ISC/12/PBFWG-3/07

The preliminary result of stock dynamics for Pacific Bluefin Tuna
- The descriptions of stock assessment model –

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Nov. 2012

Working document submitted to the ISC Pacific bluefin tuna Working Group, International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean (ISC), 10-17 November 2012, Honolulu, Hawaii. **Document not to be cited without author's permission.**

Abstract

The paper presents a setting of stock assessment model for Pacific Bluefin Tuna. The problem of duplication of the natural stock for Pacific Bluefin Tuna is due to the complication of the data set. In the document, the description objected to match the fishery information and to fit in a balanced manner to the size composition data and CPUE time series is presented.

The setting of base case which we recommended is introduced for stock assessment in this document. In the May-June stock assessment meeting, the fit to the CPUE time series for Japanese long line and size compositions are main issue. We suggested the recommended settings of Stock synthesis model 3 (SS3) which object to fit well not only CPUE but also size composition data and explain the actual fishery status reasonably. The results of this document are not agreed setting among ISC PBFT members.

1. Introduction

Stock assessment of Pacific Bluefin tuna (PBF: *Thunus Olientalis*) has been conducted by PBF Working group of International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC). The latest stock assessment of PBF was conducted in July 2010 using the Stock Synthesis (recent version of SS is produced by Methot 2011, http://nft.nefsc.noaa.gov/Stock_Synthesis_3.htm). In stock assessment in 2010, the catch and length data (Abe et al. 2010) were simply updated until 2007 in fishing year (until June 2008 in calendar year). CPUE series are also updated until 2007 as for Japanese coastal long line, Japanese coastal troll and Taiwanese long line fisheries. In the May-June stock assessment meeting, input data of stock assessment for was up to until 2010 by adding the data of fishing years of 2008, 2009 and 2010 to evaluate the most recent stock status. To evaluate stock status, the Stock Synthesis 3.23b (SS) was applied. SS is software program that implements a length /age-based structure, forward-simulation population model with flexibility to address parameterization (Such as selectivity, catchability, stock recruitment relationship, biological parameters, etc.) and uncertainty within the overall model.

However, in May-June ISC PBF stock assessment meeting, the scientists among members did not achieve to get consensus of model descriptions. ISC plenary in 2012 advised to open stock assessment meeting again. So the stock assessment meeting holds in Honolulu, Hawaii, in November 2012. This working paper is to describe and discuss about the setting of the stock assessment model, and the treatment of input data (fishery data and size composition data should be fixed at the May-June working group.

So, in the November meeting, 2012, the emphasis coefficients would be discussed in the working paper.).

This working paper presents: 1) the preliminary result of stock assessment of the base case; 2) the general description of model based on some consensus until the May-June stock assessment meeting; 3) The descriptions of stock assessment model in 2012 November meeting; 4) the introduction of the result of stock assessment model; 5) the sensitivity analysis for options which were selected in last ISC PBF WG in February, 2012 (About Growth curve, natural mortality and steepness).

2. Data and model configuration

In this section, short introduction is made on input data (See, detail of input data, Uematsu et al. 2012). The definition of fleet is summarized in the Table 1. This classification is same as in the 2012 May-June working group. By the agreement in the 2012 ISC plenary meeting, the fishery and size composition data are mainly fixed. However, we can modify the data if there is some problem on the data. In this section, the input data for stock assessment is summarized.

2.1 Fishery data and CPUE time series

Temporal stratification

The time period converted by this assessment is 1952-2010. Within this period, fishery-catch and size (length or weight) composition data were compiled into quarters (1st quarter as July-September, 2nd October-December, 3rd January-March and 4th April-June). Especially, in the PBF stock assessment fishery year is applied. Fishery year starts on July 1st and ends on June 30th. In this document we use the fishing year even for the quarters as described above. (See. Uematsu et al. ISC/12/PBFWG-2/02).

Fishery and CPUE definition

After the discussions at the data preparatory meeting of ISC PBF WG in February, 2012, WG agreed to use 13 fishery definitions instead of previous ten fisheries as had been adopted in past assessments (see. Table 1) and to use 11 CPUE time series, but not 17 (See Oshima et al., ISC/12/PBFWG-2/01). The updating of PBF catch, the details of fishery definitions and CPUE time series are listed on Uematsu et al. ISC/12/PBFWG-2/02.) except CPUE of Japanese Long line. It is recommended to keep point estimated value of CPUE time series. However, by the discussion in Ichinokawa and Takeuchi (ISC/12/PBFWG-3/06) and Oshima et al. (ISC/12/PBFWG-3/05), it is pointed out that the uncertainty of CPUE for Japanese long line in recent year is high.

