New future projection program for North Pacific albacore tuna (*Thunnus alalunga*) : considering two-sex age-structured population dynamics [1]

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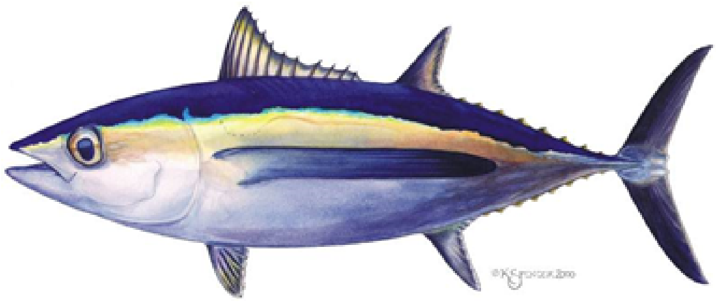

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Abstract

In 2014, International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) albacore working group (ALBWG) conducted a stock assessment for North Pacific albacore tuna. In this assessment, ALBWG assumed two-sex age-structured population dynamics and R software package SSfuture was used for future projection. However, ALBWG couldn't predict total biomass and expected albacore catch, because SSfuture couldn't calculate sex-different population dynamics. Here we constructed new future projection program considering two-sex age-structured population dynamics. We used R software package Rcpp which makes a seamless integration between R and C++. To clarify this new program work, we addressed simple future projection and compared with the projection result from Stock Synthesis 3 (SS3). The new future projection program worked approximately same as SS3. Hence this program is useful for next North Pacific albacore tuna stock assessment.

Introduction

Stock Synthesis 3 (SS3) is an integrated stock assessment model that needs several kinds of data such as catch amount, length frequency, abundance index and biological parameters[1]. SS3 was widely used tuna and tuna-like species by regional fisheries management organizations (RFMO) and focus on the historical change of single stock size and the function of the future projection part is limited. However, in the actual stock assessment for tuna and tuna-like species, it needs to predict the various future situation (e.g., recruitment uncertainty, customized management, and specific biology). The tunas fishery and that management are complex and different by spices. Thus future projection programs that correspond to SS3 were constructed (SSfuture and Rebuilder)[2],[3],[4].

SSfuture that was written in R language was used for Pacific bluefin tuna (*Thunnus orientalis*) and North Pacific albacore tuna (*Thunnus alalunga*) stock assessment[5],[6]. This program was assuming combined age-structured population dynamics and several types of recruitment uncertainty. In the 2014 stock assessment of North Pacific albacore tuna, the sex-different growth curve was indicated[6]. Thus ISC albacore working group (ALBWG) estimated sex-different fishing mortality and historical population dynamics (Fig.1,Fig.2). However, SSfuture could not calculate two-sex population dynamics. To address this difficulty, ALBWG estimated only future female adult albacore biomass[6]. However, ALBWG could not evaluate expected future albacore catch and total biomass. The projected future catch and total biomass are important information for fishery stakeholders. Here we constructed new future projection program considering two-sex age-structured population for North Pacific albacore. For the preliminary analysis, we addressed simple future projection and compared with future projection result of SS3. This basic program was written in C++ and can be compiled by R language because ALBWG also needs a faster and flexible program for future work of management strategy evaluation (MSE) for North Pacific albacore tuna.

Material and methods

Population dynamics model

North Pacific albacore tuna is considered a well mixed single stock and growth curve is different by sex[6]. The estimated fishing mortality of North Pacific albacore was diffetrent by sex (Fig.1). Thus we assumed the two-sex age-structured population dynamics model as

$$N_{t+1,a+1,s} = N_{t,a,s} exp(-F_{t,a,s} - M_a) \ (0 < a < A),$$

$$N_{t+1,A,s} = N_{t,A-1,s}exp(-F_{t,A-1,s} - M_{A-1}) + N_{t,A,s}exp(-F_{t,A,s} - M_A) \ \ (a = A) \quad (1)$$

where $N_{t,a,s}$ is the population number in year t at age a of sex s, $N_{t,A,s}$ is the population number of maximum age in year t of sex s, $F_{t,a,s}$ is fishing mortality in year t at age a of sex s (s=1:female, s=2:male) and M_a is natural mortality at age a respectively. The spawner-recruitment relationship was assumed Beverton-Holt model

