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A Sensitivity Analysis of Stock Assessment 2014 for Pacific bluefin tuna

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ABSTRACT

Uncertainties in the 2014 Pacific bluefin tuna stock assessment base case model which used Stock Synthesis 3 were evaluated through sensitivity analysis. Sensitivity runs were prepared in consideration of uncertainties in biological parameters, fishery data and model settings. The following uncertainties were examined in this document; natural mortality at age, maturity at age, growth curve, longevity and stock recruitment relationship for biological parameters, CPUE and size composition data for fisheries data, and, standard catch error, upper F and main recruitment deviation begin year for model settings. We observed the most prominent effect on the results in growth for biological parameters, CPUE and size composition data for fisheries data.

INTRODUCTION

The latest full stock assessment model for the Pacific bluefin tuna (hereafter PBF) had been established by the ISC Pacific bluefin tuna working group (PBFWG) in 2012, and the fishery data at 2012 and 2013 were updated in 2014 (ISC PBFWG, 2014). On the report, the PBFWG acknowledged that the model was unable to reconcile all key data sources while it represents the general conclusions about the status of stock. The reasons that model could not reconcile the key data sources might be in the conflicts among the data, misspecification of the life history parameters and model assumptions. Uncertainties in the model associated with the data and model assumption have not been captured and addressed enough. Therefore, the sensitivity analysis for each data and assumption needs to be carried out in order to find any kinds of uncertainty to improve in the 2016 stock assessment.

The purpose of this document is to evaluate the effects of the changes in biological parameters, assumptions of fisheries data and model settings to consider any uncertainty associated with the data and the model.

METHODS

In this document, the base case and fisheries definitions (Table 1) used in February 2014 ISC PBFWG was applied.

1.) BIOLOGICAL PARAMETERs

Natural Mortality

Natural mortality for the base case run were set in three levels, which were 1.6 for age 0 (M0), 0.39 for age 1 (M1) and 0.25 for age 2+ (M2+). In total, 9 sensitivity runs were carried out and these runs were categorized into 4 types. The sets SB1Run1 and SB1Run2 were set by changing a gradient of M_{young} (M0 and M1). SB1Run3–SB1Run7 were set by increasing/decreasing the M for all ages. The sets SB1Run8 was set by increasing the M for M18+, but the total sum of M for all ages was not changed for this run. SB1Run9 was set by increasing the M for M18+ and the total sum of M for all ages was decreased from the base case run for this run (Table 2).

Maturity

Maturity rates by age for the base case were set at 0, 0.2, 0.5 and 1 for ages 0 through 2, age 3, age 4 and age 5 and over, respectively. There were two sensitivity runs where slower maturity ogive (SB2Run1) and faster one (SB2Run2) assumed. The rates in SB2Run1 were set at 0.15 at age 3, 0.3 at age 4 and 5, respectively, increased by 0.14 after age 5, and, subsequently, reached 1 at age 10 in SB2Run1. The rates in SB2Run2, where maturity started from age 3, were set at 0.5 and 1 for age 3 and age 4 and over, respectively (Table 3).

Growth Curve

Growth rate coefficient (K) and lengths at the young age (L1) and old age (L2) of growth curve used in the base case were set at 0.157 /year, 21.5 cm (for age 0) and 109.2 cm (for age 3), respectively. Coefficient of variation (CV) in the base case for L1 through 2 was estimated, although CV for L2 and older was fixed at 0.05.

A total of 7 sensitivity runs were prepared through changing the parameter values of L1, L2, K and CV. The parameters estimated by Shimose et al. (2009) were used for SB3Run1, the parameters led by the result of PBF direct ageing which was described in the aging manual (FRA2014, in Press) made during 2013 Aging WS were used for SB3Run3, and the parameters estimated by re-reading otolith samples which were used in Shimose et al. (2009) based on FRA2014 manual were used for SB3Run2. In addition, CV for L1 and L2 were changed for SB3Run4, 5, 6 and 7 (Table 4).

Longevity

The longevity was 20 years-old in the base case. For sensitivity runs, it was changed into 15, 24 and 28 years-olds in SB4Run1, SB4Run2 and SB4Run3, respectively (Table 5).

Stock-Recruitment Relationship (SRR)

In the base case run, Beverton-Holt SRR was expressed as Steepness parameter (h) of 0.999 and sigma R of 0.6. The values of steepness (h) in sensitivity runs (SB5Run1—5) were set in total 5 scenarios from 1 to 0.96 at an interval of 0.01. SB5Run6 assumed a sigma R which was estimated within the model, and for SB5Run7, sigma R was set as 1.0.

In order to assume different SRR from the base case, Hockey stick model was used for SB5Run8. In the Hockey stick model, log R_0 and a fraction of virgin SSB at which inflection occurs were estimated (Table 6).

2.) FISHERIES DATA and PARAMETERS

CPUE time series

In the base case model, the following CPUEs were included and fitted; Japanese longline (S1, S2 and S3), Japanese troll in Nagasaki (S5) and Taiwanese longline (S9). Sensitivity runs were set as SF1Run1, SF1Run2 and SF1Run3 which excluded S1, S5 and S9 (terminal CPUEs) from the model respectively, SF1Run4 which excluded both S1 and S9 from the model and SF1Run5 which set CV of S1 as 0.2 (Table 7).

Size composition data

In the base case, the size selectivity and the catch in number at size were estimated by using size composition data of each fleet except the following fleets; Japanese pole-and-line (Fleet 6), Eastern Pacific Ocean (EPO) sports fishery (Fleet 13) and Others (Fleet 14). Since there was no reliable size composition data available in these excluded fleets, the selectivity of Fleet 6 and Fleet 13 were substituted by that of similar fleet, and the selectivity of Fleet 14 was fixed as the estimated value in preliminary analysis and was not estimated in the final model.

The sensitivity runs were set in total 11 runs (SF2Run1—SF2Run11), and the size composition data of each fleet except Fleet 6, Fleet 13 and Fleet 14 was excluded in each run. The selectivity of those fleets were set and fixed as the same parameters of the base case. The fits among the size composition data and the estimated catch in number at size for these 11 fleets were examined to see how the model results were affected by these changes (Table 8).

3.) MODEL SETTINGs

Catch error

Standard error (SE) of catch in the base case was set as 0.1. For sensitivity runs, it was set as 0.01 for SM1Run1 and 0.15 for SM1Run2 (Table 9).

Upper F

The upper F was set as 10 for the base case, and for a sensitivity run, it was set as 5 for SM2Run1 (Table 10).

Main recruitment deviance begin years

The main recruitment deviations begin year was set as 1942 in the base case, and 1932 and 1937 were set for the sensitivity runs (SM3Run1 and SM3Run2) (Table 11).

RESULTS and DISCUSSIONS

1.) BIOLOGICAL PARAMETERs

Natural Mortality

The sensitivity runs for the natural mortality (M) at age were conducted for nine scenarios, however, a scenario 'SB1Run7' which set the lowest M (to reduce to 60 % of the base case M in each age) among the runs was not converged well.

The run which set the lower M_{young} (SB1Run2) than the base case showed lower likelihood than that of the base case or SB1Run1 which set higher M_{young} (Figure 1). The likelihood component of Fleet 2 size composition had lower likelihood when M_{young} was low (Figure 2). Changes of M_{young} affect especially to the level of recruitment rather than SSB. Higher recruitment was observed as M_{young} were high (Figure 3). The R_0 and B_0 estimated by the SB1Run1 and SB1Run2 were shown in (Table 12).

With respect to the M for all ages (SB1Run3—6), the run which set lower M at age vector showed lower total likelihood (Figure 1), although the run which was set the lowest M (SB1Run7) did not converge well. The likelihood component of the size composition Fleet 1, Fleet 3, Fleet 4 and Fleet 11 which targeted large PBF showed lower likelihood as M for all ages were low (Figure 2). On the other hand, total survey likelihood was low as the M for all ages were high (Figure 4). This difference was caused by the troll CPUE component (S5). The CPUE components of longline except S9 did not show much difference among SB1Run3—6 and the base case

(Figure 5). R_0 and B_0 showed clear negative and positive correlation with M (Figure 6-a, b). The B_0 estimated by the SB1Run6 (lowest M scenario) was 1,395,990 tons and it was more than 2 times larger than that of the base case.

The results of SSB showed a different trend from 1980. The influence of M2-M17 was large after 1980, SSB became smaller as M2-M17 was set lower (SB1Run4, 5, 6, 8 and 9) whereas they became larger as M was set higher (SB1Run3) (Figure 7). As for runs which set lower M in all ages (SB1Run4—6), SSB before 1980 tend to become higher as M was set lower (Figure 7).

In addition, SB1Run8 and 9 which set higher M18+ than that of SB1Run6 had a different trend of likelihood. The total likelihood of both runs were higher than that of SB1Run6 and the base case (Figure 1). This implies that setting larger M in the oldest age did not make the fit to the input data improve. However, likelihood of recent longline CPUE (S1) estimated by SB1Run8 and 9 became lower than those of other sensitivity runs (Figure 5). The total sum of M for all ages in SB1Run8 was the same as that of the base case, but B_0 (1,189,800) in this run was 1.9 times larger than that of the base case.

Maturity

The result for SSB showed SB2Run1 and SB2Run2 were located lower and upper than the base case run respectively (Figure 8). This outcome was caused by the assumption which set slower maturity ogive for SB2Run1 and faster maturity ogive for SB2Run2 than that of the base case run.

As B_0 was also affected by this assumption, it became smaller (467,677 ton) in SB2Run1 and larger (672,659 ton) in SB2Run2. Owing to these changes in SSB and B_0, the depletion rate in SB2Run1 and SB2Run2 were influenced, the range of the rate for the base case was from 3% to 22%, while SB2Run1 had the range from 3 % to 17 % and SB2Run2 was from 3% to 24%.

By contrast, the results of SB2Run1 and SB2Run2 for total biomass and recruitment were almost the same as that of the base case run (Figure 9). The selectivity and age specific F for each fleet were also not influenced as the total biomass in both runs were the same as that in the base case run (Figure 10). These results originated from the steepness set as 0.999, which assumed a very weak stock-recruitment relationship.

Growth Curve

Especially SB3Run2 and SB3Run3 showed a large difference in the result. In the given growth curve, these runs shifted larger size than the base case until around age 15 (Figure 11). These runs estimated much larger SSB as compared to the base case before 1970, and SSB of SB3Run3 was almost twice as that of the base case (Figure 12). The total likelihood of SB3Run2 and SB3Run3 marked larger than that of the base case (Figure 13) and the likelihoods of these runs were increased especially in the size composition components which mainly harvesting small fish (age 0-5) such as Fleet 2, Fleet 3 and Fleet 5 (Figure 14-a, b, c). In the catch at length estimated by those runs, Fleet 3 caught larger fish as compared to the base case (Figure 15). On the other hand, the likelihoods of these runs were decreased in the size composition components of Fleet 1 and Fleet 11 (Figure 14-d, e). In addition, the fit to S1and S5 were improved in SB3Run2 and SB3Run3, and the likelihoods of these CPUEs in these runs marked the lower values than the base case (Figure 16-a, b). The results of recruitment in SB3Run2 and SB3Run3 also showed different trends from the base case, these runs estimated lower recruitment than the base case (Figure 17). As for the stock recruitment relationship (SRR), SB3Run2 and SB3Run3 had smaller R_0 and B_0 than those of the base case (Table 13).

As for SB3Run1, the growth curve was slightly different from the base case (Figure 18). In this run, the likelihoods of size composition components of Fleet 1, Fleet 3, and Fleet 11 were better than the base case (Figure 14-d, b, e). Those fleets had a peak selectivity for age 3 and older fish. On the other hand, the likelihoods of size composition components which caught (age 0–2) such as Fleet 5, Fleet 9, and Fleet 12 marked larger values than those of the base case (Figure 14-c, f, g).

With respect to the runs which varied CV of parameters, large difference was found in SB3Run4 which set larger CV for L2. This run estimated smaller SSB (Figure 19), and also affected the selectivity. The selectivity of fleets mainly harvesting large fish (Fleet 1, 3, 4, and 11) estimated by this run showed that much larger fish were caught than the base case (Figure 20). The fit to S9 was improved in this run and it was lower than the base case (Figure 16-c). However, in the most of all likelihood components of the size composition data (except Set net fleets) as well as CPUEs had larger values than the base case (Figure 14, Figure 16).

The results of other runs (SB3Run5—7) which varied CV of growth parameters were similar to those of the base case. The estimated CV of L2 parameter by SB3Run5 was 0.049, and it was almost same with the base case run which was fixed as 0.05. The sensitivity runs about CV of L1 parameter (SB3Run6 and SB3Run7) were considered to be less impact on the results, and those runs marked larger total likelihood values than that of the base case (Figure 13).

Longevity

As the results for recruitment showed all runs were similar to the base case run, it is considered that change of longevity did not have much impact on the recruitment.

As for the longevity which were extended more than the base case (SB4Run2 and SB4Run3), SSB became slightly larger than the base case before 1967 (Figure 21). In the case where longevity was set shorter (SB4Run1), SSB was lower than the base case in all years (Figure 21).

Fishing mortality (F) of SB4Run2 and SB4Run3 in most fleets were lower than the base case, but it was higher than the base case in Fleet 1 and Fleet 11 which caught the large matured PBF (Figure 22). On the other hand, F of SB4Run1 in most fleets were high, but recent F in Fleet 1 and Fleet 11 were lower than the base case (Figure 22).

Stock-Recruitment Relationship (SRR)

The model could not converge where h was tried to estimate within the SS3 model and the values were set below 0.95.

The results for SSB showed that the runs with smaller h values (SB5Run3—5) tend to be slightly larger than that of the base case before 1973 whereas these runs estimated slightly lower SSB than the base case after 1973 (Figure 23-a). As for the recruitment, the runs with smaller h values (SB5Run3—5) tend to be slightly higher until 1970 but become slightly lower after 1970 (Figure 23-b).

Changing the value of steepness h from 1 to 0.96 did not result in any obvious relationship between SSB and recruitment estimated. The total likelihood became slightly lower as the value of h decreases, and the run with the value of 0.96 (SB5Run5) had the lowest total likelihood (Figure 24) although the run which was set the steepness lower than 0.96 did not converge well. The value of B_0 and R_0 tends to be larger as the value of h becomes smaller (Figure 25).

The sigma R estimated by the SS3 model was 0.599 in SB5Run6, and it was mostly the same as the base case (fixed in 0.6). For this reason, the biomass and the likelihood of SB5Run6 imitated the base case(Figure 27). In contrast, the results of SB5Run7 which set the sigma R as 1.0 showed that the SSB before 1990 shifted upwards from the base case and this trend tends to be larger as time goes back (Figure 26-a). As for the recruitment, this run showed a difference from the base case especially before 1995 (Figure 26-b). In addition, R_0 and B_0 were larger than the base case (Table 14). The likelihood of recruitment deviation was much larger than the base case (Figure 27).

The results of SB5Run8 which assumed Hockey stick SRR showed that SSB and recruitment were about the same as the base case run (Figure 28) and there was only a small difference in likelihood. B_0 estimated by this run was 621,652 tons, and this result was similar to B_0 (623,814 tons) in the base case run. Similarly, the difference of this run and the base case for R_0 was almost none (Table 14). In addition, "fraction of virgin SSB at which inflection occurs" which was an estimated SRR parameter by this run was about 0.014, and the appearance of S-R curve for this run resembled that of the base case (Figure 29).

2.) FISHERIES DATA and PARAMETERS

CPUE time series

To highlight the relative influence of the abundance indices of large fish on the model results, two sensitivity runs for the terminal indices, namely S1and S9 were performed. The results where S9 was excluded (SF1Run3) showed better fit to the Japanese longline CPUE (S1) than that of the base case run (Figure 30) and the likelihood was decreased in the size composition component of Fleet 1 (Figure 31-a). In this case, the likelihood for Fleet 11 also decreased compared with the base case run (Figure 31).

The exclusion of S1 (SF1Run1) made the likelihood of Fleet 1 and Fleet 11 increased but the likelihood of S9 did not show any significant difference (Figure 31-a, j and Figure 32-e).