Therefore, for incorporating recent uncertainty of CPUE time series of Japanese long Line, it is recommended that CV during 2005-2010 (fishing year) set CV until 2004 as 0.2, CV at 2010 as 0.4 and CV during 2004-2010 as values with linear interpolation between 0.2 and 0.4., since this uncertainty due to data set or the target shift to Yellow Fin Tuna of this fishery (see Oshima et al. ISC/12/PBFWG-3/05). Unfortunately, to incorporate the target shift to Yellow Fin Tuna cannot incorporate completely to the estimation value of CPUE. So changing CV is the one of ways to incorporate the uncertainty of CPUE. Particularly changes of fishery definitions from previous Stock Assessment in July, 2010 are that the Japanese Tuna Purse Seine fishery has been divided into two fisheries (Pacific and Sea of Japan) and separate a Japanese Set net fishery into three fisheries. With the CPUE time series, 9 CPUE series used for Japanese coastal long-line has been reduced to 3 series (1952 until 1973, Fujioka, et al., PBFWG12-1/WP10, 1974 until 2001, Yokawa, PBFWG8-2/WP5, 1993 until 2010, Ichinokawa, PBFWG12-1/WP8). The CPUE for Tuna purse seine of Sea of Japan was added (Kanaiwa, et al., PBFWG12-1/WP9). Four CPUE series are adopted for Japanese Troll fishery instead of 3 in the past (See. Table 1). Four time series for troll fisheries were revised as presented by Ichinokawa et al. (PBFWG12-1/WP11). Taiwanese long line CPUE series are expected to be revised (Hsu et al., PBFWG12-2/14). Finally, CPUE series for the eastern Pacific Ocean (EPO) commercial fishery was presented by Aires-da-Silva et al. (PBFWG12-1/WP18). The weighting factor, lambda, of CPUE for Tuna purse Seine for (S4), Japanese Troll fishery (for Kochi and Wakayama, S6, Kochi, S7, and Wakayama, S8), commercial fishery (S10) and sports fishery (S11) of Eastern Pacific Ocean (EPO) are set to 0.

<u>Size (length or weight) composition data</u>

In this PBF stock assessment, the size composition data of Japanese set net (north part of Japan, Fleet 7) and others (Fleet 13) are in weight and the other fleets are in length by the characteristics of the data source. For the weight 40 bins are defined (See. Fujioka et al. ISC/12-2/PBFWG/03 and the setting of weight composition were changed during May-June stock assessment meeting Appendix 3 in ISC 2012 ISC plenary, Annex 8.). For the length data 65 bins are defined (bins with 2cm intervals are adopted for fish ranging 16-58 cm, 4cm bins for 58-110cm, and 6 cm bins for 110-290cm. The length and weight composition data with their weighting procedures are summarized in Uematsu et al., ISC/12/PBFWG-2/02.

3. Descriptions of stock assessment model

As a general rule, there is no change in fishery data from previous stock assessment meeting. However, through the review of sample size composition data, the uncertainty is found in some fleet. Furthermore, the issues which should be improved are listed and present the provisional setting.

The problems in the results of the stock assessment meeting in May-June working group is fit of the CPUE. Some of working group member stated that the CPUE of Japanese long line fishery was more reliable than other CPUE time series. Therefore, the setting which focus on well fit to the CPUE of Japanese Long line by using the time block function (run 2 in the Anonymous, ISC plenary report Annex 8). On the other hand, the run to achieve balanced fit to CPUE and size composition data is suggested (run 3 in the Anonymous, ISC plenary report Annex 8). So presented setting in this document improves these issues.

3.1. Biological parameters and treatment of Input data

In the subsection, the issue related input data are summarized and presented. Setting of CV for CPUE, effective sample size and data utilization presented mainly.

Japanese long line (CPUE, Survey 1)

In the May-June working group, some WG member stated that the CPUE time series of Japanese long line is more reliable than the other CPUE time series. However, Oshima et al. (ISC/12/PBFWG-3/05) pointed out relatively higher uncertainty of CPUE for Japanese longline in recent six years. As discussed in the previous section, for incorporating recent uncertainty of CPUE time series of Japanese longline, set CV until 2004 as 0.2, CV at 2010 as 0.4 and CV during 2004-2010 as values with linear interpolation between 0.2 and 0.4.

Tuna Purse Seine (Fleet 3)

The current procedure to set effective sample size is based on sample size of Tuna Purse Seine in Sea of Japan (Fleet 3) and Tuna Purse Seine in Eastern Pacific Ocean (Fleet11). However, the average sample size of them is quite different. The half of average sample sizes of Fleet3 and Fleet11 are 35.81 and 7.81, respectively. As a result, the sample sizes for the rest of the fleets are scaled with the average of Fleet 3 and Fleet 11 (12.10) (See Uematsu et al., ISC/12/PBFWG-2/02). However, why the average sample size of Fleet 3 is relatively high due to sample size at 1996 3rd quarter (in fishing year), 377.42. The average of other year and quarter is 20.29. So the sample size of 1996 3rd quarter may affect to the t of stock assessment model. After the determination of effective sample size of other fleet, the sample size in 1996 3rd quarter is reduced to the second max value in fleet 3 (68.99). Then the average sample size in fleet 3 is 22.41.

Tuna Purse Seine in the Eastern Pacific Ocean (Fleet 11)

In the previous meeting, it is discussed that sampling problem in the eastern pacific ocean in recent years. By the progression of farming in the Eastern Pacific Ocean (EPO) after 1996, the data set of Tuna Purse Seine in the EPO includes the uncertainty (Oshima et al., ISC/12/PBFWG-2/20.). To improve the uncertainty in data set, it is recommended that the data during 1996-2010 was removed.

3.2. Setting of the stock assessment model

In the following sections, we state the size selectivity and the setting of the time block, emphasis factor for size composition data (lambda), and selectivity curve.

Tuna Purse Seine in the Seas of Japan (Fleet 3)

Based on the change of fishing pattern (see. Fukuda et al. 2012), the Tuna Purse Seine in the Sea of Japan changed qualitatively from 2007 (in fishing year). Before 2007 (in fishing year), the fishery in this fleet is operate without any specific age preference. So there is no positive reason to incorporate the time block. However the operation was slightly changed after 2007 (in fishing year) to catch age 3-4 fish. So the time block from 2007 to 2010 (in fishing year) is incorporated into the setting.

