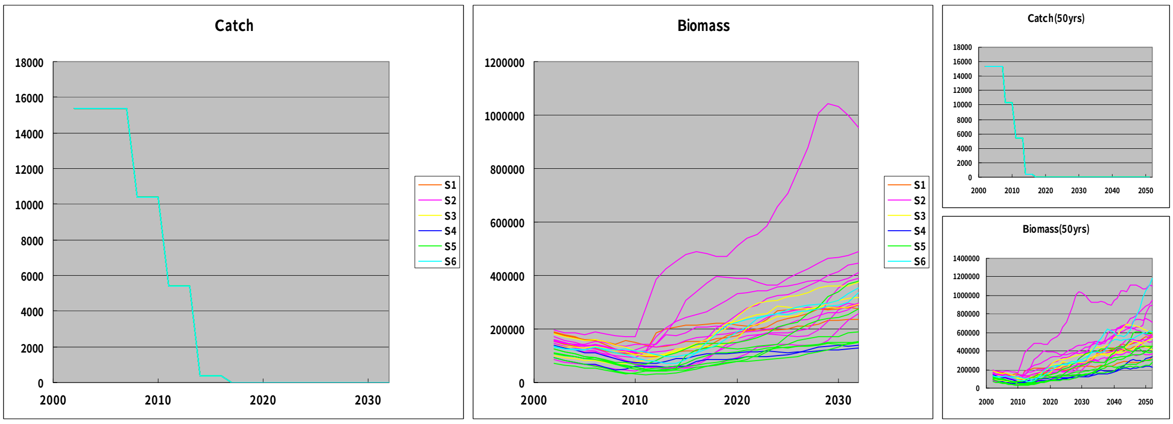


Fig.A1-11 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is CON_02_b (zero catch strategy, Option-b).

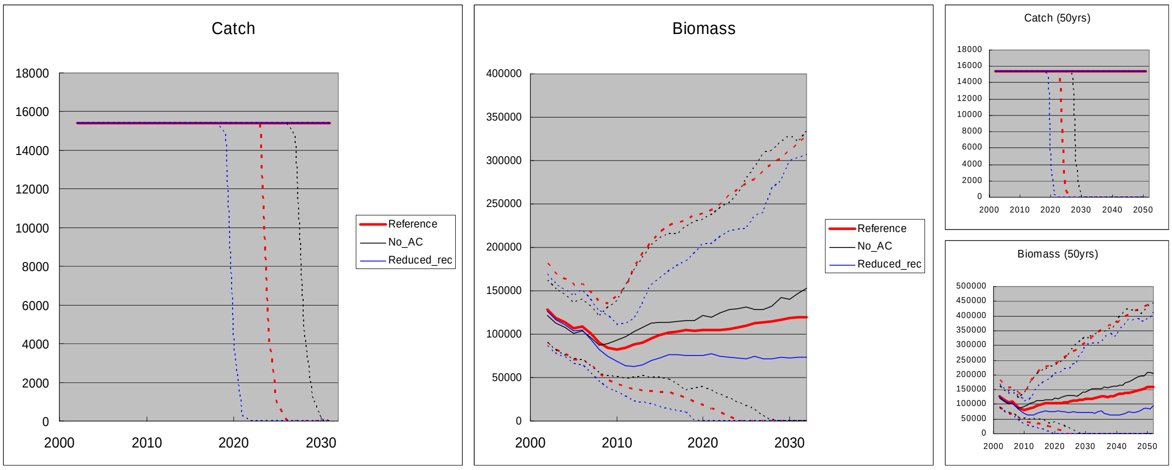


Fig.A1-12 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is CON_03_b (current catch strategy, Option-b).

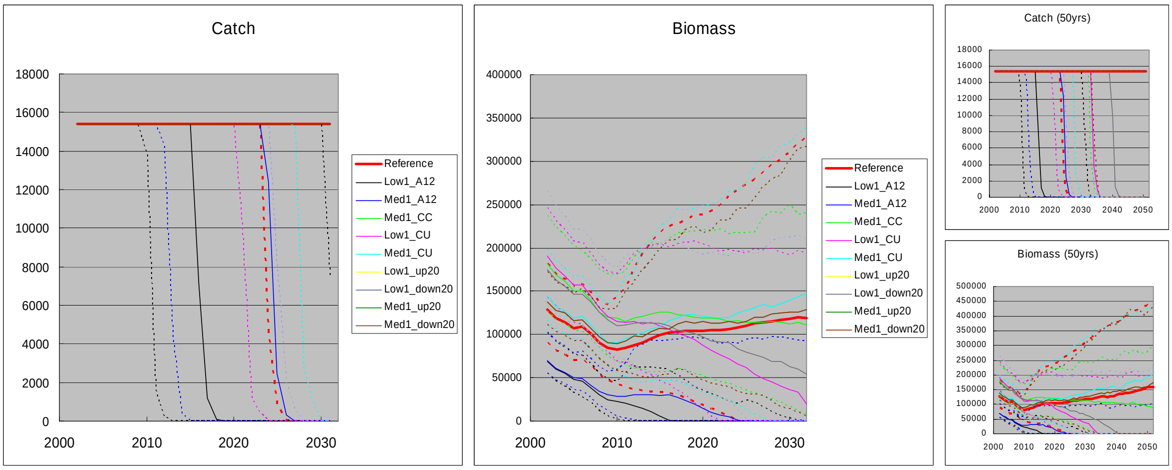


Fig.A1-13 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is CON_03_b (current catch strategy, Option-b).

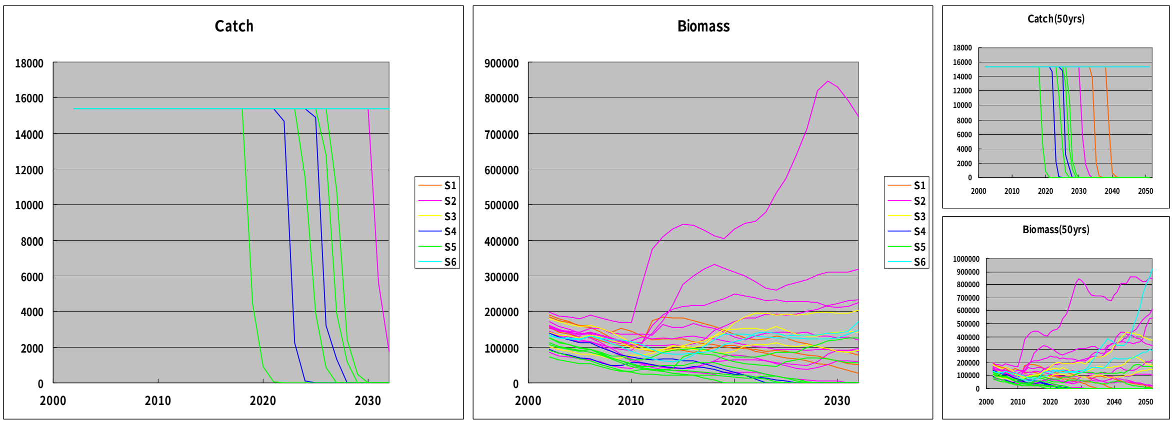


Fig.A1-14 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is CON_03_b (current catch strategy, Option-b).

Appendix 2: "HK5" – hybrid MP based on CPUE age 4 and 4+

1. Basic idea

Southern bluefin tuna are long-lived fish and fisheries target fish of different age ranges by different fleets. It might be better to use plenty of information of stock condition covering different age ranges to determine TAC robustly. This is a hybrid MP of the "HK1-dfl v2" and the "HK4-ag4 v1" (Tsuji et al., 2003). TAC is determined by CPUE trend of age 4+ and CPUE level (absolute value) of age 4 over 10 years.

CPUE of age 4 in numbers ($CPUE_{age4}$) is assumed to be an index of recruitment out of information available in the projection. Nominal CPUE of age 4 of Japanese longline is used as past data before 2000 (Fig. A2-1) and $CPUE_{age4}$ is calculated from CPUE of age 4+ and age-composition data of LL1 provided in the file "sbtOMdata" in the projection:

$$CPUE_{age4} = \frac{catch_{age4}}{catch_{age4+}} \times CPUE_{age4+} \tag{1}$$

It is also chief characteristics of this MP to adopt the lower of TACs determined by the two different methods. TAC is specified by:

$$TAC_{y+1} = \begin{cases} TAC_y + max_{up} & if \quad TAC_{y+1} - TAC_y > max_{up} \\ \min\left(TAC_{y+1}^{trend\,4+},\ TAC_{y+1}^{level\,4}\right) & if \quad max_{down} < TAC_{y+1} - TAC_y < max_{up} \\ TAC_y - max_{down} & if \quad TAC_{y+1} - TAC_y < max_{down} \end{cases} \tag{2}$$

$$TAC_{y+1}^{trend\,4+} = TAC_y \times (1 + k\lambda) \tag{3}$$

where

λ: the slope of regression of ln($CPUE_{age4+}$) over 10 years (from y - 10 to y - 1),

k: control parameter

$$TAC_{y+1}^{level\,4} = TAC_y \times \left(1 + f(CPUE_{age4,\,y-1})\right) \tag{4}$$

$$f(CPUE_{age4,\,y-1}) = \begin{cases} m_{\max} & if \quad CPUE_{age4,\,y-1} > l_{\max} \\ a \times CPUE_{age4,\,y-1} + b & if \quad l_{\min} \le CPUE_{age4,\,y-1} \le l_{\max} \\ m_{\min} & if \quad CPUE_{age4,\,y-1} < l_{\min} \end{cases} \tag{5}$$

where

$CPUE_{age4,y-1}$: average CPUE of age 4 over 10 years (from $y-10$ to $y-1$),
m_{max}, m_{min}, l_{max}, l_{min}, a, b: control parameters (l_{max} = 0.214, l_{min} = 0.048 in the default case)

Fig. A2-2 shows a relation between $CPUE_{age4}$ and TAC change in HK5_01_2b. Average nominal CPUE of age 4 in 1985-1987 (l_{min}, minimum in the past) and CPUE in 1978-1980 (l_{max}) are set as a reference value at a lower (m_{min}) and upper (m_{max}) limit of TAC change, respectively. Linear relation is assumed between the reference levels. Control parameters a and b are determined uniquely by l and m.

A moratorium option is also explored. If TAC calculated from equation (2) is under 5000 t and it is lower than TAC of the last year, TAC of the current year is that of the last year minus 5000 t. However, the minimum TAC is assumed to be 500 t, not 0 t, because CPUE data is not available in deciding resumption of fishery if fishing stops completely.

2. Notes

Parameters k, m_{max} and m_{min} are mainly changed for tuning to the specific biomass levels (Table A2-1). Especially at tuning conditions 2b (TL=1.1, Option-b) and 4b (TL=0.9, Option-b), different combinations of the three parameters are examined to see influences on TAC dynamics (HK5_02 and HK5_03).

- Substantial decrease of catch stops around 2011 in the reference scenario and continuous gentle increase is observed after that (HK5_01_2b; Fig. A2-3). There is low inconsistency between catch and biomass trend.
- Average catch over 20 years is reasonably high (11669 t), and variability of catch (AAV) is small (HK5_01_2b).
- Little extinction is observed in the all robustness scenarios (HK5_01_2b; Fig. A2-4). This tuned MP also responds appropriately and quickly to different recruitment assumptions (Fig. A2-3).
- When m_{max} is larger and m_{min} is smaller, catch decrease in 2008 is a little larger, but the minimum catch level and average catch over 20 years are larger (HK5_02_2b; Fig. A2-11). 12020 t is the largest catch among HK5 variants in the tuning condition "2b" (TL=1.1, Option-b) (Table A2-1).
- When k is larger, catch variability is larger and the minimum catch level is smaller. However, biomass variation among simulation runs is smaller and higher recovery of catch is found quickly (HK5_03_2b; Fig. A2-17).
- In case of the tuning option "4b" (TL=0.9, Option-b), extinction is often observed in the Low1_A12 scenario (HK5_01_4b; Fig. A2-12). However, this problem is resolved if the moratorium option is considered (HK5_04_4b; Fig. A2-24).
- When CPUE trend of age 4+ only is used to determine TAC (HK1_02; Tsuji et al., 2003),

catch continues to decrease even if biomass turns upward (HK1_02_2b; Fig. A2-26). HK1 faces the same problem as KH8 (Appendix 5), which is based on a similar concept, when the tuning level is 1.1. When CPUE level of age 4 is used only (HK4_01; Tsuji et al., 2003), median of catch is also hard to increase (HK4_01_2b; Fig. A2-27). In addition, catch at highly productive scenarios, especially when the tuning level is 0.9, is overshot and biomass turns to decrease and often collapses (HK4_01_4b; Fig. A2-28).

HK5 adopts the lower TAC determined by the two MPs (HK1 and HK4), which are based on the two CPUE indices covering different age ranges. If either index shows a bad sign for stock condition, this MP stops increase of TAC and avoid overshooting. In the agreed projection specification, recruitments of the current years are assumed to be quite low, so it could be better to reduce TAC quickly at medium tuning levels such as 1.1 and 0.9. HK5 uses stock index of recruitments to determine TAC and so it is able to control TAC easily without setting extreme parameter values for tuning. This means that the MP has larger room to increase TAC smoothly and quickly, when stock condition gets better in the future. In addition, HK5 increases TAC gradually to avoid overshooting. This could be why HK5 shows acceptable results: low AAV, high average catch, low inconsistency between catch and biomass trend, and reasonable response to alternative recruitment assumptions.

Table A2-1. Parameter values, B_{2022}/B_{2002} and average catch over 20 years in each MP variant.

	k	m_{max}	m_{min}	l_{min}	max_{up}	max_{down}	moratorium		B_{2022}/B_{2002}	ave C_{20yrs}
HK5_01_1b	10.0	2.5	1.0	0.048	3750	2000	-		0.699	16161.6
HK5_01_2a	1.5	1.1	0.925	0.048	3000	3000	-		1.097	11940.6
HK5_01_2b	1.5	2.0	0.49	0.048	5000	5000	-		1.097	11668.9
HK5_01_2c	1.5	2.0	0.475	0.048	8000	8000	-		1.097	11731.1
HK5_01_3b	1.5	1.2	0.07	0.1	5000	5000	-		1.496	7095.2
HK5_01_4b	1.5	2.0	0.7	0.048	5000	5000	-		0.899	14576.0
HK5_02_2b	1.5	**3.0**	**0.23**	0.048	5000	5000	-		1.100	12020.1
HK5_02_4b	1.5	**3.0**	**0.57**	0.048	5000	5000	-		0.900	14839.4
HK5_03_2b	**5.0**	2.0	**0.43**	0.048	5000	5000	-		1.104	11140.1
HK5_03_4b	**5.0**	2.0	**0.69**	0.048	5000	5000	-		0.898	14154.2
HK5_04_4b	1.5	2.0	0.7	0.048	5000	5000	+		0.899	14552.7

*Bold figures represent different values from those in the default cases (HK5_01).

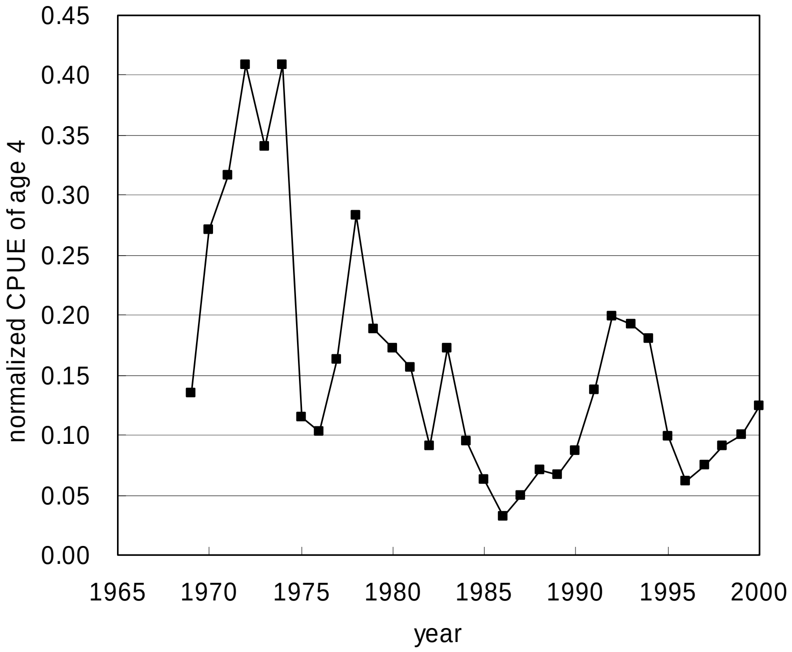


Fig. A2-1 Normalized CPUE of age 4 fish of Japanese longline used as recruitment information.

