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Biological reference points and Future projections of Pacific bluefin tuna

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Summary

This paper presents a list of biological reference points (BRPs) and results of future projection using a preliminary stock assessment result of Pacific Bluefin tuna (PBF). The stock status in relation to estimated BRPs suggests that fishing mortality on this stock during 2007-2009 exceeds those during 2002-2004. Empirical based BRP suggests that current F exceeds F_{med} by 20-30%. Future projection indicates that future spawning stock biomass (SSB) can be recovered to the historical median level on average under $F_{2002\text{-}2004}$, while current F ($F_{2007\text{-}2009}$) causes future SSB to further decline of SSB to 30-40% of historical SSB.

Evaluation of the effectiveness of five future harvesting scenarios, with the current conservation and management measure (CMM) and with Japanese regulation of purse seine fisheries, was conducted by using performance index on SSB and total catch. The trade-off for the increasing SSB is reduction of the catch is clearly appeared for most of the scenarios. However, the trajectory of a scenario ($F_{2007\text{-}2009}$ with catch regulation on Japanese purse seine fishery) shows that SSB can sharply recover with steadily increasing catch. These results mean that the balance of the performance index is better than the others. The results of the risk assessment demonstrates that the risks of future SSB to decline below the benchmarks (Minimum SSB, Average ten historical level (ATHL), historical lowest 10 %, and historical lowest 20%) are very low for all scenarios.

1. Introduction

The Western and Central Pacific Fisheries Commission (WCPFC) adopted conservation and management measure (CMM) for Pacific Bluefin tuna (PBF), *Thunnus Orientalis*, in December 2010 (WCPFC 2010). They highlighted the importance that the level of fishing mortality (F) is to be decreased below the 2002-2004 levels, particularly on juvenile age classes, for 2011 and 2012. The measure also includes reducing catches of juveniles (ages 0-3) below the 2002-2004 levels. Taking into account of the CMM and in the hope that future catch of bigger fish to be increased, the fishery Agency of Japan determined to introduce the conservation and management measures for domestic fisheries as follows: (1) Total catch for large and medium scale purse seine fisheries targeting on immature fish (defined as smaller than 30kg in round weight) in the East China Sea and the Sea of Japan is restricted to 4,500 tons a year :(2) Total catch for large and medium scale purse seine fisheries targeting on matured fish in the spawning season in the Sea of Japan is restricted to 2000 tons a year (we refer to these restrictions as “Capping” in this paper). These managements have been implemented since April 2011.

Biological reference points (BRPs) represents a state of the fishery or population and the characteristic are believed to be useful for management of the unit stock (Caddy and Mahon 1995).

Some of the BRPs for PBF were listed in the report of previous International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) PBF working group meeting in 2010 and the effects of the uncertainties in the configurations and parameterization of the Stock Synthesis (SS) model (Methot 2011) on the BRPs were examined (Kai *et al*. 2010). As the results, it was recognized that some BRPs based on yield per recruit (YPR) and spawning biomass per recruit (SPR) (i.e. F_{max}, $F_{0.1}$, $F_{20\%}$, $F_{30\%}$, and $F_{40\%}$) were sensitive to the uncertainties. On the other hand, empirical Spawning-Recruitment (*S-R*) based BRPs (i.e. F_{loss} and F_{med}) and $F_{10\%}$ were insensitive to them.

Future projections of PBF are useful to predict the future stock status and harvests if we maintain the current fishing mortality and to assess the effectiveness of the management measures. The objective of the future projection is to conduct the risk assessments and to evaluate the likelihood of the target achievement for various possible scenarios. In the previous meeting in 2010, it was concluded based on the future projection that *F* should be reduced to the level during 2002-2004, at least, for the purposes of avoiding risks for spawning stock biomass (SSB) to drop below historical lowest SSB level, which might cause recruitment overfishing, and recovering SSB near the historical median level (Ichinokawa *et al*. 2010).

This document provides (1) a list of BRPs; (2) predictions of future stock status and harvests; (3) probability of future SSB falling below threshold SSB, based on stock assessment results presented by the preliminary base case run by Iwata *et al*. (2012). In the future projection, evaluation of effectiveness of some future harvesting scenarios is also conducted.

2. Materials and Methods

The computation of the BRPs and future projections were conducted based on preliminary base case results of stock assessment of PBF (1952-2010) (Iwata *et al*. 2012). Point estimation of base case and those from 300 times bootstrap runs based on the base case are used. Estimates in terminal year (i.e. 2010) were not used because of the uncertainties of the most recent year's estimation.

Geometric mean fishing mortality (*F*) for 2007-2009 ($F_{2007\text{-}2009}$) is used as a benchmark representing the recent year's *F* (Current F), replaced from arithmetic mean of *F* used in the last stock assessment, in order to reduce the effect of the outlier among the years. The computation of BRPs and future projections are implemented using the statistical analysis software R. The future projections are composed of the age-structured population dynamics model compatible with SS (Ichinokawa 2011).

2.1 Biological reference points

Because no single biological reference point (BRPs) for PBF has been determined yet, commonly used BRPs (F_{max} (= F_{msy}), $F_{0.1}$, $F_{\%spr}$, F_{loss}, F_{med}), which were listed in the previous meeting (Kai *et al*. 2010a), are computed and compared under different benchmark years between preliminary base case in 2012 and previous base case in 2010. Periods for 2002-2004 (reference year in CMM), 2004-2006 (reference year in previous current F) and 2007-2009 (reference year in new current F) are used as benchmark years. Comparisons of the average *F* at age are shown in **Appendix**.

2.2 Future projections

2.2.1 Specification of future projections:

- We basically show 10 years trajectories of future projection to 2020 to evaluate short-term response of future management scenarios. In addition, projection to 2035, which can be seen as equilibrium statuses are also shown.
- Future recruitments are determined by random-resampling from the historical recruitments during 1952-2009. The average number of recruitments is 14,151 thousands (*CV* = 0.614).
- Total number of simulations is 6000: 300 iterations of bootstrap with 20 times stochastic simulations for each bootstrap run. Each stochastic projection is repeated 20 times using different recruitment trajectories and same bootstrap result.
- Future harvesting strategy is constant *F* as explained below. Additional management option ('Capping') are also included by setting upper limit of the catch in some specific fleets.
- The control of *F* starts from 2011. *F* in 2010 is assumed to be $F_{2007\text{-}2009}$ for all scenarios.
- In the "Capping" scenario, upper limit of catch is set to be 5000 tons for purse seine fisheries targeting on immature fish (including catch of Korean fisheries, SPSS fleet 2) and 2000 tons for Japanese purse seine fisheries targeting on mature fish in the Sea of Japan(TPS, fleet3). All the "Capping" is started from 2011.

2.2.2 Future harvesting scenarios

Five basic scenarios are provided based on the CMM and Japanese regulations.

S0: $F_{2007\text{-}2009}$

S1: $F_{2002\text{-}2004}$

S2: $F_{2007\text{-}2009}$ with "Capping"

S3: $F_{2002\text{-}2004}$ with "Capping"

S4: $F_{2002\text{-}2004}$ with "Capping", but EPO-PS is F_{2010}

2.3 Performance index on SSB and catch for the management evaluation

Eight performance indices are used to evaluate effectiveness of the 5 management scenarios from S0 to S4.