Japanese pole and Line (Fleet 6)

By the definition of Japanese Coastal Troll and Pole and line, it is difficult to distinguish between the data for Japanese Coastal Troll (Fleet5) or Japanese Coastal Long Line (Fleet6). Since the sample number of Japanese Coastal Long Line is smaller than the data for Japanese Coastal Troll (Fleet5). And the reliability of data for Japanese Coastal Troll (Fleet 5) is increase in recent year. So the emphasis factor lambda set zero as the recommended setting. The size composition of this fleet does not apply to estimate

Tuna Purse Seine in the Sea of Japan (Fleet 13)

The sample size of Size composition data in this fleet is lower than other fleet size composition data. Furthermore, the fit of this fleet is influential to the dynamics of Spawning stock Biomass and total biomass. To reduce the unexpected effect to the result of stock assessment, it is recommended that the selectivity curve in the fleet is determined by the following procedures; 1, set emphasis parameter lambda in this fleet one, 2, run and estimate the size selectivity with the setting, 3, fix the parameters following estimated size selectivity curve, 4, set the emphasis parameter lambda zero. By doing this procedure it is expected to suppress the unexpected or destabilized result of the stock assessment model.

3.3 Other matters

The other settings are summarized in the Table 2. The main differences from the May-June work shop (except the discussed issues in the previous section) are the CV of growth curve, first year of main recruitment deviation.

Firstly why the CV of the growth curve for young (old) are fixed is that estimated values are close the fixed value. To inhibit the unexpected dynamics of the result of stock assessment model, these values are fixed. Since more few parameters is favorable for the estimation. Secondly early recruitment was estimated from 1492. Why we chose the 1942 as first year of main recruitment deviation is to achieve the least likelihood. Finally, the selectivity for fleet 3 is fixed. The methods to fix the parameters are followings; 1) set lambda as 1 and run, 2) after step 1 we fix the parameters of fleet 13 with the estimated parameters, 3) set the emphasis factor lambda of fleet 13 as zero. Since, it is the best way to avoid the misspecification to the size composition data.

4. Stock assessment results

4.1 Spawning Stock Biomass and Recruitment

The result under the setting presented in previous sections is shown in the figure 1. In the figure 1, the dynamics of Spawning Stock Biomass (a, b) and Recruitment (c, d) are shown. The differences between a (c) and b (d) are the plotted with absolute value (left column) and relative value (right column). From the figure 2, the estimated recruitment deviations show relatively low variability in both periods between 1996 and 2010, and betweem1960 and 1988, the periods best informed by the data (lower panel in Figure 2). The input value of 0.6 was used as the standard deviation of log recruitment, used to define offset of the stock recruitment curve when recruitment deviations were estimated. From the figure 2, the uncertainty of recruitment seems to be low.

4.2 Fishing mortality

The estimated instantaneous fishing mortality is displayed in Figure 3. There have been important temporal changes in age-specific level of fishing mortality due to changes in effort for each fishery, which catches different ages of pacific bluefin tuna.

Fishing mortality, F for ages 0, 1, and 2 are relatively higher than F for other ages. F for ages 0, 1, and 2 has increased recently, F for ages 3-7, stayed at an almost same level, but F for over age 8 is tend to decrease.

4.3 Other matters

In the figure 4, the size selectivity curves are shown. From the figure, it seems that the size selectivity of each fleet is reasonable to fishery information. The fit of CPUE and size composition data are shown in the figure 5 and 6. The issue in May-June work shop is the fit to the CPUE time series of Japanese long line. From the figure 5, the estimated value is close to the observed value and the confidential interval. So it is interpreted by the improvement of this setting. The fit to the size composition at 1995-2002 in Tuna Purse Seine in the Sea of Japan is also main issue in the 2012 May-June workshop. However Fukuda et al. (2010) stated that the 1995-2002 year class is not specific to the Sea of Japan. So it lead to the over fit or over interpretation of actual stock status by the model to consist the fit during this period.

5. Sensitivity analysis

We do the sensitivity runs for sigma R, steepness, scenarios of natural mortality, growth parameters and the CPUE utilization.

5.1 The effect of the several settings

The effect of the sigma R value is shown in figure 7. The red line indicates the set sigma R as 1.0. From the figure, the SSB during 1952-1972 was increase.

In the figure 8, the effect of the steepness value is shown. Two runs are compared in the figure 8; one for fix steepness 1.0, the other one is fix steepness 0.8. The effect of setting 1.0 is not so large. Since the current setting of steepness is 0.999. For the case of 0.8 steepness value, the SSB would be down through the evaluation period (1952-2010). In the case the, estimated SSB may be lower than the base case result if the steepness value is low.

In the figure 9, the effect of scenario of natural mortality is shown. The runs are summarized in Table 3. As shown in the figure 9 the natural mortality change of young age class (age0 or 1) mainly affect to the dynamics of recruitment, but not the dynamics of SSB. On the other hand the natural mortality for old age class affect to both dynamics of SSB and the recruitment. In figure 10, the effect of growth is shown. The applied growth curve is Bayliff's growth curve, Shimose (2009, 2011) growth curve. From the figure, the current base case model is cloth to the run with using Shimose (2009)'s growth curve. In figure 11, the effect to the estimate US CPUE time series or Mexican CPUE time series, but it is no significant effect.

5.2 Retrospective analysis and likelihood profile

In the figure 12, the result of retrospective analysis is shown. By this figure, the SSB during recent year may be over estimate and under estimate after 1990 to 2006. However, to interpreted that totally there is no trend to the retrospective or significant pattern may be reasonable interpretation of SSB in the figure 12. On the other hand, the dynamics of recruitment is under estimate, since the estimated value increase by adding new dataset.