In the case where both S1 and S9 were excluded (SF1Run4), the likelihood component for the total size frequency showed the lowest value (Figure 33) whereas the trajectory of biomass was largely shifted upwards from the base case in recent years (Figure 34).

The results of the run which assumed CV of S1 was set as 0.2 (SF1Run5) showed the lower likelihood for the size composition of Fleet 1 while the highest likelihood was marked for the total size frequency in this case (Figure 31-a and Figure 33). These results imply that there is a conflict for the fitting to the abundance indices of two terminal indices of longline fleets. The indices, S9 also conflicted for the fitting to the size frequency data of Fleet 1 and 11. On the other hand, there is no contradiction between fit to the S1 and the size frequency of Fleet1.

As for the abundance index of young fish (age 0-1), the sensitivity analysis of S5 was carried out. Although S5 was excluded (SF1Run2), sensitivity runs fit well to S5 which was almost equivalent to the base case especially from 1994 (Figure 35). In spite of this result, fit to the size frequency especially for Fleet 3 improved from 1987 to 1992 (Figure 36) and this fleet marked the lower likelihood in the sensitivity case (Figure 31-c). The accumulation of size frequency data, which contains information about recruitment, has been enhanced since 1994. This could be considered as one of the reasons why the estimation of recruitment did not deviate from the base case from 1994 even if S5 was excluded (Figure 37).

Size composition data

Especially the runs which excluded a size composition of Fleet 1 (SF2Run1), Fleet 3 (SF2Run3), Fleet 11 (SF2Run10), and Fleet 12 (SF2Run 11) showed a large difference in the result.

As for SF2Run1, fit to the size composition data of Fleet 1 was not good for each year, although the expected catch at each size bin for all assessment period was similar between the sensitivity run and base case run. The results in both SSB and total biomass were shifted upwards from the base case before 1980 and this trend tends to be larger as time goes back (Figure 38-a). The trend of recruitment was also different from the base case run especially before 1970 (Figure 38-b). There are only 2 fleets (Fleet 1 and Fleet 12) with size composition data time series and a CPUE time series of longline before 1980. Therefore, the estimation of recruitment in those time period was relying on those data. Thus, size composition of Fleet 1 made a prominent impact on the estimation of recruitment before 1970. A large impact was also observed in the fit to the Japanese longline CPUE, where the sensitivity run did not fit well to these CPUE especially in a series of 1952 to 1973 (S2) and 1993 to 2012 (S1) (Figure 39-b, a). Although this sensitivity run did not fit well to the size frequency of Fleet 11 (Figure 40-j), the fit to S9 was improved and its component likelihood marked the lowest value (Figure 39-c, Figure 41-e).

As for SF2Run10, the result in SSB was estimated lower than the base case, especially this trend was significant around 1960 (Figure 42-a). In contrast, the result in recruitment was almost the same as the base case (Figure 42-b). The fit to S3 showed a difference after 1980 but its component likelihood was about the same as the base case (Figure 41-c). Even though the model does not fit to the size composition data of Fleet 11, the fit to S9 was improved (Figure 43). In addition, the component likelihood of Fleet 1 and S1 were increased (Figure 40-a, Figure 41-a). These results suggested that the size composition data of Fleet 11 did not conflict to the size composition and CPUE of Japanese longline (Fleet 1 and S1). On the other hand, in SF2Run10, the component likelihood of the S9 index became smaller than the base case (Figure 44-d). This outcome also suggested that there was a contradiction between the size composition data and CPUE in the Taiwanese longline (Fleet 11, S9).

As for SF2Run3, the result in SSB was situated lower than the base case in most years, and the difference became larger after 1993 (Figure 45-a). The result in recruitment showed a gap from 1980 to 2005 (Figure 45-b). The component likelihoods of S1, S5 and S9 marked the lower value than those of the base case run (Figure 41-a, d, e), thus the fits to these CPUEs were improved (Figure 46). A negative impact on the fit to the size composition data was observed in Fleet 7 (Figure 40-f). However, there were few effects on the likelihood of the other size composition components (Figure 40). Since most of the input sample sizes of Fleet 3 were larger than other fleets in each season, the size composition of this fleet had a larger impact especially on the fits to the CPUE data in recent time series.

As for SF2Run11, trends in SSB and recruitment were different from the base case until 1982 (Figure 47). Especially the fluctuation in recruitment showed a significant difference from the base case before 1982, but it was almost the same as the base case after 1982 (Figure 47-b). This outcome was originated from the reason stated in the result of SF2Run1; since there were only two size composition data (Fleet 1 and Fleet 12) time series before 1980, impact of these data to the estimation of recruitment was high in before 1980.

The fleets of set net (Fleet 7 to Fleet 10), Japanese troll (Fleet 5), purse seine in the East China Sea (Fleet 2) and purse seine off the Pacific Ocean (Fleet 4) had a limited impact on the results, even though the trends of SSB were slightly different from the base case (Figure 48).

3.) MODEL SETTINGs

Standard catch error

In SM1Run1 which set smaller standard catch error as compared to the base case, SSB was slightly higher than the base case before 1970 (Figure 49). Apart from this trend in SSB, this run did not have much impact on other components.

In addition, SM1Run2 which set larger standard error as compared to the base case also had less impact on the results.

Therefore, it can be considered that catch error had little effect on the results.

Upper F

In SM2Run1 which set smaller upper F, all parameters could be estimated without being on or near each parameter boundary. In this run, the SSB before 1980 shifted upwards from the base case (Figure 50-a). The trend of recruitment before 1975 was different from the base case, especially this trend was prominent around 1965-1970 (Figure 50-b). B_0 and R_0 in this run were similar to those in the base case. The likelihoods of all likelihood components were almost same with the base case run.

Main recruitment deviation begin year

R_0 in both runs (SM3Run1 and SM3Run2) were the same as the base case. SSB, recruitment and total likelihood in both runs (SM3Run1 and SM3Run2) were almost the same as the base case (Figure 51).

Therefore, it is suggested that this category did not have much impact on the results.

Table 1. Definition of fleets considered for size composition and abundance indices in the PBF stock assessment.

Fleet No.	Short name	Available Period	Corresponding Fisheries	Other Fisheries	Lambda (*1)	Size data type	Average input sample size or C.V.	Data quality
F1	JLL	1952-1968, 1994-2011	Japanese longline		1	Length	12.3	Catch at length
F2	SPelPS	2001-2012	Purse seinein the East China Sea	Korean small pelagic fish purse seine	1	Length	12.1	Catch at length
F3	TunaPSJS	1986-1989, 1991-2012	Japanese tuna purse seine fisheries in the Sea of Japan		1	Length	20.8	Catch at length
F4	TunaPSPO	1994-2006	Japanese purse seine off the Pacific coast of Japan		1	Length	5.8	Catch at length
F5	JpnTroll	1993-2012	Japanese troll		1	Length	12.1	Catch at length
F6	JpnPL	1994-1996, 1998-2004, 2005-2010	Japanese pole- and-line	Japanese driftnet Taiwanese driftnet Taiwanese others	0	Length	12.1	Raw mearsurement
F7	JpnSetNet NOJWeight	1993-2012	Japanese set net (northern part of Japan)		1	Weight	12.0	Catch at weight
F8	JpnSetNet NOJLength	1994-2008, 2012	Japanese set net (Q1-Q2, Hokuriku)		1	Length	12.2	Catch at length
F9	JpnSetNet OAJLength Q1-3	1993-2012	Japanese set net (other area, Q1- Q3)		1	Length	12.0	Catch at length
F10	JpnSetNet OAJLength Q4	1993-2012	Japanese set net (other area, Q4)		1	Length	12.1	Catch at length
F11	TWLL	1992-2012	Taiwanese longline	New Zealand Other country	1	Length	12.1	raw measurement (high coverage)
F12	EPOPS	1952-1965, 1969-1982, 2005-2012	Eastern Pacific Ocean commercial purse seine		1	Length	9.3	Catch at length
F13	EPOSP	1993-2003, 2005-2006, 2008-2011	Eastern Pacific Ocean sports fishery		0	Length	12.1	Raw measurement
F14	Others	1994-2012	Others	Japanese trawl Japanese other longline	0.1	Weight	12.1	Catch at weight

Table 1. Continued.

Fleet No.	Short name	Data type	Available Period	Corresponding Fisheries	Lambda (*1)	Fleet No. for size data	Average input sample size or C.V.	Data quality
S1	JpCLL	CPUE	1993-2012	Japanese coastal longline conducted in spawning area and season.	1	F1	0.26 or 0.20	Standerdized
S2	JpnDWLL Fujioka Revto74	CPUE	1952-1973	Japanese offshore and distant water longliners until 1974	1	F1	0.2	Standerdized
S3	JpnDWLL Yokawa Revfrom75	CPUE	1974-1992	Japanese offshore and distant water longliners from 1975	1	F1	0.2	Standerdized
S4	TPSJO	CPUE	1987-1989, 1991-2010	Japanese tuna purse seine in Sea of Japan	0	F3	0.2	Standerdized
S5	JpnTroll ChinaSea	CPUE	1980-2012	Japanese troll in Nagasaki (Sea of Japan and East China sea)	1	F5	0.2	Standerdized
S6	JpnTroll Pacific	CPUE	1994-2010	Japanese troll combined with Kochi and Wakayama by catch- weighted average	0	F5	0.2	Standerdized and combined by ad-hoc way
S7	JpnTR Kochi	CPUE	1981-2010	Japanese troll in Kochi (Pacific)	0	F5	0.3	Standerdized
S8	JpnTR Wakayama	CPUE	1994-2010	Japanese troll in Wakayama(Pacific)	0	F5	0.2	Standerdized
S9	TWLL	CPUE	1998-2012	Taiwanese longline	1	F11	0.2	Standerdized
S10	USPSto82	CPUE	1960-1982	EPO purse seine during US target fisheries	0	F12	0.93	Standerdized
S11	MexPSto06	CPUE	1999-2010	EPO purse seine during Mexico operating	0	F12	0.77	Standerdized

(*1) Lambda 1 indicates that size composition or abundance indices are used to tune in the base case run. Lambda 0 indicates that they are not used.

Table 2. Natural Mortality

	Age0	Age1	Age2 - Age17	Age18+	M/21 year	Assumption
Base	1.60	0.39	0.25	0.25	6.74	
Run1	1.84	0.44	0.25	0.25	7.03	Higher M @ age 0-1
Run2	1.36	0.33	0.25	0.25	6.44	Lower M @ age 0-1
Run3	1.92	0.46	0.30	0.30	8.08	Higher M
Run4	1.44	0.35	0.23	0.23	6.06	Lower M
Run5	1.28	0.31	0.20	0.20	5.39	Lower M
Run6	1.12	0.27	0.18	0.18	4.72	Lower M
Run7	0.96	0.23	0.15	0.15	4.04	Lower M
Run8	1.12	0.27	0.18	0.85	6.74	Lower M @ age 0-17, Higher M @ age 18+
Run9	1.12	0.27	0.18	0.52	5.74	Lower M @ age 0-17, Higher M @ age 18+

Table 3. Maturity

	Age0 - Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10+	Assumption
Base	0	0.2	0.5	1	1	1	1	1	1	
Run1	0	0.15	0.3	0.3	0.44	0.58	0.72	0.86	1	slower maturity ogive
Run2	0	0.5	1	1	1	1	1	1	1	faster maturity ogive

Table 4. Growth curve

	L1	L2	K	CV for L1	CV for L2	Assumption
Base	21.5	109.2	0.157	est(0.26)	0.05	
Run1	15.8	110.5	0.173	est(0.26)	0.05	Shimose et al. (2009)
Run2	32.9	119.1	0.166	est(0.26)	0.05	Shimose et al. (2009) w/ FRA 2014
Run3	38.0	124.1	0.174	est(0.26)	0.05	FRA 2014
Run4	21.5	109.2	0.157	est(0.26)	0.08	Higher CV for L2
Run5	21.5	109.2	0.157	est(0.26)	Estimate	
Run6	21.5	109.2	0.157	0.2	0.05	Lower CV for L1
Run7	21.5	109.2	0.157	0.3	0.05	Higher CV for L1

Table 5. Longevity

	Year	Assumption
Base	20	
Run1	15	
Run2	24	
Run3	28	

Table 6. Stock-recruitment relationship

	model	Steepness	sigmaR	Asummption
Base	Beverton-Holt	0.999	0.6	
Run1		1	0.6	
Run2		0.99	0.6	
Run3		0.98	0.6	
Run4		0.97	0.6	
Run5		0.96	0.6	
Run6		0.999	Estimate	
Run7		0.999	1	
Run8	Hockey stick		0.6	

Table 7. CPUE

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	Assumption
Base	1	1	1	0	1	0	0	0	1	0	0	
Run1	0	1	1	0	1	0	0	0	1	0	0	S1 lambda=0
Run2	1	1	1	0	0	0	0	0	1	0	0	S5 lambda=0
Run3	1	1	1	0	1	0	0	0	0	0	0	S9 lambda=0
Run4	0	1	1	0	1	0	0	0	0	0	0	S1,S9 lambda=0
Run5	1	1	1	0	1	0	0	0	1	0	0	S1 CV=0.2 (Fix)

Table 8. Length composition

	Fixed Fleet	Assumption
Base	-	
Run1	F1	
Run2	F2	
Run3	F3	
Run4	F4	
Run5	F5	
Run6	F7	
Run7	F8	
Run8	F9	
Run9	F10	
Run10	F11	
Run11	F12	

Table 9. Standard error of Catch

	Standard error	Assumption
Base	0.1	
Run1	0.01	
Run2	0.15	

Table 10. Upper F

	Max F	Assumption
Base	10	
Run1	5	

Table 11. Main recruitment deviation beginning year

	Start year	Assumption
Base	1942	
Run1	1932	10 yrs before Base
Run2	1937	5 yrs before Base

Table 12. R_0 and B_0 estimated by base case and sensitivity runs for natural mortality

	Base case	SB1Run1	SB1Run2	SB1Run3	SB1Run4	SB1Run5	SB1Run6	SB1Run7	SB1Run8	SB1Run9
R_0	15103	18889	12127	21895	12689	10741	9152	-	9113	9069
B_0	623814	581485	673444	409782	794981	1038760	1395990	-	1189800	1217210

Table 13. R_0 and B_0 estimated by base case and sensitivity runs for growth curve

	Base case	SB3Run1	SB3Run2	SB3Run3	SB3Run4	SB3Run5	SB3Run6	SB3Run7
R_0	15103	15296	11877	11138	14472	15119	15456	14907
B_0	623814	649880	532906	516417	604909	624316	638408	615717

Table 14. R_0 and B_0 estimated by base case and sensitivity runs for stock recruitment relationship

	Base case	SB5Run1	SB5Run2	SB5Run3	SB5Run4	SB5Run5	SB5Run6	SB5Run7	SB5Run8
R_0	15103	15050	15598	16203	16864	17588	15098	20511	15050
B_0	623814	621652	644289	669281	696587	726466	623627	847199	621652

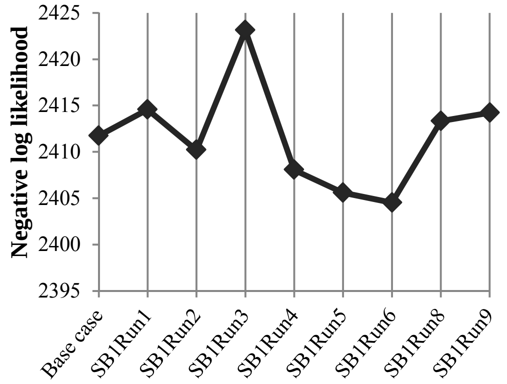


Figure 1. Total likelihood of each run which set different natural mortality scenario

