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BRIEF REVIEW OF THE METHODS FOR THE FUTURE PROJECTIONS OF PACIFIC BLUEFIN TUNA STOCK ASSESSMENT

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Introduction

Future projections from estimates of stock assessment models can provide important information on the current and near-future status of concerned fish stocks, which should influence harvest strategy and help to maintain sustainable fisheries. As modern quantitative methods for stock assessment have became highly complex and computationally intensive, methods for future projections are becoming complex and computer intensive, as well. Integrated models with non-linear function optimizers and many parameters, such as Stock Synthesis II (SSII, Methot 2007) and Multifan-CL (Founier 1999), can estimate parameter uncertainty that accounts for much of the variability in the biological and fishery data. The uncertainty estimated from an integrated model should be carried forward into the projections, but straightforward methods to incorporate parameter uncertainty in projections, such as MCMC, require lengthy run times even when using state-of-the-art computer resources (Maunder et al. 2006).

Maunder et al. (2006) introduced a less computationally intense method to estimate uncertainty in projections that included the uncertainties in both future population demographics and parameter estimation. The future confidence intervals including both uncertainties were estimated by normal approximation based on the delta method (Oehlert 1992). In application to simulated population data and yellowfin tuna in the Eastern Pacific,the method showed reasonable performance when compared with the more computer intensive methods of MCMC and stochastic projection from point estimates (Maunder et al., 2006). Projections in SS II appear to be conducted using similar methods, although the SS II manuals (Methot 2005 and Methot 2007) do not provide a detailed description of its projection methodology.

On the other hand, stochastic, computationally-intensive statistical methods for more rigorously estimating uncertainty in projections (e.g. nonparametric bootstrapping) have a long history of application in fisheries stock assessment when simpler assessment methods are employed (e.g. VPA). These stochastic methods not only account for both parameter and demographic uncertainty but do so in manner that (i) makes no distributional assumptions about the parameters (e.g. normal, lognormal, etc.) and (ii) runs relatively quickly on modern computers. For example, recent ISC assessments have used such methods for future projections of North Pacific albacore (Conser et al. 2006) and Pacific bluefin tuna in the last stock assessment (Yamada et al. 2006).

In April 2006, the Pacific bluefin tuna (PBF) working group agreed to use SS II rather than tuned VPA in the next stock assessment of Pacific bluefin tuna. Because the next stock assessment will employ more complex methodology for determining current stock size and the historical trend (with concomitant lengthy run times), it is important to evaluate the potential impacts on PBF stock size and demographic projections and the associated uncertainty. This is particularly relevant since ISC fishery managers have been relying on stochastic projection results to form the basis of fishery management. This document compares the results of future projections produced by SS II with those produced by more state-of-the-art stochastic projection methods. The results should provide background materials for working group discussion on the requirements for PBF projections that will be conducted in the next stock assessment.

Materials and methods

Sample data

We used fishery and biological data provided by the last working group (ISC PBF-WG/07-1) as sample data for SS II and future projections. Fishery and biological data for SS II were similar to that presented by Takeuchi et al. (2007) at the last working group, and model configurations were same as that by Kai et al. (2007, ISC PBF-WG/07-3/22). Because SS II was recently updated (v1.23e to v2.00g), some settings have been changed or added. Note that these PBF sample data and the SS II configurations used here are already out of date since the PBT database has been undergoing major reconstruction in preparation for the next stock assessment. Consequently, the results in this paper should only be used to examine competing projection methods but not to infer conclusions regarding the current stock status or future condition of Pacific bluefin tuna. The revised fishery and biological data as well as new potential SS II configurations will be presented in this and next meeting.

Stock evaluation and future projections by SS II were conducted using the sample data with iterative-reweighting (eight or more times) of effective sample size (McAllister and Ianelli 1997) and replacement of the SD associate with the respective CPUE indices. Each SS II run was conducted with the optional argument of '-maxfn 500' for the purpose of model stabilization. The sample data for the estimation of stock status included fishing years 1952-2004. Projections started in 2005 and continued through 2044 (40 years). Because steepness in Beverton-Holt spawner recruitment relationship was estimated as 1 in test runs, the default steepness was fixed as 1 for all runs in this paper. Further details on the settings for SS II are shown in Appendix B. The configuration described in this document is one of the most stable versions among all those produced from our experience of applying SS II to PBF. Although the sample case presented in this document can produce a positive definite Hessian matrix, most other trials (not shown here) failed to produce an inversed Hessian matrix and in many cases, or failed to even satisfy the standard convergence criteria. In addition, for a particular input option (relative F flag=2), calculation of Hessian matrix seemed to be especially unstable. In the bootstrap analysis, 44 of the 150 bootstrap replications failed to be converged, even for the most stable configuration. Finding a reasonable configuration for which parameter uncertainty can be properly estimated might be difficult task for PBF stock assessment itself (i.e. prior to conducting future projections).

Fishing scenarios for future projections with sample data

We conducted projections with three constant harvest rate scenarios: (1) SPR 0.1, (2) no-fishing, and (3) terminal year F. SPR 0.1 is the scenario where future constant harvest rates achieve future equilibrium SPR of 0.1. In this scenario, SS II projections were conducted using the harvest rates by fleet and season estimated in the terminal year (2004), and multiplied by various F multipliers. The SS II results from Scenario 2 (no fishing) were used to validate a set of stochastic projections functions written in the "R" programming language. In Scenario 3 (terminal year F), all future harvest rates were set at the 2004 level. The input settings for the SS II projections are shown in Tables 1-3 for Scenarios 1-3, respectively.

Characteristics of the projection method in SS II

As generally applied, SS II projections provide point estimates and standard deviations of the future population demographics of interest (such as recruitment and SSB) by inverting the Hessian matrix and applying the delta method[1]. In this SS II mode, a projection is simply treated as part of the estimation model rather than as a separate stochastic process based on Monte Carlo simulation, e.g. as in Conser et al. (2005) or Brodziak (2005). When using the delta method, estimation of the standard deviations assumes that the underlying distribution is the normal (Gaussian). Therefore, it is noteworthy that the estimated parameters and derived quantities from the projection (e.g. future recruitment and SSB) are assumed to be normally distributed, with parameter estimates corresponding to 'arithmetic average (or expected value)', not with median as is the case for the lognormally distribution. It should be noted that recruitment deviation was assumed to be log-normal distribution in the historical phase in SS II (with log-bias adjustment factor), but normal in the projection phase (see input file settings in 4th, 5th lines at forecast.ss2 in Table 1).

Stochastic projections with R

Demographic stochastic projections were conducted using a program coded by R (R Development Core Team 2006). The program is an improved version of that used in the previous stock assessment of Pacific bluefin tuna (Yamada et al., 2006). The code was adapted to correspond to the SS II time steps (4 quarter per year). Pseudo code of the R program is shown in Appendix A. The characteristics of the R program for stochastic projections are listed as follows.

- Because steepness was fixed as 1 in SS II, future recruitment was assumed to be occurred with random log-normal distributions (eq. 1 in Appx A).
- Stochastic simulations were conducted with 1000 replications. The median, mean and probability distribution were calculated for recruitment, SSB, etc.
- While the population dynamics model used in SS II is based on Pope's approximate equation (in the current configuration of the sample data) with estimating vulnerable biomass and exploitation rates by fleets, stochastic projections used in this document were based on the catch equation with continuous F at age (eq. 2 and 3 in appx A). F at age used in the future projections was calculated from estimated population numbers and catch at age in a 2004 (eq. 4 in appx A).
- Stochastic projections from multiple SS II bootstrap estimations were attempted.
- Random re-sampling from recruitments estimated in the historical period was also carried out. Random re-sampling of historical recruitments can inhibit extraordinarily high or low recruitments compared with the historical mean recruitment of PBF. The previous assessment of PBF used re-sampling of historical recruitments for future recruitment

[1] Since SS II is written in AD Model Builder (ADMB), it is possible to use the ADMB MCMC functions in conjunction with SS II projections. While this is an ideal way to characterize the uncertainty in projection results (as well as terminal year results), MCMC is computationally intensive, requires considerable computer memory, and results in lengthy run times (often several days). In practice, MCMC is often not practical for SS II models with the complexity likely needed for the PBT assessment.

Calculation of reference point

As an example of a reference point based on stochastic projections, we calculated the probability that the SSB will fall below the historical lowest SSB during one or more years of the projection period. The definition of this probability is following Conser et al. (2005) (eq. 1).

$$\Pr[SSB_{Future} < SSB_{observed} \mid F] = \frac{1}{1000}\sum_{k=1}^{1000}\left\| \min\{SSB^k_{2005,F},...,SSB^k_{2044}\} < \min\{SSB_{1952},...,SSB_{2004}\}\right\| \quad (1),$$

where the double bracket $\| \|$ indicates a logical test with outcome 0 (if false) or 1 (if true). We also consider another probability that SSB in 2040 (when SSB will be in equilibrium) will fall below the historical lowest SSB.

$$\Pr[SSB_{2040} < SSB_{observed} \mid F] = \frac{1}{1000}\sum_{k=1}^{1000}\left\| SSB^k_{2040} < Min\{SSB_{1952},...,SSB_{2004}\}\right\| \quad (2)$$

From the SS II projection results, we calculate the following probabilities:

$$\Pr[SSB_{future} < SSB_{observed} \mid F] = \max\left\{\begin{array}{l}\Pr[N(\mu_{2005},\sigma_{2005}) < \min\{SSB_{1952},\ldots,SSB_{2004}\}],\\ \Pr[N(\mu_{2006},\sigma_{2006}) < \min\{SSB_{1952},\ldots,SSB_{2004}\}],\ldots,\\ \Pr[N(\mu_{2044},\sigma_{2044}) < \min\{SSB_{1952},\ldots,SSB_{2004}\}]\end{array}\right\} \quad (3)$$

$$\Pr[SSB_{2040} < SSB_{observed} \mid F] = \Pr[N(\mu_{2040},\sigma_{2040}) < \min\{SSB_{1952},\ldots,SSB_{2004}\}] \quad (4)$$

The probabilities defined in Eq. 2 and Eq 4 should be similar, but probabilities by eq. 1 and eq. 3 are not equivalent in the strict sense.