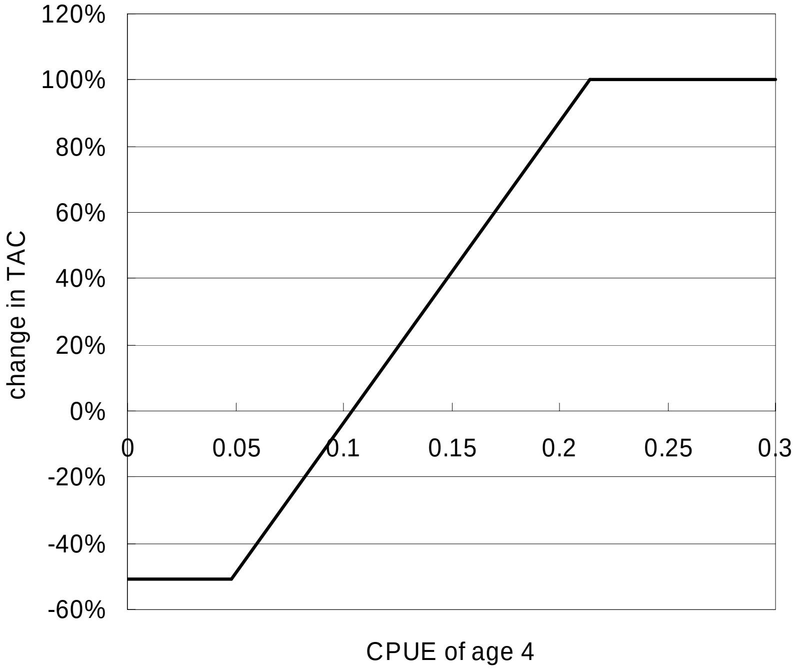


Fig. A2-2 Relation between average CPUE of age 4 over 10 years and change in TAC.

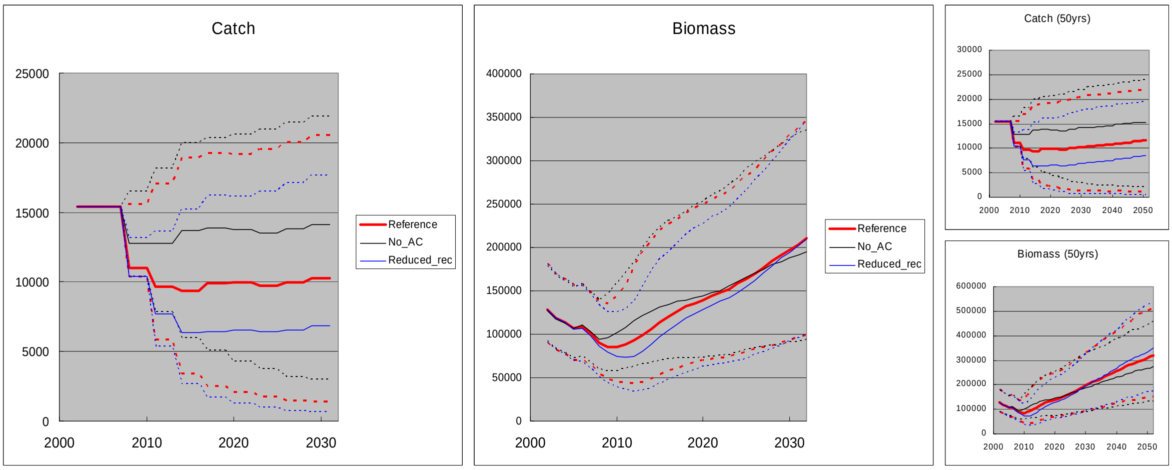


Fig.A2-3 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is HK5_01_2b (TL=1.1, Option-b).

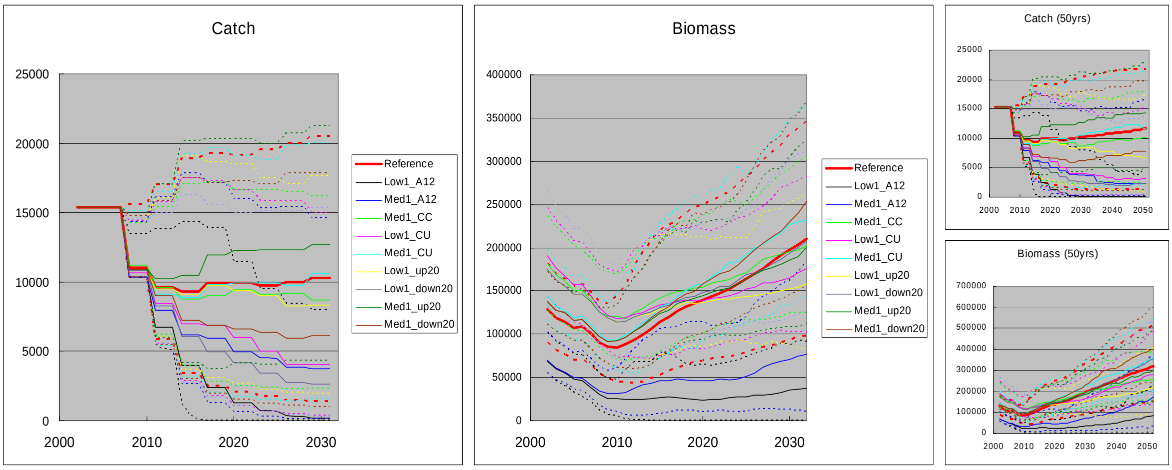


Fig.A2-4 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is HK5_01_2b (TL=1.1, Option-b).

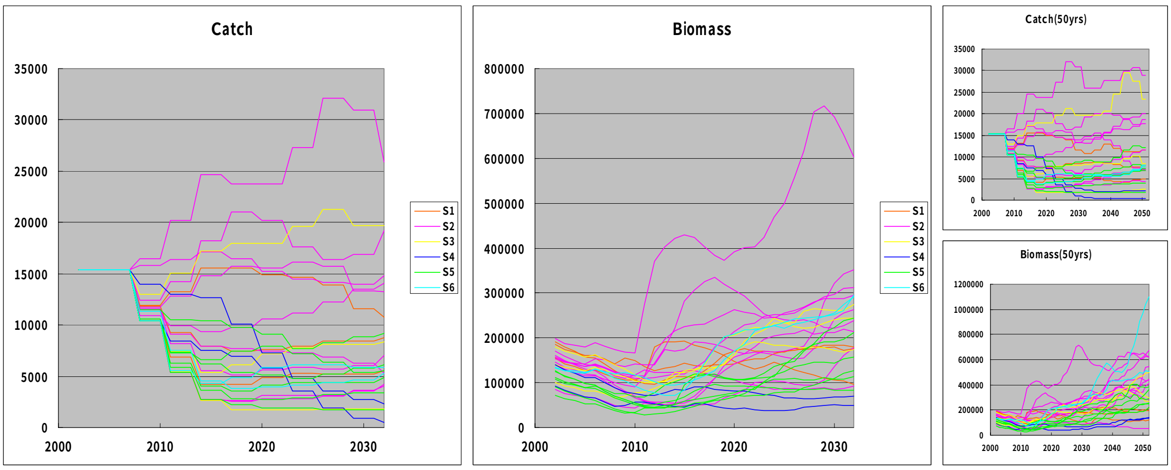


Fig.A2-5 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is HK5_01_2b (TL=1.1, Option-b).

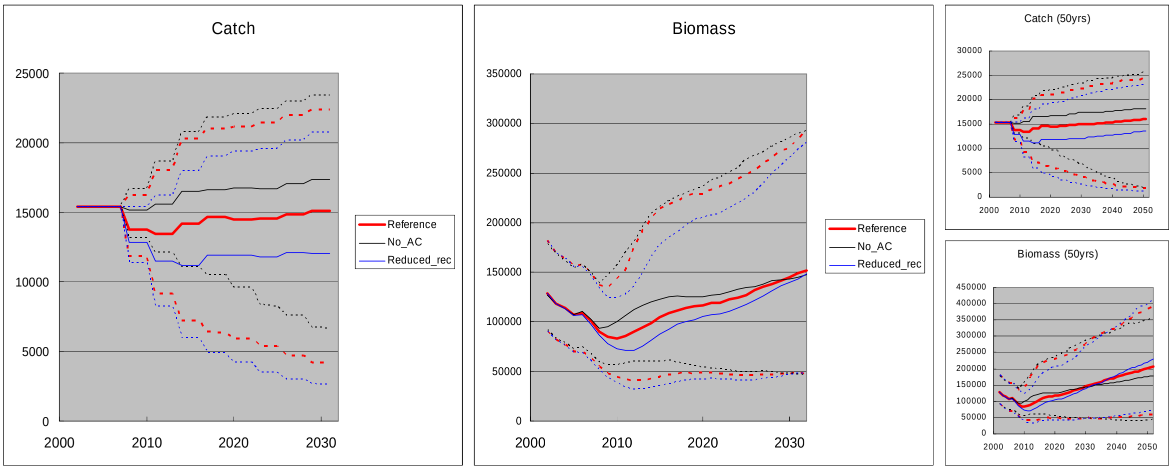


Fig.A2-6 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is HK5_01_4b (TL=0.9, Option-b).

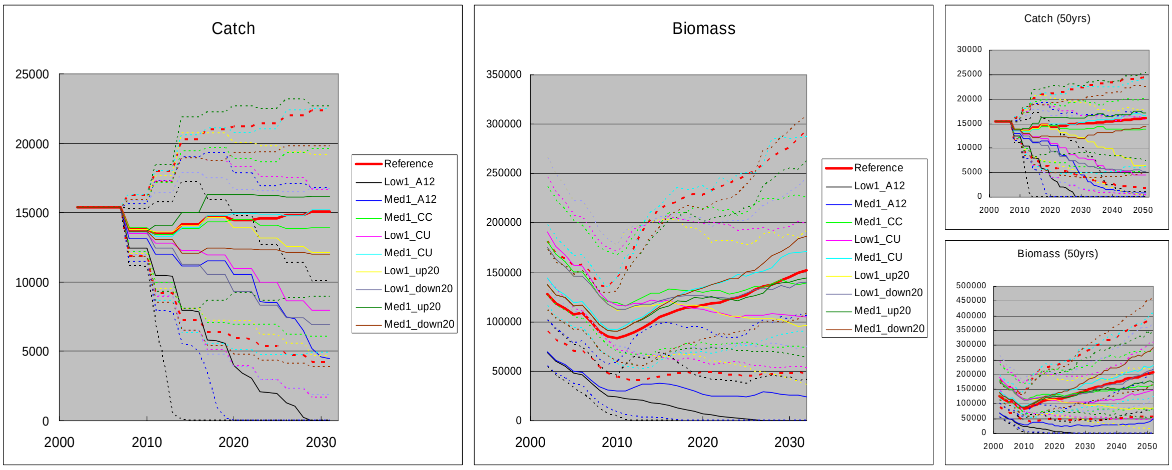


Fig.A2-7 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is HK5_01_4b (TL=0.9, Option-b).

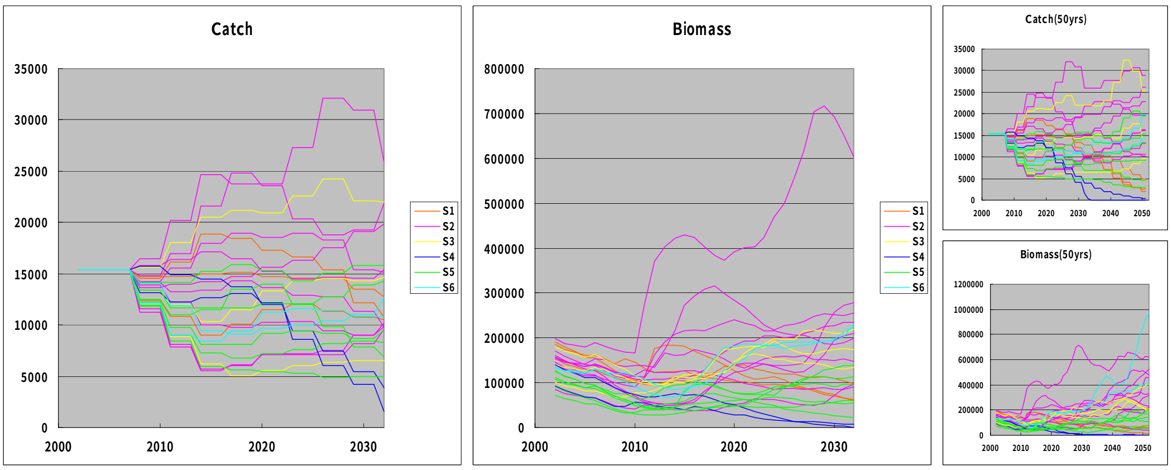


Fig.A2-8 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is HK5_01_4b (TL=0.9, Option-b).

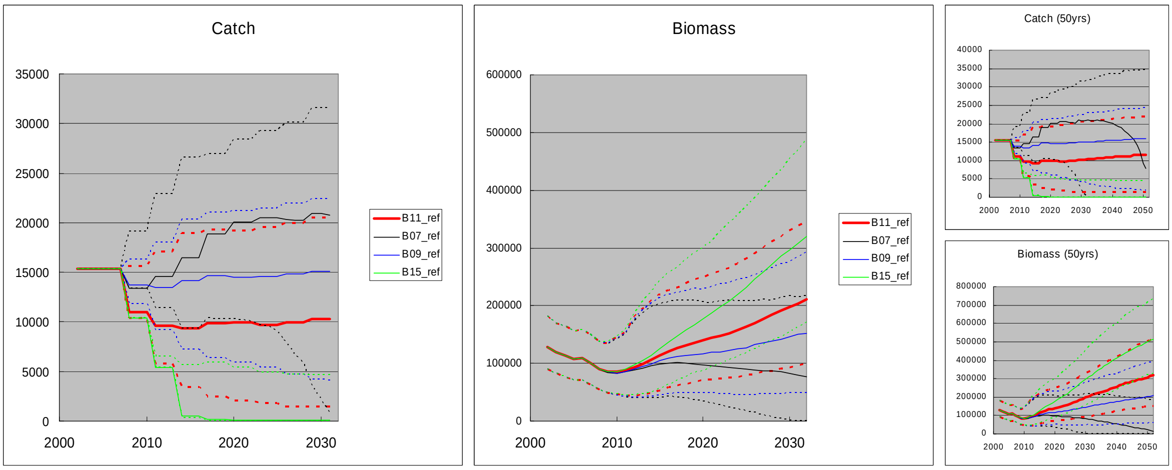


Fig.A2-9 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference scenario at four tuning levels (TL=1.1, 0.7, 0.9, 1.5) with Option-b. The MPs are HK5_01.

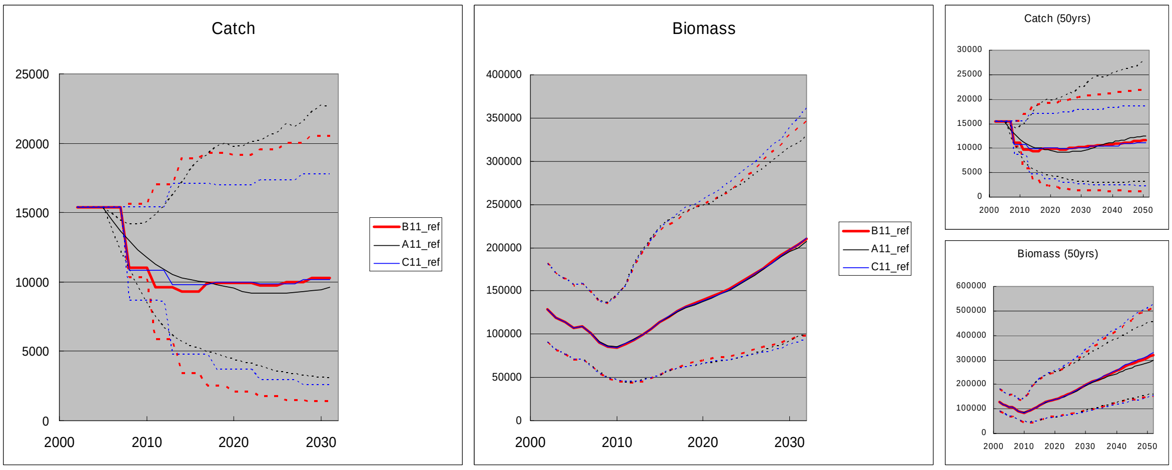


Fig.A2-10 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference scenario with three TAC change options (Option-a, b, and c) at TL=1.1. The MPs are HK5_01.