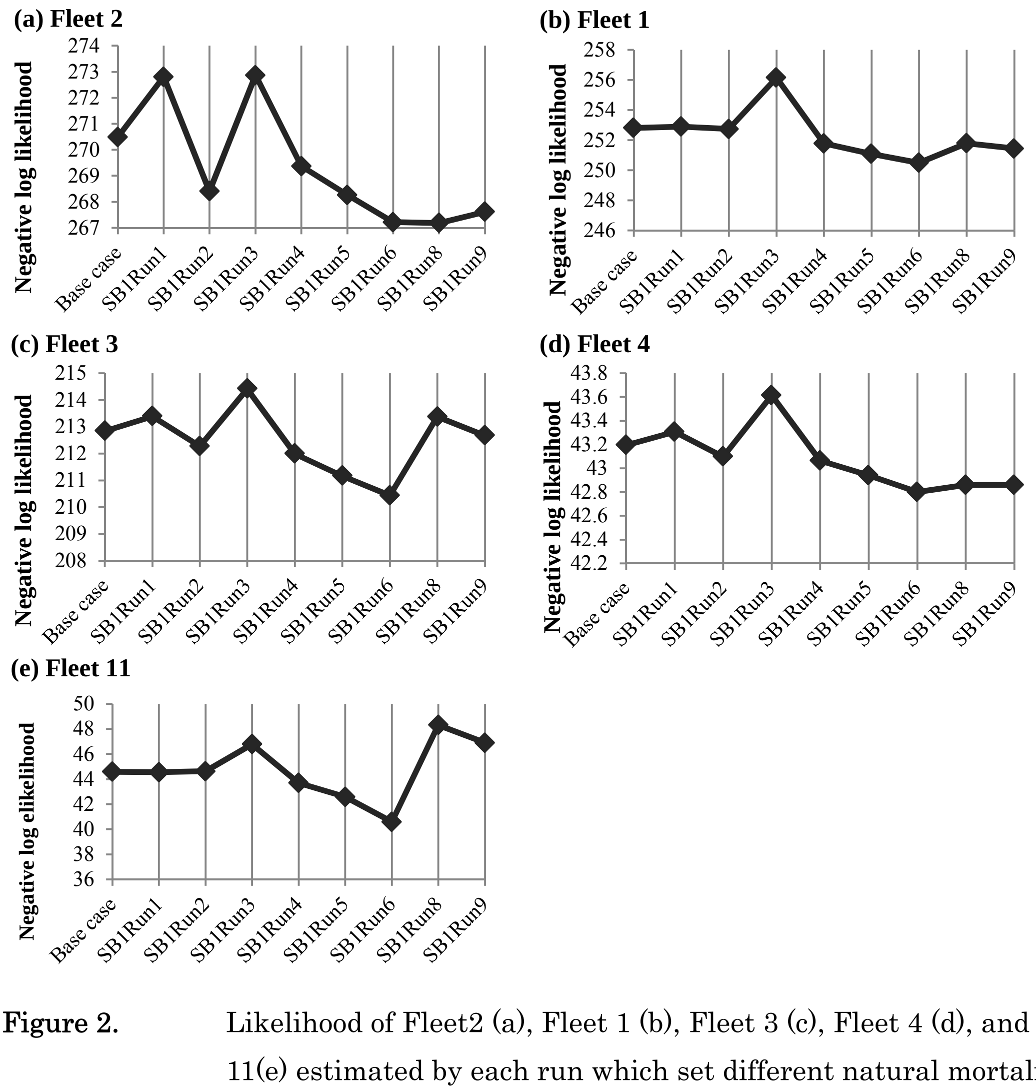


Figure 2. Likelihood of Fleet2 (a), Fleet 1 (b), Fleet 3 (c), Fleet 4 (d), and Fleet 11(e) estimated by each run which set different natural mortality scenario

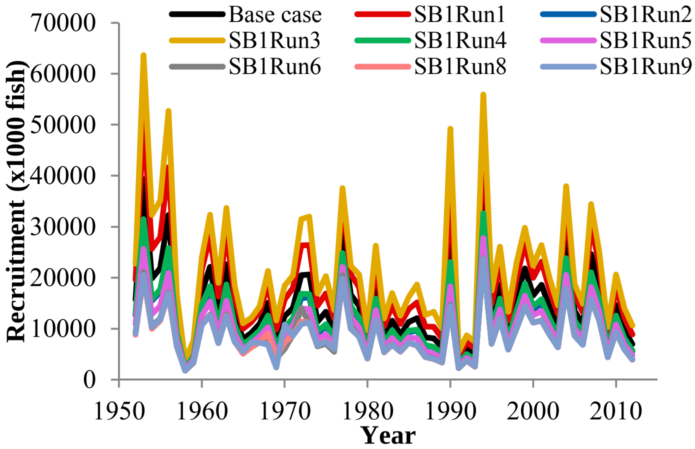


Figure 3. Recruitment for each run which set different natural mortality scenario

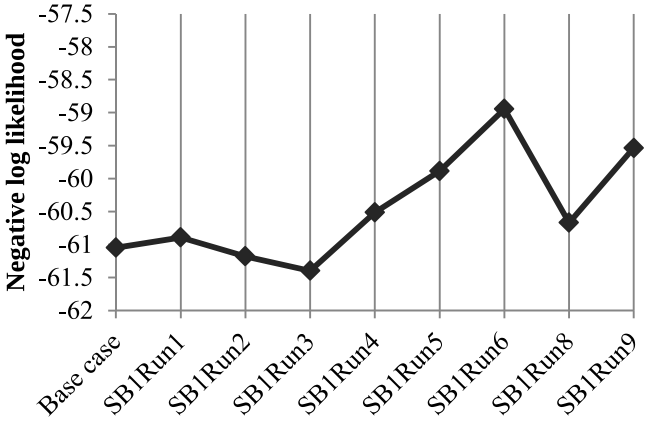


Figure 4. Total likelihood of CPUEs estimated by each run which set different natural mortality scenario

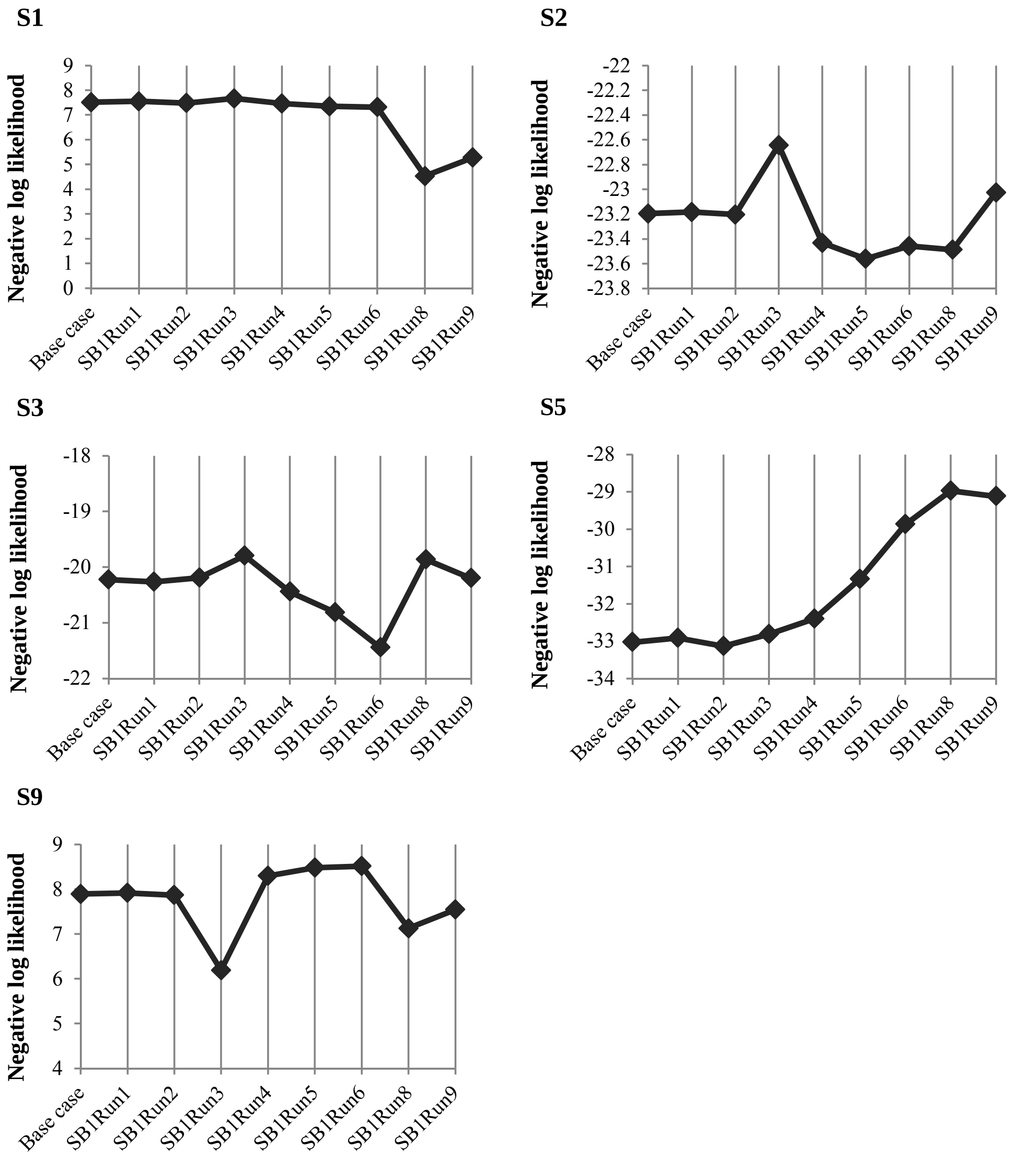


Figure 5. Likelihood of S1, S2, S3, S5 and S9 estimated by each run which set different natural mortality scenario

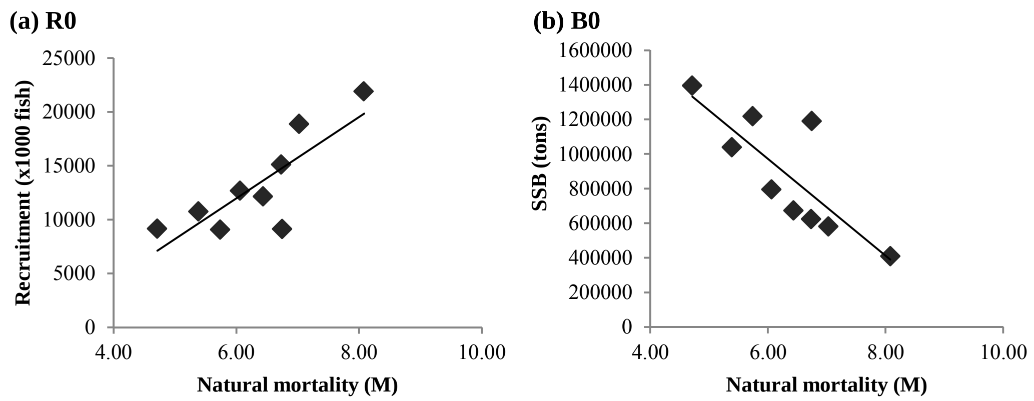


Figure 6. The relationship between M and R0 (a) and B0 (b). Blackline indicated regression line

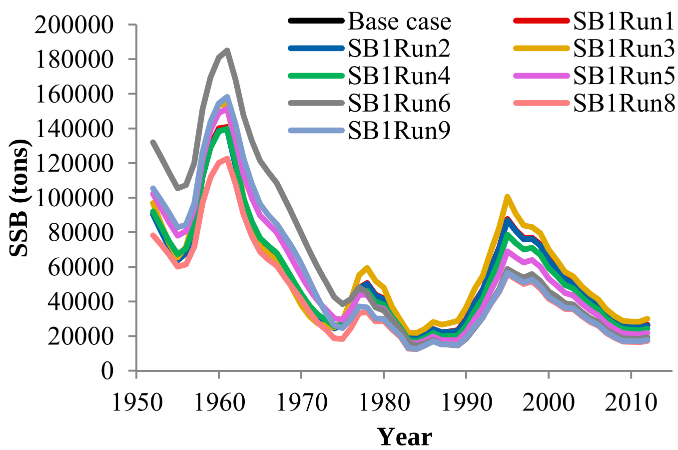


Figure 7. SSB for each run which set different natural mortality scenario

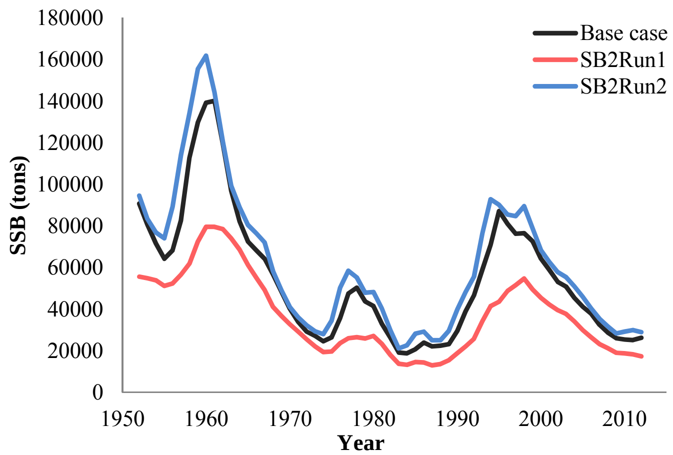


Figure 8. SSB for each run which set different maturity scenario

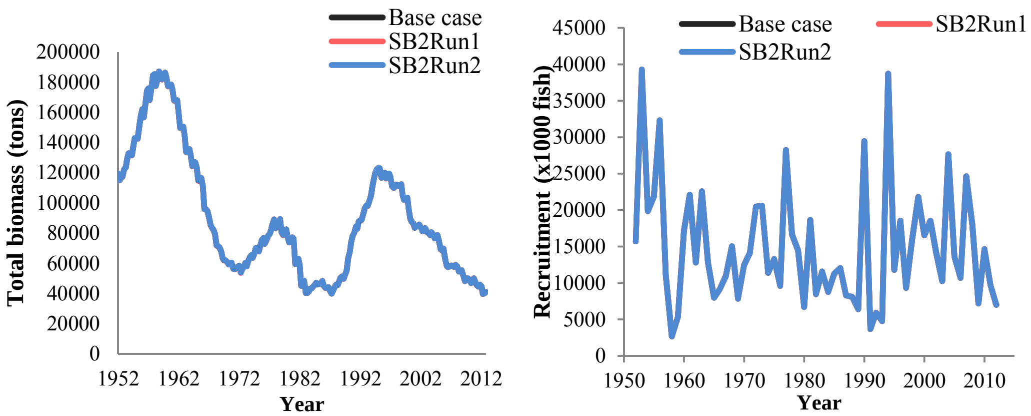


Figure 9. Total biomass (Left) and recruitment (Right) for each run which set different maturity scenario