Results and discussion

Recruitment & numbers at age

Fig. 1 shows historical recruitments estimated with SS II, and projected recruitments with SS II and stochastic projections. Estimation of future recruitments from SS II (black lines) is equal to R_0, and corresponds to the (simple) arithmetic average of the future recruitments projected by stochastic projections. On the other hand, median of the stochastic projections is less than R_0 because of the lognormal assumption for future recruitments, i.e. median = R_0*exp(-σ/2). According to the normal approximation used in SS II (delta method), the 90% confidence interval of the future recruitments should be $R_0 \pm 1.64$*(standard deviation of future recruitment). However, this resulted in negative recruitment values (see Fig 1b). Comparison of probability distributions of future recruitments in 2040 (Fig. 1b) shows clearly the difference of the two assumptions of future recruitments in SS II and Monte-Carlo based stochastic projections.

Numbers at age under SPR 0.1 scenario (fig. 2a) got similar outcomes with fig. 1a: simple average of numbers at age from stochastic projections and estimates values from SS II are corresponding each other, and median from stochastic projections is lower than that (except for the case of 20+). In the plus group, numbers at age from SS II were neither equal to average nor median from stochastic projections. Considering the observation that average of the numbers at 20+ from stochastic projections is equal to SS II results under no-fishing scenario (fig. 2b), the discrepancy of 20+ projections between stochastic and SS II would caused by different catch equations used in the two method, and wrong way for calculating F for 20+ in our R code. This problem will be solved by improvement of our R code although the effect of the bias on the total SSB would be small because of small number of 20+ group.

Spawning biomass

Trajectories of SSB are compared in fig 3 and 4, under the scenario of no-fishing and SPR0.1, respectively. Estimated SSB by SS II and average ones by stochastic projections show similar results in the both scenarios, while probability distribution at 2040 (fig. 3b and 4b) and their 5%, 50%, and 95% percentiles were different. Probability distributions of SSB at 2040 from stochastic projections were skewed to lower SSB compared with approximated normal distribution in SS II, especially in SPR 0.01 scenario. In the near future period during which demographic stochastic uncertainty introduced from 2005 don't affect future SSB, confidence intervals of stochastic projections were zero. On contrary, SS II estimated some confidence intervals more or less in the period because SS II future projection can consider parameter uncertainty as well as demographic stochastic uncertainty by using normal approximation.

Parametric bootstrap results of total exploitation rates shows parameter uncertainty of total exploitation rates (fig. 5a). Total number of reputation of bootstrap was 150 times, which took about 40 hours, and number of successful convergence was 106. The uncertainly was especially large during the last year of the assessment phase, when total exploitation rates ranged from 0.3 to 0.7 (fig. 5b).

The parameter uncertainty estimated from the bootstrap results was incorporated into stochastic projections by starting projections from the 106 bootstrap results with good convergence. Fig. 6 compares confidence intervals estimated from bootstrap+stochastic and SS II projections in the case of SPR0.1. Replication number of projections per each bootstrap result was 37 so that total number of replication was approximately 4000. Confidence interval estimated from the stochastic+bootstrap method was relatively skewed to higher SSB, and average value was not equivalent with the results from SS II. Possible reason of the higher SSB in the stochastic+bootstrap projections would be that point estimation of the total exploitation rate in 2004 was larger than average value of multiple bootstrap results (fig. 5b), which might suggest possible bias of total exploitation rate in. Consequently stochastic+bootstrap projections got more optimistic confidence interval near the future.

Projected SSB was nearly crashed both in the stochastic and SS II methods in the scenario of ending year F (fig. 7). This too pessimistic future perspective was caused from high total exploitation rates estimated in 2004. Fig. 8 shows results of retrospective analysis of total exploitation rates, and suggested that total exploitation rates of 0.55 in 2004 was the highest level among those during 1990-2003 (0.21-0.35). Fig. 8 also suggested the possibility that exploitation rates at the end year have tendency of positive bias. Bootstrap results also show large uncertainty in total exploitation rates in the end year of 2004 (fig. 5b).

Future recruitment by resampling of historical recruitments

Fig. 9 shows other results based on random draw of future recruitments from historical recruitments under the scenario of SPR0.1, compared with the assumption of lognormal recruitment. Both median and 5% lower limit of recruitments with different assumptions was coincident each other, but average and 5% upper limit in resampling scenario were lower than those in lognormal scenario. As for SSB, future estimated median of SSB by resampling was also below that by lognormal while 5% lower limits was not different. This result suggest that too much high recruitments might overestimate future.

Example calculation of reference point

Patterns of $Pr[SSB_{future}<SSB_{observed}]$ and $Pr[SSB_{2040}<SSB_{observed}]$ by fishing scenarios were different among different projection methods (Table 5). The percentages of $Pr[SSB_{future}<SSB_{observed}]$ by SS II was higher than that by stochastic projections in the smaller F multiplier, but lower in the larger F multiplier. In particular, $Pr[SSB_{future}<SSB_{observed}]$ by SS II was not zero even in SPR 0.1 scenario or the too precautionary scenario of no-fishing. Fig. 4 suggests that the lower 5% limit of SSB by SS II was below historical lowest SSB level during 2010-2014. According to the confidence interval from stochastic projections without parameter uncertainty, 'parameter uncertainty' estimated in SS II result in the lower 5% limit below historical lowest SSB during the period. It is doubtful that the estimated confidence interval by SS II is reasonably precautionary considering appropriate parameter uncertainty in this sample case since lower 5% limit estimated from bootstrap+stochastic projections was above that estimated by SSII (fig. 6).

<u>Points for discussion</u>

Definition of current F

In the default mode of SS II, harvest rates across season and fleets in the terminal year of stock assessment phase are used as 'current F' in the future projections. This caused too pessimistic results in this sample case, where end year F projections (fig. 7) showed over-exploitated condition, and multiplier F (Table 5) was small as 0.33 for achieving SPR 0.1. Harvest rates in the end year would have wide range according to the bootstrap results (fig. 5b), and might have positive bias as suggested retrospective analysis (fig. 8). Further discussion about reasonable definition of current F will be needed to avoid getting biased results in future projections.

In the previous stock assessment using tuned VPA (Yamada et al, 2006), estimated results in the last 3 years (2002-2004) were not used for future projections because estimation error is known to be accumulated toward recent years in the backward calculation used in tuned VPA. The future F pattern was determined by random draw or average from Fs during the previous 5-year period (1997-2001). Such procedures, as dropping the last a few years and averaging F in the next some recent years for current F, are common ways in the projections starting from the results by using VPA as well as MFCL. Because SS II uses population dynamics of forward calculation, its error accumulation pattern are different from that in VPA. Current F appropriate for SS II model and PBF data should be determined after enough observation of error structure of the results by SS II.

Technically, it is difficult to use arbitrary patterns of harvest rates as current F in the future projection by SSII. There is an option for setting arbitrary relative F pattern for future projection in SSII by setting 'relative F flag' to be 2 (ex. Table 4), but we observed problematic behavior of SS II in the setting, where estimated standard deviations were different from those in setting relative F flag to 1. We need further analysis or investigation of the option of 'relative F flag' in SS II. Usage of new option of 'F ballpark' in SS II newer than 2.00 might be another solution to avoid the too large harvest rates in the end year. When we set F ball park of end year of 2004 to 0.3, total exploitation rates in 2004 became smaller to 0.48. However, in setting F ball park as 0.2, calculation was not converged with large penalty, which suggested too much constraint in the last year F makes the model unstable.

Statistics and reference points to be focused

SS II can produce results on future projections as for spawning biomass, recruitments, depletion, total catch or total harvest rate and total catch per summary biomass with their estimated standard deviation (Methot 2007). However, we couldn't get exact probability distribution of the future statistics. Because some reference points such as Fssb are based on probability distribution of future focused statistics, SS II projections might not be able to deal with such a reference point. We can calculate nearly similar value even by SS II (eq. 3-4), but the probabilities was different from those produced from stochastic projections (Table 5).

Assumption of future recruitment

As SS II assumed log-normal distribution as historical recruitment deviation, it is straightforward to use the same assumption in the future projections. However, it is doubtful that higher or lower future recruitments than the historical highest or lowest level of recruitments can be really occurred in future because upper limit of recruitments might be determined biologically by possible environmental capacity, and hidden relationships between spawning biomass and recruitments might determine lower limit of recruitment. In fig. 1, both of upper 5% limits by SS II and stochastic projections were above the highest number of historical recruitments. According to the results of stochastic projections in fig. 1 (where σ_R of 1.1 was used as same as estimated in SS II), approximately 10% of recruitments were above the historical highest recruitment, and 2% was below the lowest. This suggests the possibility that extremely strong cohorts above the historically highest level, which will be occurred once per a decade approximately, might result in overestimation of future status of PBF stock.

What methods and results will be needed in the next assessment?

Based on the above discussion, we need to chose methods and results needed in the future projections for the next stock assessment for PBF. There should be many alternative methods and scenarios for future projections other than those presented in this document. It is preferable to use methods and scenarios under careful considerations of cost & benefits, and possible bias in those methods.