In figure 13, the likelihood profile is shown. In the 2012 May-June workshop, monotonically increasing of survey likelihood in the likelihood profile is one of the issues. However, such phenomenon does not improve the current base case. So this problem still remain and it may be future work for PBF working group.

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Table 1. CPUE series provided for this stock assessment.

Serial number	Nuber of fleet	Short Name	Data type	corresponding fisheries and mirroring	Size data type (fishery) or mirroring (CPUE)
1	F1	JLL	Fishery	Japanese coastal longline	length
2	F2	SPSS	Fishery	Small pelagic fish purse seine	length
3	F3	TPS	Fishery	Tuna purse seine (Sea of Japan)	length
4	F4	TPS	Fishery	Tuna purse seine (Pacific ocean)	length
5	F5	TR	Fishery	Japanese Coastal Troll	length
6	F6	PL	Fishery	Japanses Pole-and-line	length
7	F7	SN	Fishery	Japanese Set net (Northern part of Japan)	weight
8	F8	SN	Fishery	Japanses Set net (Q3&Q4 Hokuriku, Japan)	length
9	F9	SN	Fishery	Set net (Other area)	length
10	F10	TWLL	Fishery	Taiwanese long line	length
11	F11	EPOCOM	Fishery	Eastern Pavific Ocean commercial fishery	length
12	F12	EPOSP	Fishery	Eastern Pavific Ocean Sports fishery	length
13	F13	OTH	Fishery	Others	weight
14	S1	JpCLL	CPUE	Japanese coastal long line conducting spawning area and season (April to June) (WP 8 in PBF12-1)	JLL
15	S2	JpnDWLLR evto74	CPUE	CPUEs with aggregated data in Japanese offshore and distant water longliners using all quarters until 1974 (WP 10 om PBF-WG 12-1)	JLL
16	S3	JppDWLLR evfrom75	CPUE	CPUEs with aggregated data in Japanese offshore and distant water longliners using all quarters and area until 1975 (Yokawa WP "25+26", revisited)	JLL
17	S4		CPUE	Sea of Japan after 1982(L), Dome shape selectivity, share length data with FL4	TPS
18	S5	JpnTrollChi naSea	CPUE	CPUEs of Japanese troll fisheries in Nagasaki prefecture (Sea of Japan and east china sea) from 1980 to 2010	TR
19	S6	JpnTrollPac ific	CPUE	CPUEs of Japanese troll fisheries combine with Kochi and Wakayama prefecture (Pacific side) from 1980 to 2010	TR
20	S7		CPUE	CPUEs of Japanese troll fisherieswith Kochi prefecture (Pacific side) from 1980 to 2010	TR
21	S8		CPUE	CPUEs of Japanese troll fisheries with Wakayama prefecture (Pacific side) from 1980 to 2010	TR
22	S9	TWLL	CPUE	CPUEs of Taiwanese longline from 1998 to 2007	TWLL
23	S10	USPSto82	CPUE	CPUEs in US target purse seine until 1982	EPOCOM
24	S11	MexPSto06	CPUE	CPUEs in Mexico purse seine from 1999 to 2006	EPOCOM

Table 2. Recommended setting

		Agreement in May-June WG		This Working paper
Model Structure				
SS version		SS-V3.23b		SS-V3.23b
Year definition		July to June		July to June
Period		1952-2010		1952-2010
Time step		Quarter		Quarter
Number of stock, area, gender, growth pattern and growth morphs (spawning population)		Single		Single
Number of age class		21(0-20)		21(0-20)
Fishery definition		13 fleets for catch and 5 surveys of CPUE		13 fleets for catch and 5 surveys of CPUE
Popo length bin		2 cm bin (16 cm - 222 cm and 252 cm - 290 cm), 1 cm bin interval (224 cm-251 cm)		2 cm bin (16 cm - 222 cm and 252 cm - 290 cm), 1 cm bin interval (224 cm-251 cm)
Biological parameters				
Natural mortality		Age specific,year is time step Age0 =1.6 Age 1=0.386 Age2+=0.25		Age specific,year is time step Age0 =1.6 Age 1=0.386 Age2+=0.25
Maturity		Age specific Age3=0.2 Age4=0.5 Age 5+=1.0		Age specific Age3=0.2 Age4=0.5 Age 5+=1.0
Growth curve		Estimate K and Lmax from otolith data in Shimose (2012) by fixing length at age 0 to be 21.5 cm.		Estimate K and Lmax from otolith data in Shimose (2012) by fixing length at age 0 to be 21.5 cm.
Functional form of CV growth		CV=F(L)		CV=F(L)
growth CV (young)		estimate		fix (0.27)
growth CV (old)		fix (0.08)		fix (0.05)
Amin		0		0
Amx		3		3
L-W		Kai et al. 2007		Kai et al. 2007
Assumption of recruitment				
SRR		B-H		B-H
R0		Estimated		Estimated
Steepness		0.999		0.999
sigmaR		0.6, run estimate		0.6, run estimate
1st year of main Rdev		1946		1942
R0 offset		Estimated		Estimated
SR auto correlation		No		No