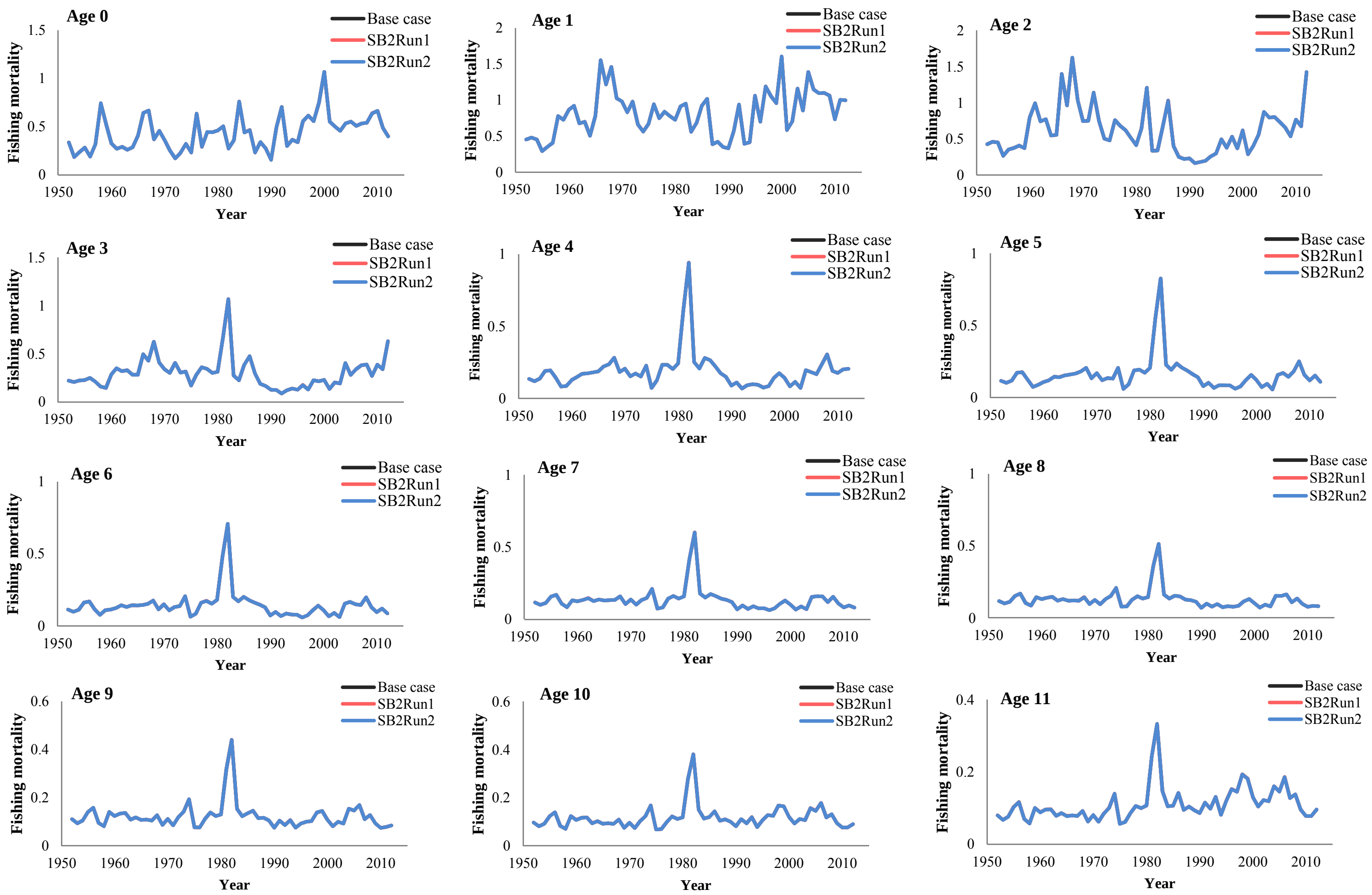


Figure 10. Age specific F from age 0 to age 11 estimated by each run which set different maturity scenario

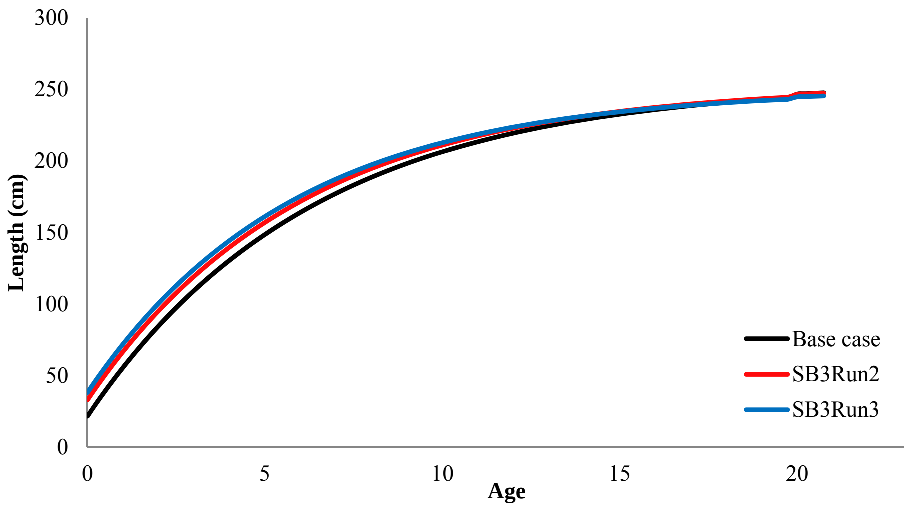


Figure 11. Growth curve for SB3Run2 and SB3Run3 which set different growth scenario

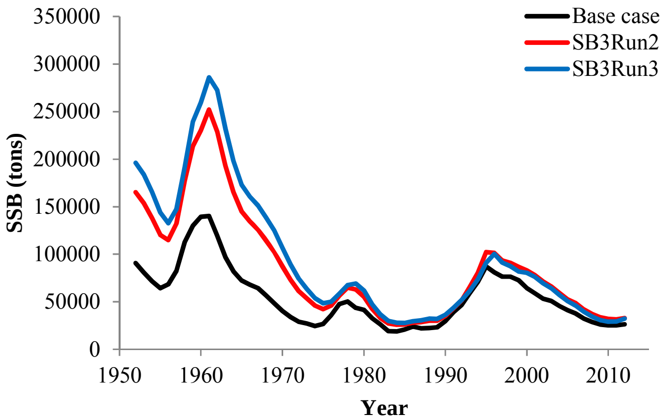


Figure 12. SSB for SB3Run2 and SB3Run3 which set different growth scenario

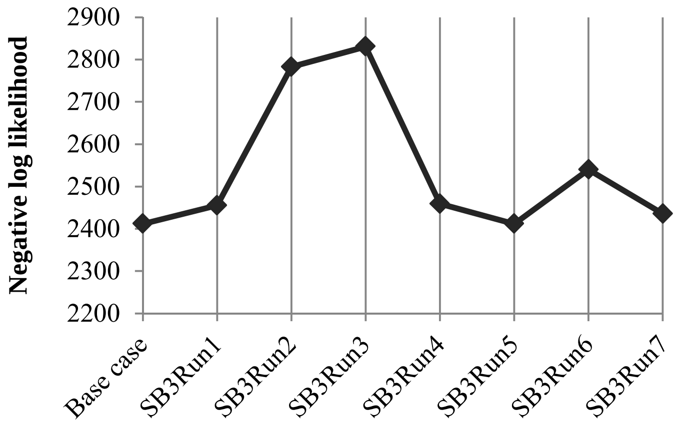


Figure 13. Total likelihood estimated by each run which set different growth scenario

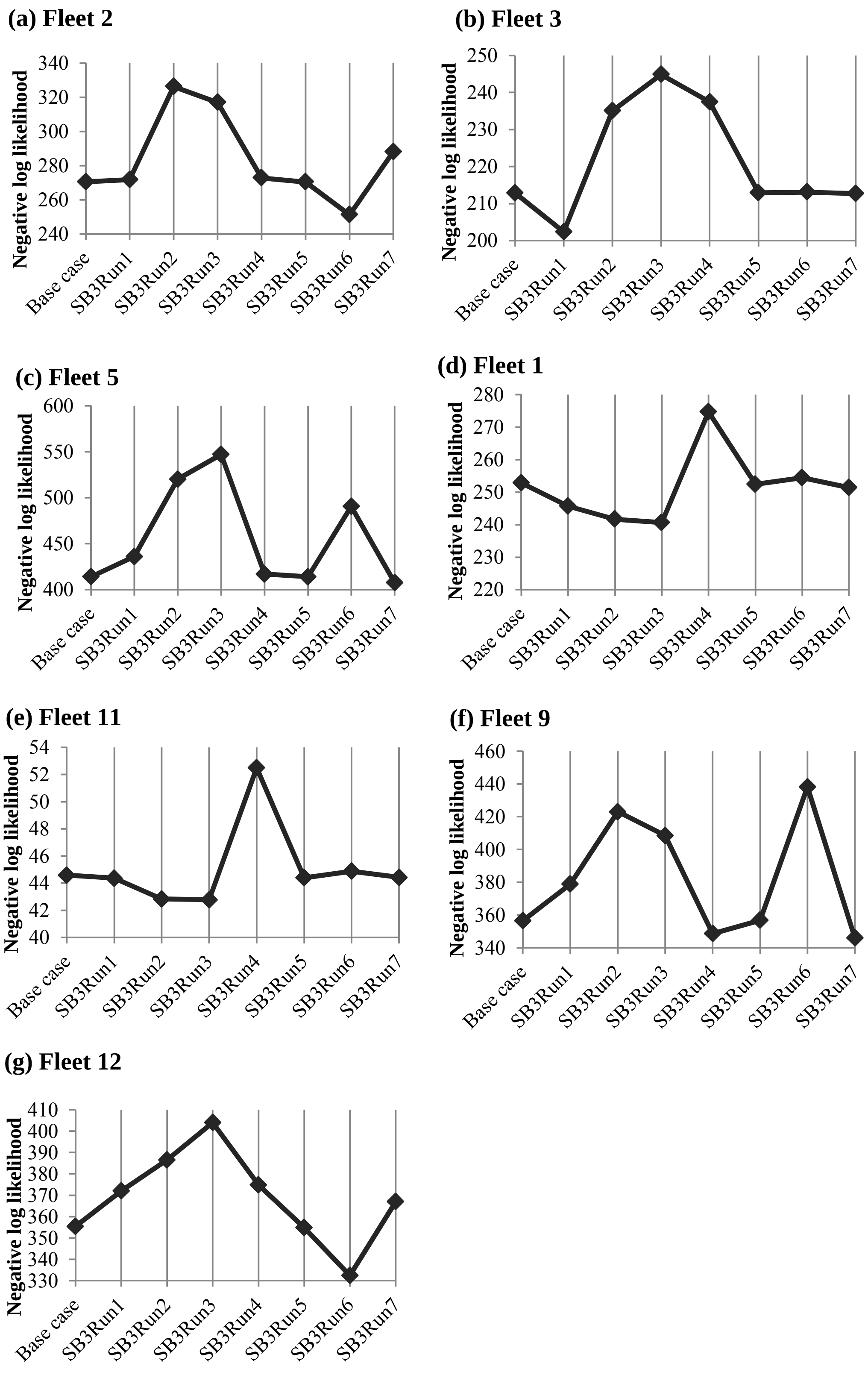


Figure 14. Likelihood of the size composition components (Fleet2 (a), Fleet3 (b), Fleet5 (c), Fleet1 (d), Fllet11 (e), Fleet9 (f) and Fleet12 (g)) estimated by each run which set different growth scenario

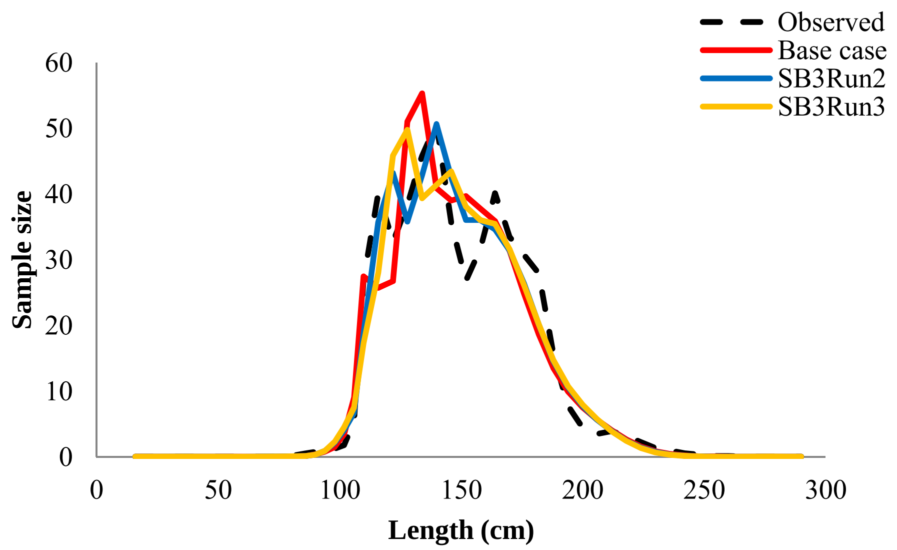


Figure 15. Catch at length (Size fit) of Fleet3 estimated by different growth scenario, SB3Run2 and SB3Run3

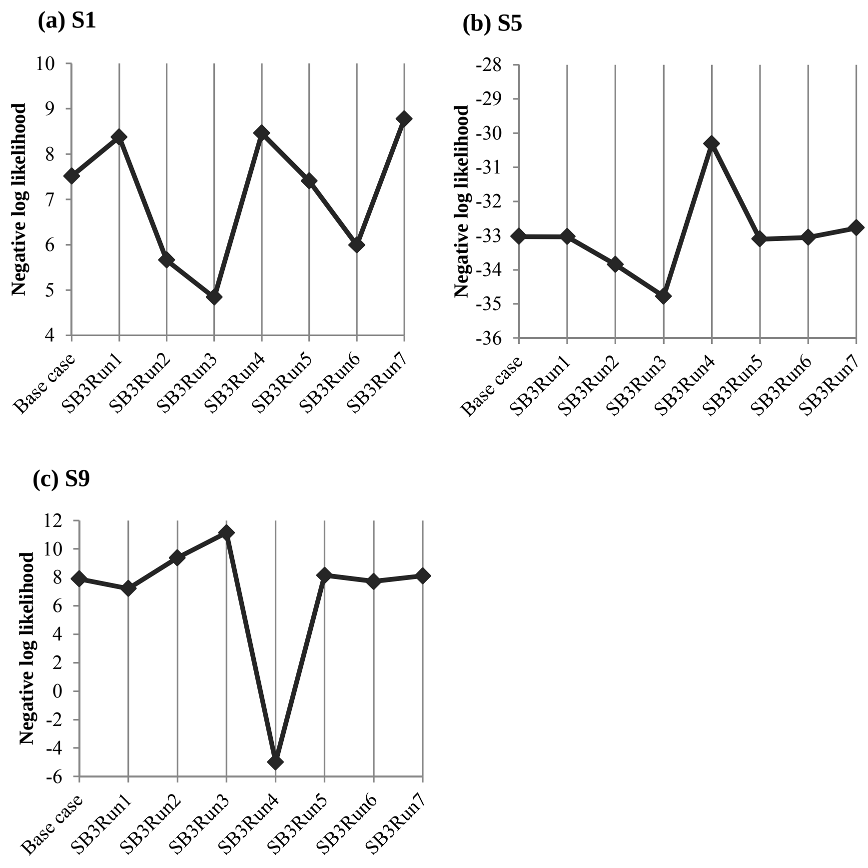


Figure 16. Likelihood of CPUEs (S1 (a), S5 (b), S9 (c)) estimated by each run which set different growth scenario

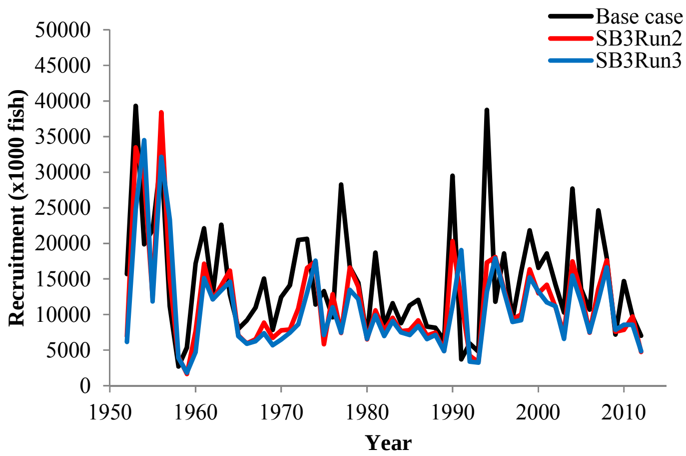


Figure 17. Recruitment for SB3Run2 and SB3Run3 which set different growth scenario

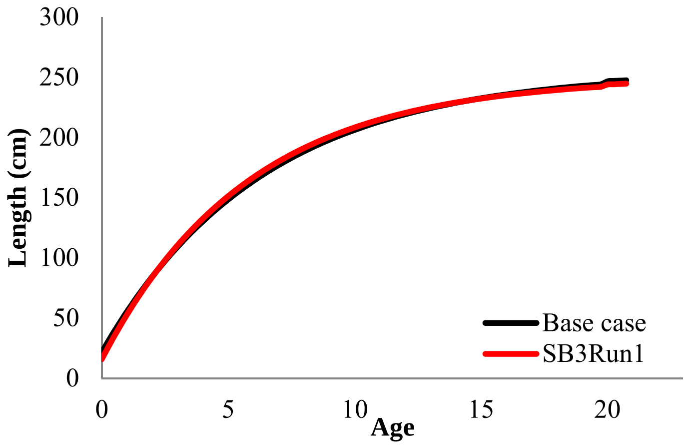


Figure 18. Growth curve for SB3Run1 which set different growth scenario

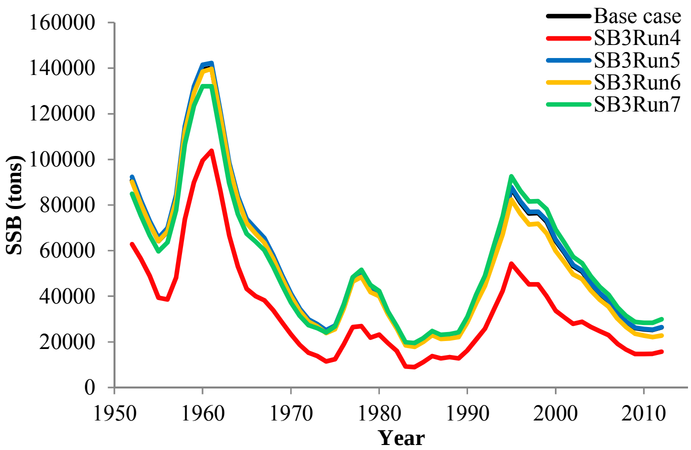


Figure 19. SSB for SB3Run4—SB3Run7 which set different growth scenario.