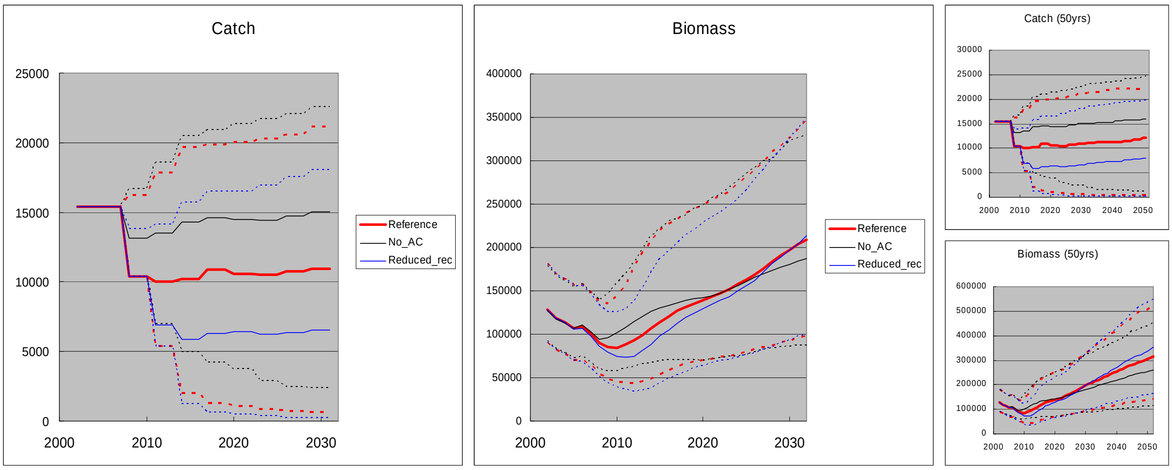


Fig.A2-11 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is HK5_02_2b (TL=1.1, Option-b).

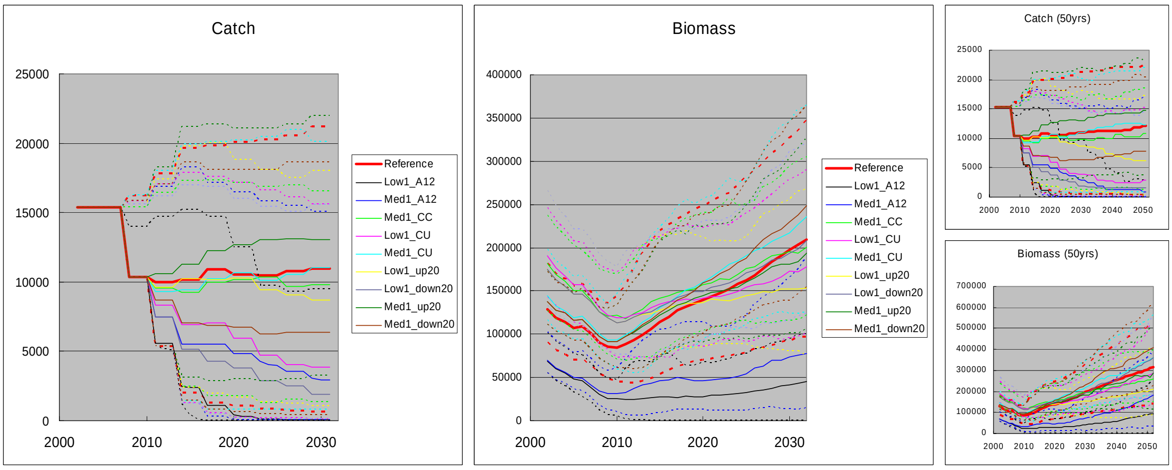


Fig.A2-12 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is HK5_02_2b (TL=1.1, Option-b).

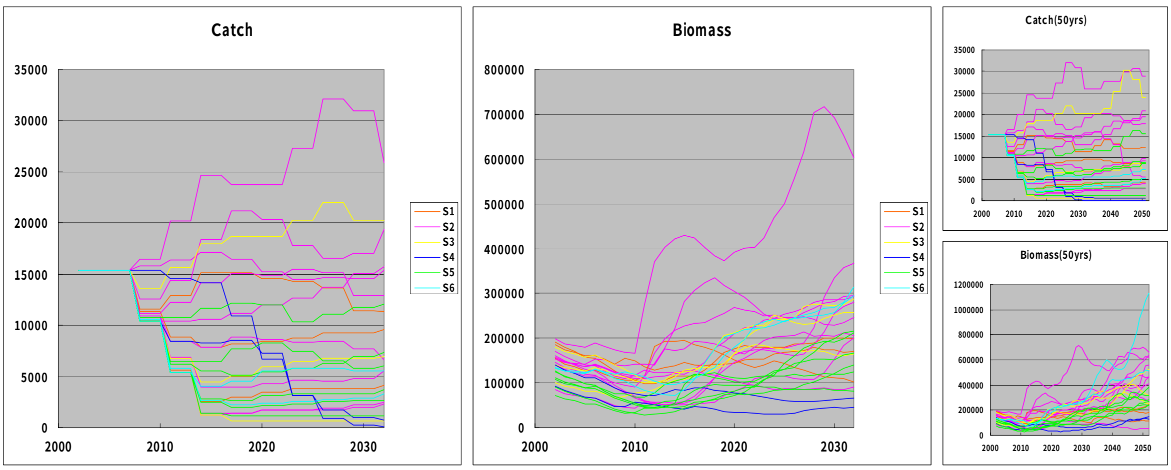


Fig.A2-13 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is HK5_02_2b (TL=1.1, Option-b).

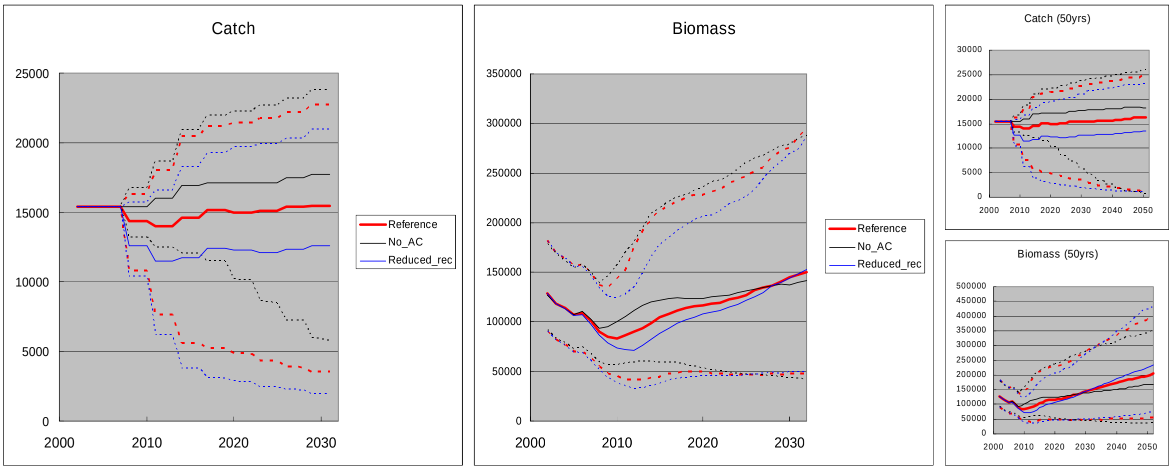


Fig.A2-14 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is HK5_02_4b (TL=0.9, Option-b).

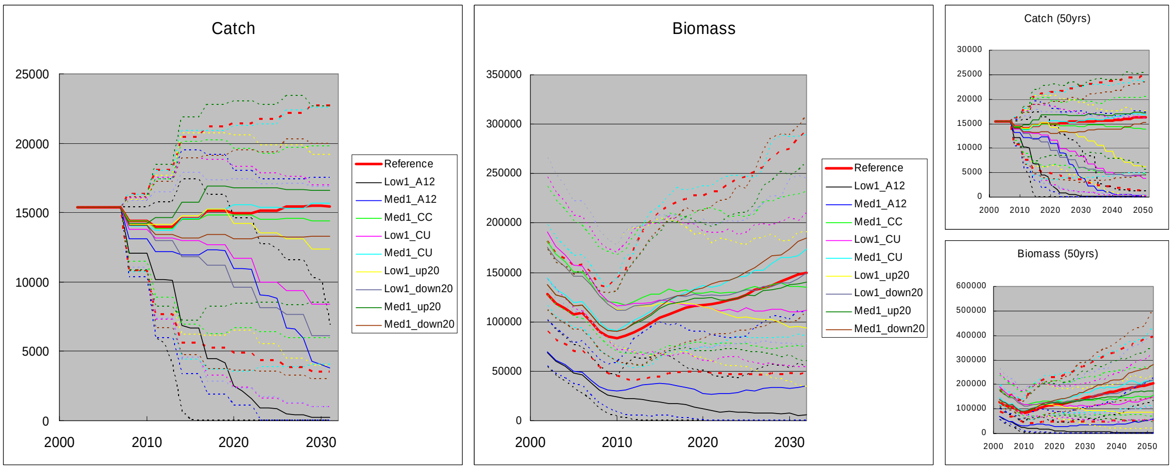


Fig.A2-15 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is HK5_02_4b (TL=0.9, Option-b).

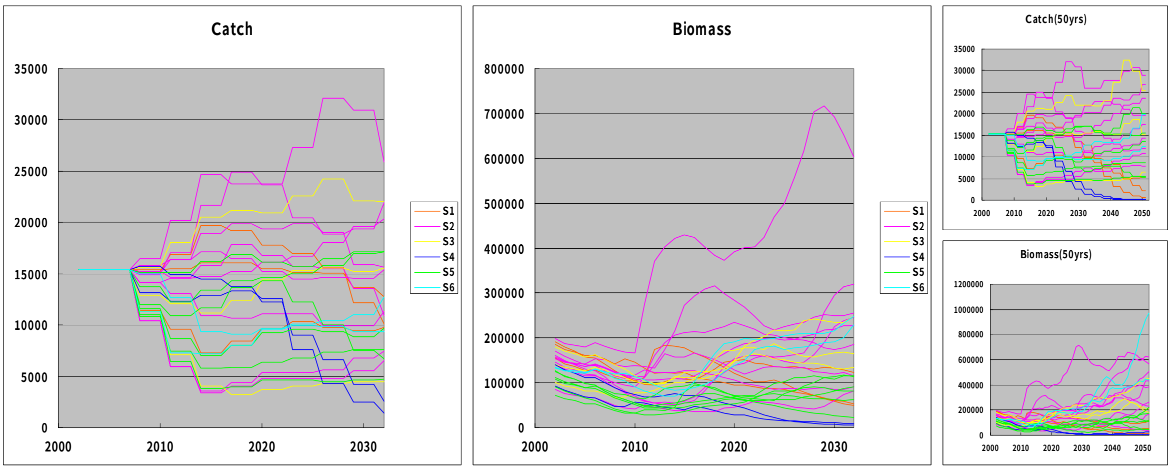


Fig.A2-16 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is HK5_02_4b (TL=0.9, Option-b).

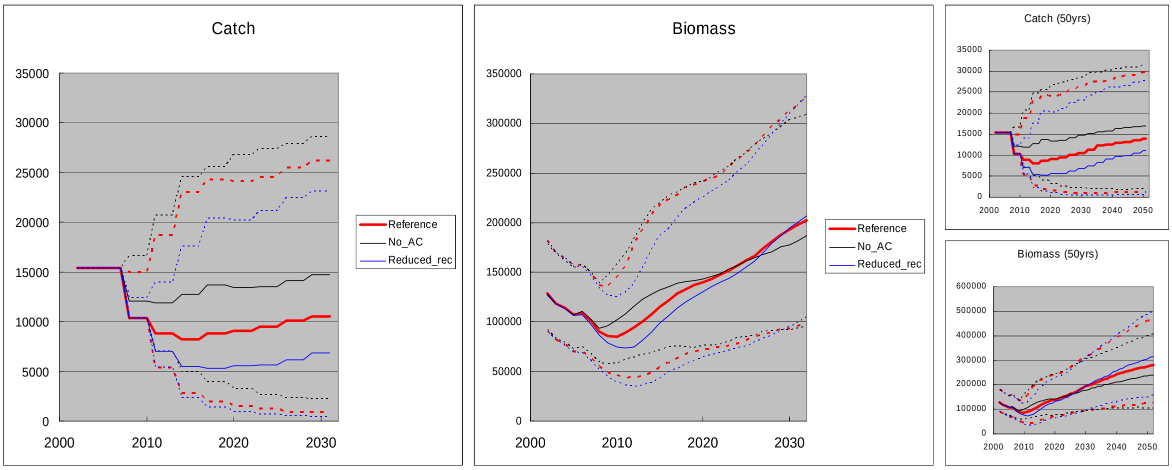


Fig.A2-17 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is HK5_03_2b (TL=1.1, Option-b).

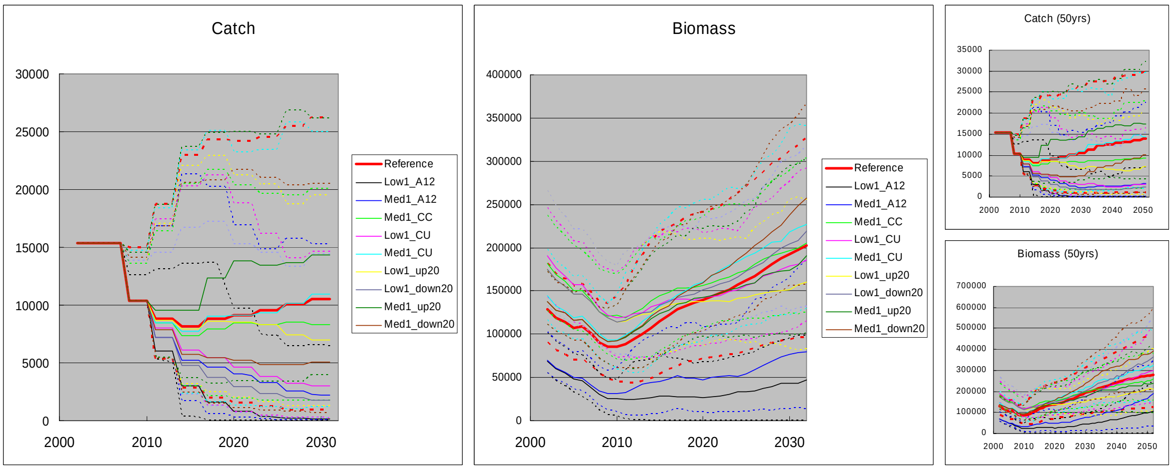


Fig.A2-18 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is HK5_03_2b (TL=1.1, Option-b).

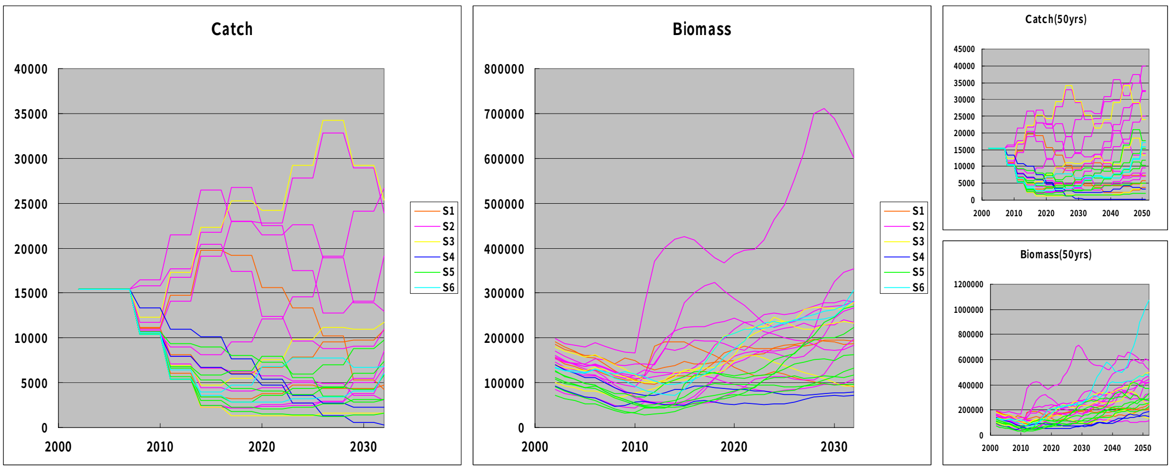


Fig.A2-19 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is HK5_03_2b (TL=1.1, Option-b).

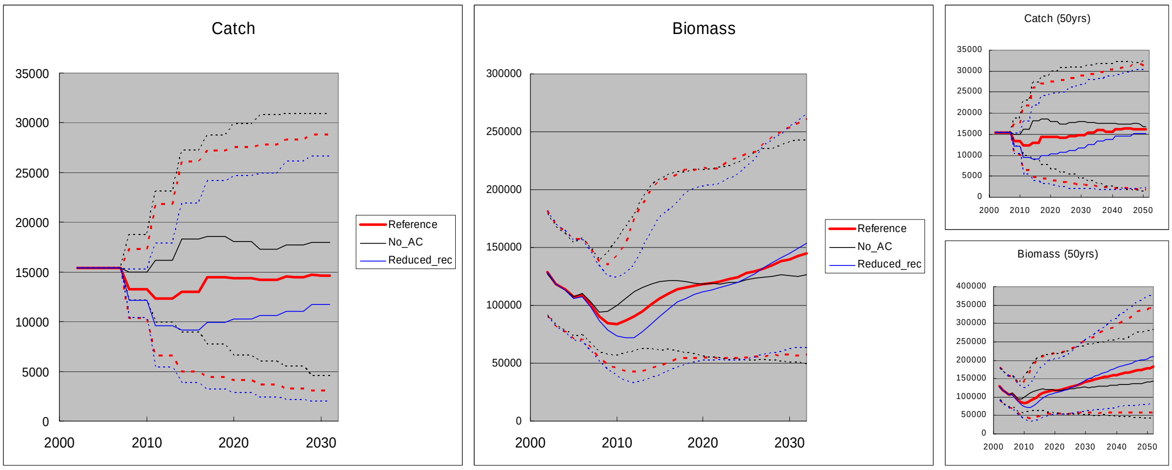


Fig.A2-20 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is HK5_03_4b (TL=0.9, Option-b).