References

Brodiziak JKT (2005) AGEPRO Version 3.1 User's Guide

Conser RJ, Crone PR, Kohin P, Uosaki K, Ogura M, Takeuchi Y (2005) Preliminary Research Concerning Biological Reference Points Associated With North Pacific Albacore Population Dynamics and Fisheries. ISC-ALBWG/05/06

Kai M, Ichinokawa M, and Takeuchi Y (2007) Reliability of stock size estimates from SS-2 - a case study of Pacific bluefin tuna. ISC/0712/PBF-WG3/22

Yamada H, Takeuchi Y, Ichinokawa M (2006) Updated stock assessment of Pacific bluefin tuna, using a tuned VPA. ISC PBF-WG / 06 / 18

McAllister MK, Ianelli JN (1997) Bayesian stock assessment using catch-age data and the sampling importance resampling algorithm. Can J Fish Aqu Sci 54: 284-300

Maunder MN, Harley SJ and Hampton J (2006) Including parameter uncertainty in forward projections of computationally intensive statistical population dynamic models. ICES J Mar Sci 63: 969-979

Methot RD (2005) Technical Description of the Stock Synthesis II Assessment Program Version 1.17, March

Methot RD (2007) User Manual for the Integrated Analysis Program Stock Synthesis 2 (SS2). Model Version 2.00c, Feb 27, 2007 - Updated Mar 26, 2007

Oehlert GW (1992) A note on the delta method. The American Statistician 46: 27-29

R Development Core Team (2006). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Takeuchi Y, Kai M, Yamada H, Oshima K, Ichinokawa M (2007) Advances in analytical population modeling of Pacific bluefin tuna from ISC-PBF-2006. ISC/07/PBF-1/18

Appendix A. Pseudo code for the future projections with R

$N^k_{a,y}$ is the total number of future population at age a (=0, 0.25, 0.5, 0.75,...,19.75,20), year y (=2005,2005.25,2005.5,2005.75,2006,2006.25,2006.5,2006.75,2007,...,2043.75,2044) in the kth simulation (k=1,2, 3,...,500). Because SS II for the stock assessment for Pacific bluefin tuna is based on the time step with 4 seasons per year, future time series and age is considered as sequential vectors with 0.25 intervals. In the future time series, 2005, 2005.25, 2005.5 and 2005.75 are corresponding with 1st, 2nd, 3rd and 4th quarter in 2005, respectively. The time series before future projections is expressed by lower case and similar way of numbering. For example, numbers at age in the stock assessment phase can be expressed by $n_{0,1952}$, $n_{0.25,1952}$, $n_{0.5,1952}$.

For the first step of the stochastic future projections, all recruitments were determined on the basis of the assumption that recruitments occurs at the 1st quarter each year by random lognormal distribution with average of R_0 and standard deviation of σ^2, which is estimated from SS2 .

$$N^k_{0,y} = \begin{cases} \sim R_0 \exp(\mathrm{N}(-\sigma^2/2, \sigma^2)) & \text{for } y = 2005, 2006, 2007, 2008, ..., 2043, 2044 \\ 0 & \text{for } y = 2005.25, 2005.5, 2005.75, 2006.25, 2006.5, ..., 2042.75 \end{cases} \quad \textbf{(1)}$$

In this calculation, we didn't consider any spawning-recruitment relationships because we can't find any relationships between estimated spawning biomass and recruitments in the current version of PBF assessment by SS2.

Given the estimates of number at age $n_{a,2005}$ except for recruitment of $N_{0,2005}$ by SS2 at the 1st quarter in 2005, expressed as, numbers at age in the first time step for future projections ($N^k_{a,2005.25}$) can be calculated as the following.

for k=1, 2, 3,...., 499, 500

$$N^k_{a,2005.25} = \begin{cases} N_{0,2005} \exp(-(F_{0,cur} + M_0)) & \text{for } a = 0.25 \\ n_{a-0.25,2005} \exp(-(F_{a-0.25,cur} + M_{a-0.25})) & \text{for } a = 0.5, 0.75, ..., 19.75 \\ n_{19.75,2005} \exp(-(F_{19.75,ur} + M_{19.75})) + n_{20,20055} \exp(-(F_{20,cur} + M_{20})) & \text{for } a = 20 \end{cases} \quad (2)$$

end for

for k=1, 2, 3, …, 499, 500

for y=2006.25, 2006.5, 2006.75, 2007, …., 2046.75, 2047

$$N^k_{a,y} = \begin{cases} N^k_{a-0.25,2005.75} \exp(-(F_{a-0.25} + M_{a-0.25})) & \text{for } a = 0.25, 0.5, 0.75, ..., 19.75 \\ N^k_{19.75,2005.75} \exp(-(F_{19.75} + M_{19.75})) + N^k_{20,2005.75} \exp(-(F_{20} + M_{20})) & \text{for } a = 20 \end{cases} \quad (3)$$

end for

end for

F_a in the above algorism are depending on future fishing scenarios. We calculates F_a according to $f_{a,2004,s}$ calculated from estimated numbers at age ($n_{a,2004,s}$) and catch at age ($c_{a,2004,s}$) at sth quarter in 2004 by solving the following catch equation.

$$c_{a,2004,s}\cdot F_{multi}=\begin{cases}\dfrac{f_{a,2004,1}}{f_{a,2004,1}+M_a}(n_{a,2004,1}-n_{a-0.25,2003,4}) & \text{for s} = 1\\ \dfrac{f_{a,2004,s}}{f_{a,2004,s}+M_a}(n_{a,2004,s}-n_{a-0.25,2004,s-1}) & \text{for s} = 2,3,4\end{cases} \quad (4)$$

F_{multi} is a multiplier to the catch in the end year of 2004, which is derived from harvest multiplier estimated from SS II to archive target SSB level. The multipliers of F_{multi} should be 0 in no-fishing scenario and 1 in F_{2004} scenario. Future F_a is depending on the season as follows.

$$F_a=\begin{cases} f_{a,1} \text{ for } y=2006,2007,...,2047\\ f_{a,2} \text{ for } y=2006.25,2007.25,...,2046.25\\ f_{a,3} \text{ for } y=2006.5,2007.5,...,2046.5\\ f_{a,4} \text{ for } y=2006.75,2007.75,...,2046.75\end{cases} \quad (5)$$

After repeating the simulation 1000 times, future statistics of total biomass (B_y^k) and SSB (SSB_y^k) are calculated.

$$B_y^k=\sum_{a=0}^{20} w_a N_{a,y}^k \text{ for } y=2006,2006.25,...,2046.75,2047 \quad (6)$$

$$SSB_y^k=\sum_{a=0}^{20} w_a Q_a N_{a,y}^k \text{ for } y=2006,2006.25,...,2046.75,2047 \quad (7)$$

Then, an arithmetic average of B_y^k $\left(\sum_{k=1}^{1000} B_y^k\right)/1000$, and percentiles of 5, 50 and 95% are calculated.

Appendix table. Definition of Terms

a	a age index; a=0,0.25,0.75,1,1.25,…,19.5,19.75,20+
y	y year index; y=1975, 1976,…,2030,2031
k	k index for bootstrap replication number; k=0,…,499,5003
$N_{a,y}^k$	Population numbers at the middle (?) of the quarter
$n_{a,y}^k$	Population numbers at the middle (?) of the quarter
M_a	M instantaneous rate of natural mortality (yr-1)
F_a	Instantaneous rate of fishing mortality in future
$F_{a,y}$	Instantaneous rate of fishing mortality in estimation phase
$c_{a,y}$	Estimated catch at age in weight in estimation phase
w_a	Weight at age of an individual at the middle (?) of the year
Q_a	Maturity rates at age
B	Stock biomass at the beginning of the year (?)
SSB	SSB spawning stock biomass at the beginning (?) of the spawning season