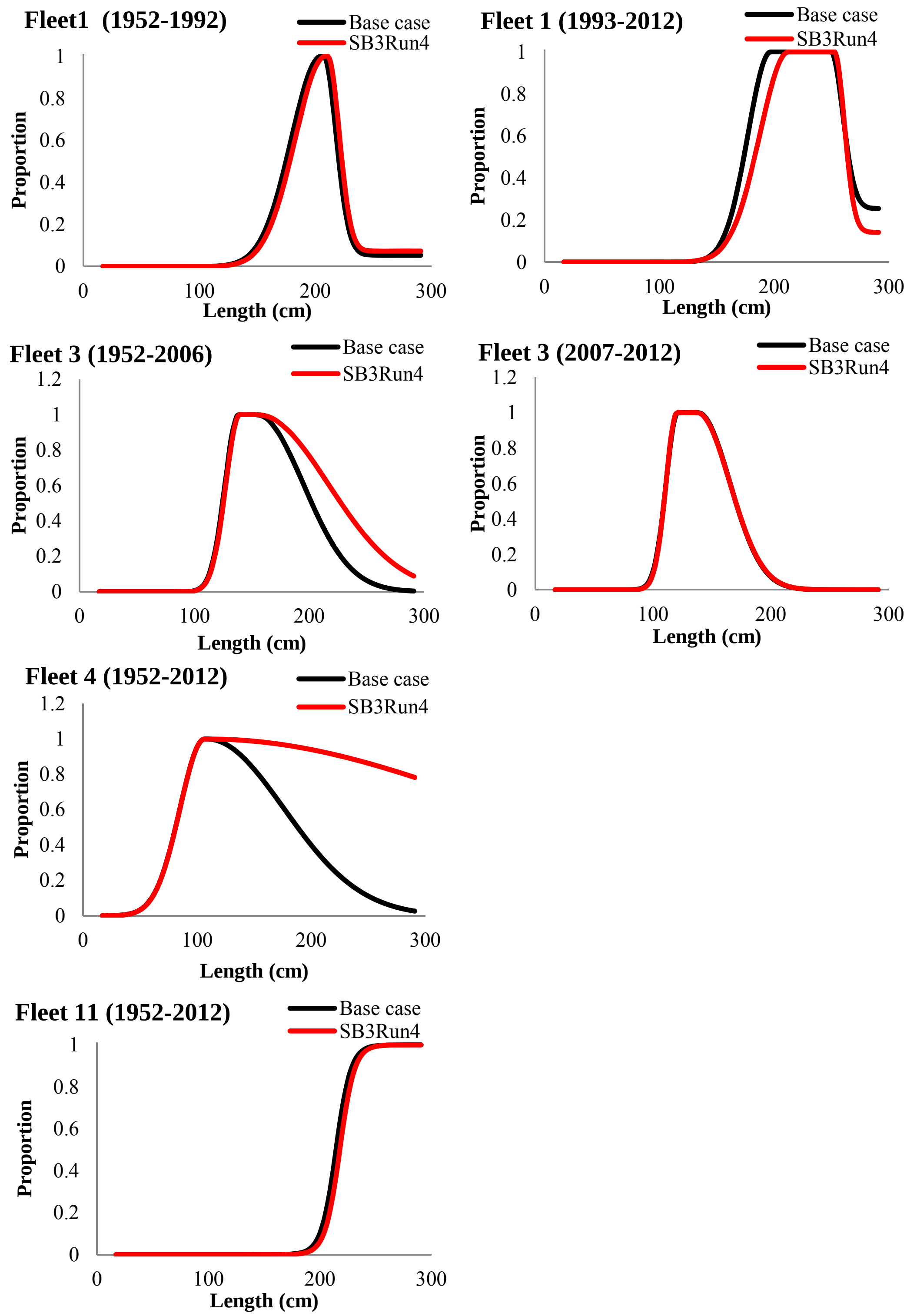


Figure 20. The selectivity of Fleet1, Fleet3, Fleet4, and Fleet11 estimated by SB3Run4 which set different growth scenario

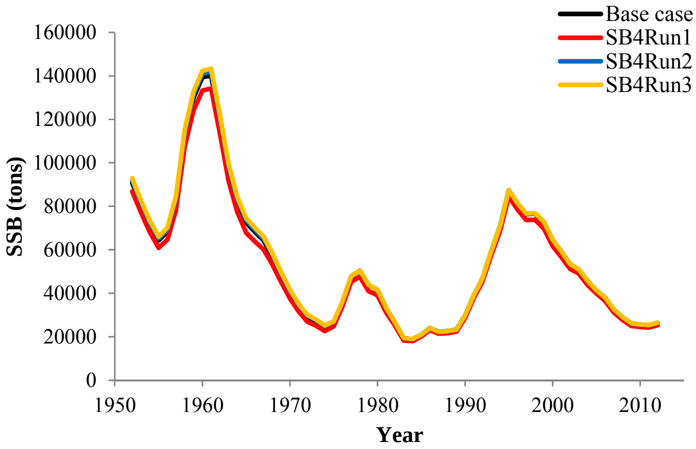


Figure 21. SSB for each run which set different longevity scenario

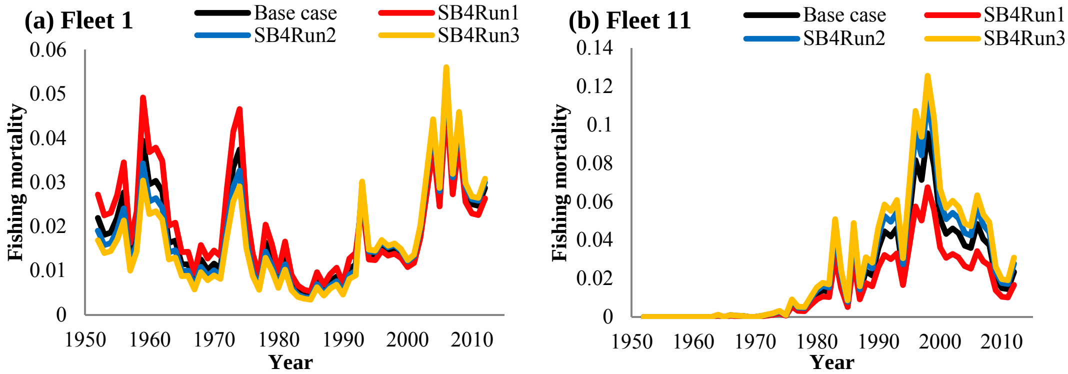


Figure 22. F by fleet for Fleet1 (a) and Fleet11 (b) estimated by each run which set different longevity scenario

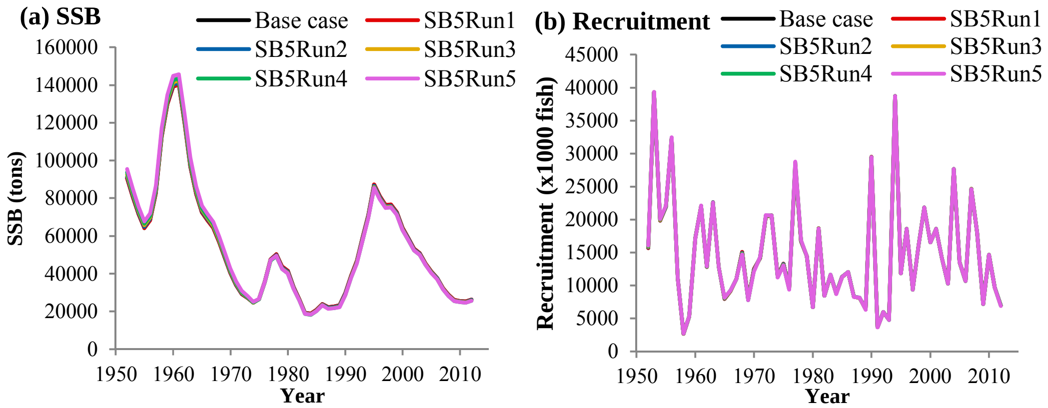


Figure 23. SSB (a) and recruitment (b) for SB5Run1—5 which set different Steepness (h) scenario

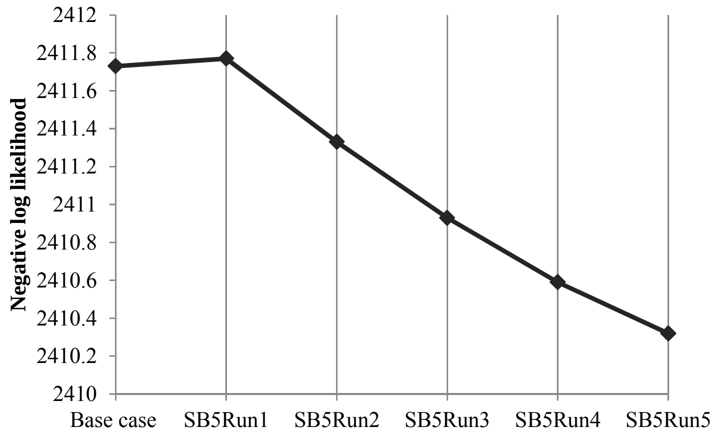


Figure 24. Total likelihood for SB5Run1—5 which set different steepness (h) scenario

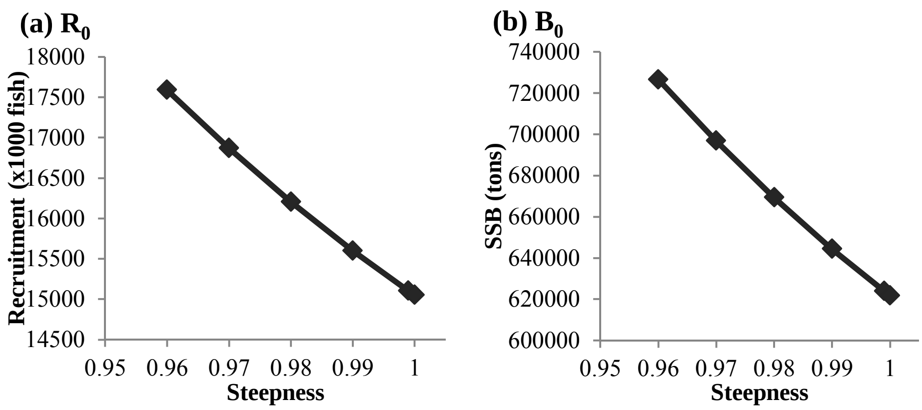


Figure 25. The relationship between steepness (h) and R0 (a) and B0 (b)

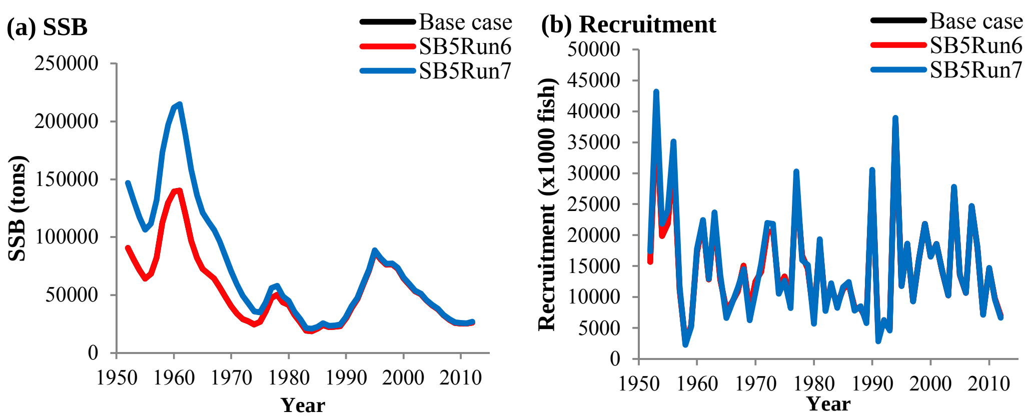


Figure 26. SSB (a) and recruitment (b) for SB5Run6 and 7 which set different sigma R scenario

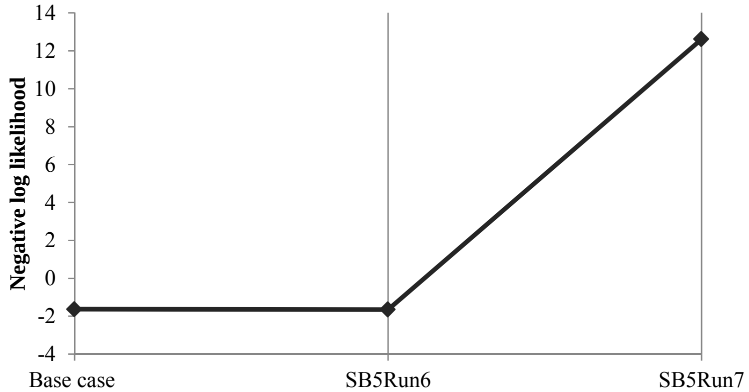


Figure 27. Likelihood of recruitment for SB5Run6 and SB5Run7 which set different sigma R scenario

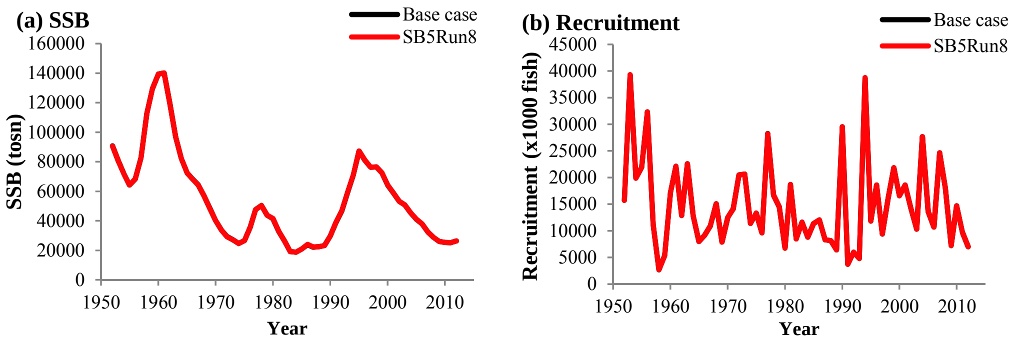


Figure 28. SSB (a) and recruitment (b) for SB5Run8 which assumed Hockey stick model for stock recruitment relationship (SRR)

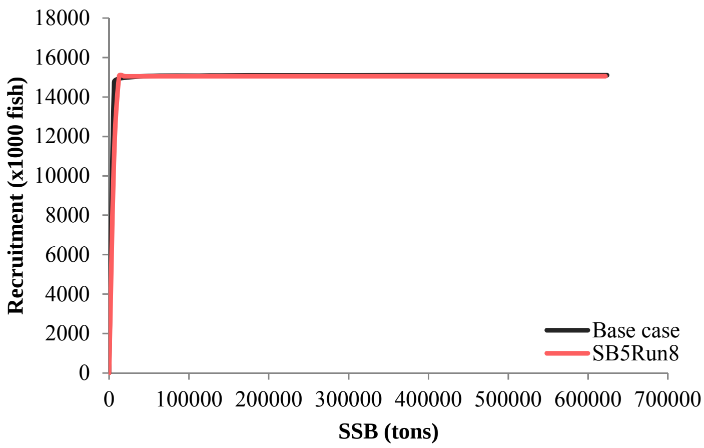


Figure 29. SRR curve for SB5Run8 which assumed Hockey stick model for stock recruitment relationship (SRR)