(1) Mean SSB (tons) for 2011-2020 years

(2) Minimum SSB (tons) for 2011-2020 years

(3) Mean SSB (tons) for 2017-2020 years (Last 3 years)

(4) Coefficient of variation (*CV*) on the SSB (tons) for 2011-2020 years

(5) Mean catch (tons) for 2011-2020 years

(6) Mean catch (tons) for 2011-2013 years (Initial 3 years)

(7) Mean catch (tons) for 2018-2020 years (Last 3 years)

(8) Coefficient of variation (*CV*) on the catch (tons) for 2011-2020 years

2.4 Risk assessment and likelihood evaluation

We assessed the probability that future minimum SSB would fall below a threshold SSB (**Table1,Figure1**) during future 10 years from 2011 to 2020, and assessed the likelihood that future SSB in 2020 exceeds a target SSB (**Table1,Figure1**). In these assessments, we calculated the probability with the following six threshold level of SSB;

(1) Minimum SSB (tons)

(2) Average ten historical lowest (ATHL) SSB (tons)

(3) 10% historical lowest SSB (tons)

(4) 20% historical lowest SSB (tons)

(5) 30% historical lowest SSB (tons)

(6) 40% historical lowest SSB (tons)

The probability is defined based on the following formulae:

$$\Pr\left[\mathrm{SSB}_{future}^{k,b} < \mathrm{SSB}_{threshold}\middle|F\right] = \frac{1}{b_{max}k_{max}}\sum_{k=1}^{b_{max}k_{max}} ||\min\left(\mathrm{SSB}_{2011-2020}^{k,b}\right) < \mathrm{SSB}_{threshold}||$$

(i),

where k (k=1,2,…,$k_{\max}$(=20)) is number of stochastic simulation, b(b=1,2,…,$b_{\max}$(=300)) is number of bootstrap iterations, and double bracket || indicates a logical test with outcome 0 (if false) or 1(if true).

And we calculate the likelihood with the following a target level of SSB;

(7) Historical median of the SSB (tons)

$$\mathrm{Likelihood}\left[\mathrm{SSB}_{future}^{k,b} \geq \mathrm{SSB}_{target}\middle|F\right] = \frac{1}{b_{max}k_{max}}\sum_{k=1}^{b_{max}k_{max}} ||\mathrm{SSB}_{2020}^{k,b} \geq \mathrm{SSB}_{target}|| \quad \text{(ii)}$$

We use three types of threshold and target on SSB: (I) Point estimation of SSB during stock assessment period based on the preliminary base case: (II) Point estimation of SSB during stock assessment period based on each bootstrap run (Note that the each threshold and target is used for every 20 future stochastic runs): (III) Median of the 300 threshold and target on SSB (each threshold and target is computed from the results of 300 bootstrap runs by using second type method(II)) (**Table 1**, **Figure 1**).

3. Results

3.1 Biological reference points

The ratios of BRPs (F of potential BRPs to F in benchmark years) from the current base-case in 2012 were almost identical to those from the previous base-case in 2010 for $F_{2002\text{-}2004}$ and $F_{2004\text{-}2006}$ (**Table 2, Figure 2**). But the respective ratios of F_{med} and F_{loss} from base-case in 2012 were slightly decreased and increased compared to those from base-case in 2010. All of the ratios for $F_{2007\text{-}2009}$ became worse than those for $F_{2002\text{-}2004}$.

3.2 Future projections

Some examples of future trajectories on the SSB (tons) were shown in **Figure 3**. The future trajectories show great differences between runs and the confidence intervals become wider with the years (the maximum range of the SSB is about 40,000 tons). This result indicated that future projections have a large uncertainty.

Past and future trajectories on SSB and total catch for basic harvest scenarios (S0-S4) were shown in **Figure 3-5**. The trajectory of S0 ($F_{2007\text{-}2009}$) showed that future median SSB would not exceed the historical median level on an average. On the other hand, the trajectory of S1 ($F_{2002\text{-}2004}$) showed that future median SSB would be above the historical median level **(Figure 4)**. In addition, the trajectories of S2 ($F_{2007\text{-}2009}$ with Capping) and S3 ($F_{2002\text{-}2004}$ with Capping) showed that future median SSB exceeds the historical median level **(Figure 4, 5)**. However, the trajectories of S4 ($F_{2002\text{-}2004}$ with "Capping", but F for EPO-PS remains at the level in 2010) showed that future median SSB would not exceed the historical median level **(Figure 5)**. The medians of future trajectories on SSB (tons) and catch (tons) were compared among the five scenarios (**Figure 6**). The trade-off for the increasing SSB is reduction of the catch was clearly appeared for the trajectories of S1 ($F_{2002\text{-}2004}$) and S3 ($F_{2002\text{-}2004}$ with Capping). However, the trajectory of S2 ($F_{2007\text{-}2009}$ with Capping) showed that SSB was sharply recovered and catch was constantly increased.

3.3 Performance index on SSB and catch for the management evaluation

Comparisons of the eight performance indices scaled by the averages among five scenarios (S0-S4) were shown in **Tables 3-4**, and **Figure 7** and the effectiveness of the management for each scenario was evaluated using the radar charts (**Figure 8**). Increase of SSB and catch can't be expected for S0 ($F_{2007\text{-}2009}$). Increase of SSB and stable catch can be expected for S2 ($F_{2007\text{-}2009}$ with Capping), although the variation of SSB was large. Rapid recovery of the SSB can be expected for S1 ($F_{2002\text{-}2004}$) and S3 ($F_{2002\text{-}2004}$ with Capping). However, the variation of the SSB was large for S3 ($F_{2002\text{-}2004}$ with Capping). As for the catch, increasing speed of the catch was slow for either of them (S1 and S3) and the variation of the catch was large for S1 ($F_{2002\text{-}2004}$). The recovery of the SSB may not be expected for S4 ($F_{2002\text{-}2004}$ with Capping, but with F for EPO-PS at 2010 level), but the increase of the catch may be expected.

3.4 Risk assessment and likelihood evaluation

Probability that future minimum SSB falling below the threshold benchmarks on SSB during next 10 years and the likelihood that future SSB in 2020 is beyond a target SSB were shown in **Table 5-7**. Similar trends of the probabilities were observed between the tables. The probabilities that future minimum trajectory falling below the benchmarks of Minimum SSB, ATHL, lowest 10 %, and lowest 20% were very low for all scenarios. However, the probability that future minimum trajectory falling below the benchmark of lowest 30% was sharply increased except for S1 ($F_{2002\text{-}2004}$) and S3 ($F_{2002\text{-}2004}$ with Capping). The likelihood that future SSB in 2020 attained the target benchmark (Historical median) was very low for S0 ($F_{2007\text{-}2009}$) and S4 ($F_{2002\text{-}2004}$ with Capping, but with F for EPO-PS at 2010 level). On the contrary, the likelihood was relatively high for S1 ($F_{2002\text{-}2004}$) and S3 ($F_{2002\text{-}2004}$ with Capping).

4. Discussion

The results of the BRPs suggested that fishing impacts on this stock during 2007-2009 become higher than those during 2002-2004 (**Table2**, **Figure 2**). Hence, the fishing mortality (F) is needed to reduce to attain the level of each BRP, except for F_{loss}.

Future projection (S1 and S3) indicated that future SSB would recover to the historical median level on average under average F for 2002-2004 (**Figure 6**). These results suggest that the current CMM ensure future SSB to maintain historical median level on an average. On the other hand, current fishing mortality ($F_{2007\text{-}2009}$) would drive future SSB to further decline to 30-40 % of historical SSB.