$$\overline{R_t} = \frac{4hR_0SB_t}{SB_0(1-h) + SB_t(5h-1)}, \quad (2)$$

where $\overline{R_t}$ is expected recruitment in year t from female spawning biomass in year t (SB_t), h is steepness that means a strength of stock-recruitment relationship, $R0$ is the equilibrium recruitment that correspond to equilibrium female spawning biomass $B0$. SB_t is total weight of mature female $SB_t = \sum_{a=1}^{A} f_a w_{a,1} N_{t,a,1}$, where f_a is female maturity at age a and $w_{a,1}$ is weight at age a by female. We assumed sex ratio of recruitment is 1:1. The process error of recruitment express lognormal variance (${\sigma_R}^2$). Hence realistic recruitment was estimated by

$$R_{t,s} = 0.5\overline{R_t}exp(\varepsilon_t - 0.5{\sigma_R}^2), \ \ \varepsilon_t \sim N(0, {\sigma_R}^2). \quad (3)$$

Future projection program flow

To construct future projection program for North Pacific albacore tuna, we used R and R software package Rccp that makes a seamless integration between R and C++. We designed four step program, and these levels are controlled by R to keep transparency because R is usually used for fishery scientist (Fig.3). Firstly, it needs to read SS3 output (Report.sso, CumReport.sso and Forcast-report.sso). To read SS3 output, we used R software package r4ss. Secondly, list of the input data for the future projection program were made. These values are current population number, maturity age, weight at age by sex and F at age by sex in year t ($F_{t,a,s}$). Fishing mortality at age by sex in year t $F_{t,a,s}$ was not available from SS3 out put. Hence , we obtained $F_{t,a,s}$ to solve the Baranov catch equation using the Newton method,

$$C_{t,a,s} = \frac{F_{t,a,s}}{F_{t,a,s} + M_{a,s}}(1 - exp(-F_{t,a,s} - M_{a,s}))N_{t,a,s} \ \ (0 =< a =< A), \quad (4)$$

where $C_{t,a,s}$ is catch number in year t at age a of sex s and $C_{t,a,s}$, $M_{a,s}$ and $N_{t,a,s}$ were given by SS3 result. SS3 summarized catch number by year, quarter, age and sex. The spawning season of North Pacific albacore was assumed in quarter 2. Thus $C_{t,a,s}$ was summed quarter 2-3 in year t and quarter 1 in year $t+1$. The biological reference point are also calculated and we set a management scenario in this section. Thirdly, all listed data sets put into new future projection program. We used R package of the Rcpp that provides R functions written in C++ language for the future projection program[7]. Rcpp can integrate R and C++ seamlessly and this program faster than R program. The output of this program are $N_{t,a,s}$, SB_t and total catch amount H_t that was given by

$$H_t = \sum_{s=1}^{2}\sum_{a=1}^{A} w_{a,s}C_{t,a,s}. \quad (5)$$

Test run

To verify the work of the new future projection program, we addressed simple deterministic prediction (Do not consider uncertainty). The projection results of $N_{t,a,s}$ were compared with SS3 results. The detail of this future projection as follows:

- Constant fishing mortality scenario that arithmetical average is between 2010 to 2012 (F_{1012}).
- Sexual different population dynamics are assumed (growth and fishing mortality are different).
- Basic assumption of albacore biology and the stock were followed by the 2014 stock assessment.
- The projection period is 2013-2042.

We also addressed future stochastic simulation that iterations were 100 times. In this simulation, we set process error of the recruitment ($\sigma_R = 0.5$). The other assumptions were same as deterministic projection.