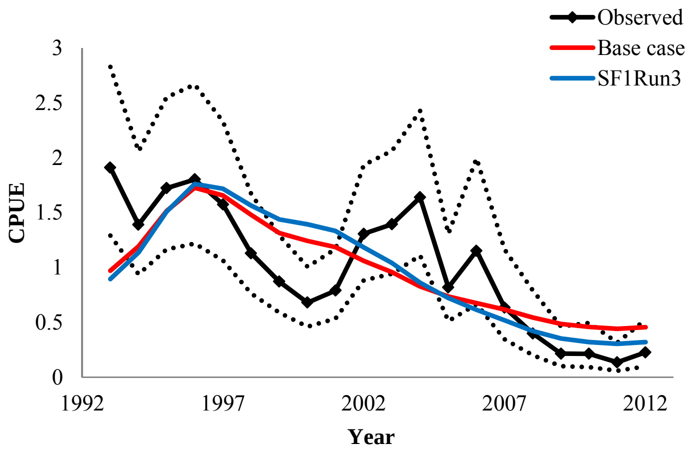


Figure 30. The fit to S1 estimated by SF1Run3 which set different CPUE scenario

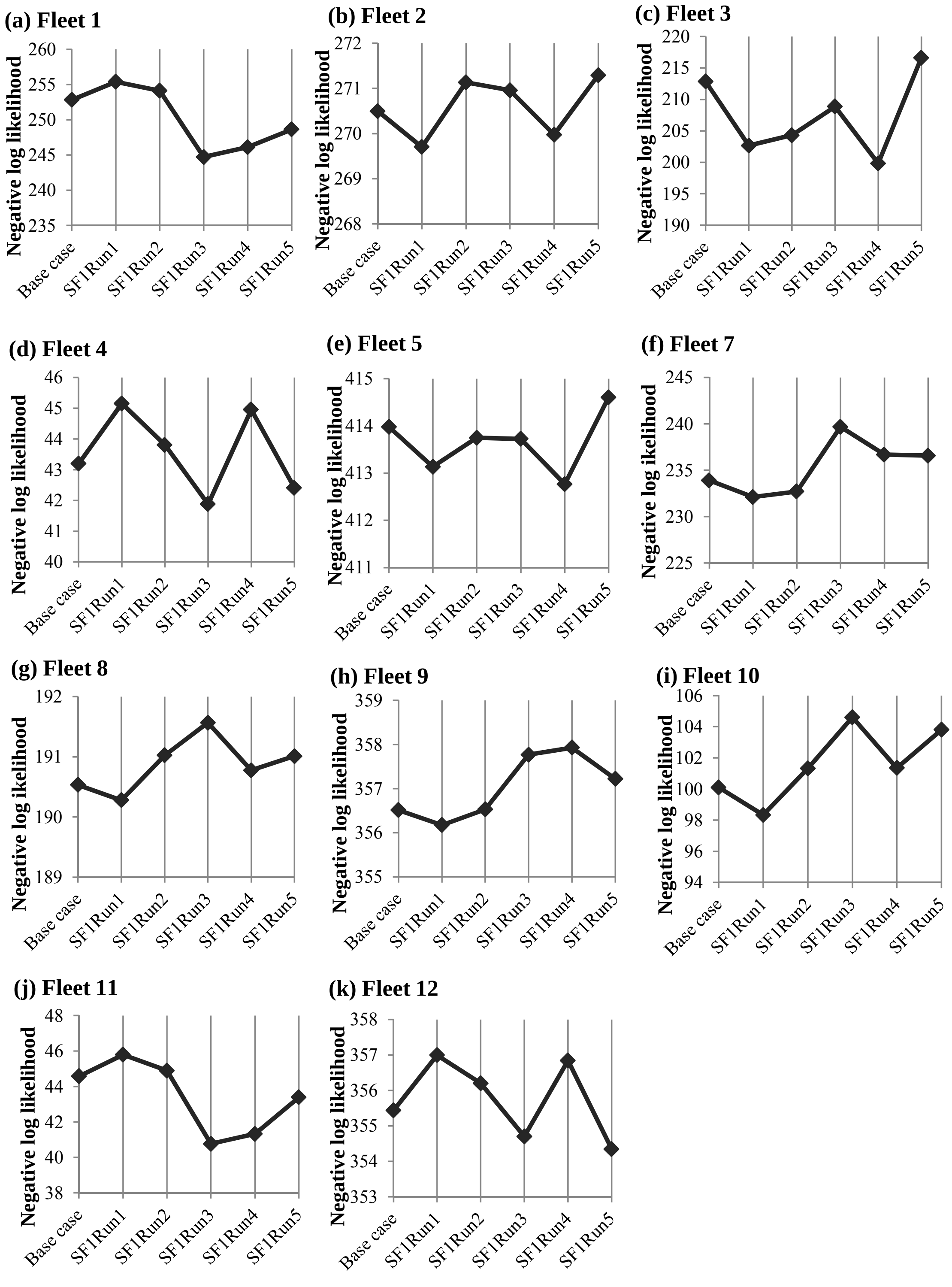


Figure 31. Likelihood of each Fleet (a—k) estimated by each run which set different CPUE scenario

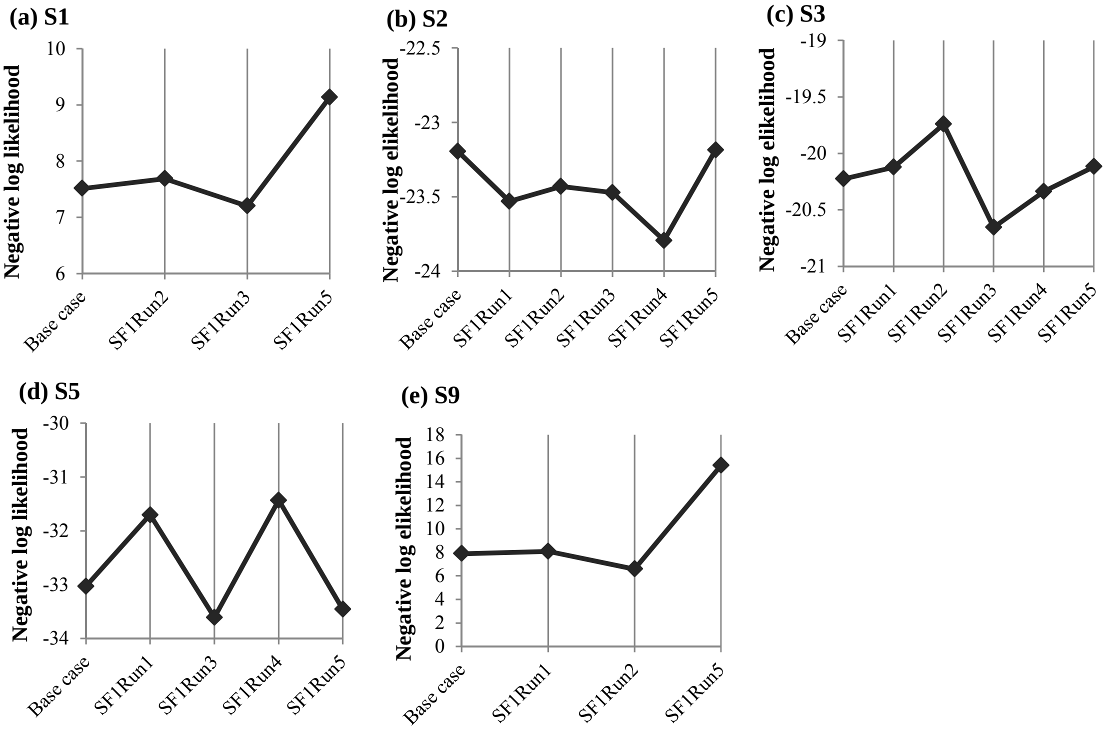


Figure 32. Likelihood of S1 (a), S2 (b), S3 (c), S5 (d) and S9 (e) estimated by each run which set different CPUE scenario

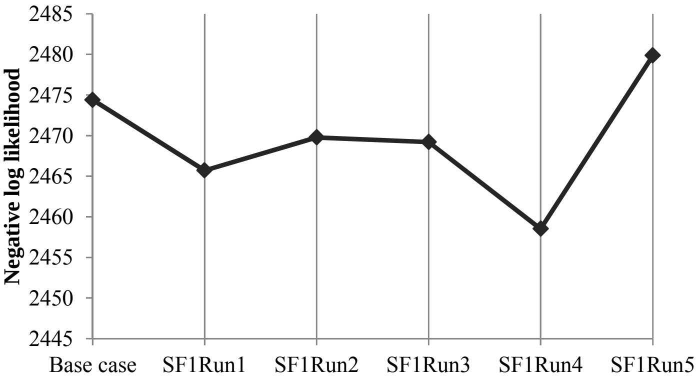


Figure 33. Likelihood component for the total size frequency estimated by SF1Run1—5 which set different CPUE scenario

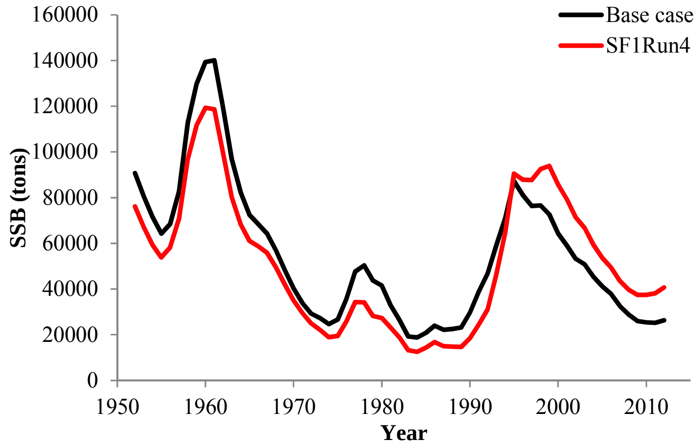


Figure 34. SSB for SF1Run4 which set different CPUE scenario

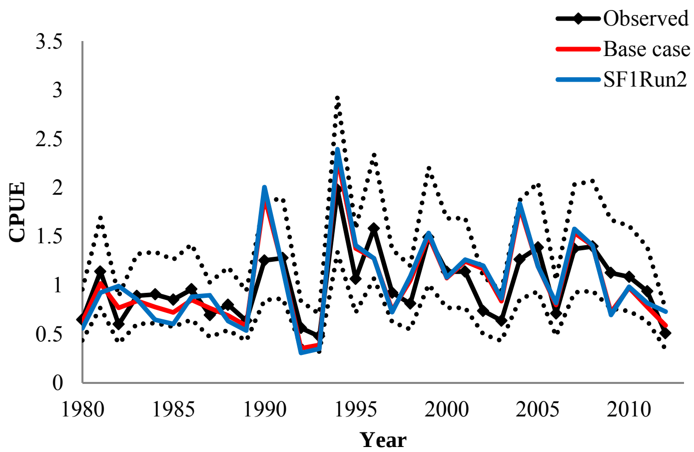


Figure 35. The fit to S5 estimated by SF1Run2 which set different CPUE scenario

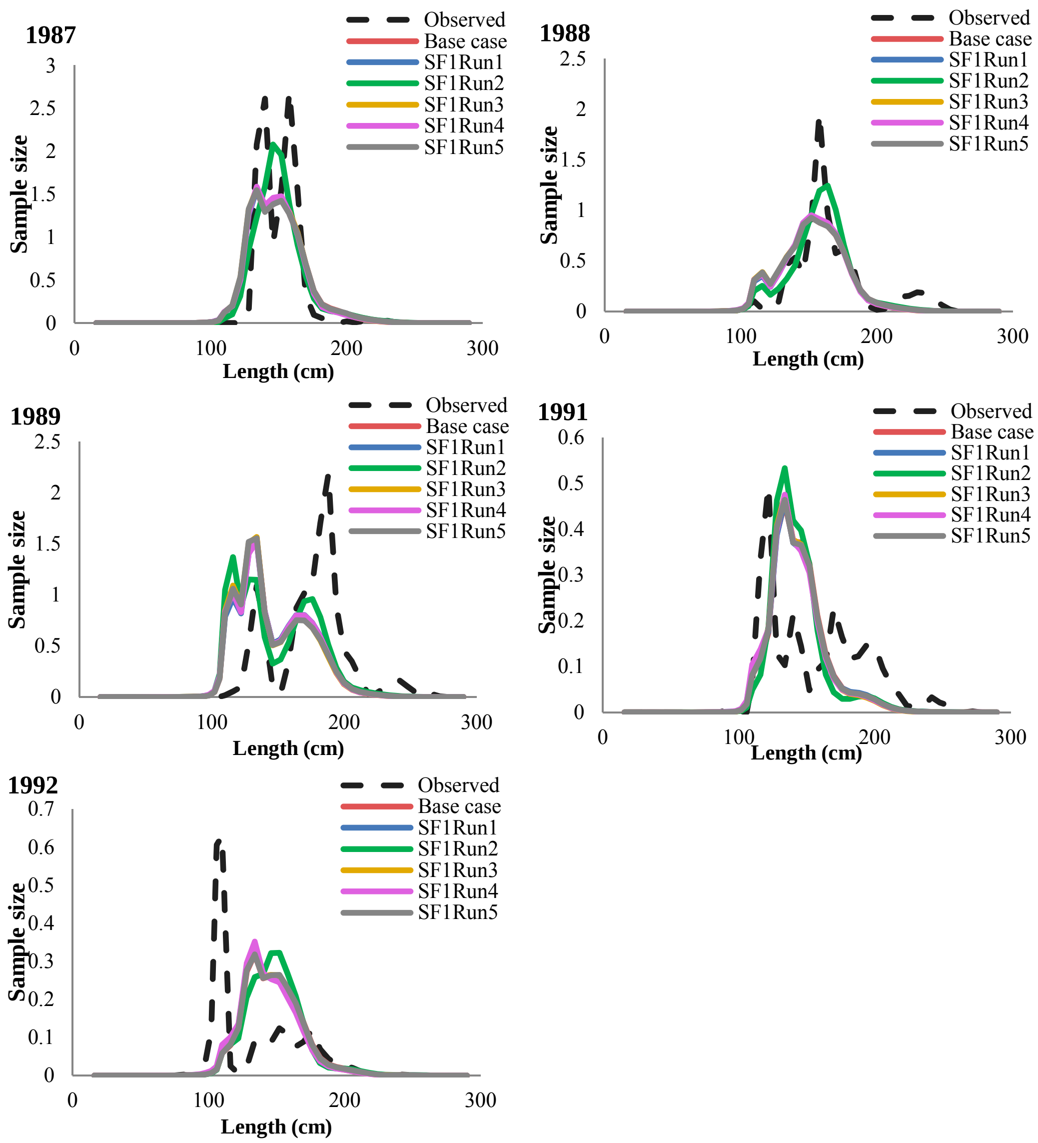


Figure 36. Catch at length (size fit) of Fleet 3 estimated by each run which set different CPUE scenario