Future projection (S2) indicated that future SSB may recover even with increasing catch and without reducing the current F to 2002-2004 level (**Figure 6**) only if the Japanese purse seine fisheries observe the current capping. Purse seine fishery in the Eastern Pacific Ocean (EPO) mainly catches the immature PBF ranged 50-120cm (Bayliff 1994) and the recent annual catch fluctuates significantly from 1000 to 7200 tons (Oshima *et al*. 2012). It seems that the catch in the EPO largely depends on the availability of the population. The result of future projection (S4) suggested that purse seine fishery in the EPO, at least, should not increase the *F*, because future SSB would not exceed the historical median level even if *F* of each fleet other than EPO-PS is reduced to average *F* for 2002-2004 and with “Capping” (**Figure 6**). This may be caused by the increase of the availability of the PBF in the EPO due to the increase of the survival of the smaller sized fish in the Western Pacific Ocean (WPO). Regulation on the Japanese purse seine would be less effective if there is no regulation on the PBF catch in the EPO.

Increased weighting of Japanese longline CPUE resulted in more pessimistic perspective on this stock relative to all the BRPs (**Table 8**) indicating that the future projected median SSB would not exceed the historical median level even with $F_{2002\text{-}2004}$ (**Figure 9**). However, even with higher weight for the longline CPUE, it would be possible to achieve the object if capping was added to the regulation of keeping the *F* at 2002-2004 level **(Figure 9)**.

The future projection starts from 2010. Therefore, the catch for 2010 is already estimated value by the projection, being different from the actual reported catch. This is only valid if the capping for the purse seine fisheries targeting on immature fish would be kept 5000 tons. The quota of the capping contains the future catch of Korean fishery. However, it might be underestimated because of the increasing recent catch of Korean purse seine (Oshima *et al*. 2012).

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Tables

Table 1. Seven benchmarks based on the point estimation of SSB for 1952-2009 years and the median of the SSB with 90% confidence intervals (CI) from 300 times bootstrap runs.

	Minimum	ATHL	Lowest-10%	Lowest-20%	Lowest-30%	Lowest-40%	Medium
$SSB_{\text{point estimate}}$ (tons)	10,843	14,009	14,967	17,982	27,469	32,295	42,627
$SSB_{\text{Median from bootstrap}}$ (tons)	11,490	14,745	15,722	18,833	27,341	34,097	42,038
$SSB_{5\%CI}$ (tons)	9,469	13,077	13,803	16,847	24,072	30,641	37,105
$SSB_{95\%CI}$ (tons)	13,685	16,571	17,529	20,916	30,842	37,863	47,647

Table 2. Biological reference points (BRPs) from base-case in 2012 and 2010. The values indicate the ratio of fishing mortality (*F*) of potential BRPs to *F* in benchmark years.

	Fmax	F0.1	Fmed	Floss	F10%	F20%	F30%	F40%
$F_{2007\text{-}2009}$ (Basecase_2012)	0.51	0.36	0.78	1.16	0.74	0.51	0.38	0.29
$F_{2004\text{-}2006}$ (Basecase_2012)	0.46	0.32	0.70	1.04	0.66	0.46	0.34	0.26
$F_{2002\text{-}2004}$ (Basecase_2012)	0.60	0.42	0.96	1.44	0.91	0.63	0.47	0.35
$F_{2004\text{-}2006}$ (Basecase_2010)*	0.51 (0.50)	0.36 (0.35)	0.83 (0.81)	1.02 (1.09)	0.77 (0.75)	0.53 (0.52)	0.40 (0.38)	0.30 (0.29)
$F_{2002\text{-}2004}$ (Basecase_2010)*	0.61 (0.58)	0.43 (0.40)	1.04 (0.97)	1.28 (1.31)	0.97 (0.90)	0.67 (0.62)	0.49 (0.46)	0.37 (0.35)

Table 3. Performance index for the management evaluation based on the SSB (tons) with median and 90 % confidence intervals computed from 300 times bootstrap runs.

Scenarios	**SSB_{mean}**			**SSB_{min}**			**$SSB_{2018\text{-}2020}$**			**SSB_{CV}**
	Median	**95% CI**	**5% CI**	**Median**	**95% CI**	**5% CI**	**Median**	**95% CI**	**5% CI**	**Median**
S0:F2007-2009	31,533	41,833	24,065	27,441	37,195	19,480	30,297	45,078	20,926	0.098
S1:F2002-2004	41,373	53,146	32,909	34,302	41,660	28,253	47,020	67,215	33,877	0.133
S2:F2007-2009＋Cap	37,065	56,096	25,972	29,848	39,044	20,617	41,776	79,772	23,200	0.168
S3:F2002-2004＋Cap	43,418	60,090	33,170	34,293	41,734	28,253	51,049	84,934	34,362	0.171
S4:F2002-2004+ EPOPS_F2010+Capping	33,933	44,713	26,271	29,128	37,671	21,341	32,911	52,102	22,518	0.113

Table 4. Performance index for the management evaluation based on the catch (tons) with median and 90 % confidence intervals computed from 300 times bootstrap runs.

Scenarios	**$Catch_{mean}$**			**$Catch_{2011\text{-}2013}$**			**$Catch_{2018\text{-}2020}$**			**$Catch_{CV}$**
	Median	**95% CI**	**5% CI**	**Median**	**95% CI**	**5% CI**	**Median**	**95% CI**	**5% CI**	**Median**
S0:F2007-2009	17,944	23,065	13,944	17,547	25,286	12,911	17,726	24,953	12,958	0.204
S1:F2002-2004	17,619	22,796	13,687	15,959	23,539	11,672	18,257	25,291	13,493	0.199
S2:F2007-2009＋Cap	18,218	23,698	14,207	17,039	23,793	12,886	18,835	26,253	13,648	0.164
S3:F2002-2004＋Cap	17,773	23,376	13,802	15,911	22,878	11,712	18,802	26,207	13,737	0.178
S4:F2002-2004+ EPOPS_F2010+Cap	18,868	24,927	14,581	17,916	26,164	12,907	18,865	27,405	13,454	0.203

Table 5. Probability (%) that future minimum SSB falling below the threshold benchmarks (Minimum SSB, ATHL, Lowest-10%, Lowest-20%, Lowest-30%, and Lowest-40%) on SSB during

future 10 years and the likelihood(%) that future SSB in 2020 exceed a target SSB (Median). The benchmark is a point estimation computed from preliminary base case for 1952-2009.

Scenarios	$P(SSB<SSB_{min})$	$P(SSB<SSB_{ATHL})$	$P(SSB<SSB_{10\%})$	$P(SSB<SSB_{20\%})$	$P(SSB<SSB_{30\%})$	$P(SSB<SSB_{40\%})$	$P(SSB_{2020}>=SSB_{med})$
S0:F2007-2009	0.0	0.1	0.2	2.3	50.3	80.2	8.4
S1:F2002-2004	0.0	0.0	0.0	0.0	3.2	28.6	71.8
S2:F2007-2009＋Cap	0.0	0.0	0.1	1.3	34.9	67.0	52.4
S3:F2002-2004＋Cap	0.0	0.0	0.0	0.0	3.2	28.0	77.5
S4:F2002-2004+ EPOPS_F2010+Cap	0.0	0.0	0.0	0.7	37.1	73.1	20.0

Table 6. Probability (%) that future minimum SSB falling below the threshold benchmarks (Minimum SSB, ATHL, Lowest-10%, Lowest-20%, Lowest-30%, and Lowest-40%) on SSB during future 10 years and the likelihood(%) that future SSB in 2020 exceed a target SSB (Median). The benchmark is a point estimation computed from each bootstrap run.