Appendix B. Control file of SS II applied to this simple data

```
#    bluefin model with quarterly fisheries, annual cpue,
#    Size data and catch data was updated at April, 2007
1      # N_growth_patterns
1      # N_sub-morphs per gender x growth pattern
1      # N_areas
1 1 1 1 1    1 1 1 1 1    1 1 1 1 1    #area for each fleet survey
#_recruit_design_(G_Pattern_x_birthseas_x_area)_X_(0/1_flag)
1 0 0 0 # season1-4
0    # recr_dist_interaction
0    # domigration
0    1    1      #    season1    # Movement Pattern by season x source x destination
0    1    1      #    season2
0    1    1      #    season3
0    1    1      #    season4
# Block parameters
4      # Nblock_patterns
1 1 2 2 # Blocks_per_pattern
#1981 2004
1994 2004 # vectors of beginning and ending years for blocks in design 1
1986 2004 # Fleet 7
1960 1980 1981 2004
1986 1993 1994 2004
# Entries that are common to all growth patterns,genders, and morphs
0.5 # Fraction of female to all growth pattern
1      # submorph_between/within stdev_ratio
-1      # vector submorphdist
# mortality and growth parms
0      #last age for nat mortality young
3      #first age for nat mortality old
0        #age lmin
15    #age lmax
0.1 # SD_add_to _LAA
1      # CV_pattern
#-4    #MG parm dev phase
1      # Maturity option
3      # First Mature Age
1      # MGparam_as_offset
1
-1    # MGparams_Dev_Phase
# Read Mortality and Growth Parameters
# lo    hi    init    prior pr_type sd phase env-var use_dev dvmnyr dvmxyr dvsddv block blktype
  0.01 2    1.6    1.6    0    0.8 -3 0      0    0    0    0.5    0    0 # M young
  0.1    0.4    0.25    0.25 0    0.8 -3 0      0    0    0    0.5    0    0 # Natmort_old
                                                  # Natural mortality for ages>=NMold
  3    200 22.5    26    0    1000 -6 0      0    0    0    0.5    0    0 #Lmin
  201    400 257    257    0    1000 -4 0      0    0    0    0.5    0    0 #Lmax
  0.01 0.65 0.1035 0.1035 0    0.2 -4 0      0    0    0    0.5    0    0 #vbk
  0.01 0.25 0.08    0.08 0    999 -3 0      0    0    0    0.5    0    0 #CV for size age age, age<=AFIX
  0.01 0.25 0.08    0    0    0.8 -3 0      0    0    0    0.5    0    0 #CV for size at age, age>=AFIX2
#len-wt and maturity
      -3    3      0.00003 0.00003 0      0.8 -3    0      0      0      0      0.5 0      0      #wt len      a
      -3    3      2.9085    2.9085    0      0.8 -3    0      0      0      0      0.5 0      0      # wt len2 b
      -3    3      130 130 0      0.8 -3    0      0      0      0      0.5 0      0                  #Maturity inflect
      -3    3      -.64        -.64        0      0.8 -3    0      0      0      0      0.5 0      0      #Maturity 2
      0      1      1      1      0      0.8 -3    0      0      0      0      0.5 0      0                  #egg/gram
      0      1      0      0      0      0.8 -3    0      0      0      0      0.5 0      0                  #egg.gram slope
#pop*growth morph for the prop of each morph in each area
```

```
	-4	4	0	1	-1	99 -3	0	0	0	0	0.5 0	0	# fraction morph 1 to area 1
#pop lines for the prop assigned to each area
	-4	4	0	1	-1	99 -3	0	0	0	0	0.5 0	0	# redistribution_by_area
	-4	4	0	1	-1	99 -3	0	0	0	0	0.5 0	0	# redistribution_by_season
	-4	4	0	1	-1	99 -3	0	0	0	0	0.5 0	0	# redistribution_by_season
	-4	4	0	1	-1	99 -3	0	0	0	0	0.5 0	0	# redistribution_by_season
	-4	4	0	1	-1	99 -3	0	0	0	0	0.5 0	0	# redistribution_by_season
	-4	4	0	1	-1	99 -3	0	0	0	0	0.5 0	0	# ?
0	# cust env read
0 #custom block read
#SR section
1	#1=beverton holt with flat top beyond Bzero
#	lo	hi	init	prior	prtype	sd	phase
	10	16 12	12	0	1000	2	# Ln(R0)
	0.2 1	0.99	0.7 0	1000	3	#Steepness
	0	2	0.6	0.6 0	1000	3	#sd recruitments
	-5	5	0	0	0	1	-3	#env link
	-5	5	0	0	0	1	-4	#init_eq
	-5	5	0	0	0	-1	-4	#future
0	#SR_env_link
0	# SR-env_target
1	# Do_recr_dev
#	start_rec end_rec Lower upper	phase
	1952	2004	-20 20	2
1492 # First_Yr_fullbias_adj_in _MPD
#init_F
#	Lo	Hi	init	prior	prtype	sd	phase
	0	.9	0.10001 0.100000	0	10000	1 #fishery1 catch
	0	.2	0.000 0.0000	0	10000	-1 #fishery2
	0	.9	0.10001 0.10001	0	10000	1 #fishery3	catch
	0	.9	0.10000 0.100000	0	10000	1 #fishery4	catch
	0	.9	0.10000 0.10000	0	10000	1 #fishery5	catch
	0	.9	0.10000 0.10000	0	10000	1 #fishery6	catch
	0	.9	0.10000 0.10000	0	10000	1 #fishery7	catch
	0	.2	0.000 0.00000	0	10000	-1 #fishery8
	0	.9	0.1000 0.100000	0	10000	1 #fishery9 catch
#Qsetup
0	0	0	0	1	30	#	fishery1	JLL
0	0	0	0	1	30	#	fishery2	Jpel PS
0	0	0	0	1	30	#	fishery3	Jtuna PS
0	0	0	0	1	30	#	fishery4	J Troll
0	0	0	0	1	30	#	fishery5	J PL
0	0	0	0	1	30	#	fishery6	J SetNet
0	0	0	0	1	30	#	fishery7	EPO
0	0	0	0	1	30	#	fishery8	TWLL
0	0	0	0	1	30	#	fishery9	Other
0	0	0	0	1	30	#	cpue1	JLL1
0	0	0	0	1	30	#	cpue2	JLL2
0	0	0	0	1	30	#	cpue3	J tuna PS
0	0	0	0	1	30	#	cpue4	J troll
0	0	0	0	1	30	#	cpue5	EPO1
0	0	0	0	1	30	#	cpue6	EPO2

#selex and retention
#selextype	doretention do male	mirror
1	0	0	0	#fleet1 JLL
24	0	0	0	#fleet2 Jpn Pel PS
24	0	0	0	#fleet3 NWPO PS
24	0	0	0	#fleet4 Jpn Troll
```

```
24    0    0    0    #fleet5 JpnPL
24    0    0    0    #fleet6 Set net
24    0    0    0    #fleet7 EPO
24    0    0    0    #fleet8
24    0    0    0    #fleet9
5    0    0    1    #fleet10 CPUE small JLL from 1994
5    0    0    1    #fleet11 CPUE dw JLL til 1994
5    0    0    4    #fleet12 CPUE Jpn troll
5    0    0    3    #fleet13 CPUE Jpn WPS
5    0    0    7    #fleet14 CPUE EPO
5    0    0    7    #fleet15 CPUE EPO

#age selex
11    0    0    0    #fleet1 JLL
11    0    0    0    #fleet2 Jpn Pel PS
11    0    0    0    #fleet3 NWPO PS
11    0    0    0    #fleet4 Jpn Troll
11    0    0    0    #fleet5 Jpn PL
11    0    0    0    #fleet6 Set net
11    0    0    0    #fleet7 EPO
11    0    0    0    #fleet8
11    0    0    0    #fleet9
11    0    0    0    #fleet10 cpue JLL
11    0    0    0    #fleet11 cpue JLL
11    0    0    0    #fleet12
11    0    0    0    #fleet13
11    0    0    0    #fleet14
11    0    0    0    #fleet15

#LO   HI    INIT    PRIOR    PR_type   SD    PHASE    env-variable    use_dev   dev_minyr
dev_maxyr    dev_stddev    Block_Pattern
# JLL logistic curve
19    250    200    200    0    999    2    0    0    0    0    0    0    0
0.001    80    30    30    0    999    3    0    0    0    0    0    0    0
#fleet 1 JLL selex option24
#20    280    173    173    0    999    2    0    0    0    0    0    0    0    # peak1
#-6    4    -4.3    -4.3    0    999    2    0    0    0    0    0    0    0    #Top
#-1    9    7.8    7.8    0    999    2    0    0    0    0    0    0    0    #ASC-width ln(width)
#-1    9    7.3    7.3    0    999    2    0    0    0    0    0    0    0    #DESC-WIDTH ln(width)
#-5    9    -5    -5    0    999    2    0    0    0    0    0    0    0    # INITIAL sel at the first size bin
#-5    9    9    9    0    999    -2    0    0    0    0    0    0    0    # FINAL sel at the last size bin

#fleet 2 JK PS selex option24
21.2    284.1    60    60    0    999    2    0    0    0    0    0    0    0    # peak1
-6    4    -6    -6    0    999    2    0    0    0    0    0    0    0    #Top
-1    9    5.3    5.3    0    999    2    0    0    0    0    0    0    0    #ASC-width ln(width)
-1    9    4.4    4.4    0    999    2    0    0    0    0    0    0    0    #DESC-WIDTH ln(width)
-5    9    -5    -5    0    999    2    0    0    0    0    0    0    0    # INITIAL sel at the first size bin
-5    9    -5    -5    0    999    2    0    0    0    0    0    0    0    # FINAL sel at the last size bin

#fleet 3 NWPO PS selex option24
21.2    284.1    125    125    0    999    2    0    0    0    0    0    4    2    # peak1
-6    4    1    1    0    999    2    0    0    0    0    0    4    2    #Top
-1    9    6.5    6.5    0    999    2    0    0    0    0    0    4    2    #ASC-width ln(width)
-1    9    9    9    0    999    2    0    0    0    0    0    4    2    #DESC-WIDTH ln(width)
-5    9    -5    -5    0    999    2    0    0    0    0    0    4    2    # INITIAL sel at the first size bin
-5    9    -5    -5    0    999    2    0    0    0    0    0    4    2    # FINAL sel at the last size bin

#fleet 4 Jpn troll selex option 24
```

```
21.2    284.1    51.7    51.7   0   999    2   0   0   0   0   0   0   2   # peak1
-6      4       -6.0      -6.0      0   999    2   0   0   0   0   0   0   2   #Top
-1      9        6.5      6.5    0   999    2   0   0   0   0   0   0   2   #ASC-width ln(width)
-1      9        5.9      5.9    0   999    2   0   0   0   0   0   0   2   #DESC-WIDTH ln(width)
-5      9        -0.5      -0.5     0   999   2   0   0   0   0   0   0   2   # INITIAL sel at the first size bin
-5      9        -5        -5      0   999    2   0   0   0   0   0   0   2   # FINAL sel at the last size bin

#fleet 5 Jpn PL selex option24
21.2    284.1    36     36   0   999    2   0   0   0   0   0   0   2   # peak1
-6      4      -6      -6      0   999    2   0   0   0   0   0   0   2   #Top
-1      9        3       3    0   999    2   0   0   0   0   0   0   2   #ASC-width ln(width)
-1      9        7.8      7.8    0   999    2   0   0   0   0   0   0   2   #DESC-WIDTH ln(width)
-5      9        -5        -5      0   999     2   0   0   0   0   0   0   2   # INITIAL sel at the first size bin
-5      9        -5        -5      0   999     2   0   0   0   0   0   0   2   # FINAL sel at the last size bin

#fleet 6 Jpn Set selex option 24
21.2    284.1    73.5    73.5   0   999    2   0   0   0   0   0   0   2   # peak1
-6      4      -6      -6      0   999    2   0   0   0   0   0   0   2   #Top
-1      9      6.8      6.8    0   999    2   0   0   0   0   0   0   2   #ASC-width ln(width)
-1      9      7.3      7.3    0   999    2   0   0   0   0   0   0   2   #DESC-WIDTH ln(width)
-5      9        -5        -5      0   999    2   0   0   0   0   0   0   2   # INITIAL sel at the first size bin
-5      9        -5        -5      0   999    2   0   0   0   0   0   0   2   # FINAL sel at the last size bin

#fleet 7 EPO selex option 24
21.2    284.1    74.3    74.3   0   999    2   0   0   1952   2004   0.2   2   2   # peak1
-6      4      -0.5      -0.5      0   999    2   0   0   0   0   0   2   2   #Top
-1      9        5.8      5.8    0   999    2   0   0   0   0   0   2   2   #ASC-width ln(width)
-1      9        5.4      5.4    0   999    2   0   0   0   0   0   2   2   #DESC-WIDTH ln(width)
-5      9        -5        -5      0   999    2   0   0   0   0   0   2   2   # INITIAL sel at the first size bin
-5      9        -5        -5      0   999    2   0   0   0   0   0   2   2   # FINAL sel at the last size bin

#fleet 8 TWLL selex option 24
21.2    284.1    252.6    252.6   0   999    2   0   0   0   0   0   0   2   # peak1
-6      4      -5      -5      0   999    2   0   0   0   0   0   0   2   #Top
-1      9      5.8      5    0   999    2   0   0   0   0   0   0   2   #ASC-width ln(width)
-1      9      6.3      6    0   999    2   0   0   0   0   0   0   2   #DESC-WIDTH ln(width)
-5      9        -5        -5      0   999    2   0   0   0   0   0   0   2   # INITIAL sel at the first size bin
-5      9        9        9      0   999    2   0   0   0   0   0   0   2   # FINAL sel at the last size bin

#fleet 9 Other selex option 24
21.2    284.1    76.4    76.4   0   999    2   0   0   0   0   0   0   2   # peak1
-6      4      0.5      0.5      0   999    2   0   0   0   0   0   0   2   #Top
-1      9      6.4      6.4    0   999    2   0   0   0   0   0   0   2   #ASC-width ln(width)
-1      9      8      8    0   999    2   0   0   0   0   0   0   2   #DESC-WIDTH ln(width)
-5      9        -5        -5      0   999   2   0   0   0   0   0   0   2   # INITIAL sel at the first size bin
-5      9        -5        -5      0   999   2   0   0   0   0   0   0   2   # FINAL sel at the last size bin

#CPUE1
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45   64   63   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
#CPUE2
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45   64   63   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
#CPUE3
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45   64   63   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
#CPUE4
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45   64   63   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
```

```
#CPUE5
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45   64   63   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
#CPUE6
1   14   1   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
45   64   63   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror

# age selex
# fleet 1
0   1   0   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
10   20   20   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
# fleet 2
0   1   0   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
10   20   20   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
# fleet 3
0   1   0   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
10   20   20   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
# fleet 4
0   1   0   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
10   20   20   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
# fleet 5
0   1   0   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
10   20   20   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
# fleet 6
0   1   0   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
10   20   20   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
# fleet 7
0   1   0   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
10   20   20   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
# fleet 8
0   1   0   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
10   20   20   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
# fleet 9
0   1   0   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
10   20   20   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
# fleet 10
0   1   0   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
10   20   20   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
# fleet 11
0   1   0   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
10   20   20   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
# fleet 12
0   1   0   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
10   20   20   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
# fleet 13
0   1   0   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
10   20   20   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
# fleet 14
0   1   0   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
10   20   20   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
# fleet 15
0   1   0   1   0   25   -99   0   0   0   0   0.5   0   0   # fleet 2 start mirror low
10   20   20   63   0   25   -99   0   0   0   0   0.5   0   0   #fleet 2 upper mirror
# selparm adujest method
1
# custom env read
0
#custom block read
1
```

```
# block parameters
#-3 3 0 0 0 5    6 #
20     280     124.5     124.5    0    999     2     # peak1    Fleet3 1986-1993
20     280     185.8     185.8    0    999     2     # peak1    Fleet3 1994-2004
-6      4       -4.8       -4.8      0    999     4     #Top
-6      4       -6       -6       0    999     2     #Top
-1      9        7.2       7.2     0    999     2     #ASC-width ln(width)
-1      9        8.1       8.1     0    999     2     #ASC-width ln(width)
-1      9        8.3       8.3     0    999     2     #DESC-WIDTH ln(width)
-1      9        7       7     0    999     2     #DESC-WIDTH ln(width)
-5      1        -5        -5       0    999     2     # INITIAL selectivity at the first size bin
-5      1        -5        -5       0    999     2     # INITIAL selectivity at the first size bin
-5      1        -5        -5       0    999     2     # FINAL selectivity at the last size bin
-5      1        -5        -5       0    999     2     # FINAL selectivity at the last size bin

#20     60     40     35.7    0    999     2     # peak1 Fleet5 1994-2004
#-22      10      -5       -6       0    999     2    #Top
#2     4        2.5       3     0    999     2    #ASC-width ln(width)
#2     4        2.5       3     0    999     2    #DESC-WIDTH ln(width)
#-5      1        -5        -5       0    999     2    # INITIAL selectivity at the first size bin
#-5      1        -5        -5       0    999    -2    # FINAL selectivity at the last size bin

20     280     88.8     88.8    0    999     2    # peak1 Fleet7 1985-2004
-6      4       -0.2       -0.2      0    999     2    #Top
-1     9        5.8       5.8     0    999     2    #ASC-width ln(width)
-1     9        6.3       6.3     0    999     2    #DESC-WIDTH ln(width)
-5      1        -5        -5       0    999     2    # INITIAL selectivity at the first size bin
-5      1        -5        -5       0    999     2    # FINAL selectivity at the last size bin

-4    # phase for selex parms dev
#0
#variance adjustment factors
# row 1    value added to survey CV (set to zero for no effect)
0 0 0 0 0    0 0 0 0 0    0 0 0 0 0
# row 2    value added to discard stddev
0 0 0 0 0    0 0 0 0 0    0 0 0 0 0
# row 3    value added to mean body wt stddev
0 0 0 0 0    0 0 0 0 0    0 0 0 0 0
# row 4    multiplier for lencomp effective N (set to 1.0 for no effect)
1 1 1 1 1    1 1 1 1 1    1 1 1 1 1
# row 5    multiplier for agecomp effective N (set to 1.0 for no effect)
0 0 0 0 0    0 0 0 0 0    0 0 0 0 0
# row 6    multiplier for size-at-age effective N (set to 1.0 for no effect)
0 0 0 0 0    0 0 0 0 0    0 0 0 0 0
#
30    # DF for T dist used to scale discard deviations
30    # DF for T dist used to scale mean body wt dev
1 #max lambda phases
0 # include (1) or not (0) the constant offset for Logs(s) in the Log(like) calculation
# survey lambdas
1 1 1 1 1    1 1 1 1 1    1 1 1 1 1
# discard lambdas
0 0 0 0 0    0 0 0 0 0    0 0 0 0 0
0 # mean body wt
#lenfreq lambda
1 1 1 1 1    1 1 1 1 1    1 1 1 1 1
#age freq lambda
0 0 0 0 0    0 0 0 0 0    0 0 0 0 0
# mean size at age
```

```
0 0 0 0 0    0 0 0 0 0    0 0 0 0 0
1 #init equlib F
1 #rec lambda
0 #parm prior lambda
0 #prior dev timeseries lambda
100 #crashpen lambda
0.9 #max F
999
```