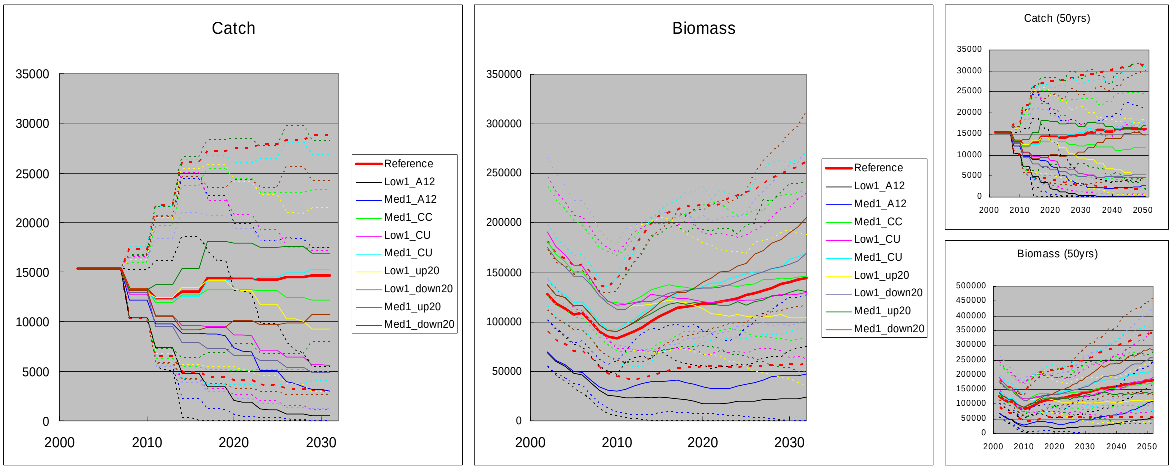


Fig.A2-21 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is HK5_03_4b (TL=0.9, Option-b).

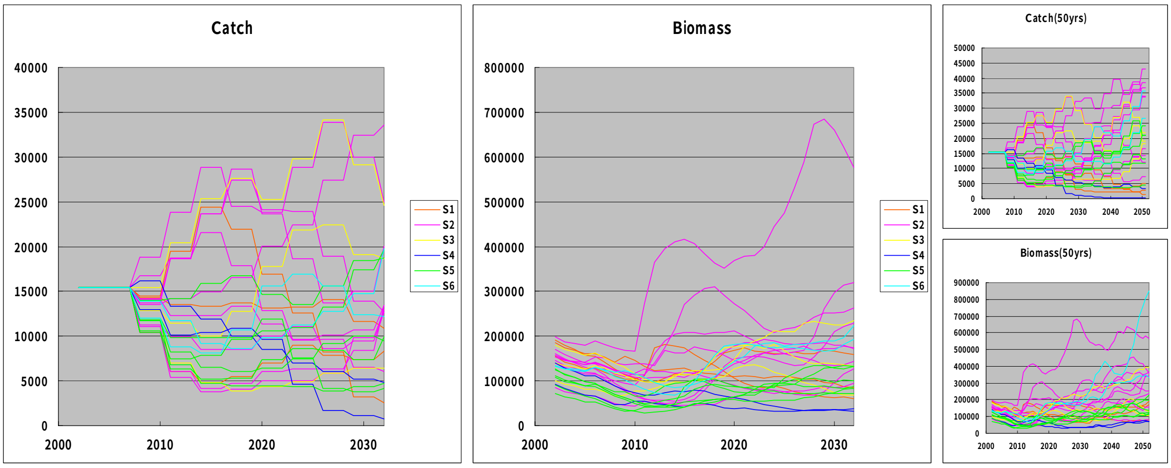


Fig.A2-22 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is HK5_03_4b (TL=0.9, Option-b).

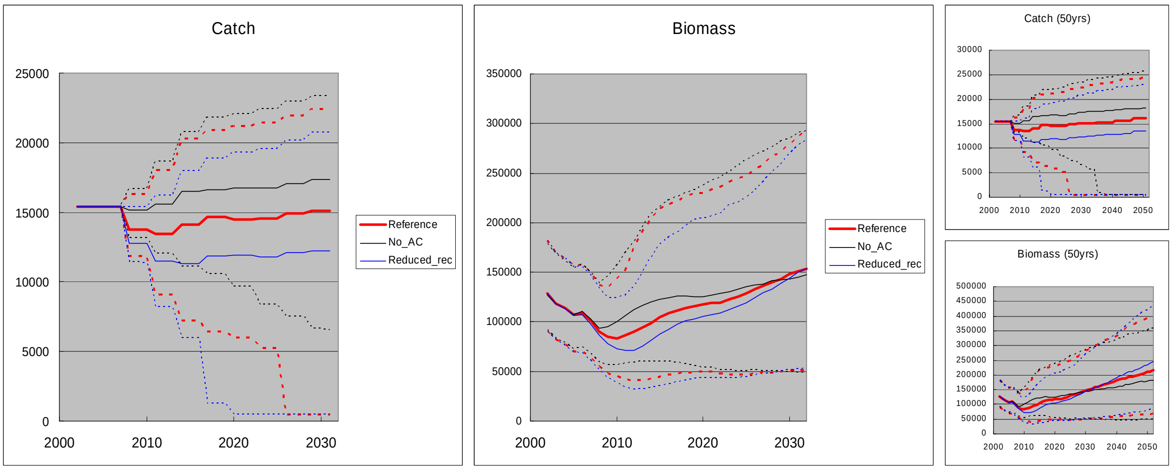


Fig.A2-23 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is HK5_04_4b (TL=0.9, Option-b).

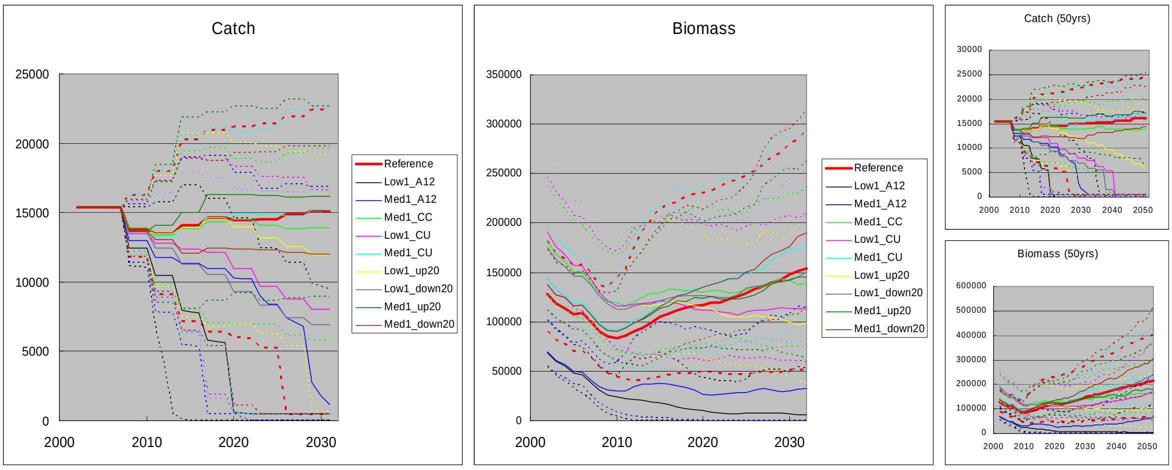


Fig.A2-24 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is HK5_04_4b (TL=0.9, Option-b).

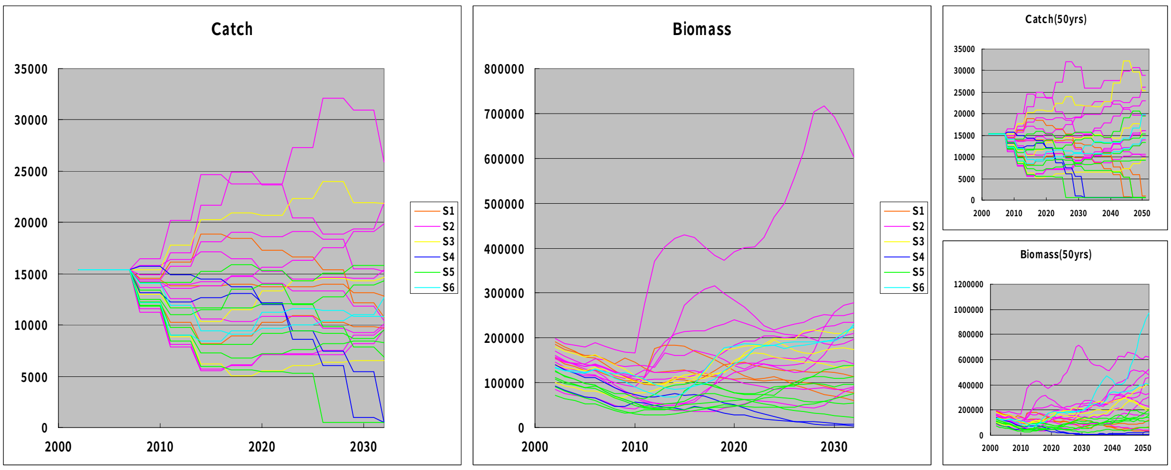


Fig.A2-25 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is HK5_04_4b (TL=0.9, Option-b).

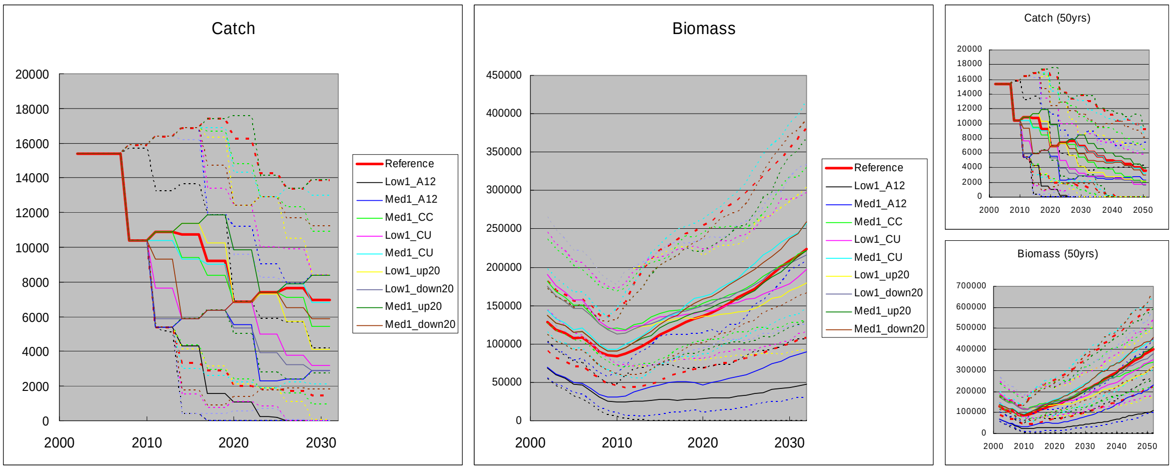


Fig.A2-26 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is HK1_02_2b (TL=1.1, Option-b), which is based on information of CPUE trend of age4+ only.

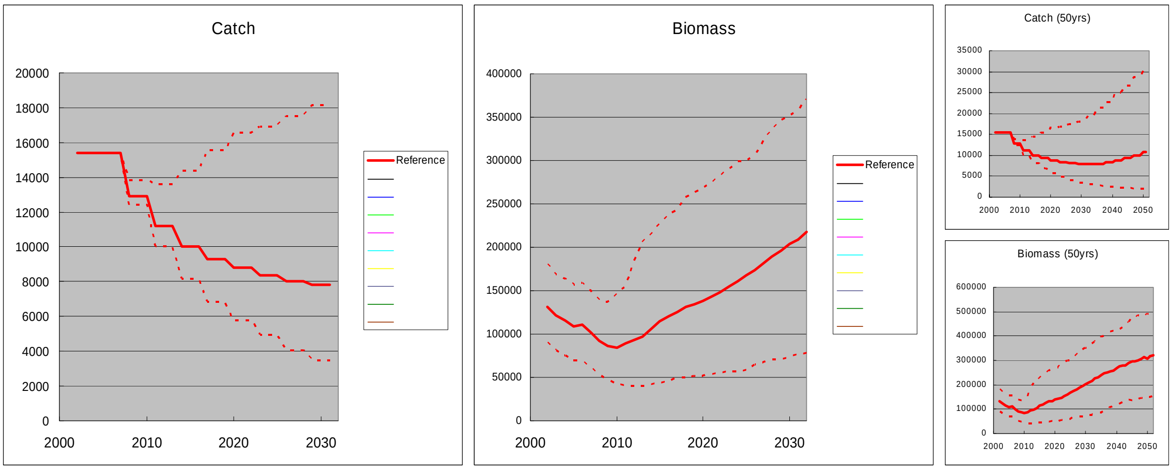


Fig.A2-27 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference scenario. The MP is HK4_01_2b (TL=1.1, Option-b), which is based on information of CPUE level of age4 only.

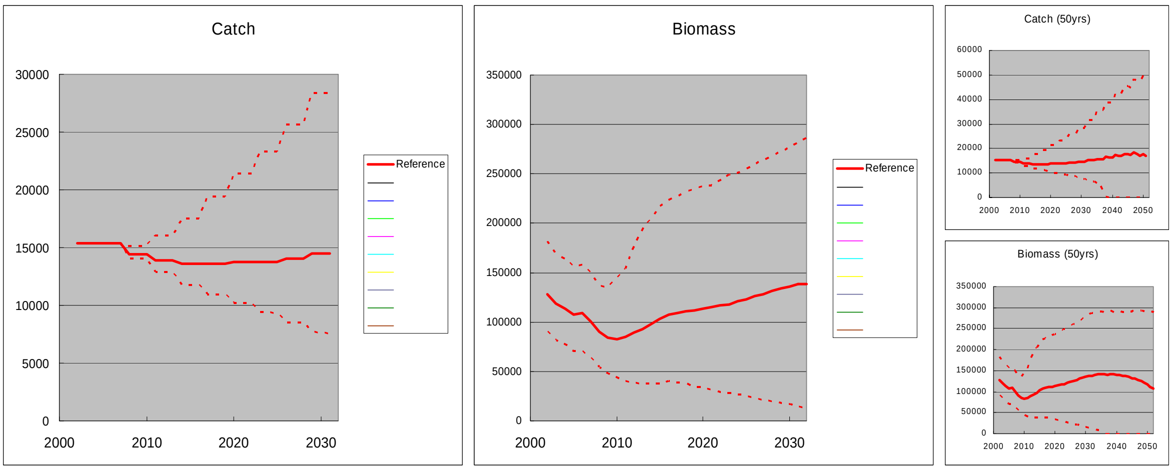


Fig.A2-28 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference scenario. The MP is HK4_01_4b (TL=0.9, Option-b), which is based on information of CPUE level of age4 only.

Appendix 3: "HST"-Tanaka's feedback method

1. Basic idea

We adopted the Tanaka's feedback method used when making the revised management procedure (RMP) in IWC. In this method, annual TAC is decided based on not only the year trend of CPUE (or Biomass) but also the absolute level of that. It gives us more robust MP-rule for TAC control to use the information about both CPUE trend and target CPUE (i.e. CPUE level) than that only using the trend of CPUE in many cases.

Annual TAC is calculated from the following equation:

$$TAC_{y+1} = \begin{cases} TAC_y[1+\gamma\{\alpha * g(CPUE_y) + \beta * h(CPUE_y)\}] & \alpha g(\ ) + \beta h(\ ) > 0 \\ TAC_y[1+\alpha * g(CPUE_y) + \beta * h(CPUE_y)] & \alpha g(\ ) + \beta h(\ ) \le 0 \end{cases} \qquad (1)$$

where

$g(\ )$: function of CPUE trend,

$h(\ )$: function of CPUE level,

α : parameter for providing the relative weight of CPUE trend,

β : parameter for providing the relative weight of CPUE level,

γ : parameter for providing the degree of "non-symmetric" about TAC control.

We utilized the following functional forms as $g(\ )$ and $h(\ )$ in this case. The structure of $h(\ )$ is rather similar to that of so-called 'Hilborn's 2nd model'.

$$g(CPUE_y) = \lambda_y^T$$

$$h(CPUE_y) = \frac{average(CPUE_y)}{\text{target}(CPUE_y)} - 1$$

$$average(CPUE_y) = \frac{1}{L}\sum_{i=1}^{L} CPUE_{y-i} \qquad (2)$$

$$\text{target}(CPUE_y) = \frac{1}{L}\sum_{i=1}^{L} level(CPUE_{y-i})$$

$$level(CPUE_y) = \begin{cases} initCPUE & \text{(the initial year of calculation)} \\ level(CPUE_{y-1}) + step & \text{(otherwise)} \end{cases}$$

where

λ_y^T : the slope of the regression of log(CPUE) versus time over T years,

T : parameter for providing the time period of CPUE trend,

L : parameter for providing the time period of CPUE level,

initCPUE : initial value of level(CPUE) (This is not a control parameter.)