Scenarios	$P(SSB<SSB_{min})$	$P(SSB<SSB_{ATHL})$	$P(SSB<SSB_{10\%})$	$P(SSB<SSB_{20\%})$	$P(SSB<SSB_{30\%})$	$P(SSB<SSB_{40\%})$	$P(SSB_{2020}>=SSB_{med})$
S0:F2007-2009	0.0	0.1	0.3	3.2	49.8	91.1	8.8
S1:F2002-2004	0.0	0.0	0.0	0.0	1.9	47.1	74.3
S2:F2007-2009＋Cap	0.0	0.1	0.2	1.7	34.0	81.3	54.1
S3:F2002-2004＋Cap	0.0	0.0	0.0	0.0	2.0	46.3	79.9
S4:F2002-2004+ EPOPS_F2010+Cap	0.0	0.0	0.0	1.0	36.5	85.9	20.9

Table 7. Probability (%) that future minimum SSB falling below the threshold benchmarks (Minimum SSB, ATHL, Lowest-10%, Lowest-20%, Lowest-30%, and Lowest-40%) on SSB during future 10 years and the likelihood(%) that future SSB in 2020 exceed a target SSB (Median). The benchmark is a median of 300 estimates computed from 300 times bootstrap runs.

Scenarios	$P(SSB<SSB_{min})$	$P(SSB<SSB_{ATHL})$	$P(SSB<SSB_{10\%})$	$P(SSB<SSB_{20\%})$	$P(SSB<SSB_{30\%})$	$P(SSB<SSB_{40\%})$	$P(SSB_{2020}>=SSB_{med})$
S0:F2007-2009	0.0	0.2	0.4	3.6	49.2	87.4	9.2
S1:F2002-2004	0.0	0.0	0.0	0.0	3.0	47.7	74.0
S2:F2007-2009＋Cap	0.0	0.1	0.2	2.0	34.2	77.8	53.8
S3:F2002-2004＋Cap	0.0	0.0	0.0	0.0	3.1	47.9	79.3
S4:F2002-2004+ EPOPS_F2010+Cap	0.0	0.0	0.0	1.2	35.9	82.8	21.5

Table 8. Biological reference points (BRPs) from preliminary base case in 2012 with increased weighting of Japanese longline CPUE. The values indicate the ratio of fishing mortality (*F*) of potential BRPs to *F* in benchmark years.

	Fmax	F0.1	Fmed	Floss	F10%	F20%	F30%	F40%
$F_{2007\text{-}2009}$ (BasecaseJLL5_2012)	0.29	0.21	0.62	0.89	0.48	0.33	0.24	0.18
$F_{2004\text{-}2006}$ (BasecaseJLL5_2012)	0.30	0.21	0.63	0.89	0.49	0.33	0.25	0.19
$F_{2002\text{-}2004}$ (BasecaseJLL5_2012)	0.39	0.27	0.91	1.31	0.71	0.48	0.35	0.26

Figures

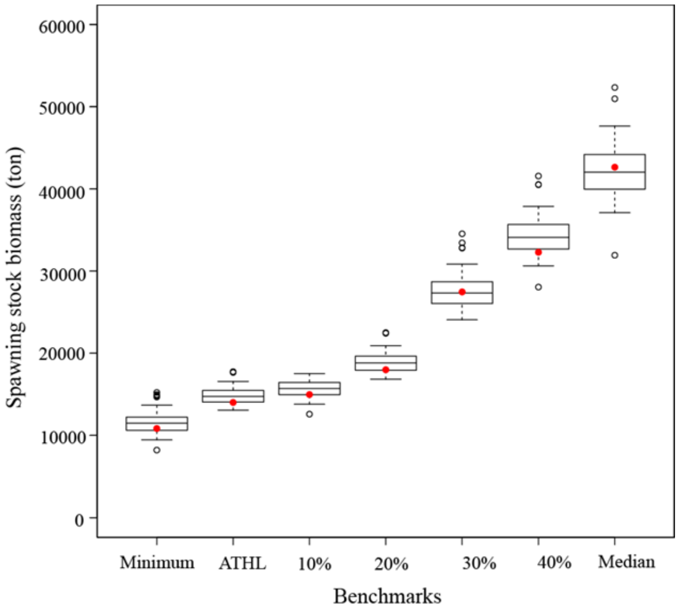

Figure 1. Seven benchmarks based on the point estimation of SSB for 1952-2009 years (Red filled circle) from preliminary base case and the median of the benchmarks on SSB with 90% confidence intervals (CI) from 300 times bootstrap runs. The horizontal line in the box indicates a median and the whiskers indicate the ranges of the 90% confidence intervals.

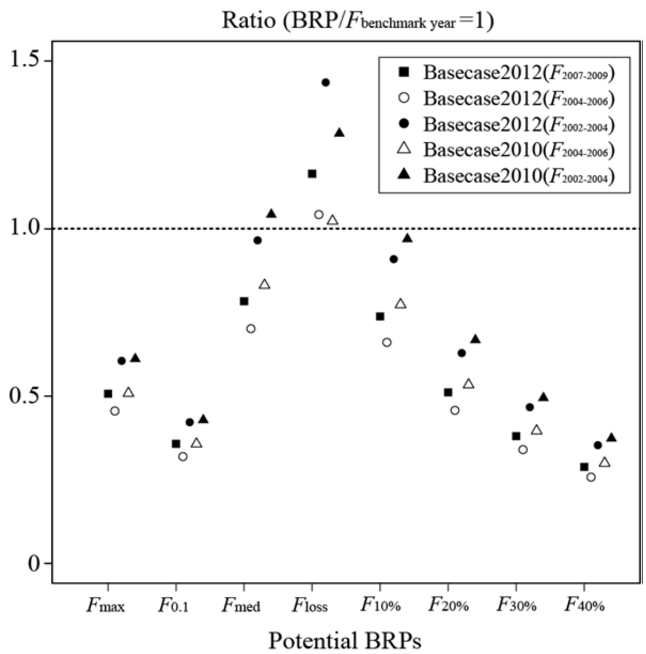

Figure 2. Biological reference points (BRPs) from preliminary base case in 2012 and base case in 2010. The values indicate the ratio of fishing mortality (*F*) of potential BRPs to *F* in benchmark years.

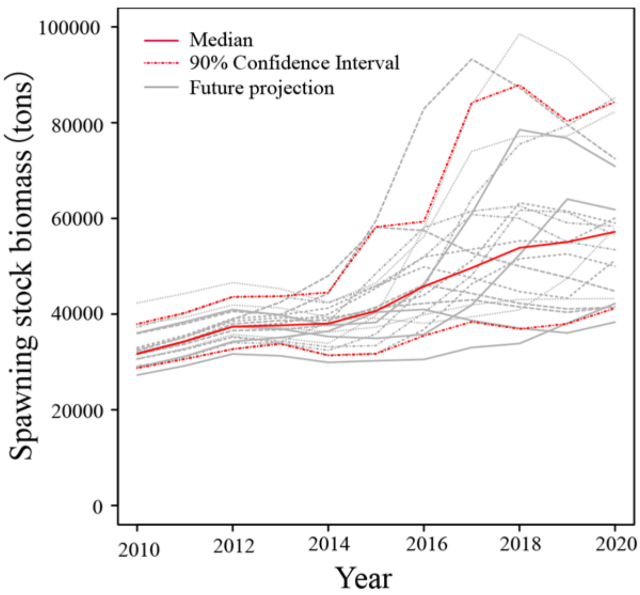

Figure 3. Some examples of future trajectories on SSB (tons, grey lines). A solid red line indicates the median and dotted red lines indicate 90% confidence intervals of the trajectories.