Result and discussion

We constructed new future projection model considering two-sex age-structured population dynamics for North Pacific albacore tuna and addressed a simple deterministic simulation. As a result, we obtained the future trajectory of each population number of North Pacific albacore tuna (Fig.4, Fig.5). To clarify our program accuracy, we compared with the SS3 result that was operated on the same assumption of the new projection program. The projected female population number was approximately same, and that maximum difference was 2.4% in year 2022 at age 12 (Fig.4). The male population number was estimated by the new program was also same as SS3 (the maximum difference was 3.5% in year 2022 at age 12) (Fig.5). The maximum difference of female spawning biomass between SS3 and new projection model were 0.6% in year 2041 (Fig.6). These results showed similar performance as SSfuture [2]. We also addressed stochastic future projection using recruitment process error ($\sigma_R = 0.5$) (Fig.7). The mean female spawning biomass showed the same trend as the result of SS3 (Fig.7 a). This reason is obvious because we assumed Beverton-Holt stock recruitment relationship in this simulation. To consider the two-sex age-structured population dynamics model, we could estimate future total catch amount of North Pacific albacore tuna (Fig.7 b). In the previous stock assessment of North Pacific albacore tuna, ALBWG couldn't calculate total catch amount. Hence, this new program is better than the SSfuture that can't address sex difference.

We attempted to make new future projection program using C++ language. This program performed approximately same as the result of SS3 and faster than SSfuture written in R language. Hence, this new projection program can be useful for next stock assessment of North Pacific albacore. However, there is some improvement that needs to address until the next stock assessment as follows:

1. We need to develop constant catch programming code.
2. It needs to reflect future projection scenarios of next North Pacific albacore stock assessment (e.g., Constant catch scenario, several kinds of recruitment hypothesis).
3. It needs to make initial population number that can be considered uncertainty.

References

[1] Richard D Methot and Chantell R Wetzel. Stock synthesis: a biological and statistical framework for fish stock assessment and fishery management. *Fisheries Research*, Vol. 142, pp. 86–99, 2013.

[2] Momoko Ichinokawa. Operating manual and detailed algorithms for conducting stochastic future projections with r packages of ' ssfuture ' . 2011.

[3] Tetsuya Akita, Isana Tsuruoka, Hiromu Fukuda, Kazuhiro Oshima, and Yukio Takeuchi. Update of r packages ' ssfuture ' for stochastic projections in future. 2015.

[4] AE Punt. Ssc default rebuilding analysis: Technical specifications and user manual. jan. 2010. 2010.

[5] ISC pacific bluefin tuna working group. 2016 pacific bluefin tuna stock assessment. 2016.

[6] ISC albacore working group. Stock assessment of albacore tuna in the north pacific ocean in 2014. 2014.

[7] Dirk Eddelbuettel, Romain François, J Allaire, John Chambers, Douglas Bates, and Kevin Ushey. Rcpp: Seamless r and c++ integration. *Journal of Statistical Software*, Vol. 40, No. 8, pp. 1–18, 2011.

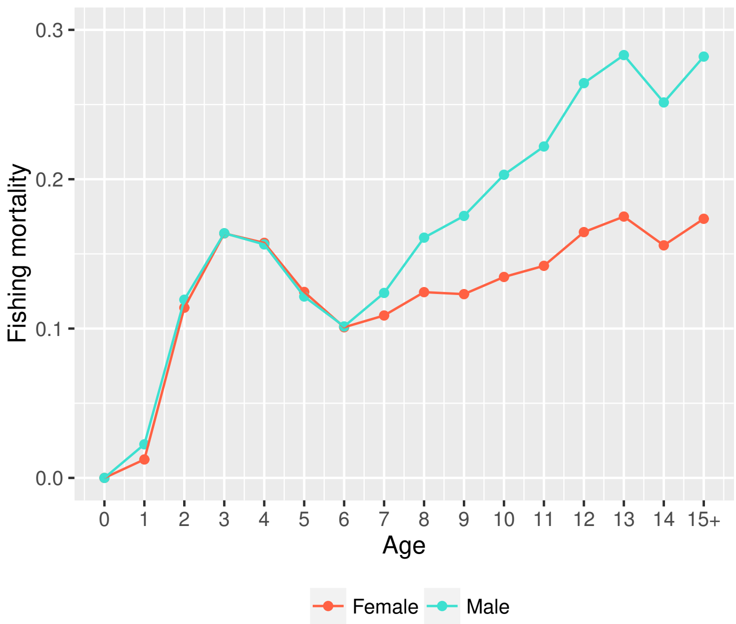

Figure 1: Average fishing mortality at age of North Pacific albacore tuna (2010-2012) that was estimated by 2014 stock assessment.