Remark) This initial value "*initCPUE*", which is corresponding to past one observed CPUE, is automatically decided based on the control parameter "*L*".

2. Notes

We carried out the calculation of "Tuning" (i.e. decided the values of above parameters) so as to satisfy the agreed conditions (i.e. levels of B2022/2002, assumptions of TAC change etc.). We present the figures (Figure A3-1~A3-8) of "Tuning", where number of simulation year is set to 50. In addition, we performed another "Tuning" assuming that simulation period is 30 years in order to compare to other candidate MPs using the results of graphs by R software.

The procedure of "Tuning" in HST-model with many parameters is as follows:

1. Fix the parameters of α , T (α =1.0, T=9) and *step* (per year).

$$step = \begin{cases} 0.001 \text{ (tuning level=0.7)} \\ 0.0015 \text{ (tuning level=0.9)} \\ 0.002 \text{ (tuning level=1.1)} \\ 0.003 \text{ (tuning level=1.5)} \end{cases} \tag{3}$$

2. Assume the parameter of L (i.e. initCPUE) based on each tuning level.

3. Adjust the parameters of β and γ so as to satisfy the exact tuning level.

Parameter values and main performance statistics in both cases (50years and 30years) are shown in Table 1 and 2, respectively.

Table 1. Summary of "Tuning" (Simulation period is 50 years).

Name	Scenario	Replicate	α	β	γ	Step	T	L	initCPUE (Year)	B2022/B2002	C(20years)
HST_01_1b	Reference	2000	1	0.25	2	0.001	9	10	0.472859 (1996)	0.697	16245
HST_01_4b	Reference	2000	1	0.75	0.3	0.0015	9	7	0.473037 (1999)	0.900	14080
HST_01_4b	Robustness	200									
HST_01_4b	no_AC	2000								0.949	16168
HST_01_4b	Reduced_rec	2000								0.830	12182
HST_01_2a	Reference	2000	1	0.12	0.4	0.002	9	11	0.713774 (1993)	1.099	11611
HST_01_2b	Reference	2000	1	0.43	0.4	0.002	9	11	0.719861 (1995)	1.103	11606
HST_01_2b	Robustness	200									
HST_01_2b	no_AC	2000								1.225	12610
HST_01_2b	Reduced_rec	2000								0.963	10822
HST_01_2c	Reference	2000	1	0.56	0.4	0.002	9	11	0.719861 (1995)	1.100	11721
HST_01_3b	Reference	2000	1	2.6	0.3	0.003	9	13	0.713774 (1993)	1.501	7063

Table 2. Summary of "Tuning" (Simulation period is 30 years).

Name	Scenario	Replicate	α	β	γ	Step	T	L	initCPUE (Year)	B2022/B2002	C(20years)
HST_01_1b	Reference	2000	1	0.1	2	0.001	9	10	0.472859 (1996)	**0.704**	16183
HST_01_4b	Reference	2000	1	0.7	0.25	0.0015	9	7	0.473037 (1999)	**0.897**	14229
HST_01_4b	Robustness	200									
HST_01_4b	no_AC	2000								0.980	15950
HST_01_4b	Reduced_rec	2000								0.822	12373
HST_01_2a	Reference	2000	1	0.13	0.4	0.002	9	11	0.713774 (1993)	**1.103**	11725
HST_01_2b	Reference	2000	1	0.45	0.4	0.002	9	11	0.719861 (1995)	**1.100**	11530
HST_01_2b	Robustness	200									
HST_01_2b	no_AC	2000								1.236	12495
HST_01_2b	Reduced_rec	2000								0.964	10734
HST_01_2c	Reference	2000	1	0.58	0.4	0.002	9	11	0.719861 (1995)	**1.097**	11640
HST_01_3b	Reference	2000	1	3	0.1	0.003	9	13	0.713774 (1993)	**1.501**	7039

- It seems to be a little difficult to do "Tuning" using complicated MP with many parameters such as "HST" model.
- Substantial TAC reduction seems to be necessary to satisfy the medium tuning level (i.e. B2022/B2002=1.1).

Compared with other Japanese candidate MPs,

- The degree of Catch increase in 2010s (when Biomass gradually increases), especially about the trend of median in the Reference case (and two additional scenarios, no_AC and Reduced_rec), seems not to be so large.
- HST-model can avoid the collapse of biomass in "Low1_A12" scenario (with low productivity) at Tuning_level=0.9.

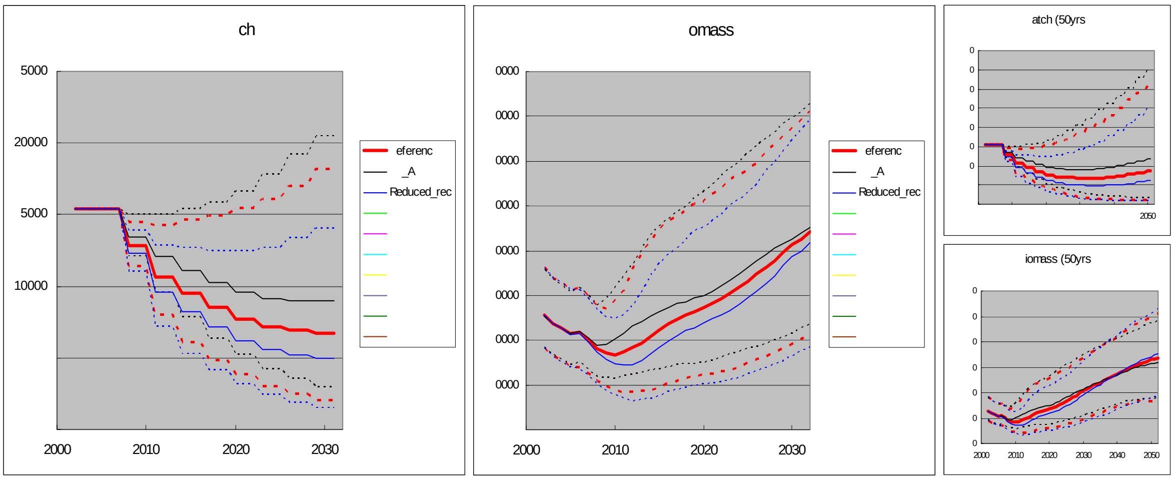


Fig.A3-1 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is HST_01_2b (TL=1.1, Option-b).

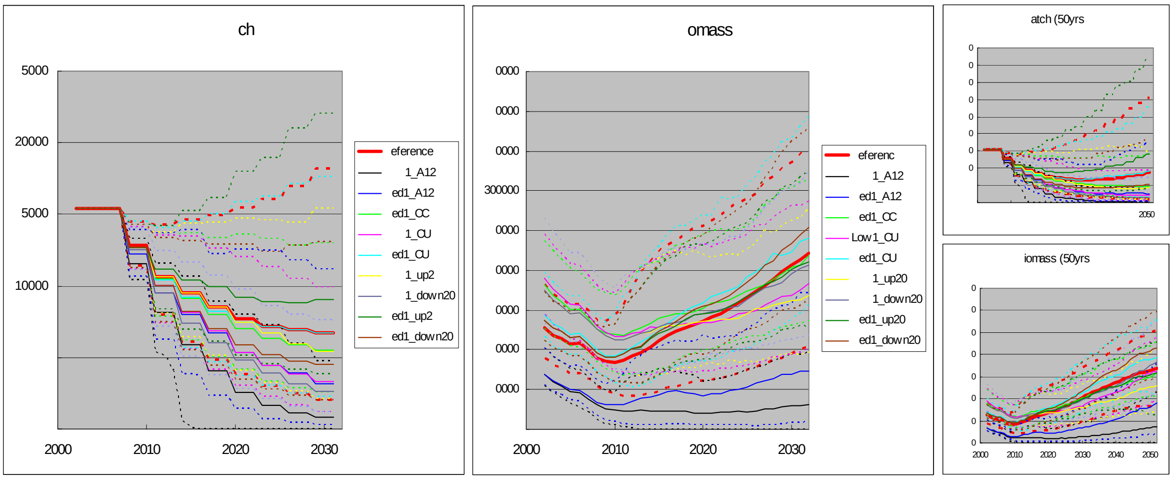


Fig.A3-2 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is HST_01_2b (TL=1.1, Option-b).

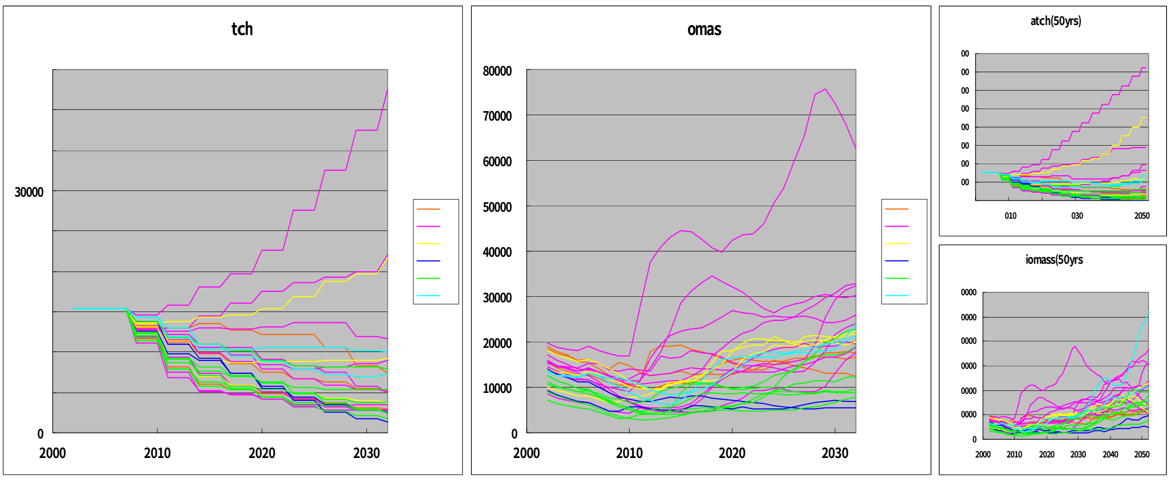


Fig.A3-3 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is HST_01_2b (TL=1.1, Option-b).

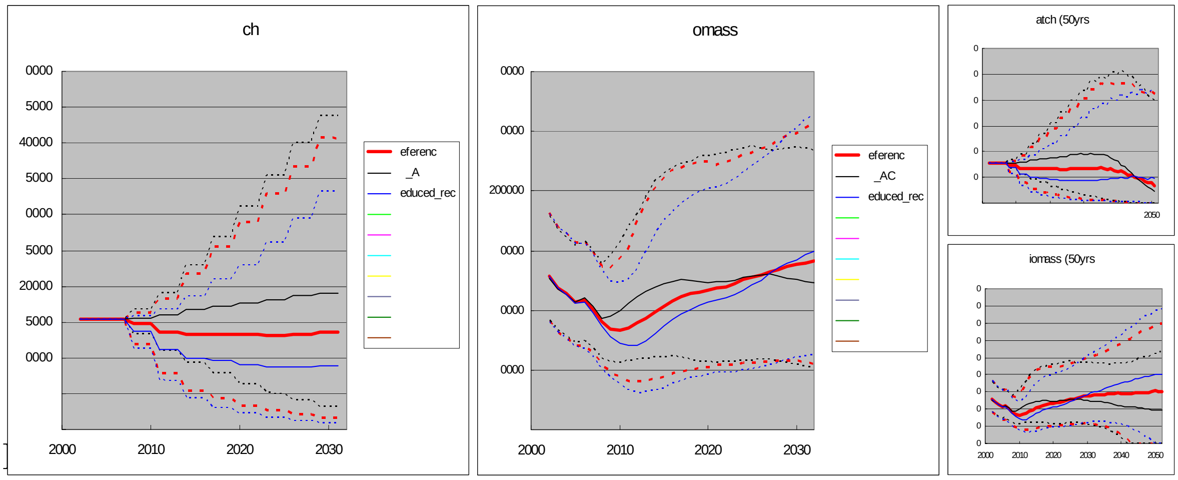


Fig.A3-4 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is HST_01_4b (TL=0.9, Option-b).

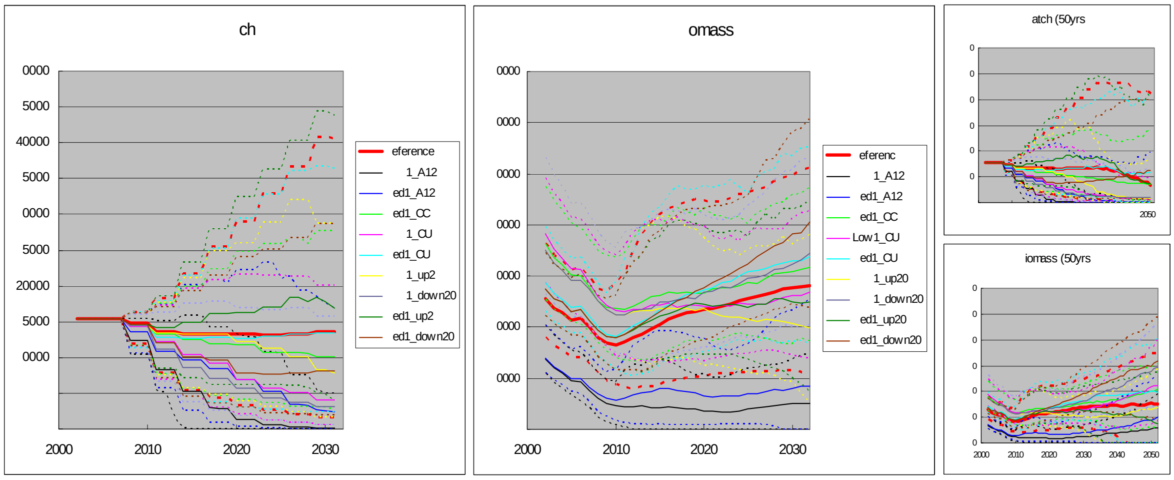


Fig.A3-5 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is HST_01_4b (TL=0.9, Option-b).

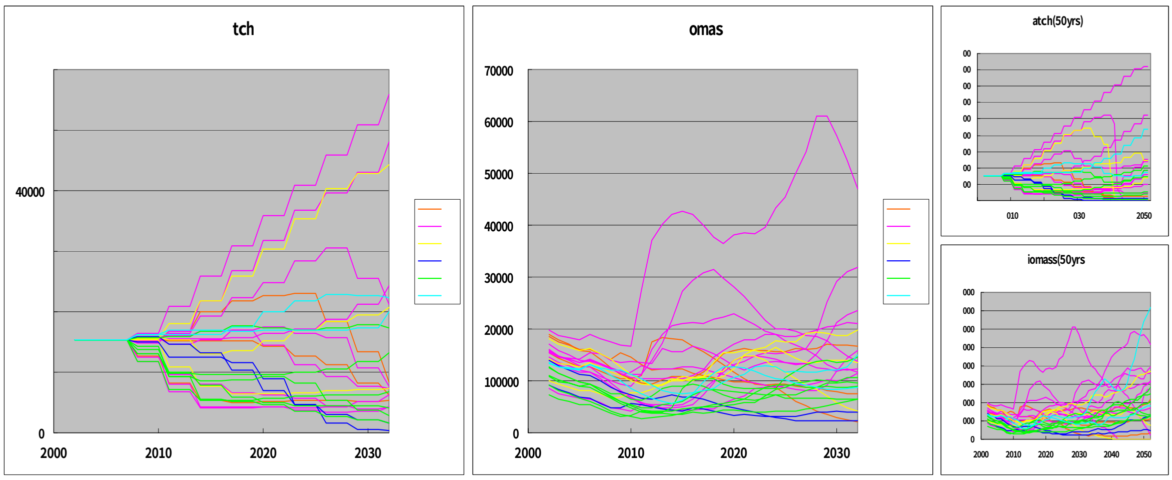


Fig.A3-6 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is HST_01_4b (TL=0.9, Option-b).