Table 1. Example files of starter.ss2 and forecast.ss2 when assuming SPR0.1.

	starter.ss2
	…… (abbr.) …..
22	1 #Forecast option (moved from forecast.ss2 and change index #assignment) #0 = no forecast #1 = use F(spr) for forecast #2 = use F(msy) for forecast #3 = use F(btarget) for forecast #4 = use ending year F for forecast
23	1 #MSY option (moved from forecast.ss2 and change index assignment) #0 = no MSY calc #1 = set F(msy) = F(spr) #2 = calc F(msy) #3 = set F(msy) = F(Btarget) #4 = set F(msy) = ending year F
24	1 #Do output for west coast groundfish rebuilder package #0=skip, but items two below still must exist to be read. Also, if #forecast is turned off, then this should be turned off also. #1=do
25	-1 # year declared for rebuilder package #This is the first year for which catch could have been set to zero #(Ydecl). SS2 will output the age composition at the beginning of this #year. #Default = -1 will set to 1999
26	-1 #start year for rebuilder package #This is the year from which the rebuilder package will start #simulations (Yinit). SS2 will output the age composition at the #beginning of this year. #Default = -1 will set to endyr+1
	forecast.ss2
1	0.1 # Target SPR
2	40 # Number of forecast years
3	40 # Number of forecast years with stddev, must be less # than or equal to total forecast years. Nearly all model dimensioning uses this value
4	1 # recruitment deviation emphasis -- see below
5	1 # Fraction log-bias adjustment Before End Year+1
6	0 # Fraction log-bias adjustment After End Year
7	0 # Top of 400 Option
8	10 # Bottom of 400 Option
9	1 # OY Scalar to ABC
10	-3 # First year (relative to endyr) for averaging fishery selectivity
11	0 # last year for average selectivity
12	1 # Relative F Flag # 1=set relative F from endyr # 2= use relative F read below # then enter the pattern of relative harvest rate to be used when Option 2 # above is selected. Otherwise, the pattern of harvest rates across seasons and fleets in the endyear # is used when finding Fmsy, Fspr and doing the forecast.
13	0 0 0 0 0 0 0 0 0 # relative harvest rate for fleet0-9 in season 1 0 0 0 0 0 0 0 0 0 # relative harvest rate for fleet0-9 in season 2 0 0 0 0 0 0 0 0 0 # relative harvest rate for fleet0-9 in season 3 0 0 0 0 0 0 0 0 0 # relative harvest rate for fleet1-9 in season 4
14	999
15	-1 -1 -1 -1 -1 -1 -1 -1 -1 # year 1 season 1 fleet 1-9 -1 -1 -1 -1 -1 -1 -1 -1 -1 # year 1 season 2 fleet 1-9 -1 -1 -1 -1 -1 -1 -1 -1 -1 # year 1 season 3 fleet 1-9 -1 -1 -1 -1 -1 -1 -1 -1 -1 # year 1 season 4 fleet 1-9

	-1 -1 -1 -1 -1 -1 -1 -1 -1 # year 2 season 1 fleet 1-9 …. (abbr.) ….