Figure 2: Population number of North Pacific albacore tuna (age 0 to age 15+) estimated by 2014 stock assessment.

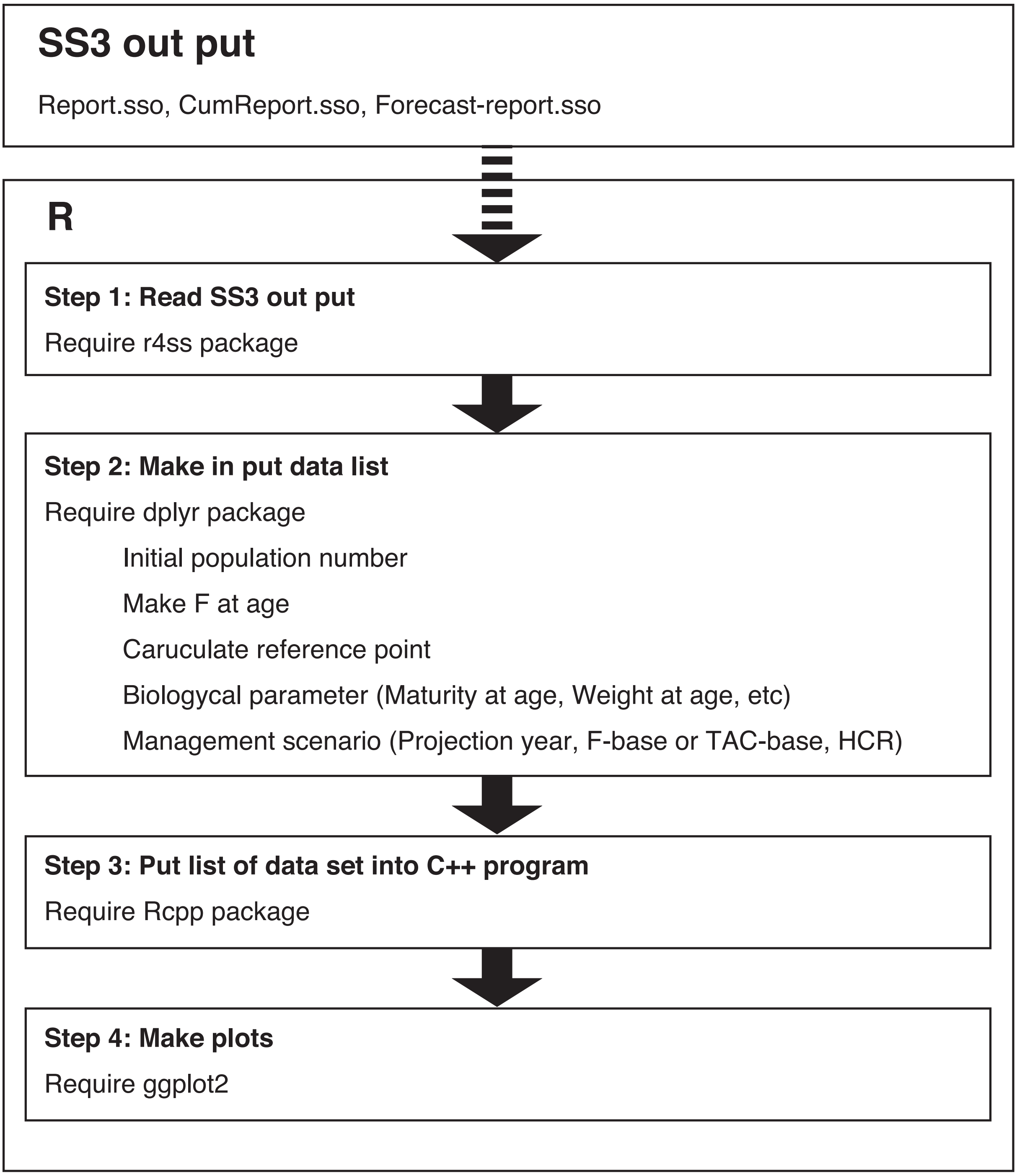

Figure 3: Future projection flow.