Table 2 (cont.). Recommended setting

		Agreement in May-June WG		This Working paper	
Fishery & fishing					
Catch unit		Weight		Weight	
Catch error		0.1		0.1	
Initial catch		Equilibrium catch of F4 is set to be zero, becasue initial F of F4 hits lowe bound of the parameter (0).		Equilibrium catch of F4 is set to be zero, becasue initial F of F4 hits lowe bound of the parameter (0).	
Initial F		Estimate initial F for F1 and F5		Estimate initial F for F1 and F5	
F-method		3 (solve catch eq)		3 (solve catch eq)	
iteration		5		5	
upperF		10		10	
CPUE assumption					
CPUE likelihood		lognormal		lognormal	
CPUE lambda		1 for F14, F15, F16, F18, F19, F22 and 0 for F17, F20, F21		1 for F14, F15, F16, F18, F22 and 0 for F17, F19, F20, F21	
CV of CPUE		Lowest CV is set as 0.2		Lowest CV is set as 0.2 Only F14, set CV of recent 6year 0.3	
Length comps & Selectivity					
Data structure		Generalized size composition (bin definition is different among fleets) Details are in ISC/12-2/PBFWG/02 for length bin and appendix XX for weight bin)		Generalized size composition (bin definition is different among fleets) Details are in ISC/12-2/PBFWG/02 for length bin and appendix XX for weight bin)	
effN for LenComps		Scale to have same effN to FL11,FL3(SOJ)		Scale to have same effN to FL11,FL3(SOJ)	
ESS		(Reset length lambda=1, then re-weight)		No reset ESS	
Selectivity, Data treatment and Time block	F1	Double normal, Eliminate data in 1st quarter of 1956 as outlier	F1	Double normal	Eliminate data in 1st quarter of 1956 as outlier, weight=1
	F2	Double normal	F2	Double normal	weight=1
	F3	Double normal	F3	Double normal	Introduce time block during 2007-2010
	F4	Double normal, Eliminate data before 1993 and after 2007. Super period combining q1 and q4	F4	Double normal	Eliminate data before 1993 and after 2007, super period combining q1 and q4
	F5	Double normal	F5	Double normal	weight=1
	F6	Mirror F5 selectivity	F6	Mirror F5 selectivity	weight=0
	F7	Double normal	F7	Double normal	weight=1
	F8	Double normal	F8	Double normal	weight=1
	F9	Double normal	F9	Double normal	weight=1
	F10	Flat top	F10	Flat top	weight=1
	F11	Double normal, down weight=0.1	F11	Double normal	weight=1, Eliminate data after 1996
	F12	Mirror F11 selectivity, weight=0	F12	Mirror F11 selectivity	weight=0
	F13	Double normal, down weight=0.1	F13	Double normal	weight=0 after fix the selectivity
Others					
Diagnostics of the model		Bootstrap, retrospective analysis		Bootstrap, retrospective analysis	

Table 3. Sensitivity runs for the several M scenarios

	M for age 0	M for age 1	M for age 2+
Basecase	1.6	0.386	0.2
M Scenario 1	1.6	0.45	0.25
M Scenario 2	1.6	0.35	0.25
M Scenario 3	1.4	0.386	0.25
M Scenario 4	1.8	0.386	0.25
M Scenario 5	1.6	0.386	0.2
M Scenario 6	1.6	0.386	0.3

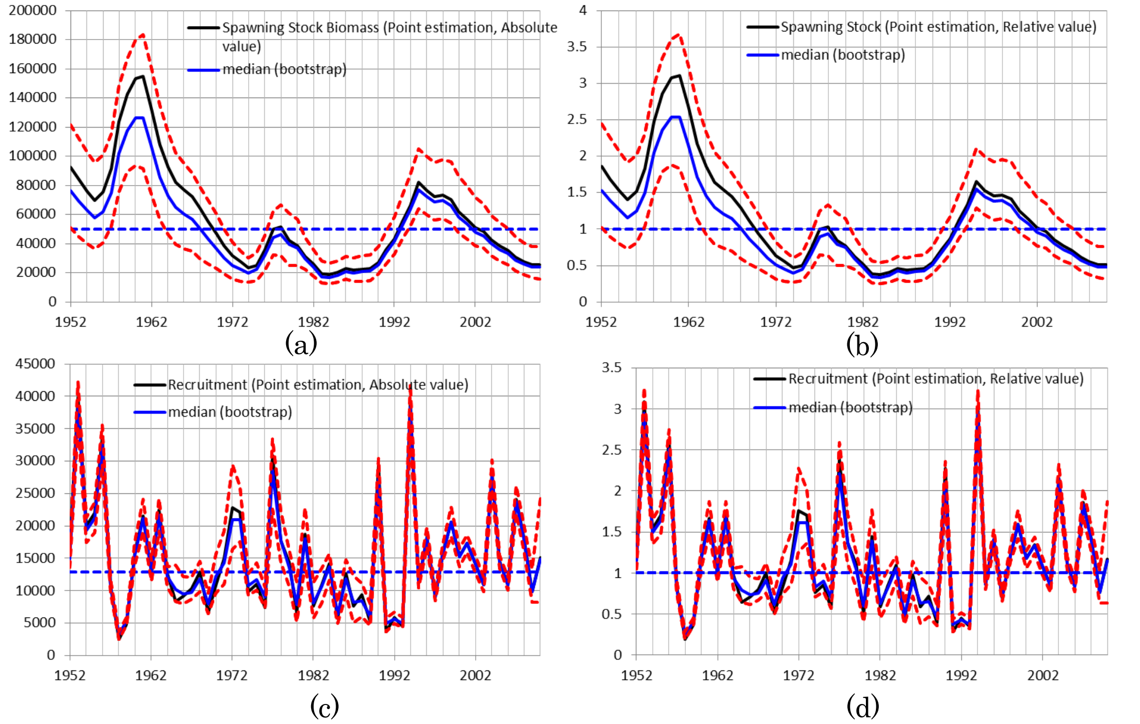


Figure 1. Temporal dynamics of Spawning Stock Biomass (a, b) and Recruitment (c, d). Left column figures indicate the absolute value and Right column indicates the relative value. The dashed red lines indicated interval from 2.5 percentile to 97.5 percentile. Black line indicates the point estimated value. Blue line indicates the median line of the result for bootstrap. Green dashed thin lines indicate 0 or 100 percentile.