Table 2. Example files of starter.ss2 and forecast.ss2 when assuming no-fishing for projections. Parts expressed by (abbr.) are same as the settings shown in Table 1.

	starter.ss2
	…… (abbr.) …..
22	4 #Forecast option (moved from forecast.ss2 and change index
	…… (abbr.) …..

	forecast.ss2
	…… (abbr.) …..
12	2 # Relative F Flag
13	0 0 0 0 0 0 0 0 0 # relative harvest rate for fleet0-9 in season 1
	0 0 0 0 0 0 0 0 0 # relative harvest rate for fleet0-9 in season 2
	0 0 0 0 0 0 0 0 0 # relative harvest rate for fleet0-9 in season 3
	0 0 0 0 0 0 0 0 0 # relative harvest rate for fleet1-9 in season 4
14	999
	…. (abbr.) ….

Table 3. Example files of starter.ss2 and forecast.ss2 when assuming F 2004. Parts expressed by (abbr.) are same as Table 1.

	starter.ss2
	…… (abbr.) …..
22	4 #Forecast option (moved from forecast.ss2 and change index
	…… (abbr.) …..

	forecast.ss2
	…… (abbr.) …..
12	1 # Relative F Flag
13	0 0 0 0 0 0 0 0 0 # Average harvest rate for fleet 0-9 in season 1 from 2002 to 2004
	0 0 0 0 0 0 0 0 0 # Average harvest rate for fleet 0-9 in season 1 from 2002 to 2004
	0 0 0 0 0 0 0 0 0 # Average harvest rate for fleet 0-9 in season 1 from 2002 to 2004
	0 0 0 0 0 0 0 0 0 # Average harvest rate for fleet 0-9 in season 1 from 2002 to 2004
14	999
	…. (abbr.) ….

Table 4. Example files of starter.ss2 and forecast.ss2 when assuming current F from 2002 to 2004. Parts expressed by (abbr.) are same as the settings shown in Table 1.

	starter.ss2
	…… (abbr.) …..
22	4 #Forecast option (moved from forecast.ss2 and change index
	…… (abbr.) …..

	forecast.ss2								
	…… (abbr.) …..								
12	2 # Relative F Flag								
13	0.01	0.09	0.07	0.02	0.03	0.02	0.10	0.00	0.01
	0.01	0.54	0.00	0.46	0.11	0.01	0.00	0.00	0.01
	0.01	0.17	0.00	0.19	0.03	0.00	0.00	0.00	0.00
	0.07	0.41	0.03	0.16	0.10	0.03	0.05	0.26	0.00
	# The above values are average exploitation in 2002-2004								
14	999								
	…. (abbr.) ….								

Table 5. Probability that the SSB will fall below the histrorical lowest SSB during one or more years of the projection period. F multiplier means a scalar multiplied by matrix of exploiatation rates by fleet and season to the last year of 2004, for which target SSB level will be archieved. In the scenarios of blank columns, calculation was not conducted because of limitation of time and computer resources. In the attached figure, x axis was shown by F multiplier to the F at the last year 2004, for achieving future target SSB level.

$Pr[SSB_{future}<SSB_{observed}|F]$

	F multiplier	SS II	Stochastic	Stochastic with bootstrap	Stochastic with resampled recruitment
No fishing	0	0.06	0.00	0.00	0.00
SPR 0.1	0.33	0.07	0.00	0.00	0.00
SPR 0.05	0.44	0.12	0.01	0.04	0.00
SPR 0.03	0.51	0.18	0.31	0.47	0.24
SPR 0.01	0.66	0.60	1.00	0.64	1.00
Current F	1.00	1.00	1.00	1.00	1.00
$Pr[SSB_{2040}<SSB_{observed}|F]$					
	F multiplier	SS II	Stochastic	Stochastic with bootstrap	Stochastic with resampled recruitment
No fishing	0	0.00	0.00	0.00	0.00
SPR 0.1	0.33	0.01	0.00	0.00	0.00
SPR 0.05	0.44	0.03	0.00	0.00	0.00
SPR0.03	0.51	0.09	0.01	0.02	0.01
SPR 0.01	0.66	0.54	0.59	0.99	0.85
Current F	1.00	1.00	1.00	1.00	1.00

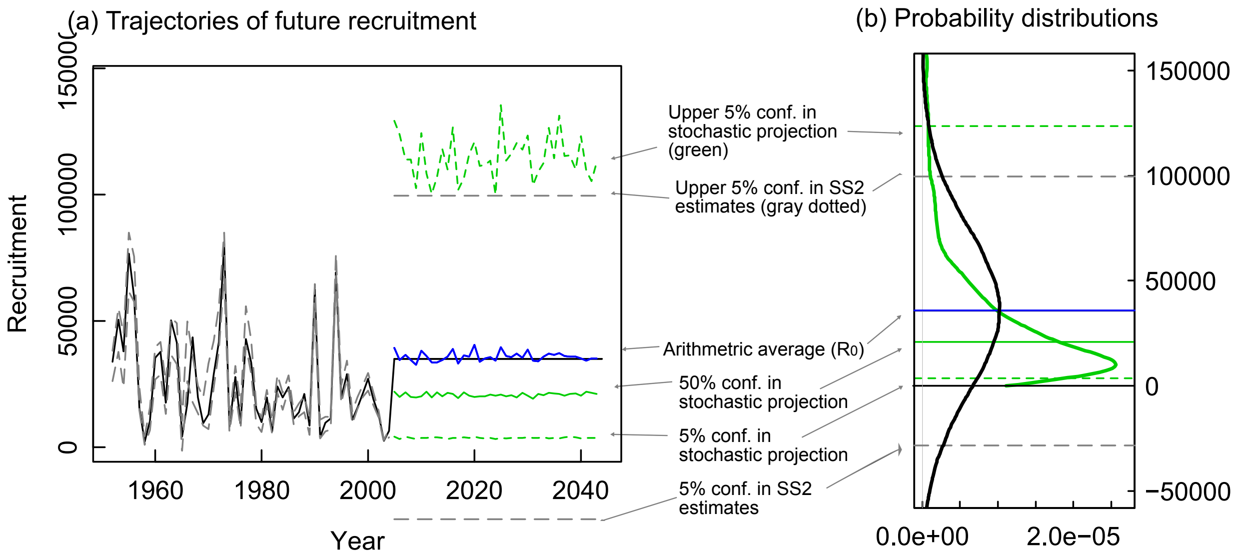

Fig. 1. Comparison of the assumed future recruitments between SS2 and stochastic projection. (a) Future trajectories of SSB. Green sold and dotted lines show median and 90% confidence interval by by stochastic projection. Blue line shows arthmetric average of SSB estimated from stochastic projection. Estimated average and ±1.64σ from SS2 are shown by black and gray dotted lines, respectively. (b) Probability distribution of SSB in 2040. black: SS2, green: stochastic projection