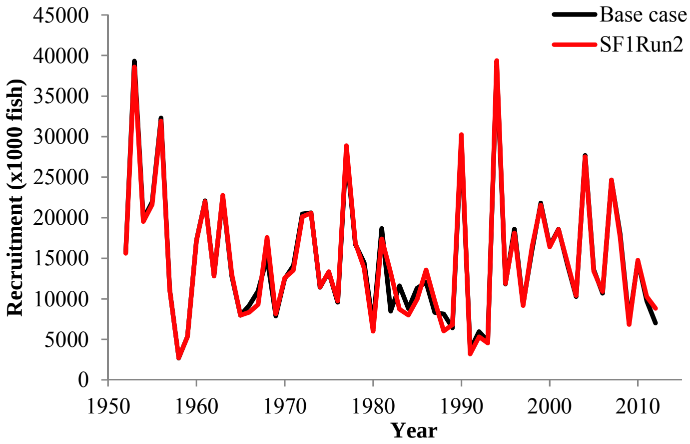


Figure 37. Recruitment for SF1Run2 which set different CPUE scenario

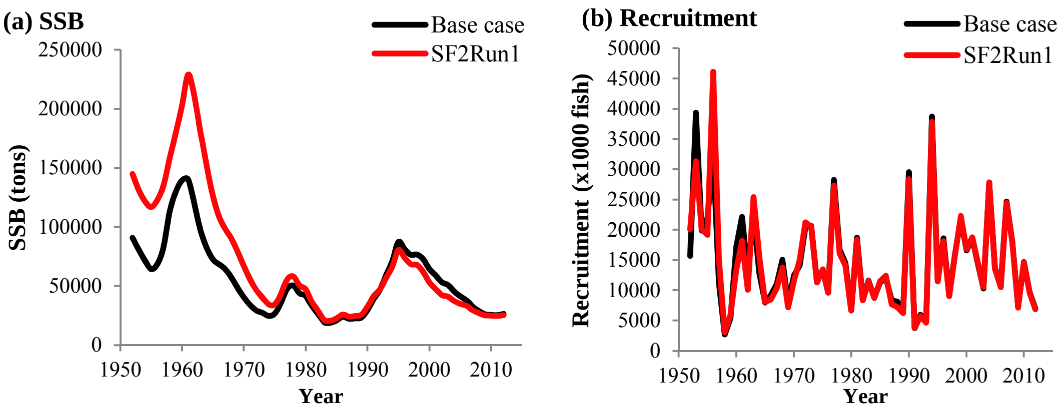


Figure 38. SSB (a) and recruitment (b) for SF2Run1 which set different size composition data scenario

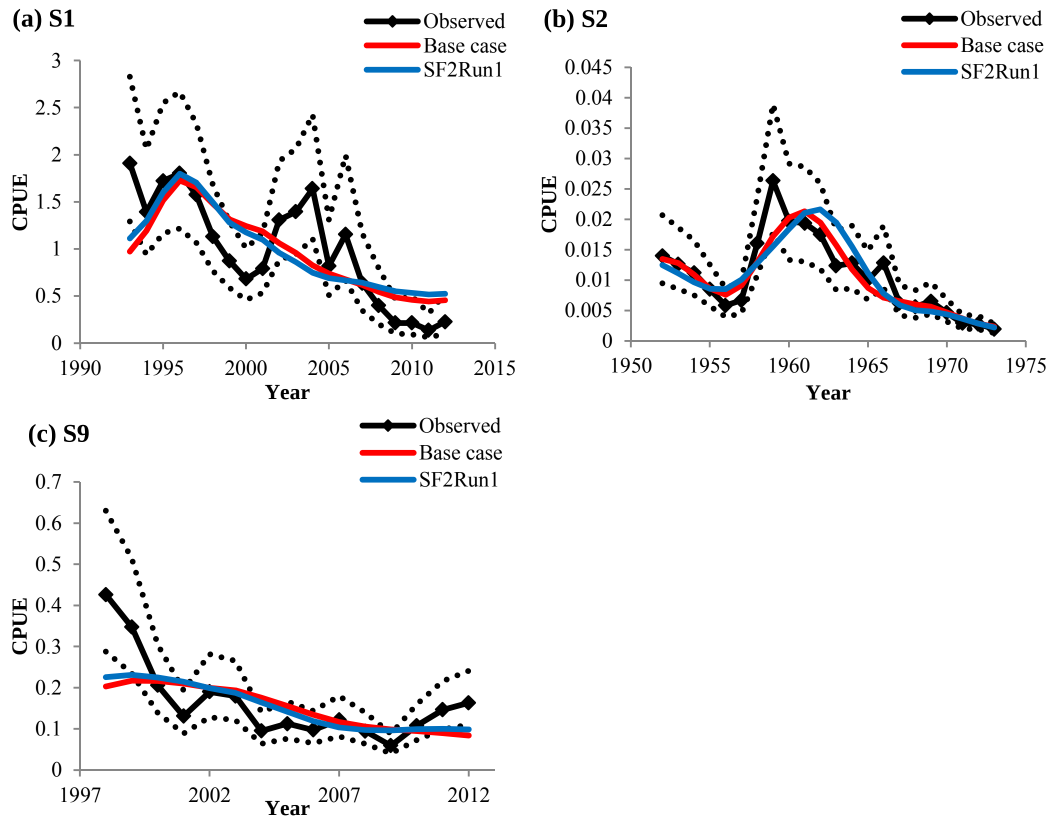


Figure 39. The fit to S1 (a), S2 (b), and S9 (c) estimated by SF2Run1 which set different size composition data scenario

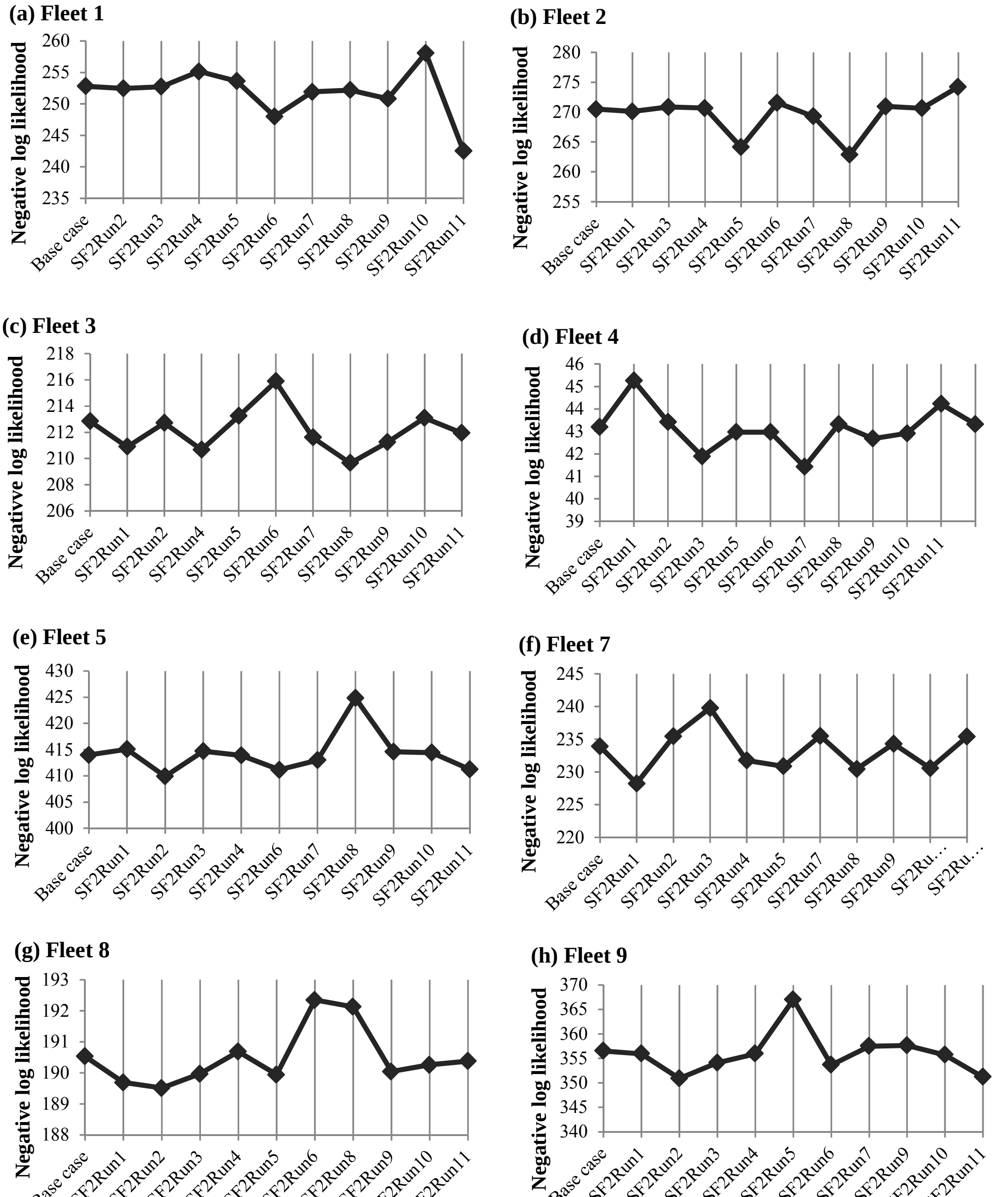
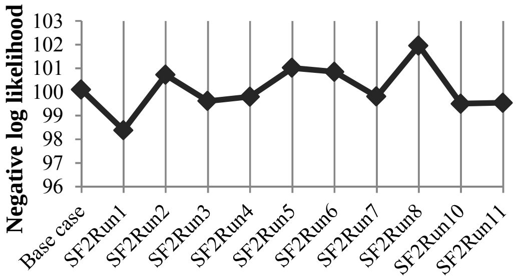
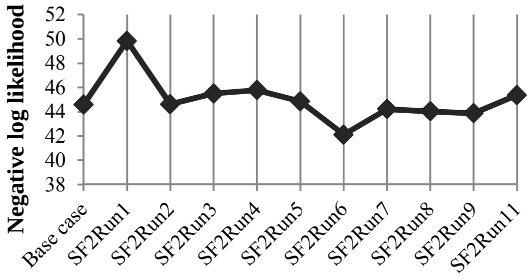


Figure 40. Likelihood of Fleet 1 (a), Fleet 2 (b), Fleet 3 (c), Fleet 4 (d), Fleet 5 (e), Fleet 7 (f), Fleet 8 (g), Fleet 9 (h), Fleet 10 (i), Fleet 11 (j) and Fleet 12 (k) estimated by each run which set different size composition data scenario

(i) Fleet 10



(j) Fleet 11



(k) Fleet 12

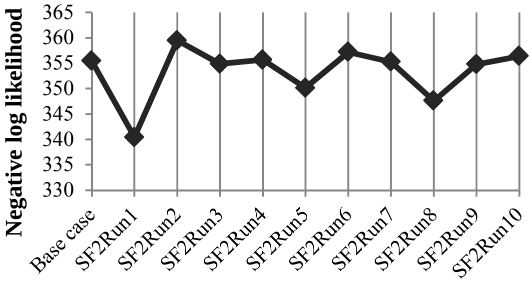


Figure 40. Continued

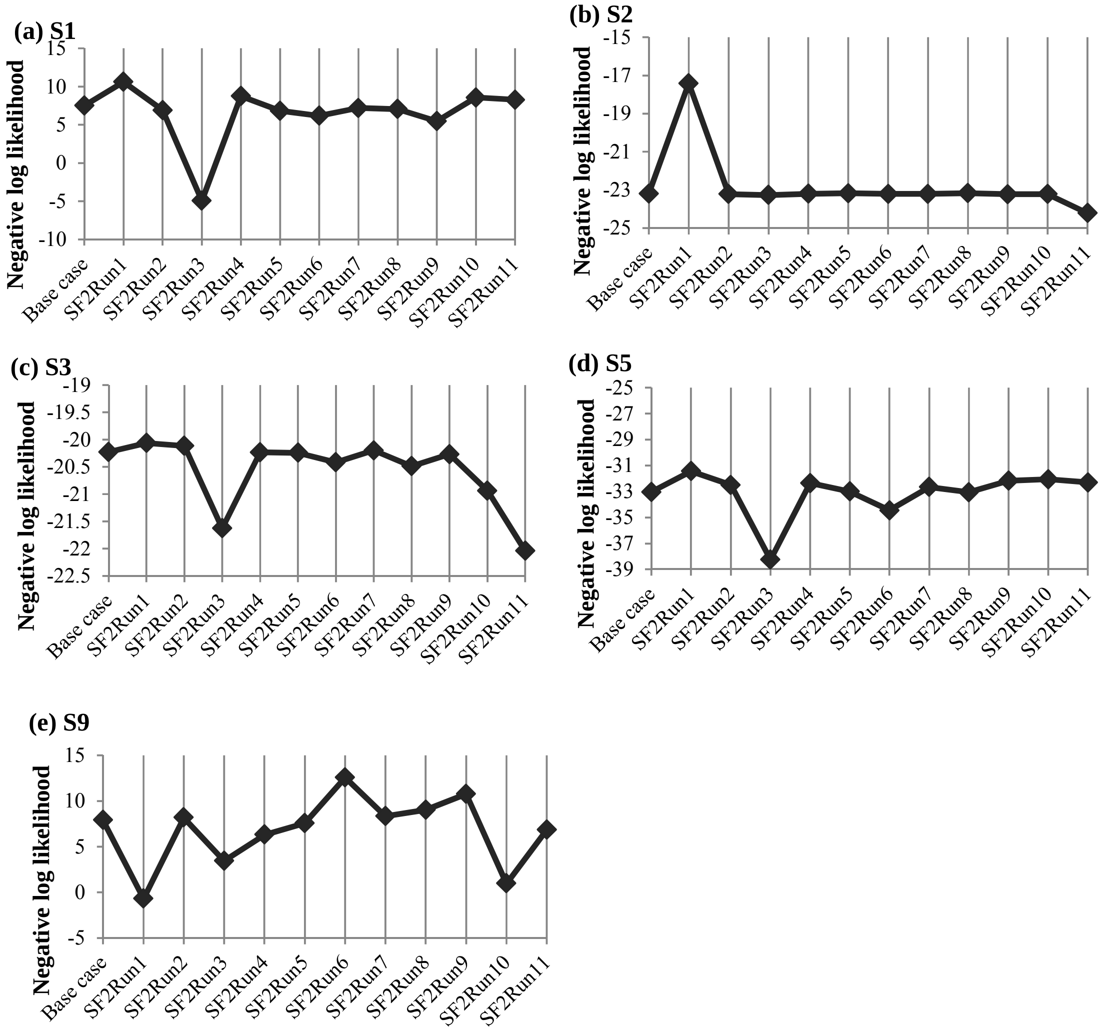


Figure 41. Likelihood of S1 (a), S2 (b), S3 (c), S5 (d) and S9 (e) estimated by each run which set different size composition data scenario

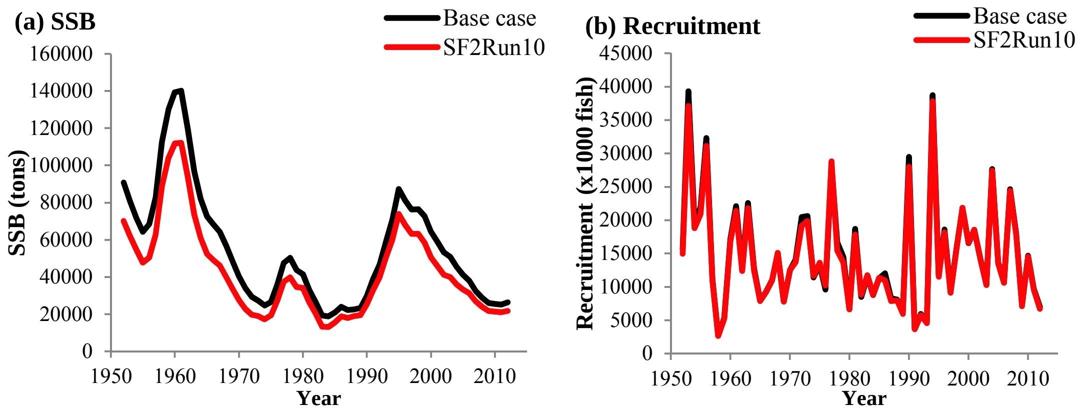


Figure 42. SSB (a) and recruitment (b) for SF2Run10 which set different size composition data scenario

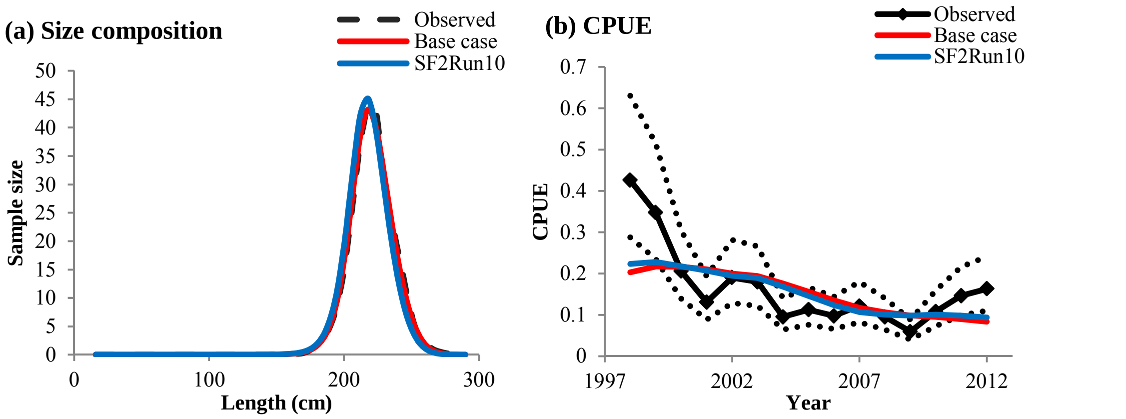


Figure 43. The size fit to Fleet 11 (a) and the fit to S9 (b) estimated by SF2Run10 which set different size composition data scenario