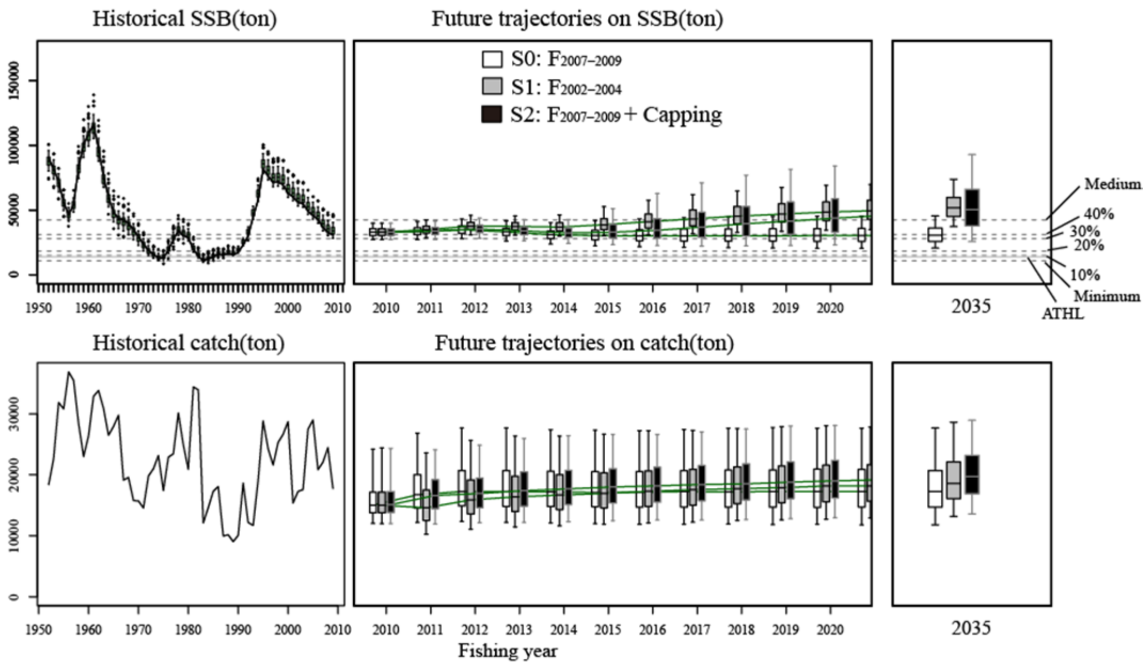

Figure 4. Past and future trajectories on spawning stock biomass (upper figure) and total catch (lower figure) with base case S0:$F_{2007\text{-}2009}$ (white), S1:$F_{2002\text{-}2004}$ (gray) and S2:$F_{2007\text{-}2009}$ + Capping (black). The boxplot indicates the values with 90% confidence intervals and medians, estimated from 300 times bootstrap runs

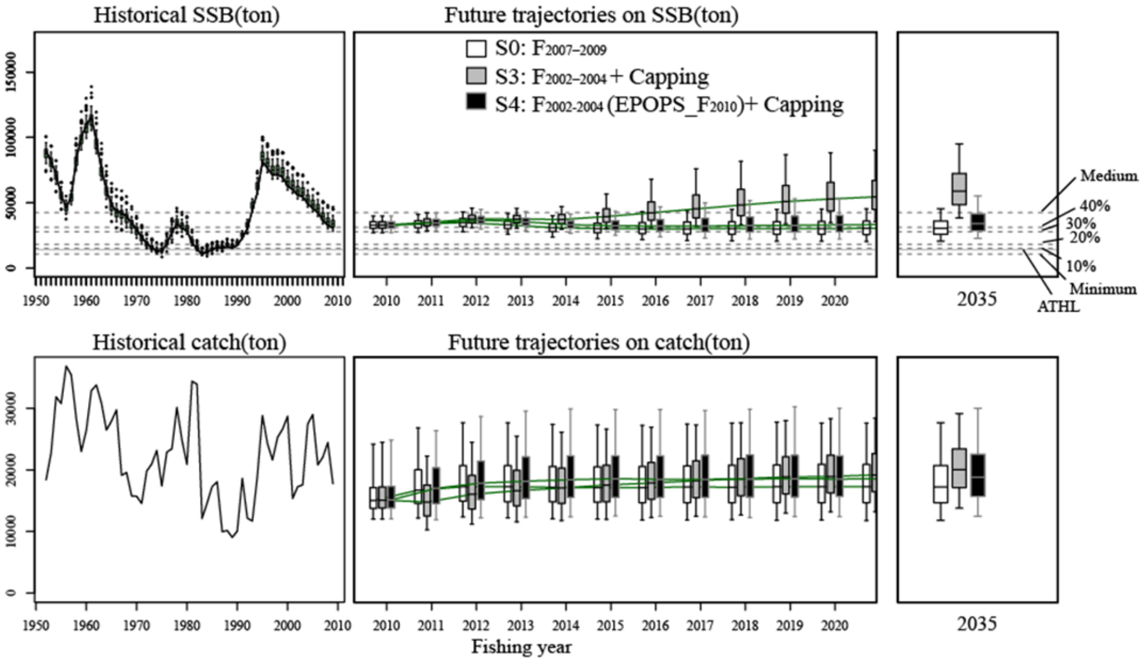

Figure 5. Past and future trajectories on spawning stock biomass (upper figure) and total catch (lower figure) with base case S0:$F_{2007\text{-}2009}$ (white), S3:$F_{2002\text{-}2004}$ + Capping (gray) and S4:$F_{2002\text{-}2004}$ + F_{2010} (EPOPS) + Capping (black).

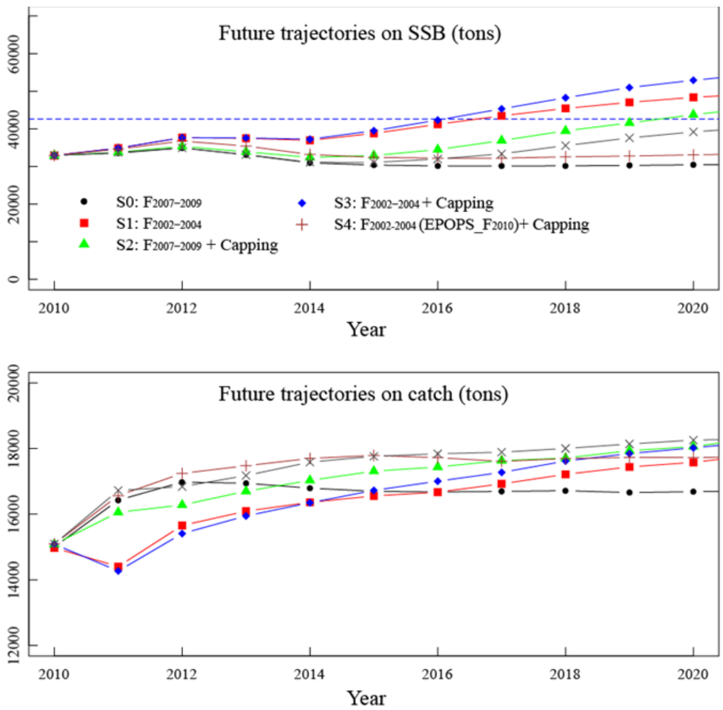

Figure 6. Comparison of median future trajectories on spawning stock biomass (upper figure) and total catch (lower figure) among five scenarios (S0-S4).