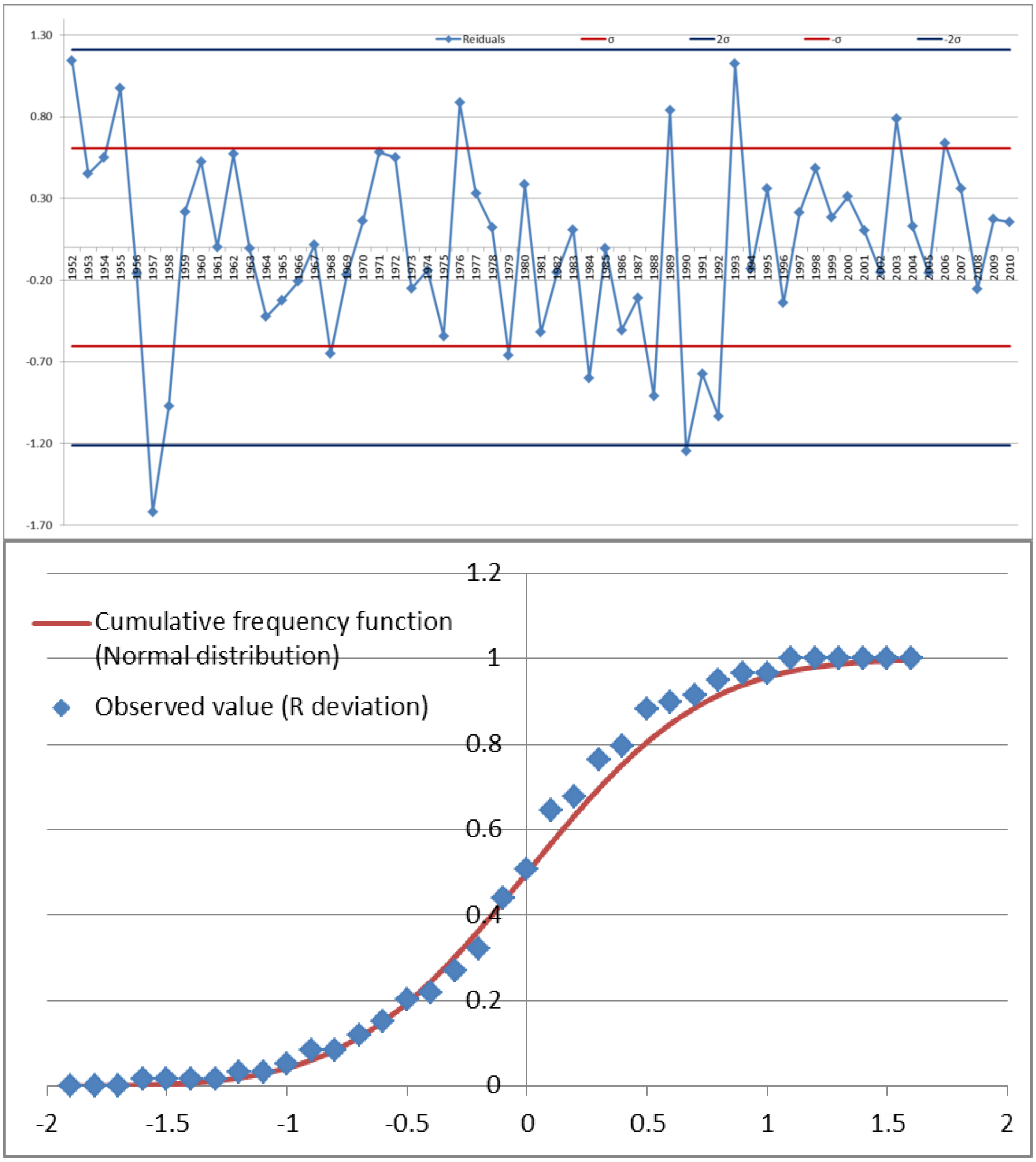
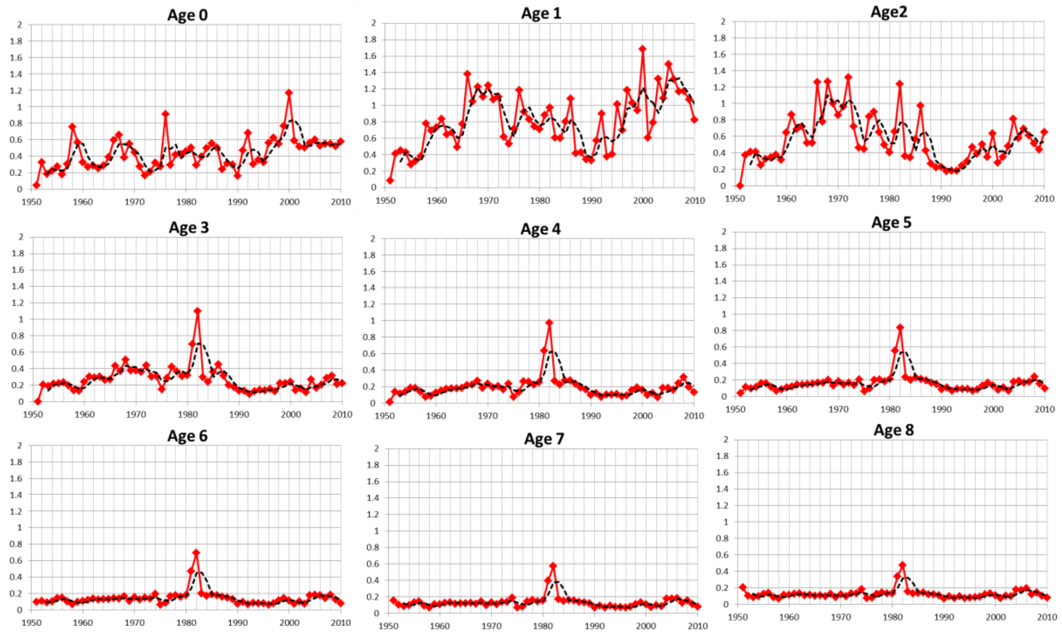