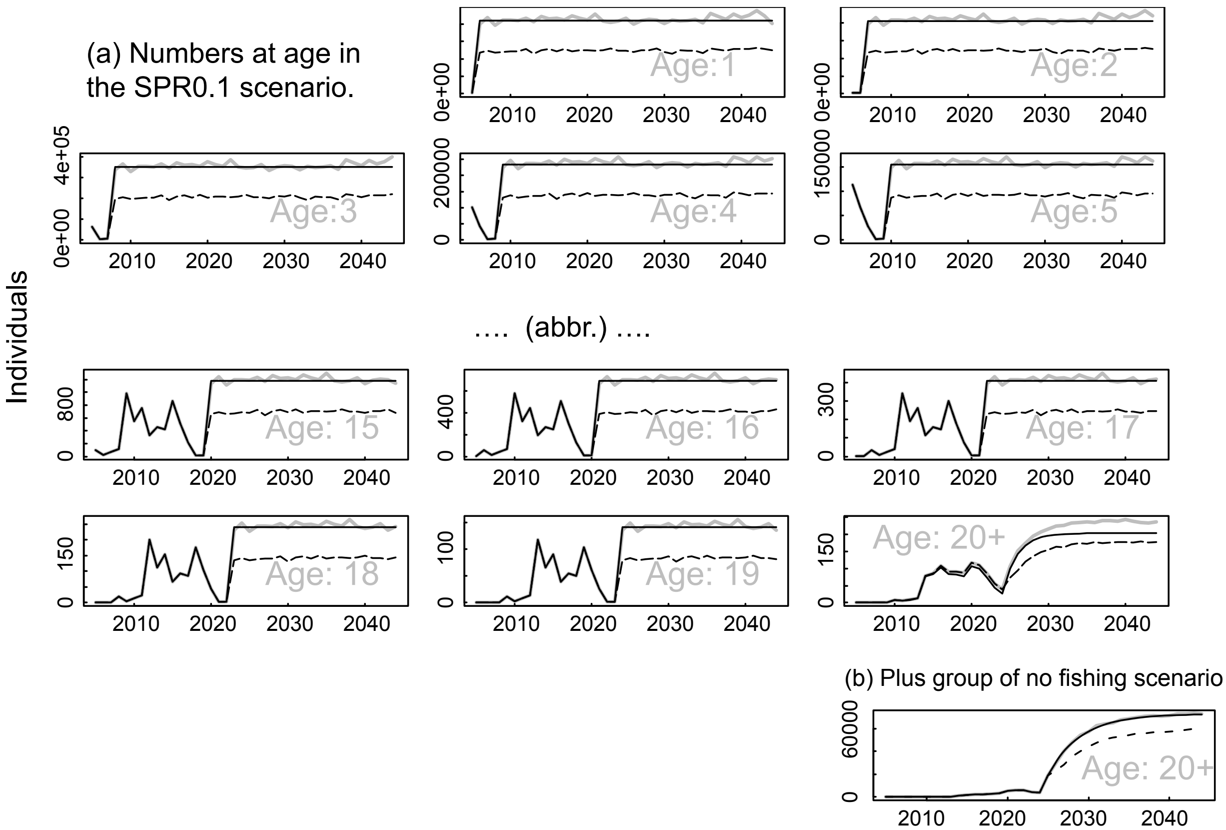

Fig. 2. Comparison between projected numbers at age by SS II and stochastic projections. Gray and balck dotted lines show simple average and median of stochastic projections, respectively, and black solid lines show resutls by SS2.

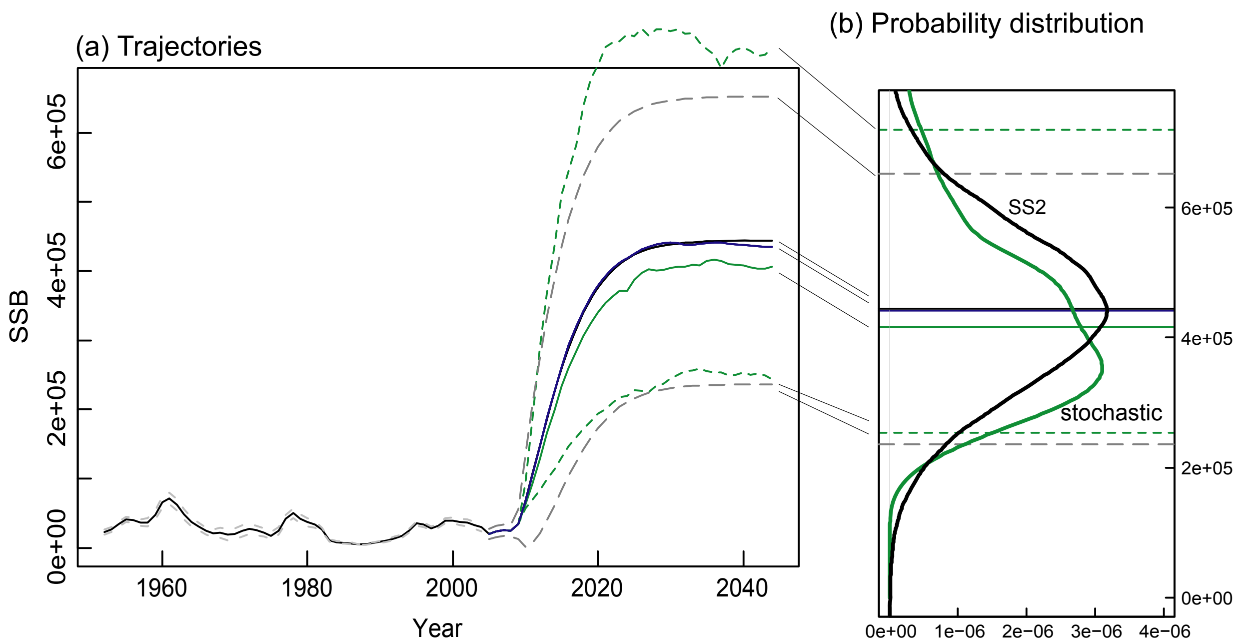

Fig. 3. Comparison between projected SSBs and probability distributions in 2040 by SS II and stochastic projection under the scenario of no-fishing. Figure legend is same as in fig. 1.

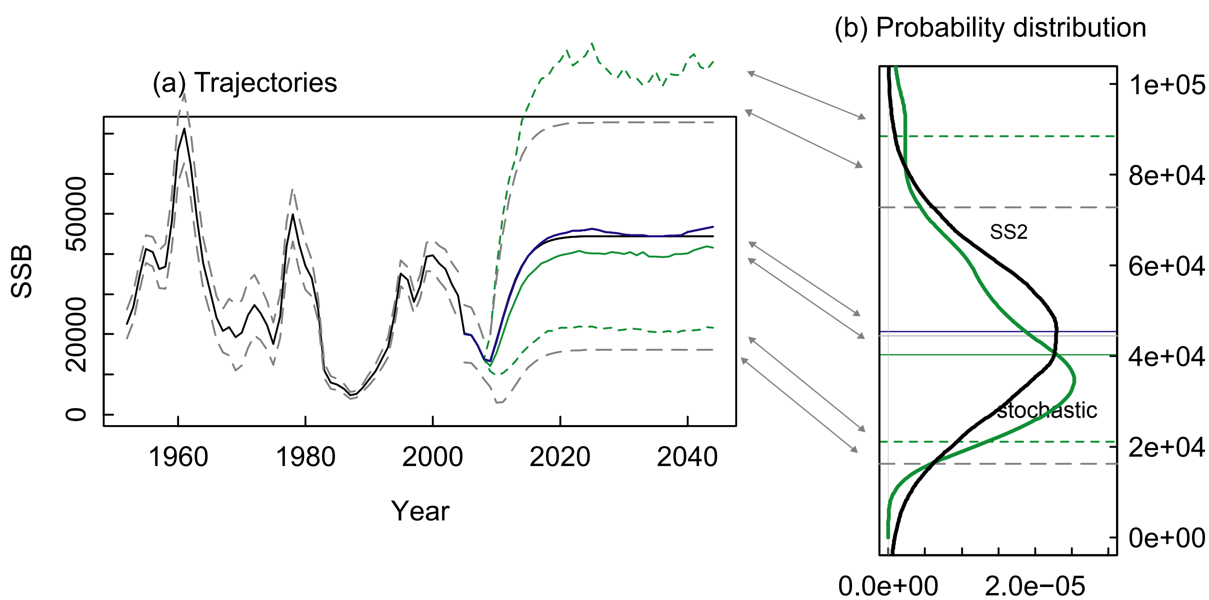

Fig. 4. Comparison between projected SSBs and probability distributions in 2040 by SS II and

stochastic projection under the scenario of SPR=0.1. Figure legend is same as in fig. 1.

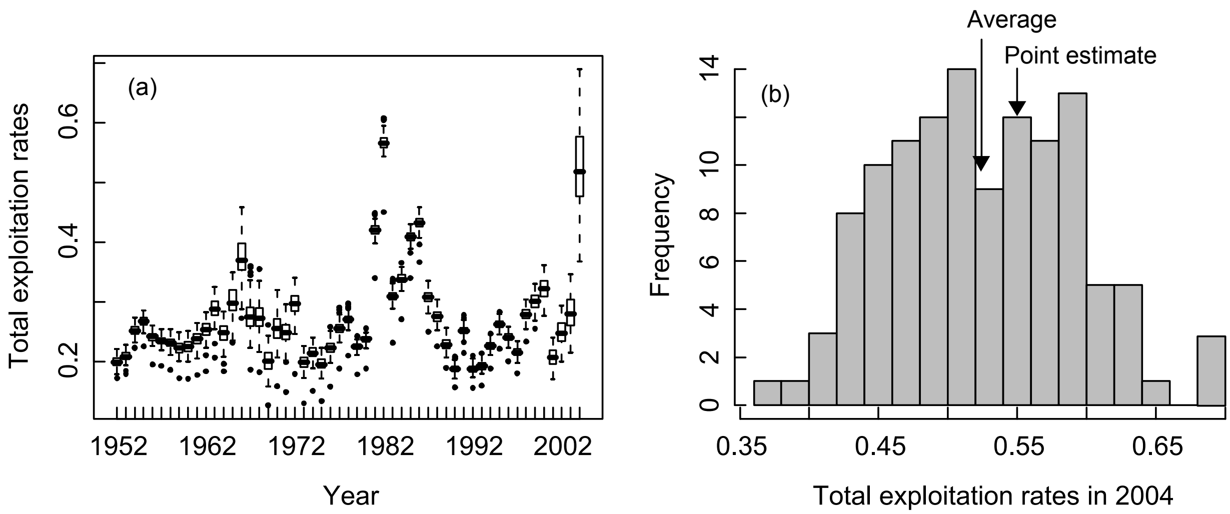

Fig. 5. Total exploitation rates estimated by bootstrap 150 times tirals. (a) Historical exploitation rates (b) total exploitation rates in the end year of 2004. Average and point estimate of total exploitation rate in 2004 was also shown by two arrows.