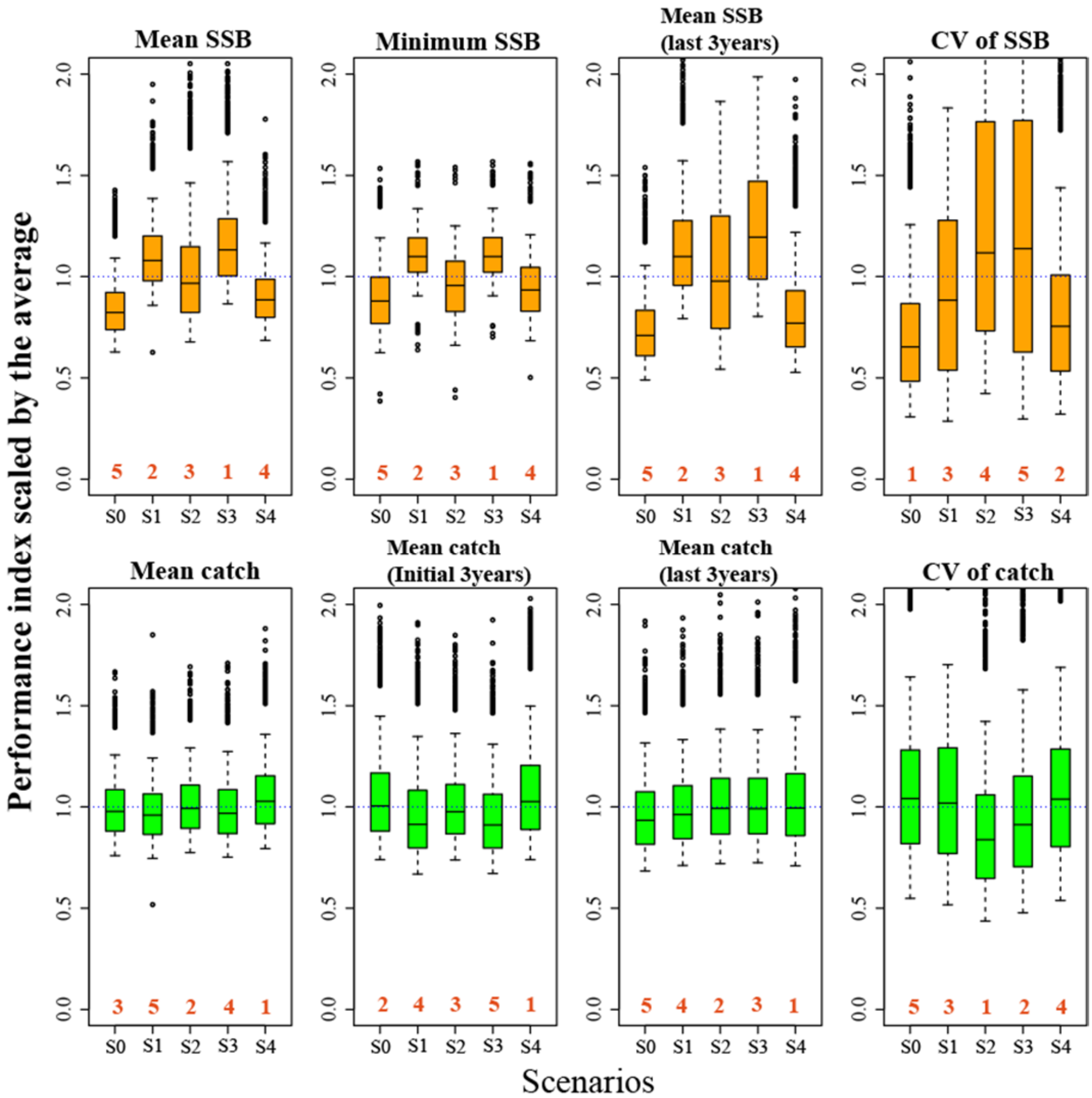

Figure 7. Comparison of the performance index scaled by the averages among five different scenarios (S0-S4). The horizontal blue dotted line (=1) indicates scaled average value. The numbers in the bottom represents the ranking of the performance index.

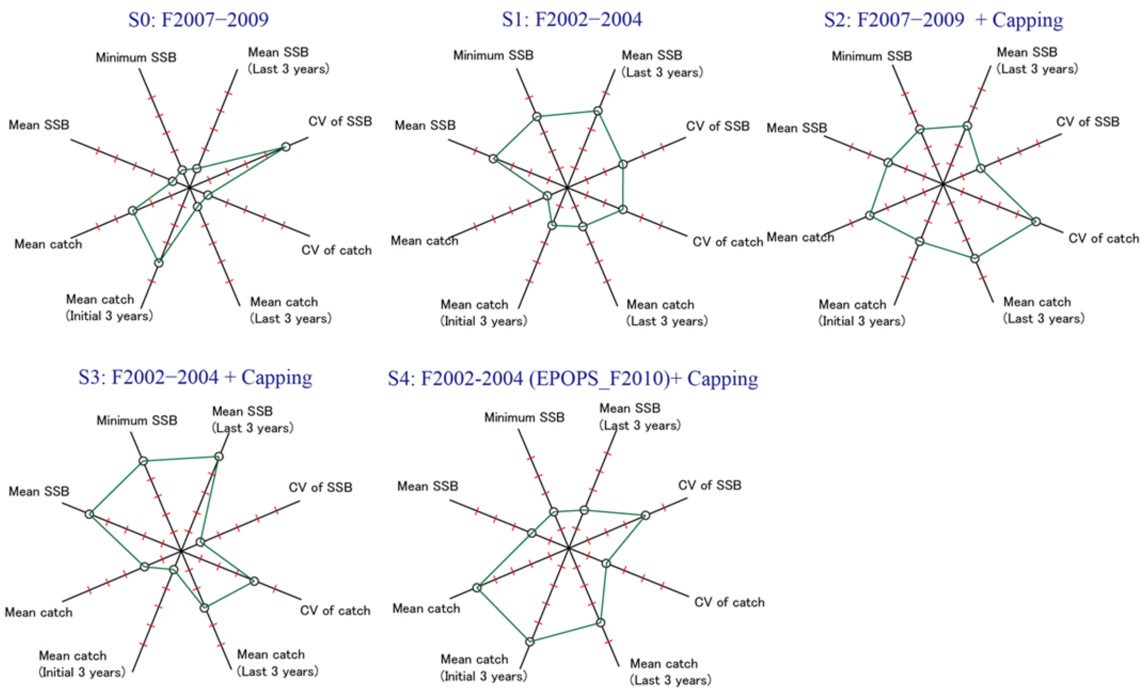

Figure 8. Radar chart of the performance indices for five different scenarios.