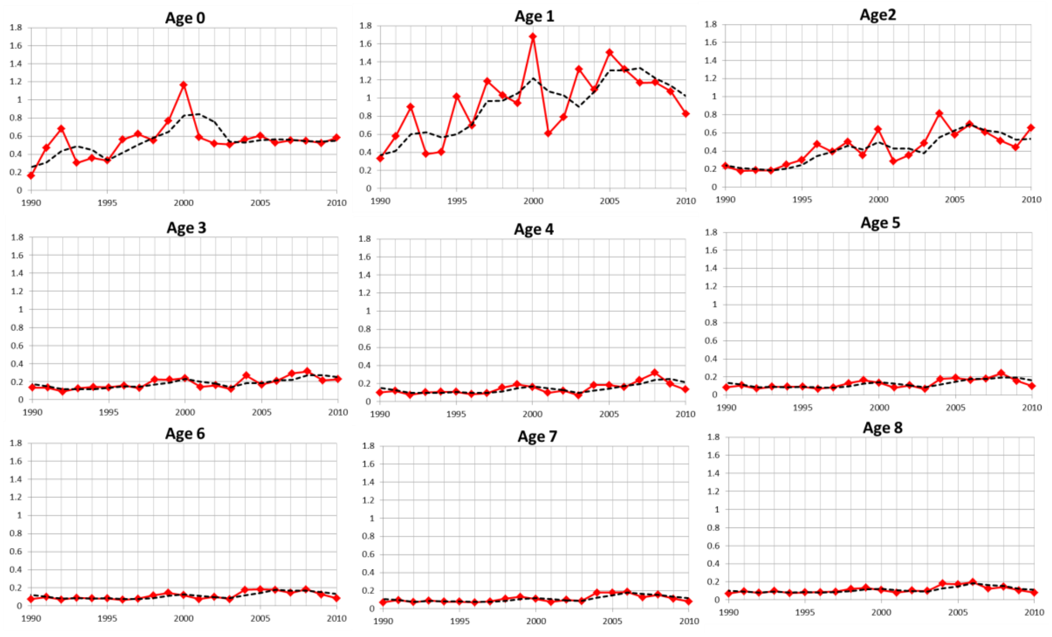