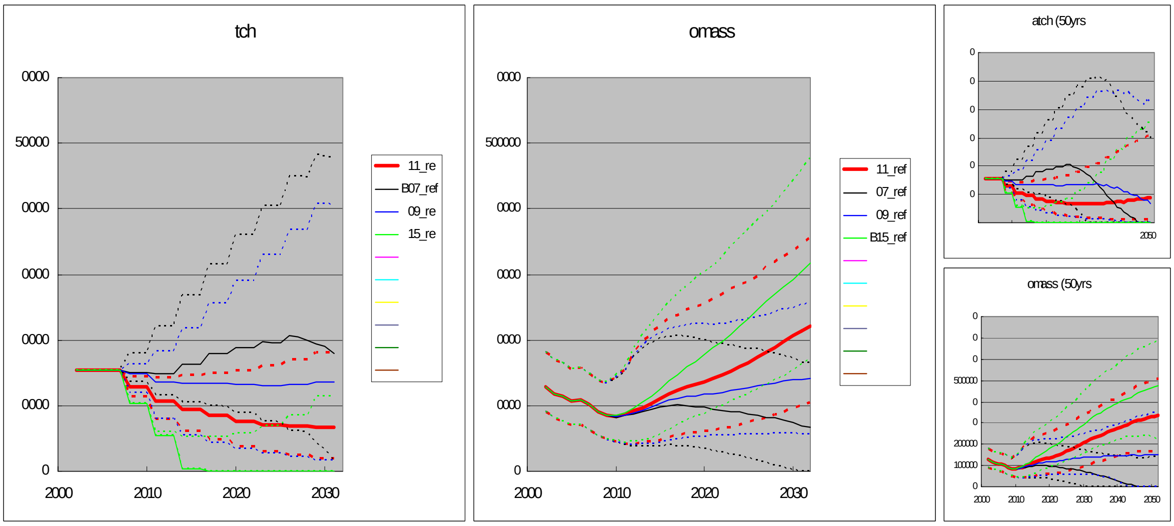


Fig.A3-7 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference scenario at four tuning levels (TL=1.1, 0.7, 0.9, 1.5) with Option-b. The MPs are HST_01.

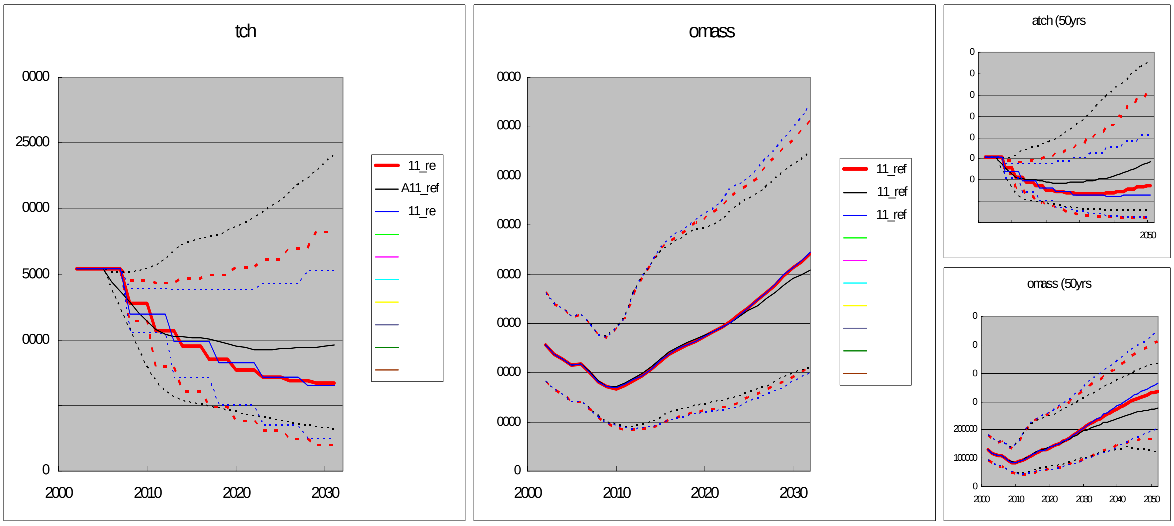


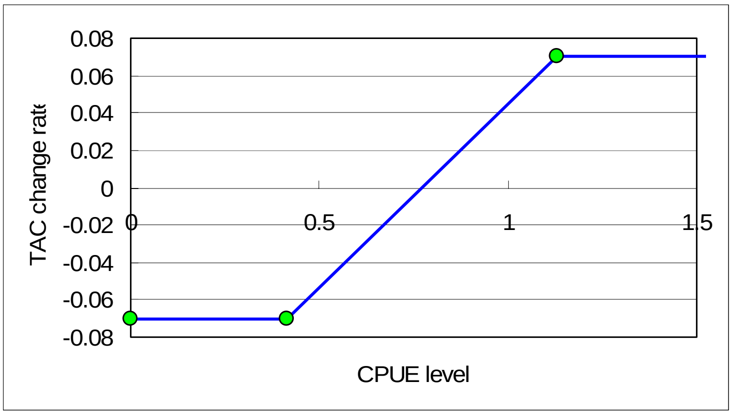
Fig.A3-8 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference scenario with three TAC change options (Option-a, b, and c) at TL=1.1. The MPs are HST_01.

Appendix 4: "STL"-hybrid MP based on CPUE age 4+

1. Basic idea

The structure of this MP is the same as the "STlv1.1v1" presented in the last SAG (Tsuji et al. 2003). This MP determines TAC corresponding to either 4+ CPUE level or CPUE slope. TAC is firstly specified using CPUE level and slope separately in the MP, and then final TAC is set as a minimum of TAC specified by the either ways. Details of TAC specifications by CPUE level and slope are explained as follows.

The relationship between 4+ CPUE level and the rate of TAC change is predefined as a function. The relationship is represented in the following figure.



Two inflection points of the function correspond to CPUE of historically lowest level (0.4146) and 1980 level (1.1299), respectively, and the corresponding TAC change rates (R1 and R2) are the parameters.

TAC specification of using CPUE level is:

$$TAC_{y+1} = TAC_y \times (1 + r)$$

where r is the rate of TAC change determined from the function above, applying the most recent 4+ CPUE available.

TAC specification by CPUE slope is:

$$TAC_{y+1} = \begin{cases} TAC_y \times (1 + k\lambda) & \lambda \geq 0 \\ TAC_y \times (1 + ak\lambda) & \lambda < 0 \end{cases}$$

where

λ: the slope of the regression of ln(4+ CPUE) versus time over T years, a, k, T: control parameters

Final TAC is set as a minimum of TAC values specified using CPUE level or slope.

2. Notes

We present results of trials of following two candidate MPs.

STL_01: T=4, a=0.3 (asymmetric response to **λ**)

STL_02: T=10, a=1.0 (symmetric response to **λ**)

Parameter values used for 50 years simulations are as follows.

MP name	R1	R2	k	a	T	B_{2022}/B_{2002}	C20yrs
STL_01_1b	-0.015	1.50	5.0	0.3	4	0.699	16445
STL_01_2a	-0.125	0.50	5.0	0.3	4	1.099	11720
STL_01_2b	-0.311	0.50	5.0	0.3	4	1.100	11381
STL_01_2c	-0.373	0.50	5.0	0.3	4	1.100	11360
STL_01_3b	-0.950	-0.20	5.0	0.3	4	1.496	7320
STL_01_4b	-0.135	0.50	5.0	0.3	4	0.900	13986

MP name	R1	R2	k	a	T	B_{2022}/B_{2002}	C20yrs
STL_02_1b	*						
STL_02_2a	-0.164	0.50	2.0	1.0	10	1.098	11205
STL_02_2b	-0.309	0.50	2.0	1.0	10	1.099	11365
STL_02_2c	-0.367	0.50	2.0	1.0	10	1.100	11482
STL_02_3b	-0.95	-0.20	2.0	1.0	10	1.496	7320
STL_02_4b	-0.154	0.50	2.0	1.0	10	0.900	13958

*not available

Results (Figs.A4-1 to -16) indicates that STL_01 shows higher interannual variability in TACs and rapid recovery of TAC when biomass starts to increase.

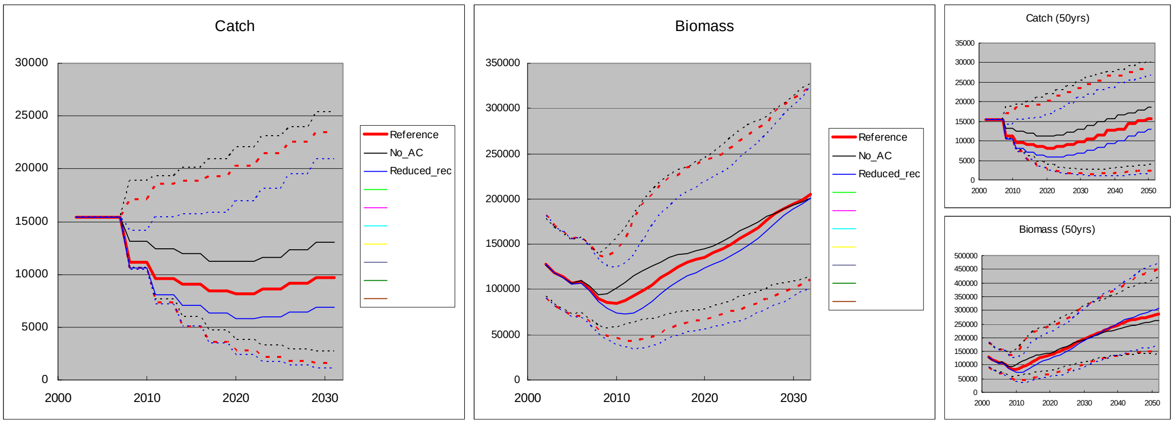


Fig.A4-1 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is STL_01_2b (TL=1.1, Option-b).

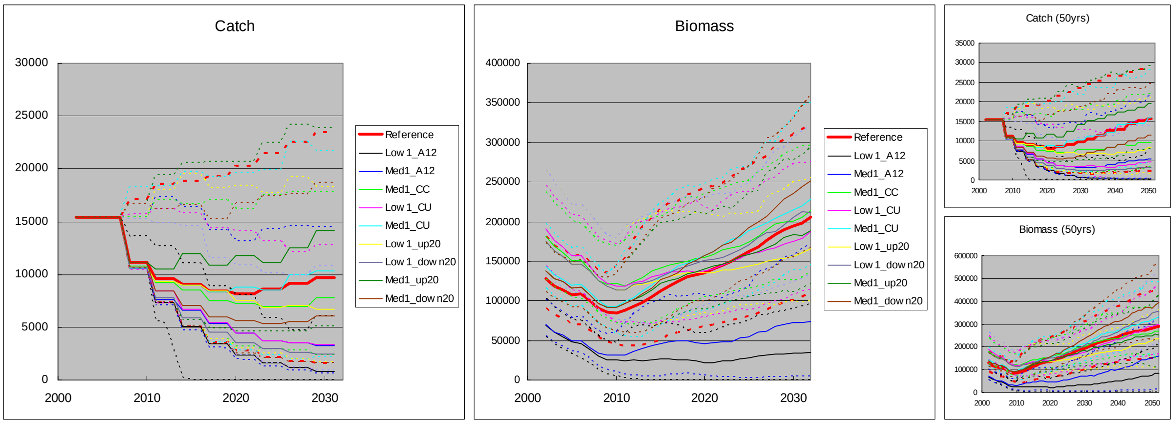


Fig.A4-2 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is STL_01_2b (TL=1.1, Option-b).

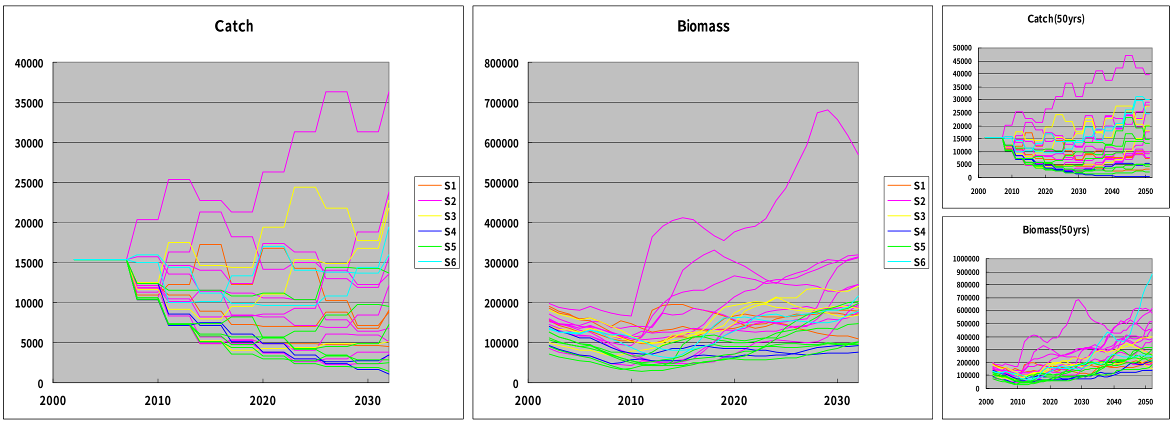


Fig.A4-3 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is STL_01_2b (TL=1.1, Option-b).

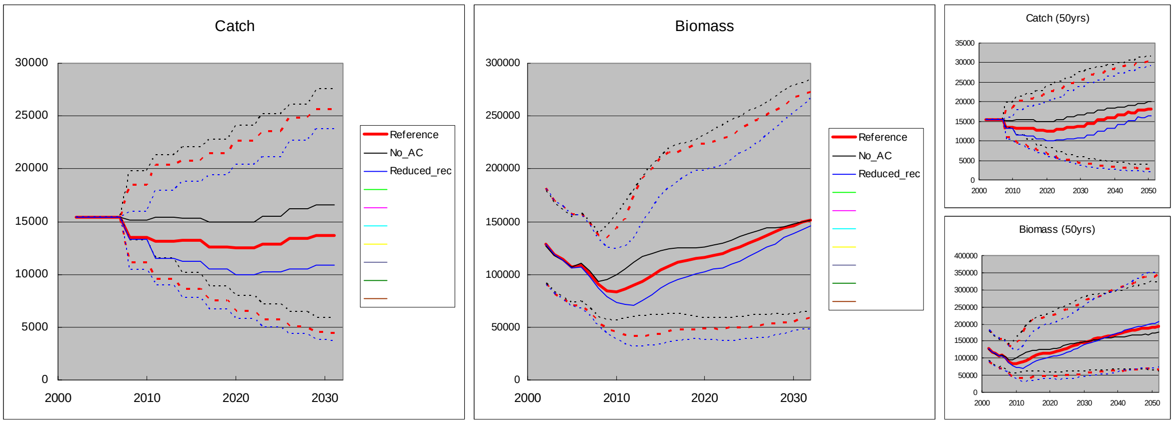


Fig.A4-4 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is STL_01_4b (TL=0.9, Option-b).

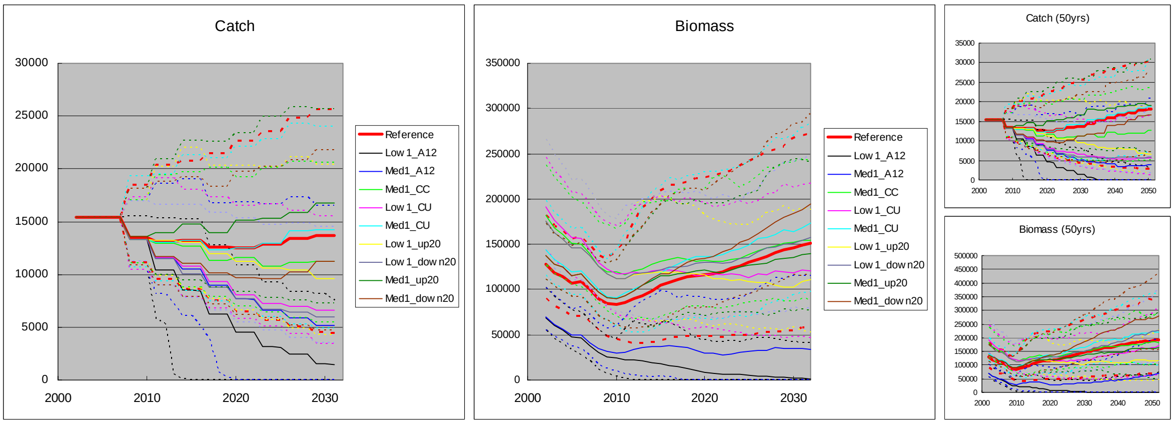


Fig.A4-5 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is STL_01_4b (TL=0.9, Option-b).

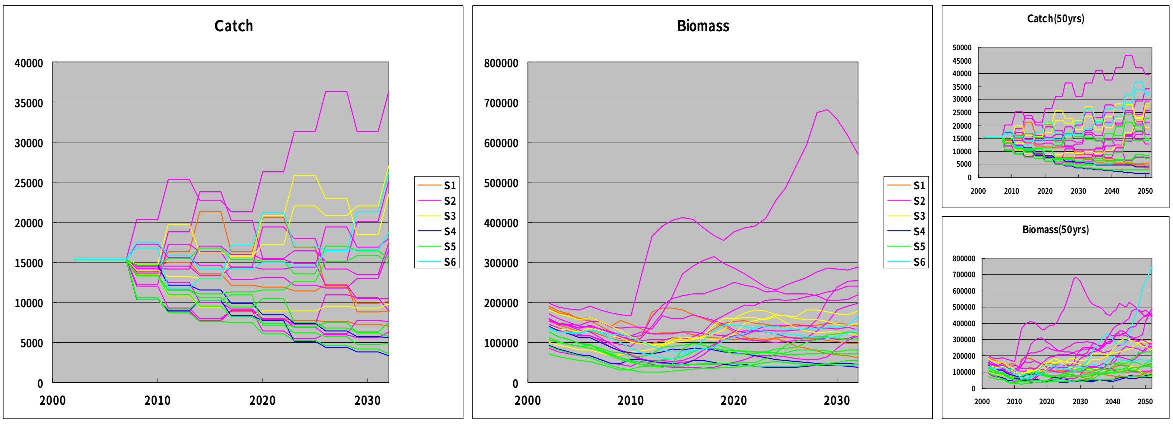


Fig.A4-6 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is STL_01_4b (TL=0.9, Option-b).