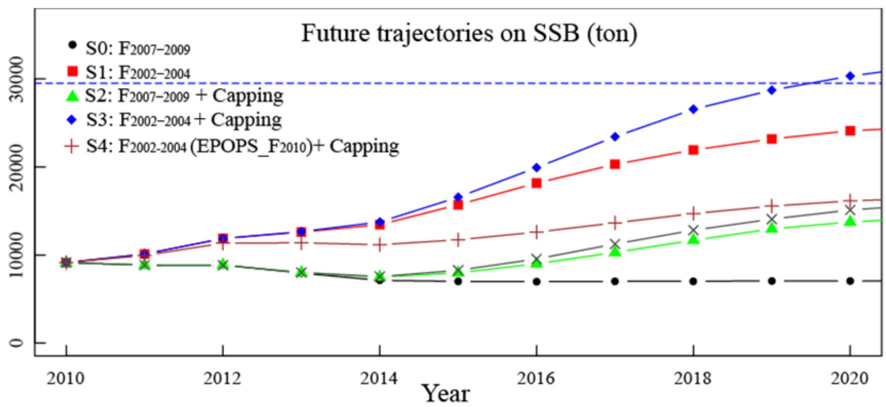

Figure 9. Comparison of median future trajectories on spawning stock biomass among five different scenarios for increased weighting of Japanese longline CPUE.

Appendix

A1.Comparisons of average *F* at age for benchmark years (Figure A1, Table A1)

$F_{2007\text{-}2009}$ (Average F at age for 2007-2009) was higher than $F_{2002\text{-}2004}$ (Average F at age for 2002-2004) for all age classes, while $F_{2007\text{-}2009}$ was lower than $F_{2004\text{-}2006}$ for all age classes.

A2.Comparisons of $F_{2002\text{-}2004}$ between previous and preliminary base case (Figure A2)

$F_{2002\text{-}2004}$ in 2012 was higher than that in 2010 for younger age classes (1-2 ages), but lower for age 0 and older age classes (7-10+ ages). The difference was caused by the change of the selectivity curve.

A3.Comparisons of YPR and SPR curves (Figure A3)

(a) YPR of previous base case in 2010 was higher than that of preliminary base case in 2012, while SPR was similar for both base cases.

(b) F_{max} for preliminary base case with $F_{2007\text{-}2009}$ was smaller than that with $F_{2002\text{-}2004}$. SPR of preliminary base case in 2012 $F_{2007\text{-}2009}$ was smaller than that with $F_{2002\text{-}2004}$.

(c) F_{max} for preliminary base case with up-weighting of JLL was further smaller than preliminary base case with $F_{2002\text{-}2004}$. SPR of preliminary base case was larger.

(d) Similar trend with (b) was observed for preliminary base case with up-weighting of JLL cpue.

A4.Comparisons of YPR and SPR curves (Figure A4)

There were no clear relationships between SSB and recruits for all cases.

Table A1. Fishing mortality (*F*) at ages from preliminary base case in 2012 for 2001-2010 and geometric mean of *F* for 2002-2004, 2004-2006 and 2007-2009 with medians and 90% confidence intervals, estimated from 300 times bootstrap runs.

Periods	Year (Statistics)	Ages										
		0	1	2	3	4	5	6	7	8	9	10+
F from 2001 to 2009	2001	0.52	0.73	0.27	0.08	0.06	0.06	0.07	0.09	0.10	0.11	0.13
	2002	0.51	0.74	0.30	0.09	0.07	0.07	0.09	0.10	0.12	0.13	0.14
	2003	0.46	1.13	0.46	0.14	0.09	0.07	0.07	0.08	0.09	0.10	0.12
	2004	0.52	0.99	0.76	0.23	0.18	0.16	0.16	0.17	0.17	0.17	0.15
	2005	0.65	1.47	0.57	0.19	0.17	0.18	0.18	0.17	0.16	0.14	0.11
	2006	0.53	1.36	0.72	0.21	0.17	0.16	0.17	0.17	0.17	0.17	0.15
	2007	0.49	1.06	0.60	0.20	0.17	0.16	0.16	0.15	0.15	0.14	0.12
	2008	0.56	1.13	0.47	0.16	0.17	0.20	0.21	0.20	0.18	0.16	0.12
	2009	0.71	1.29	0.48	0.14	0.12	0.13	0.13	0.13	0.13	0.12	0.09
	2010	0.68	1.01	0.82	0.23	0.18	0.13	0.11	0.10	0.09	0.09	0.07
$F_{2002\text{-}2004}$	Point estimate	0.49	0.92	0.45	0.13	0.10	0.09	0.10	0.11	0.12	0.12	0.13
	Median	0.48	0.89	0.42	0.12	0.09	0.08	0.09	0.10	0.12	0.13	0.14
	5%	0.46	0.85	0.39	0.11	0.08	0.07	0.08	0.09	0.10	0.11	0.12
	95%	0.51	0.93	0.45	0.13	0.10	0.09	0.10	0.11	0.13	0.15	0.16
$F_{2004\text{-}2006}$	Point estimate	0.55	1.24	0.66	0.20	0.17	0.16	0.17	0.17	0.17	0.16	0.13
	Median	0.55	1.20	0.62	0.18	0.16	0.15	0.15	0.16	0.16	0.16	0.14
	5%	0.52	1.14	0.57	0.17	0.14	0.13	0.14	0.14	0.14	0.14	0.12
	95%	0.57	1.26	0.66	0.20	0.18	0.16	0.17	0.18	0.18	0.18	0.17
$F_{2007\text{-}2009}$	Point estimate	0.57	1.11	0.51	0.16	0.15	0.16	0.16	0.16	0.15	0.14	0.11
	Median	0.56	1.08	0.47	0.14	0.13	0.14	0.15	0.15	0.15	0.15	0.13
	5%	0.53	1.00	0.43	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.11
	95%	0.60	1.16	0.52	0.16	0.15	0.16	0.17	0.17	0.17	0.17	0.16

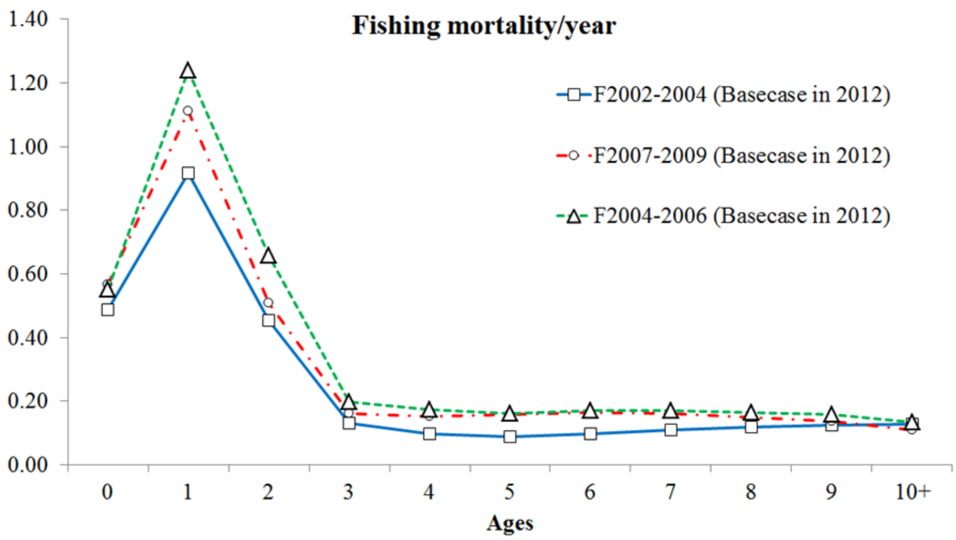

Figure A1. Fishing mortality (*F*) at age for 2007-2009, 2004-2006, and 2002-2004 from preliminary base case in 2012.