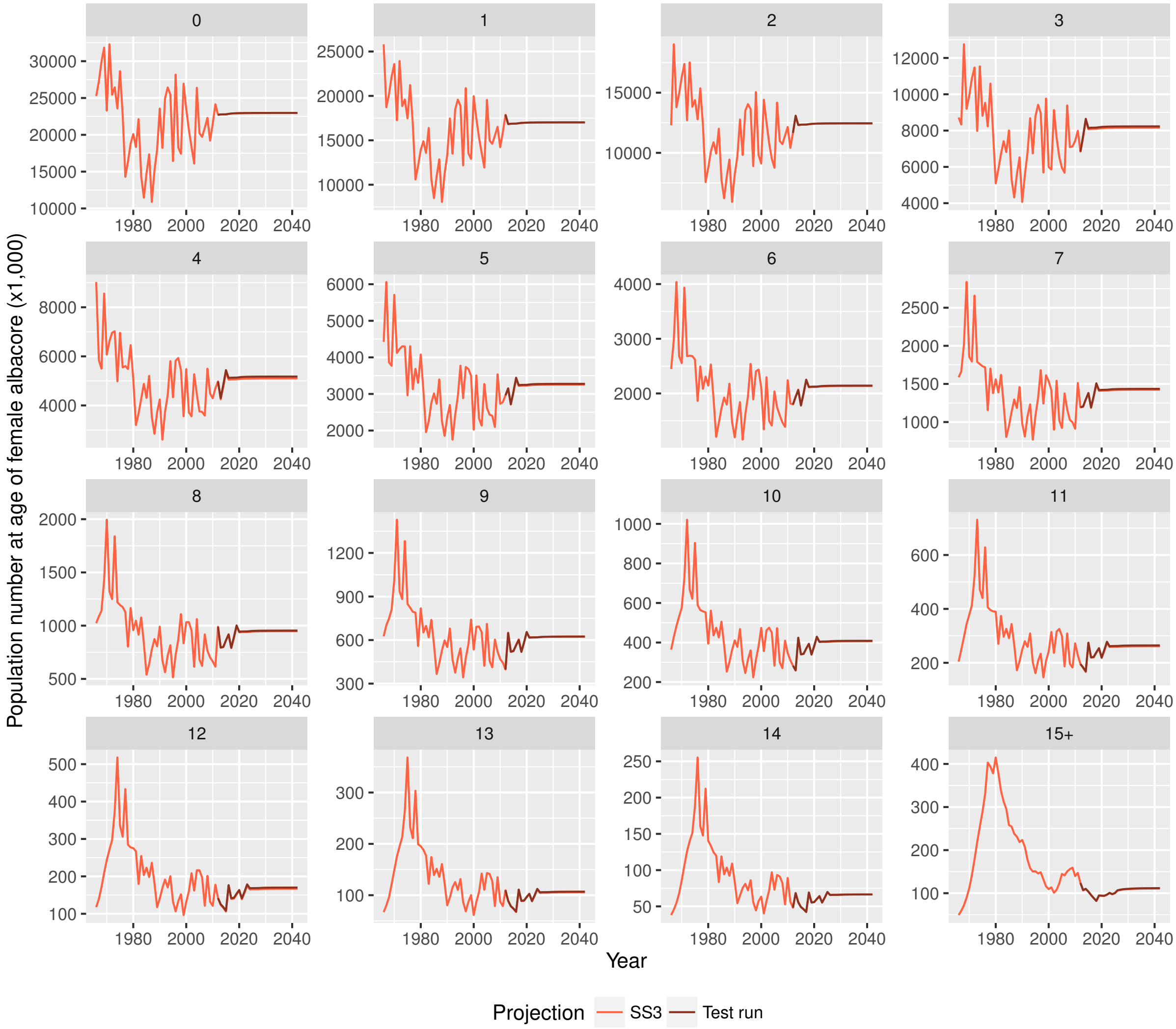

Figure 4: Future population number of North Pacific female albacore tuna (age 0 to age 15+) estimated by SS3 and new future projection program. Deterministic projection was based on the constant fishing mortality scenario (F_{1012}) using Beverton-Holt stock recruitment relationship (without process error).