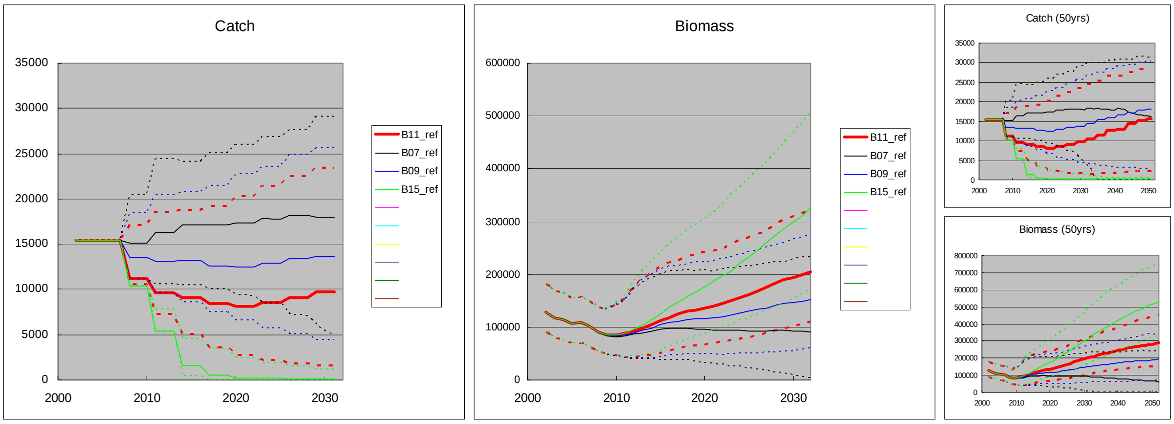


Fig.A4-7 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference scenario at four tuning levels (TL=1.1, 0.7, 0.9, 1.5) with Option-b. The MPs are STL_01.

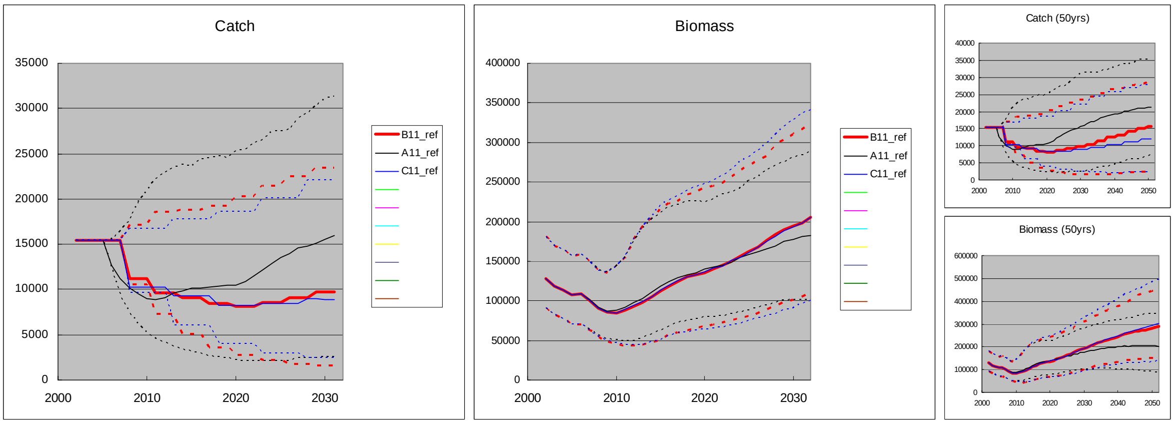


Fig.A4-8 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference scenario with three TAC change options (Option-a, b, and c) at TL=1.1. The MPs are STL_01.

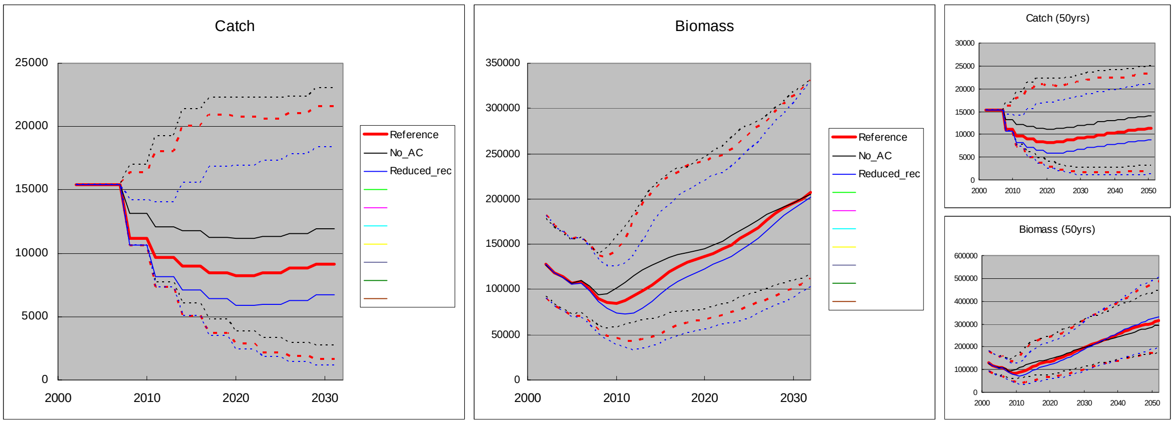


Fig.A4-9 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is STL_02_2b (TL=1.1, Option-b).

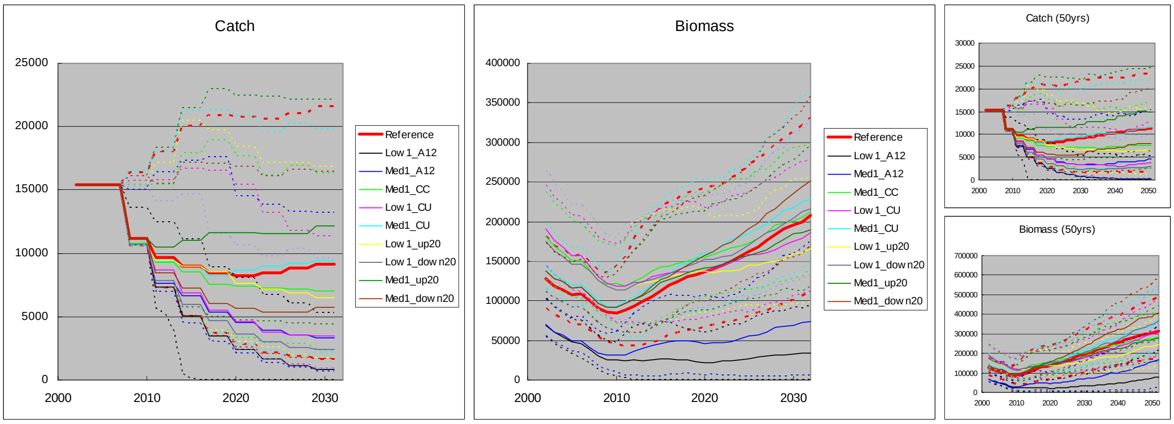


Fig.A4-10 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is STL_02_2b (TL=1.1, Option-b).

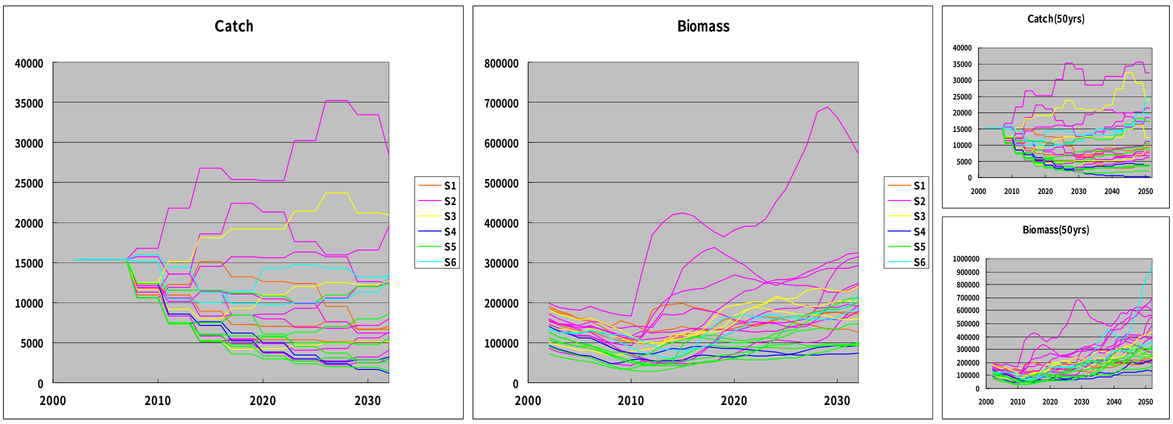


Fig.A4-11 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is STL_02_2b (TL=1.1, Option-b).

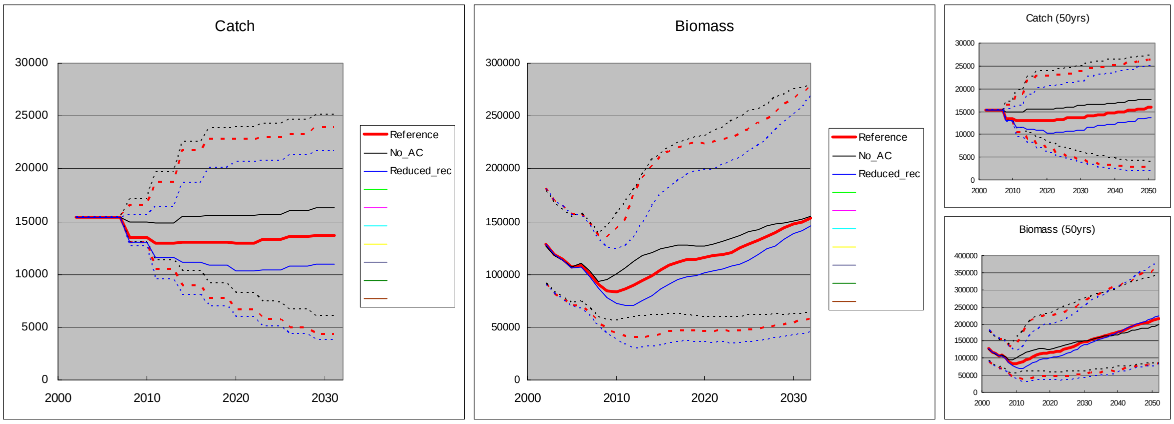


Fig.A4-12 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is STL_02_4b (TL=0.9, Option-b).

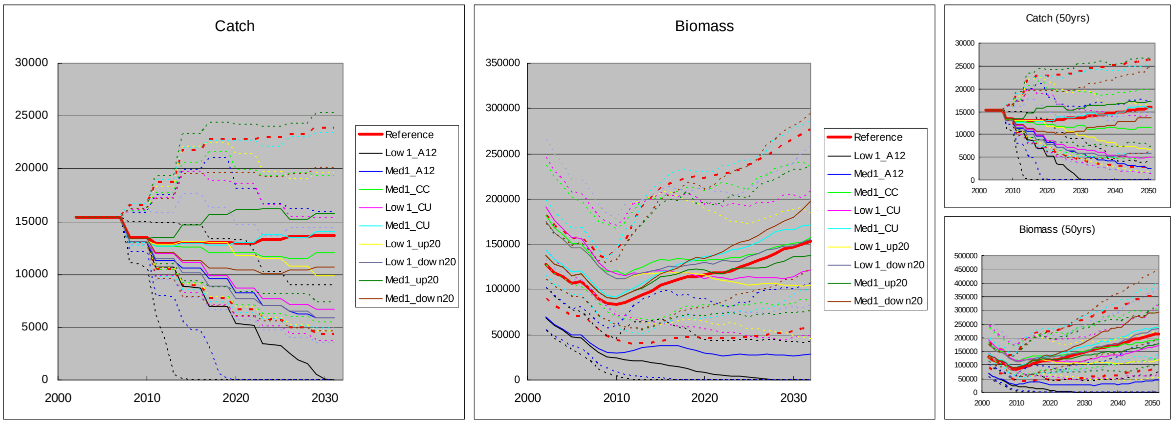


Fig.A4-13 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is STL_02_4b (TL=0.9, Option-b).

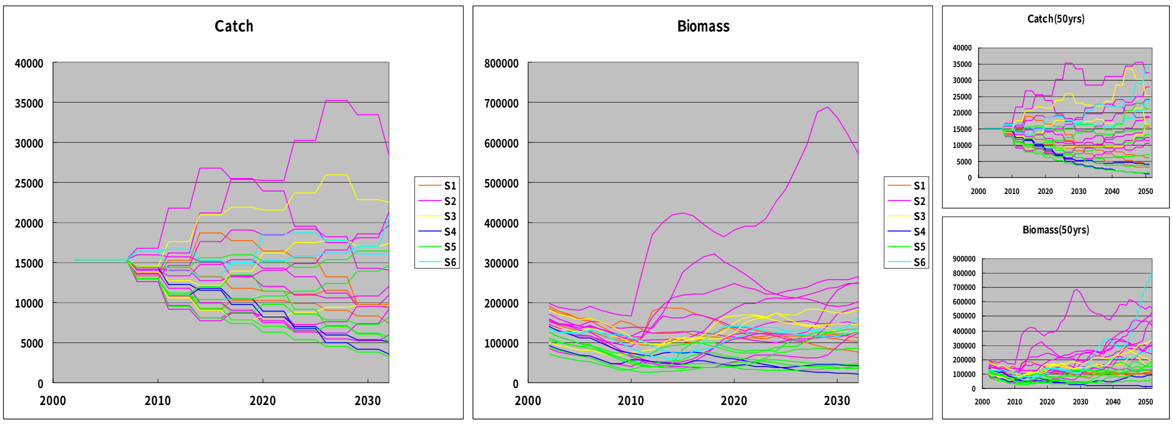


Fig.A4-14 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is STL_02_4b (TL=0.9, Option-b).

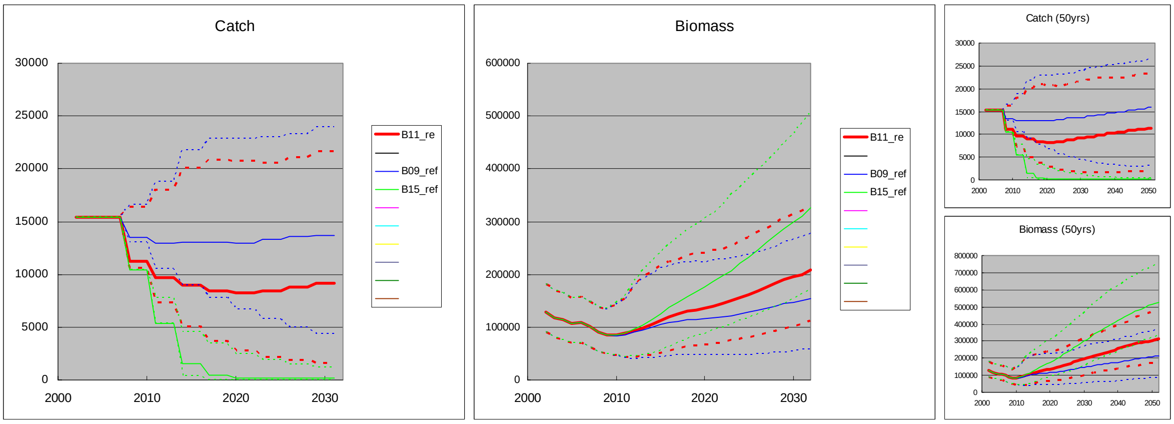


Fig.A4-15 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference scenario at three tuning levels (TL=1.1, 0.9, 1.5) with Option-b.   The MPs are STL_02.