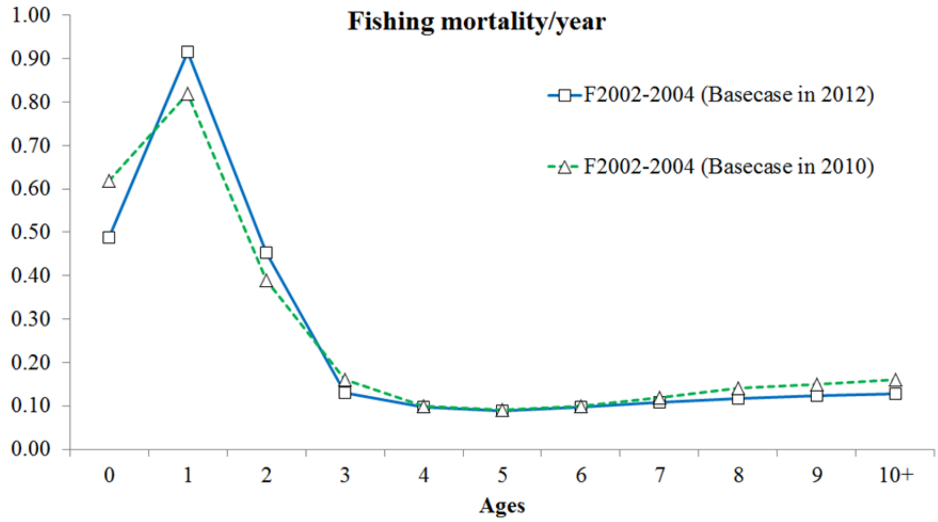

Figure A2. Fishing mortality (F) at age for 2002-2004 from preliminary base case in 2012 and previous base case in 2010.

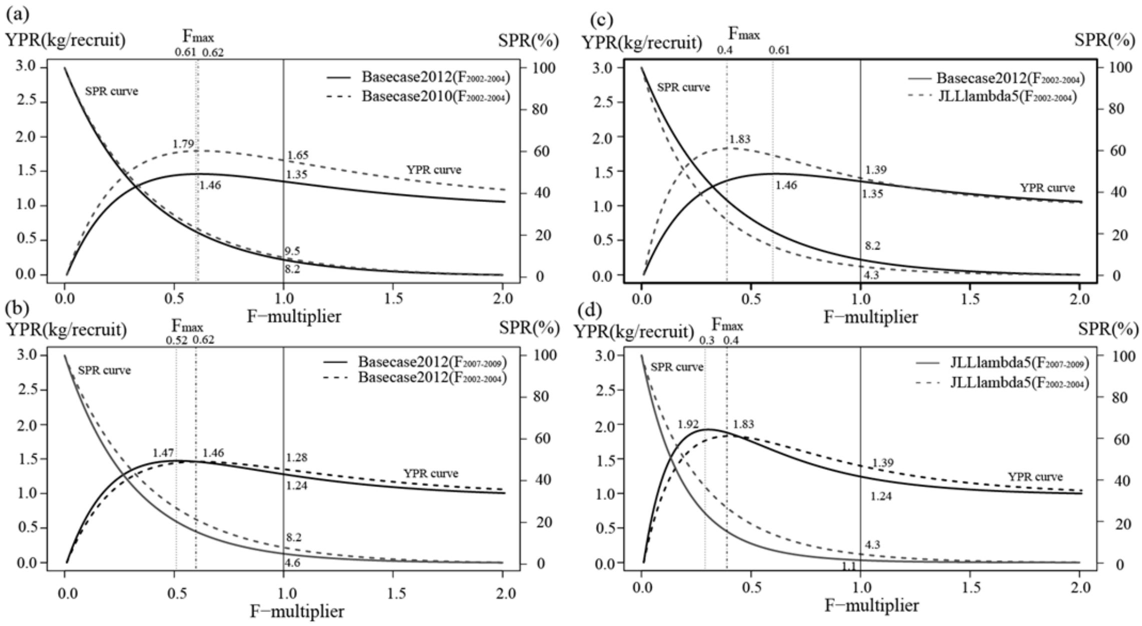

Figure A3. Yield (kg) per recruit (YPR) and Spawning per recruit (SPR, %). (a) Comparison of previous and preliminary base case. (b) Comparison of $F_{2002\text{-}2004}$ and $F_{2007\text{-}2009}$ for preliminary base case. (c) Comparison between preliminary base case and that with increased weighting of JLL cpue. (d) Comparison of $F_{2002\text{-}2004}$ and $F_{2007\text{-}2009}$ for preliminary base case with increased weighting of JLL CPUE.

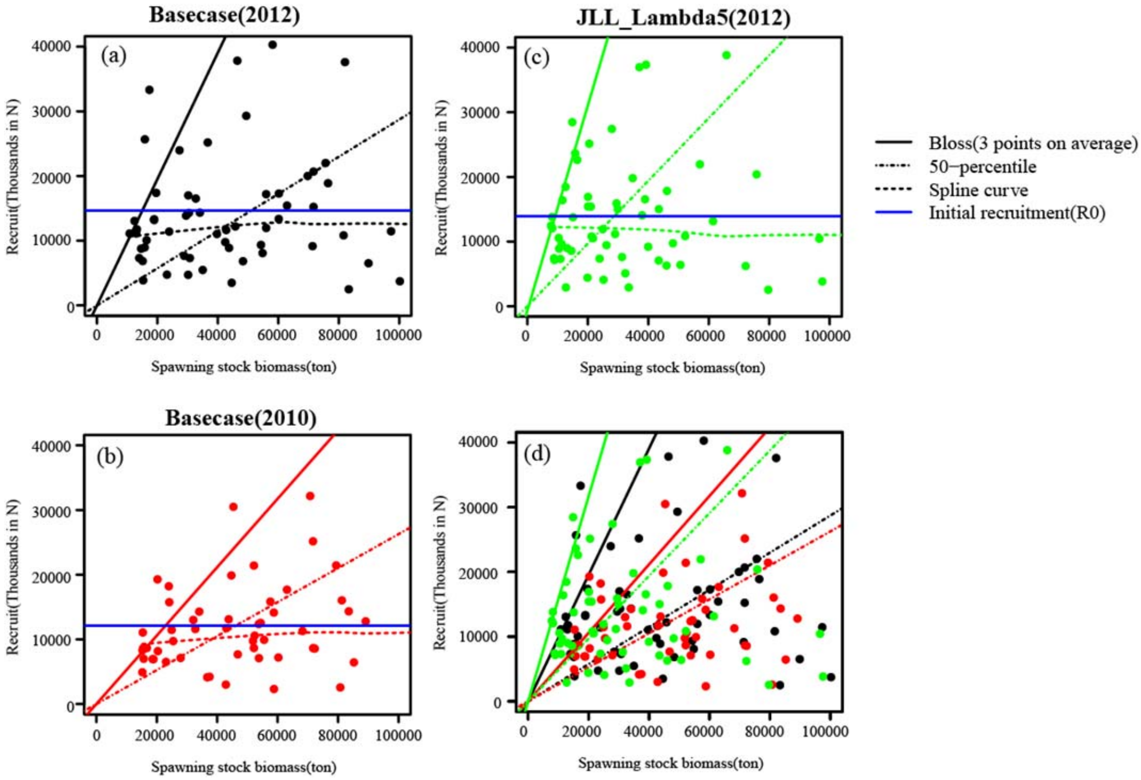

Figure A4. Relationships between spawning stock biomass (tons) and recruit (thousands in number). (a) Preliminary base case in 2012. (b) Previous base case in 2010. (c) Preliminary base case in 2012 with increased weighting of JLL CPUE. (d) Comparison of the three cases.