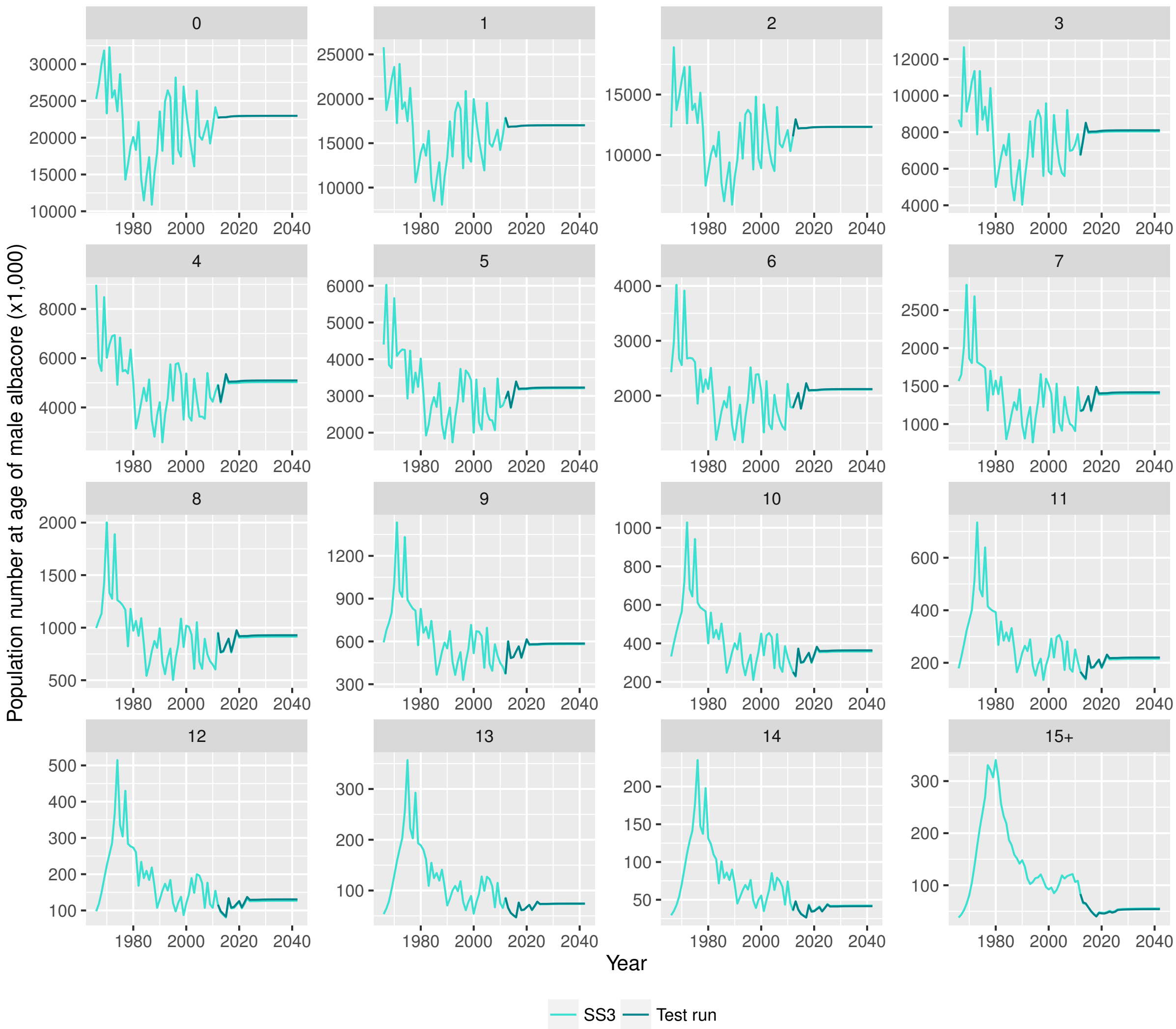

Figure 5: Future population number of North Pacific male albacore tuna (age 0 to age 15+) estimated by SS3 and new future projection program. Deterministic projection was based on the constant fishing mortalityscenario (F_{1012}) using Beverton-Holt stock recruitment relationship (without process error).