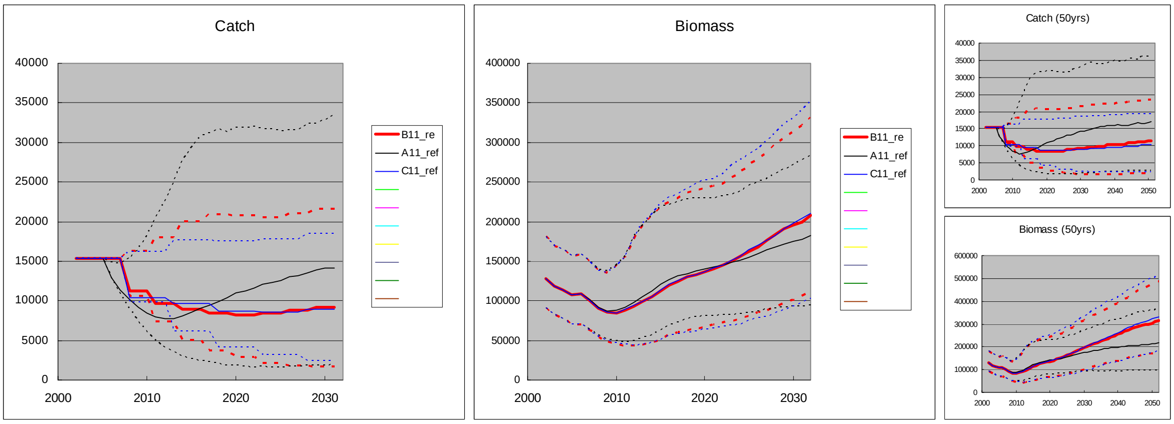


Fig.A4-16 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference scenario with three TAC change options (Option-a, b, and c) at TL=1.1.   The MPs are STL_02.

Appendix 5: “KH8”-asymmetric TAC response

1. Basic idea

The structure of KH8 is the same as the KH5 presented in the last SAG (Tsuji et al. 2003), except for the inclusion of the agreed constraints for year to year changes in TACs. The TAC is calculated as follows.

$$TAC_{y+1} = \begin{cases} TAC_y \times \left(1 - \frac{C_1^2}{4C_2}\right) & \left(1 - \frac{C_1^2}{4C_2}\right) < \left(1 + C_1\lambda + C_2\lambda^2\right) \\ TAC_y \times \left(1 + C_1\lambda + C_2\lambda^2\right) & C_3 \le \left(1 + C_1\lambda + C_2\lambda^2\right) \le \left(1 - \frac{C_1^2}{4C_2}\right) \\ TAC_y \times C_3 & \left(1 + C_1\lambda + C_2\lambda^2\right) < C_3 \end{cases}$$

where,

λ : the slope of the regression of ln(CPUE) versus time over the 10 years

C_1、C_2、C_3 : control parameters (here $C_2 \leqq 0$)、

Asymmetric TAC change in response to λ is a feature of this MP.

2. Notes

Parameter values used for 50 years simulations are as follows.

MP name	C1	C2	C3	B_{2022}/B_{2002}	C20yrs
KH8_01_1b	3.0	-0.1	0.932	0.701	16425
KH8_01_2a	2.1	-17.3	0.7	1.102	11956
KH8_01_2b	5.0	-500	0.5	1.100	11755
KH8_01_2c	5.0	-450	0.5	1.101	11500
KH8_01_3b	*				
KH8_01_4b	2.1	-23	0.7	0.901	16425

*not available

Results indicated that in many cases TAC continue to decrease even though biomass starts to increase at the tuning levels of 0.9 and 1.1. The cause of this discrepancy seems to be asymmetric TAC change in response to λ, and hence we did not explore this MP further.

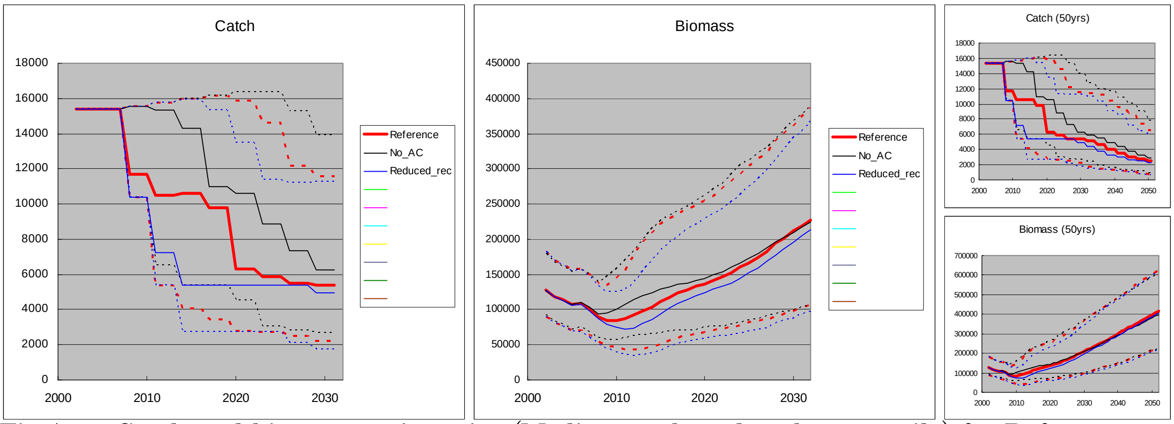


Fig.A5-1 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is KH8_01_2b (TL=1.1, Option-b).

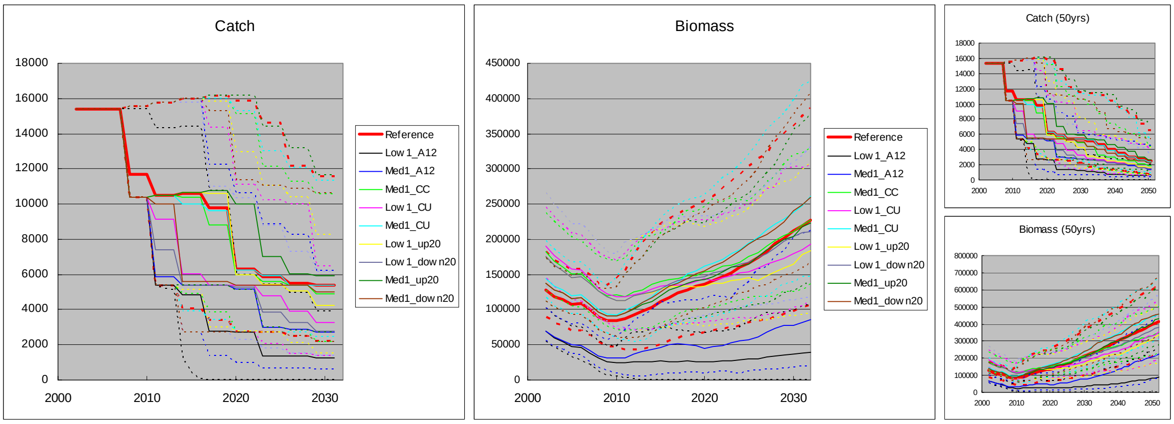


Fig.A5-2 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is KH8_01_2b (TL=1.1, Option-b).

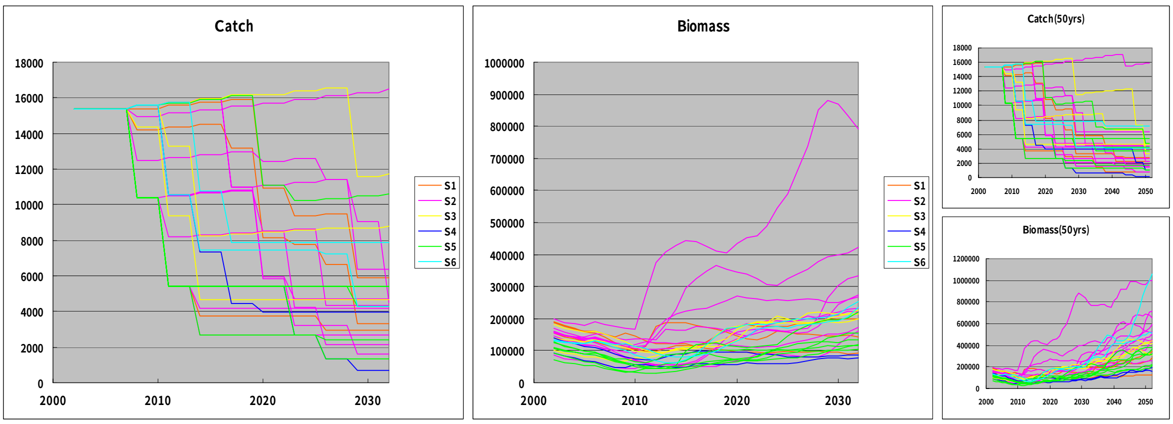


Fig.A5-3 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is KH8_01_2b (TL=1.1, Option-b).

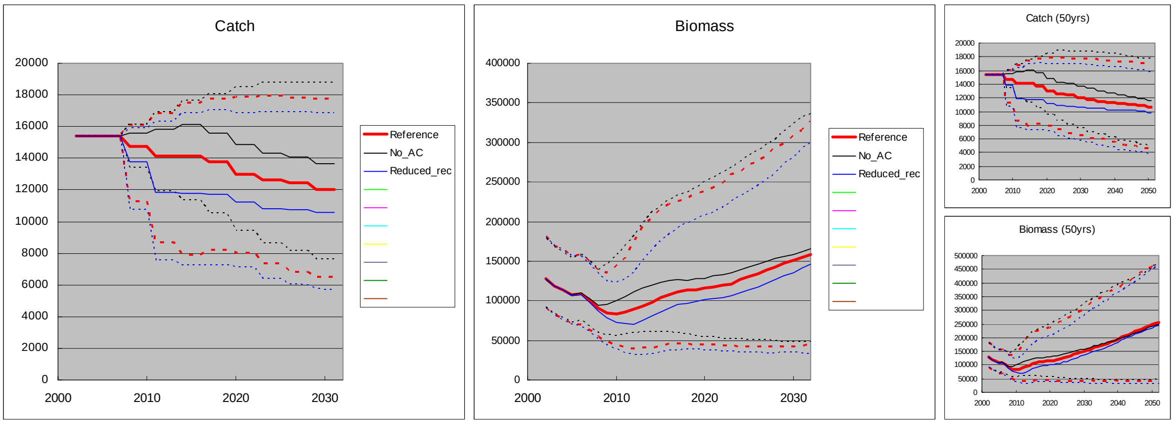


Fig.A5-4 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, No_AC and Reduced_rec scenarios. The MP is KH8_01_4b (TL=0.9, Option-b).

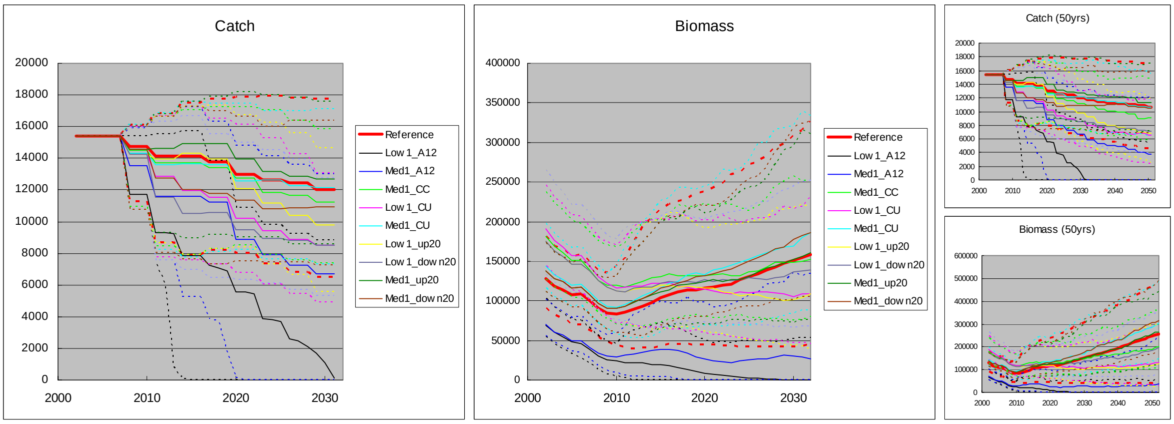


Fig.A5-5 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference, and nine robustness scenarios. The MP is KH8_01_4b (TL=0.9, Option-b).

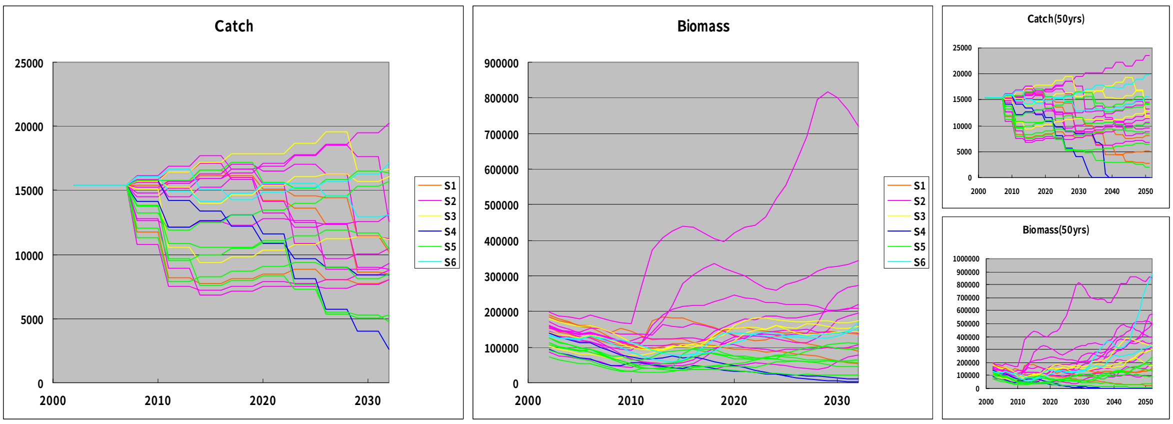


Fig.A5-6 Individual trajectories of catch and biomass for Reference scenario. Each reference scenario (S1 to S6) is indicated by different colors. The MP is KH8_01_4b (TL=0.9, Option-b).

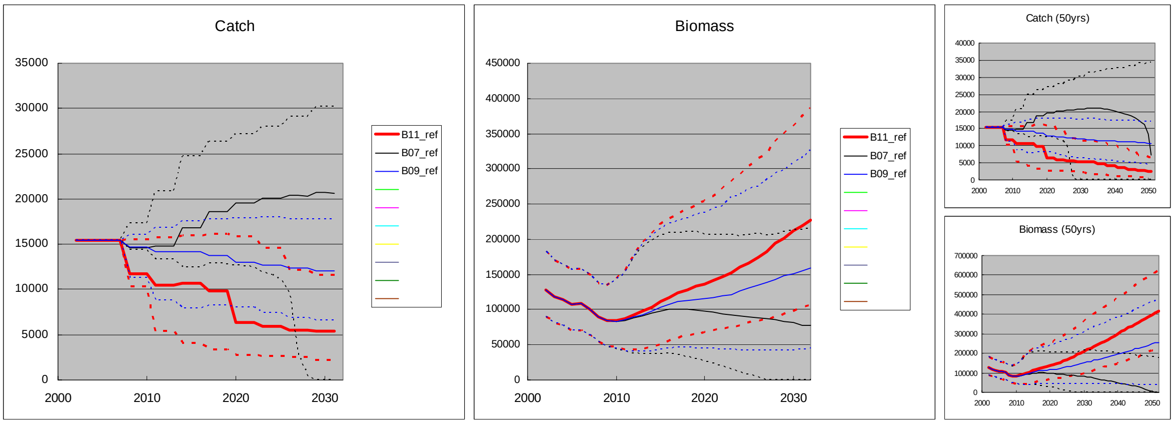


Fig.A5-7 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference scenario at three tuning levels (TL=1.1, 0.7, 0.9) with Option-b. The MPs are KH8_01.

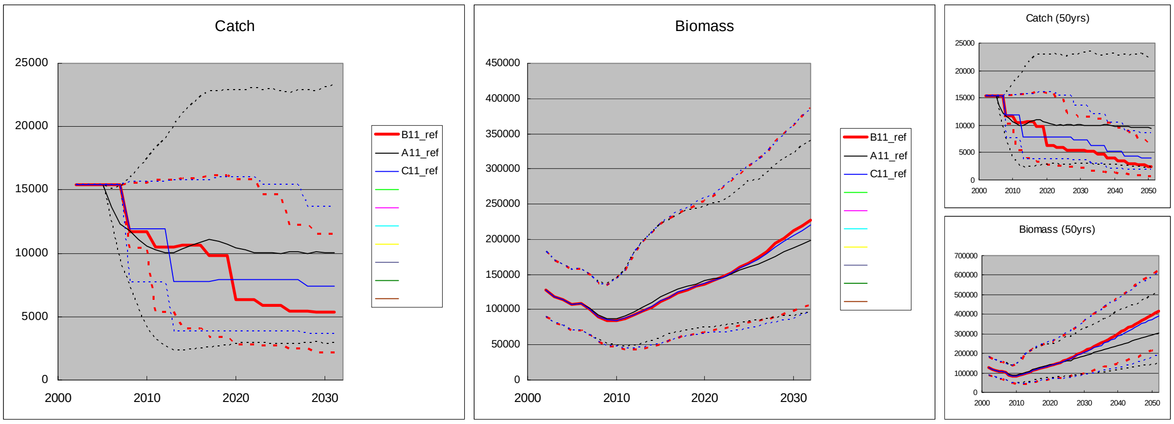


Fig.A5-8 Catch and biomass trajectories (Median, 10th and 90th percentile) for Reference scenario with three TAC change options (Option-a, b, and c) at TL=1.1. The MPs are KH8_01.