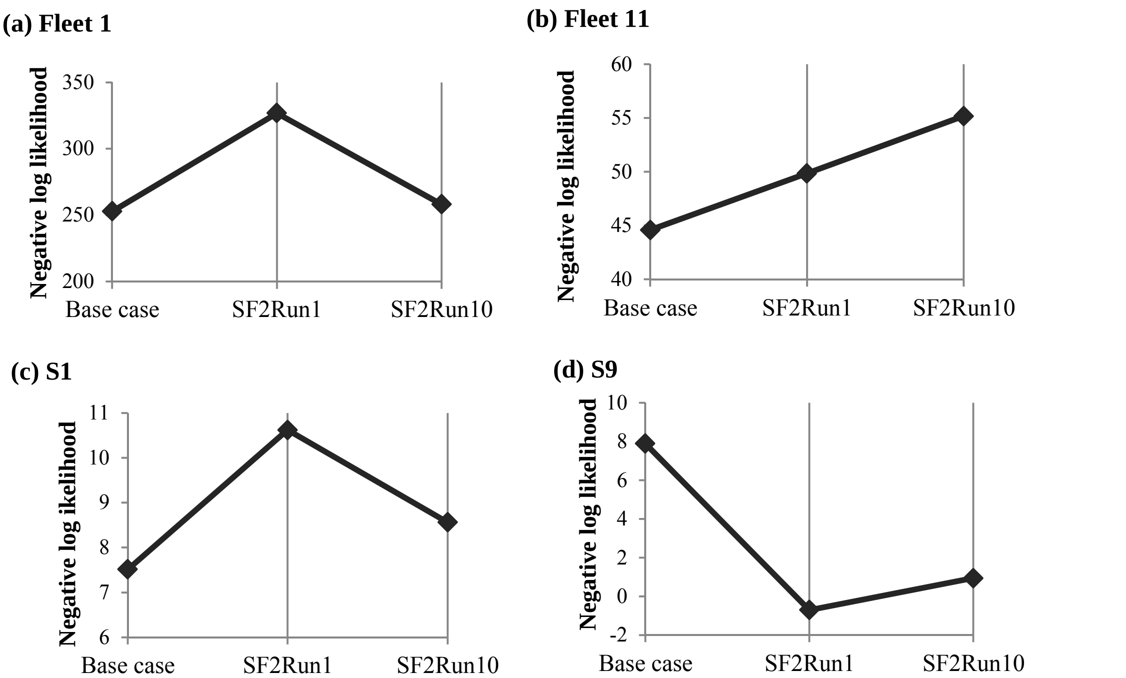


Figure 44. Likelihood of Fleet 1(a), Fleet 11 (b), S1 (c) and S9 (d) estimated by SF2Run1 and SF2Run10 which set different size composition data scenario

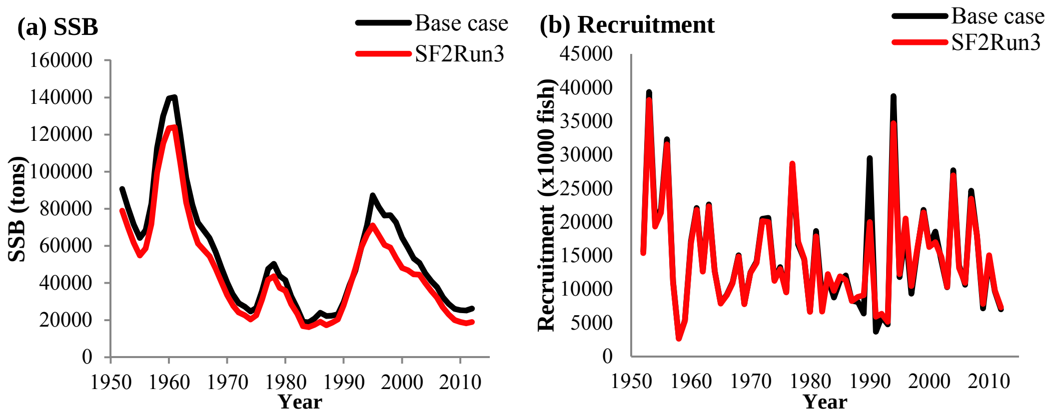


Figure 45. SSB (a) and recruitment (b) for SF2Run3 which set different size composition data scenario

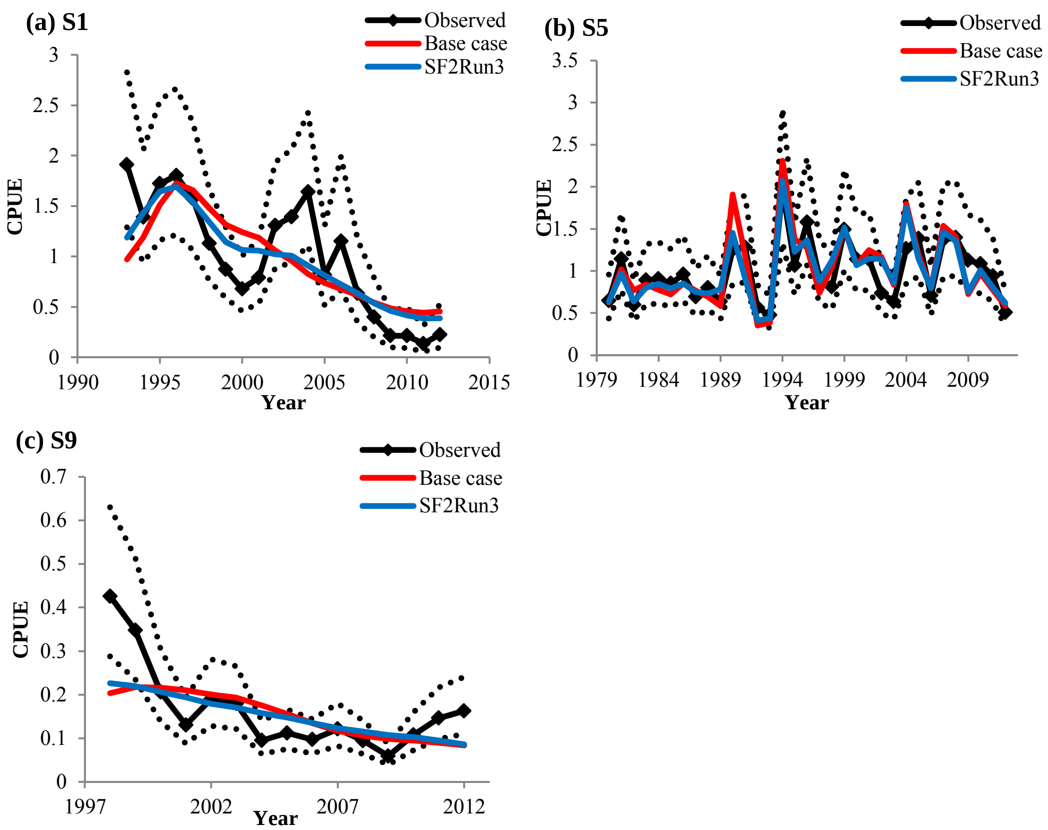


Figure 46. The fit to S1 (a), S5 (b), and S9 (c) estimated by SF2Run3 which set different size composition data scenario

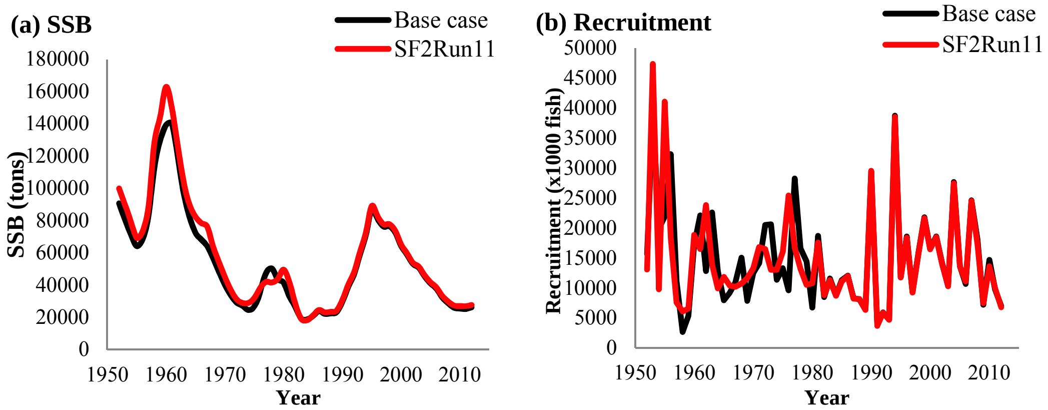


Figure 47. SSB (a) and recruitment (b) for SF2Run11 which set different size composition data scenario

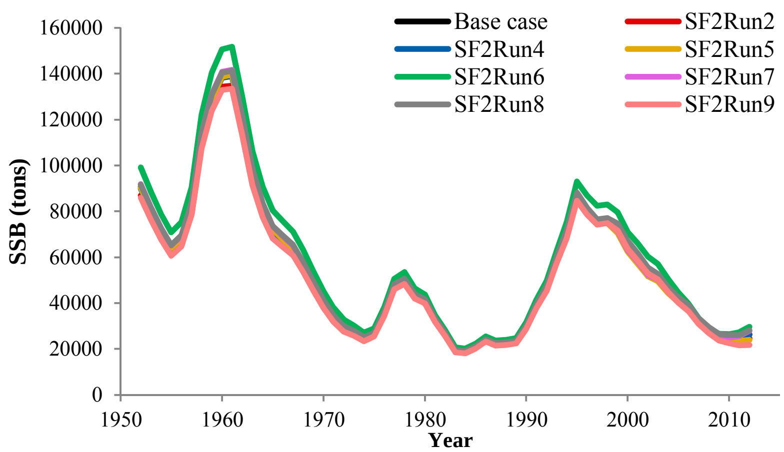


Figure 48. SSB for SF2Run2, SF2Run4—SF2Run9 which set different size composition data scenario

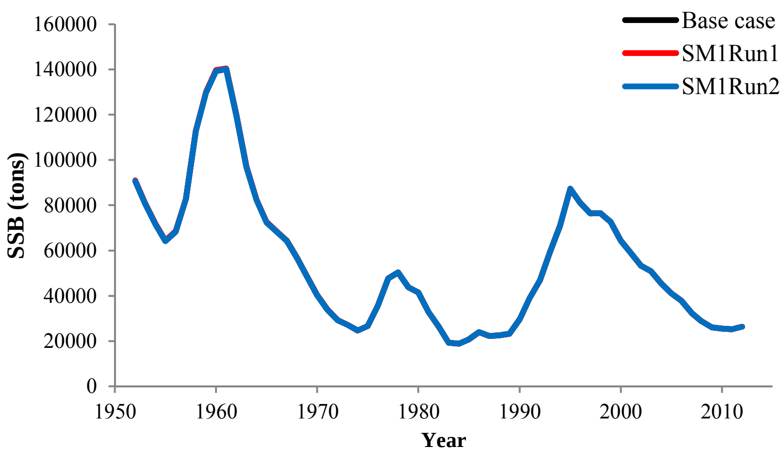


Figure 49. SSB for each run which set different standard catch error scenario

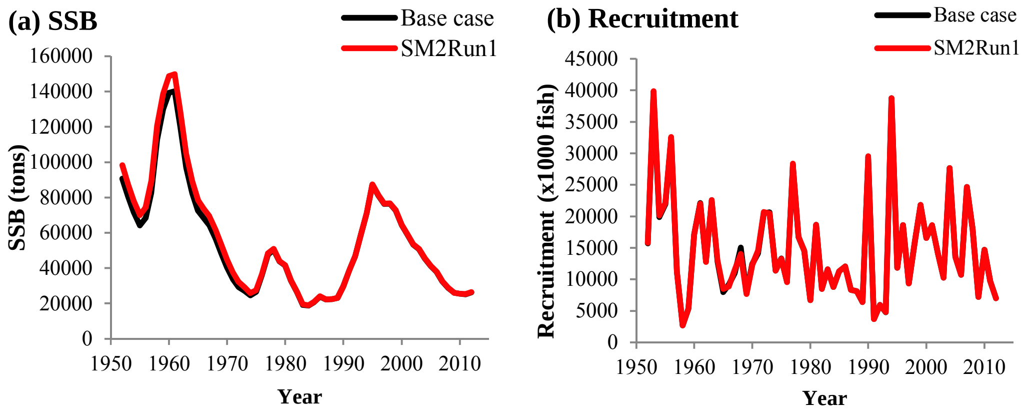


Figure 50. SSB (a) and recruitment (b) for SM2Run1 which set different upper F scenario

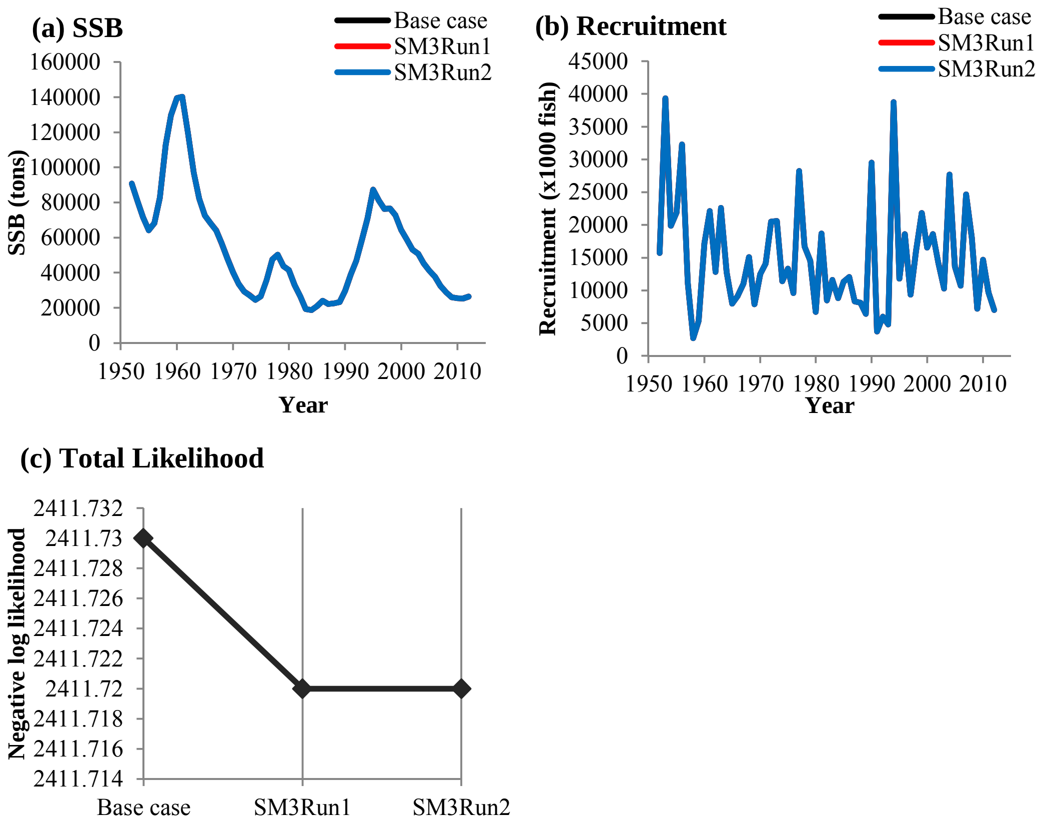


Figure 51. SSB (a), recruitment (b), and total likelihood (c) for each run which set different main recruitment deviation begin year scenario