Figure 6: Future female spawning biomass of North Pacific albacore tuna estimated by SS3 and new future projection program. Deterministic projection was based on the constant fishing mortalityscenario (F_{1012}) using Beverton-Holt stock recruitment relationship (without process error).

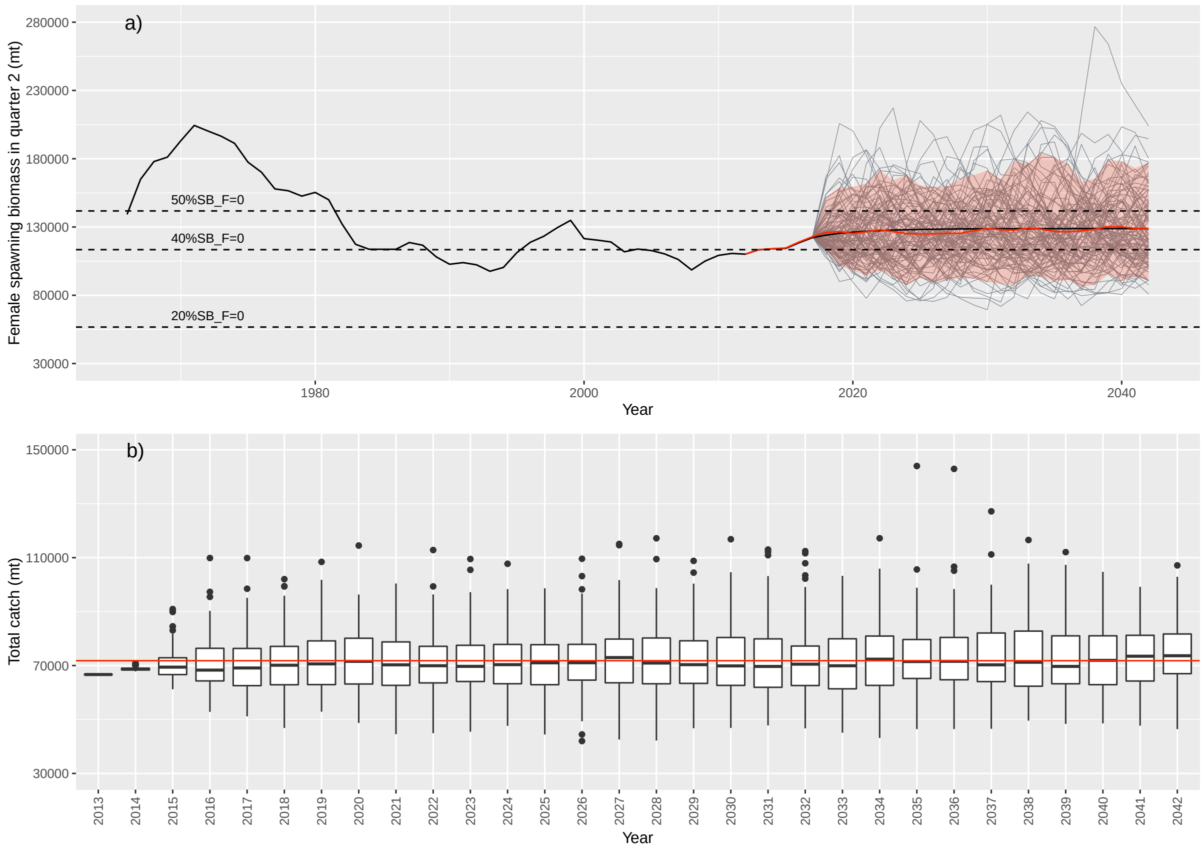

Figure 7: The 100 times stochastic simulation result of North Pacific albacore tuna stock that based on the constant fishing mortality scenario (F_{1012}). Stock recruitment relationship was assumed process error (Beverton-Holt with lognormal error: ${\sigma_R}^2 = 0.5$). a) Female spawning biomass of North Pacific albacore tuna. Black line was estimated by SS3. Gray line is each result of 100 iteration. Red line is mean value of 100 iteration. Filled area is 95 percent tile of the simulation result. Dynamic B0 ($SB_{F=0}$) was calculated between 2010 and 2012. b) Total catch amount of North Pacific albacore tuna. Red line is historical average catch amount.