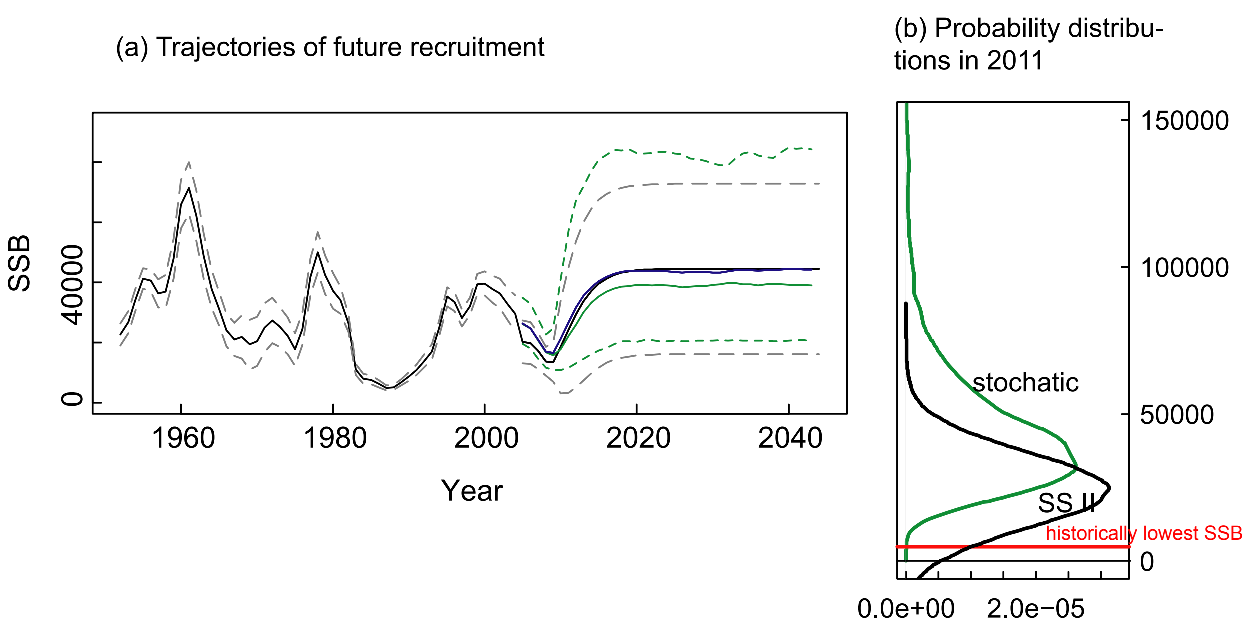

Fig. 6. Results by stochastic projection with bootstrap estimates. (a) trajectories of SSB. (b) Probability distribution of SSB in 2011

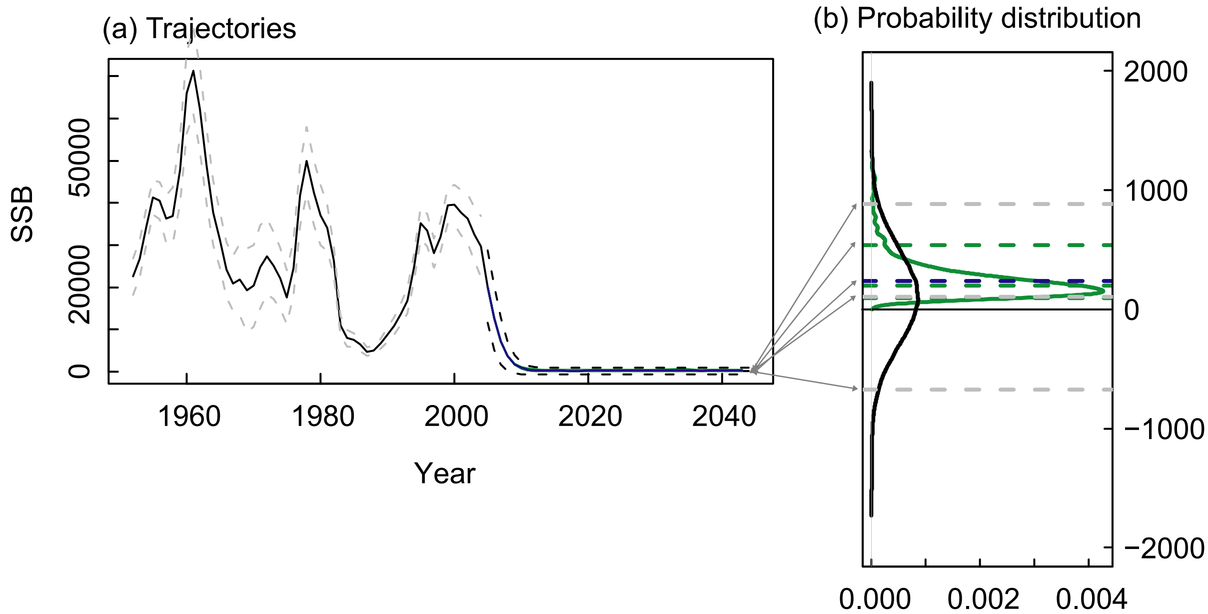

Fig. 7. Comparison between projected SSBs and probability distributions in 2040 by SS II and stochastic projection under the scenario of F in the year. Figure legend is same as in fig. 1.

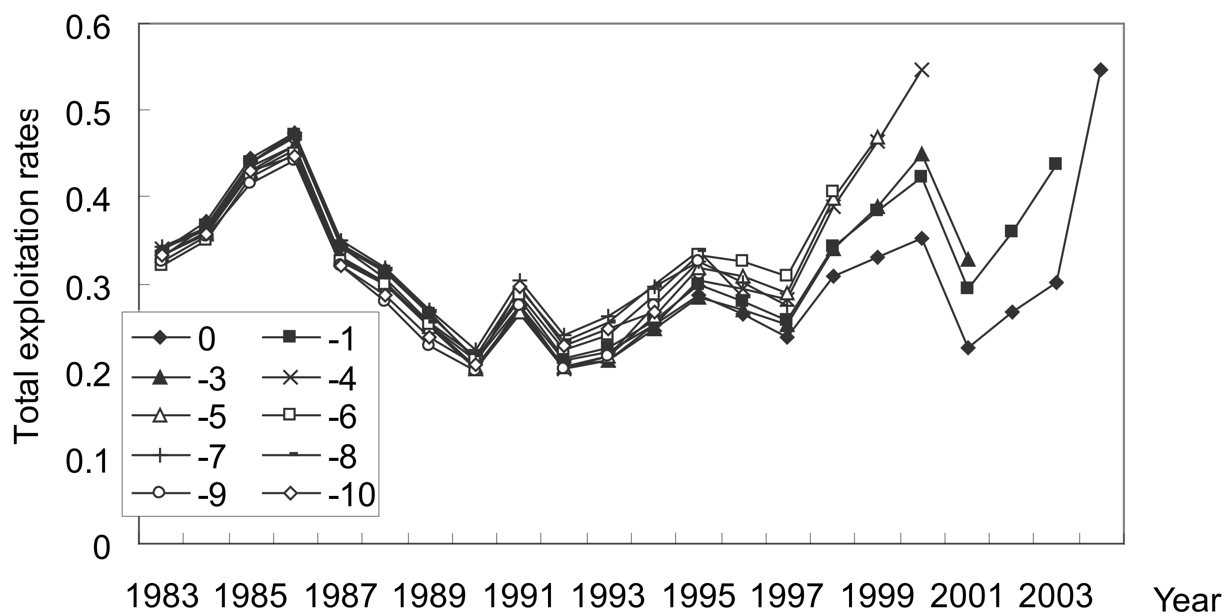

Fig. 8. Retrospective pattern of the total exploitation rates. Results of exploitation rates in minus 2 years data was not shown because of no convergence of the model.

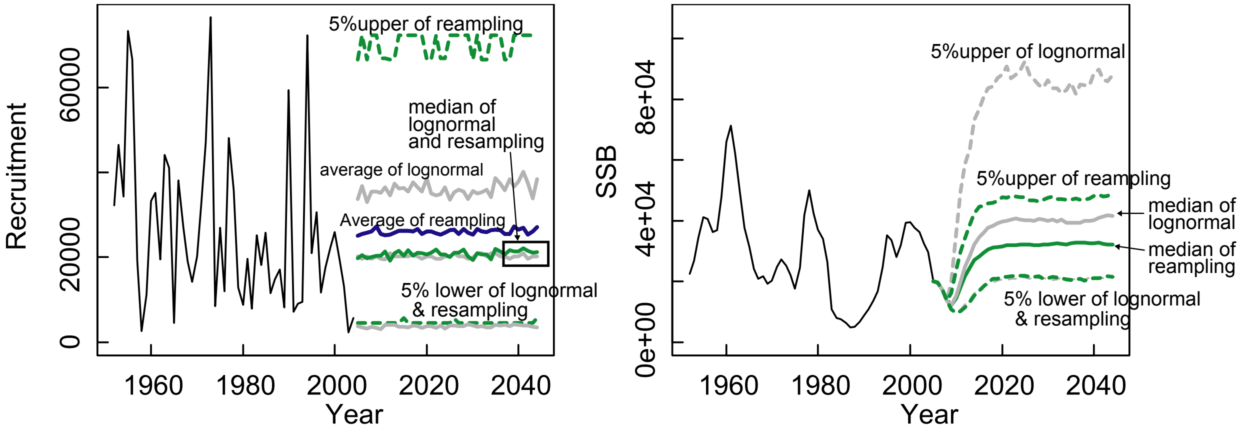

Fig. 9. Comparison of stochastic projections between different recruitment scenarios of lognormal (gray) and resampling (green) under the scenario of SPR0.1. Trejectories of future recruitment (a) and SSB (b) are shown.