Figure 2. Residuals of recruitment deviation. Top: Temporal dynamics of observed value (R deviation). Red line indicates σ and -σ. Deep blue line indicates 2σ and -2σ. Bottom: Observed value (R deviation) and Cumulative frequency function (Normal distribution with mean 0, deviation 0.6).



(a)



(b)

Figure 3. Dynamics of fishing mortality, F. (a) Plot of fishing mortality, F during 1952-2010. (b) Plot of fishing mortality, F during 1990-2010. .

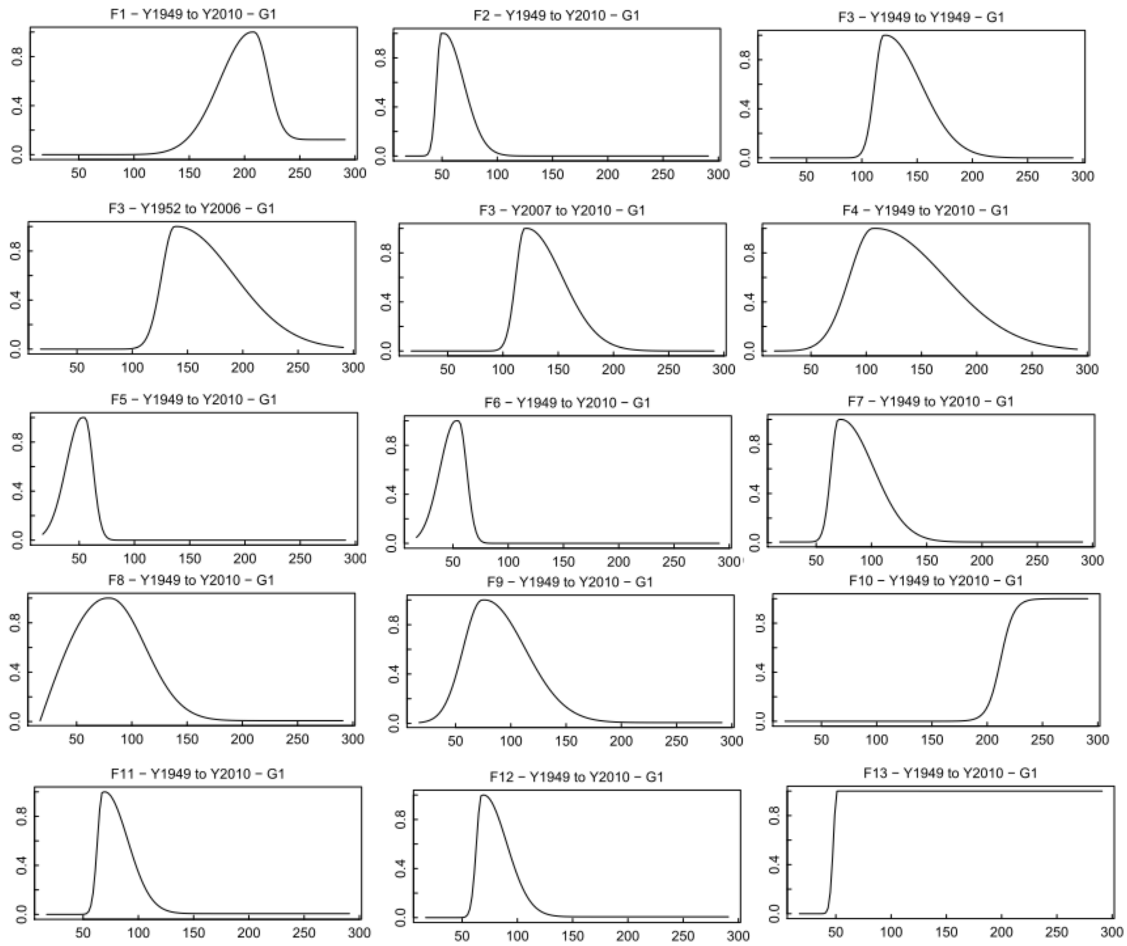


Figure 4. Selectivity curve

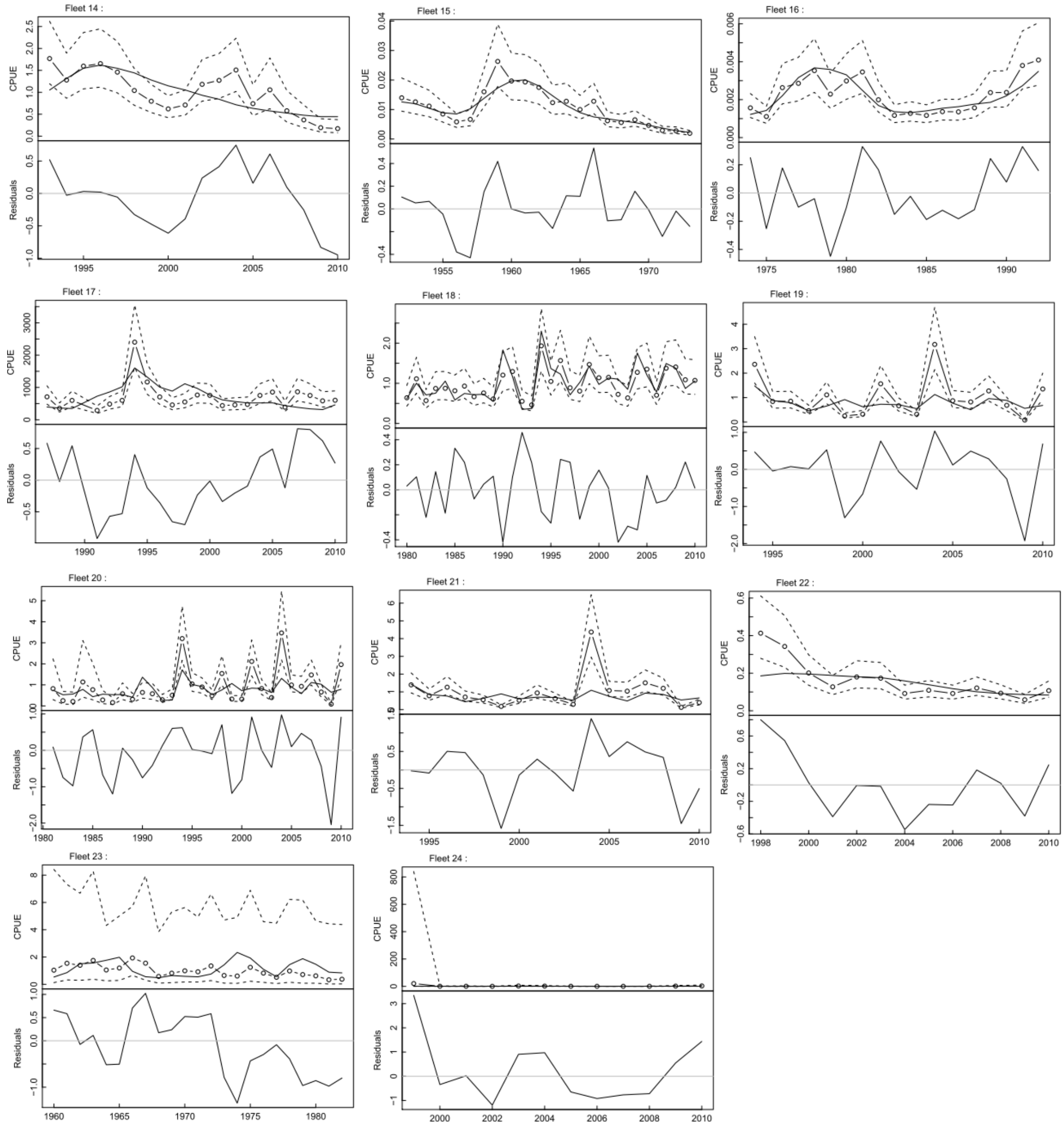


Figure 5. Observed and expected CPUE, and its residuals. Expected (line) and observed (line + circle)Residuals (Observed value – expected value)

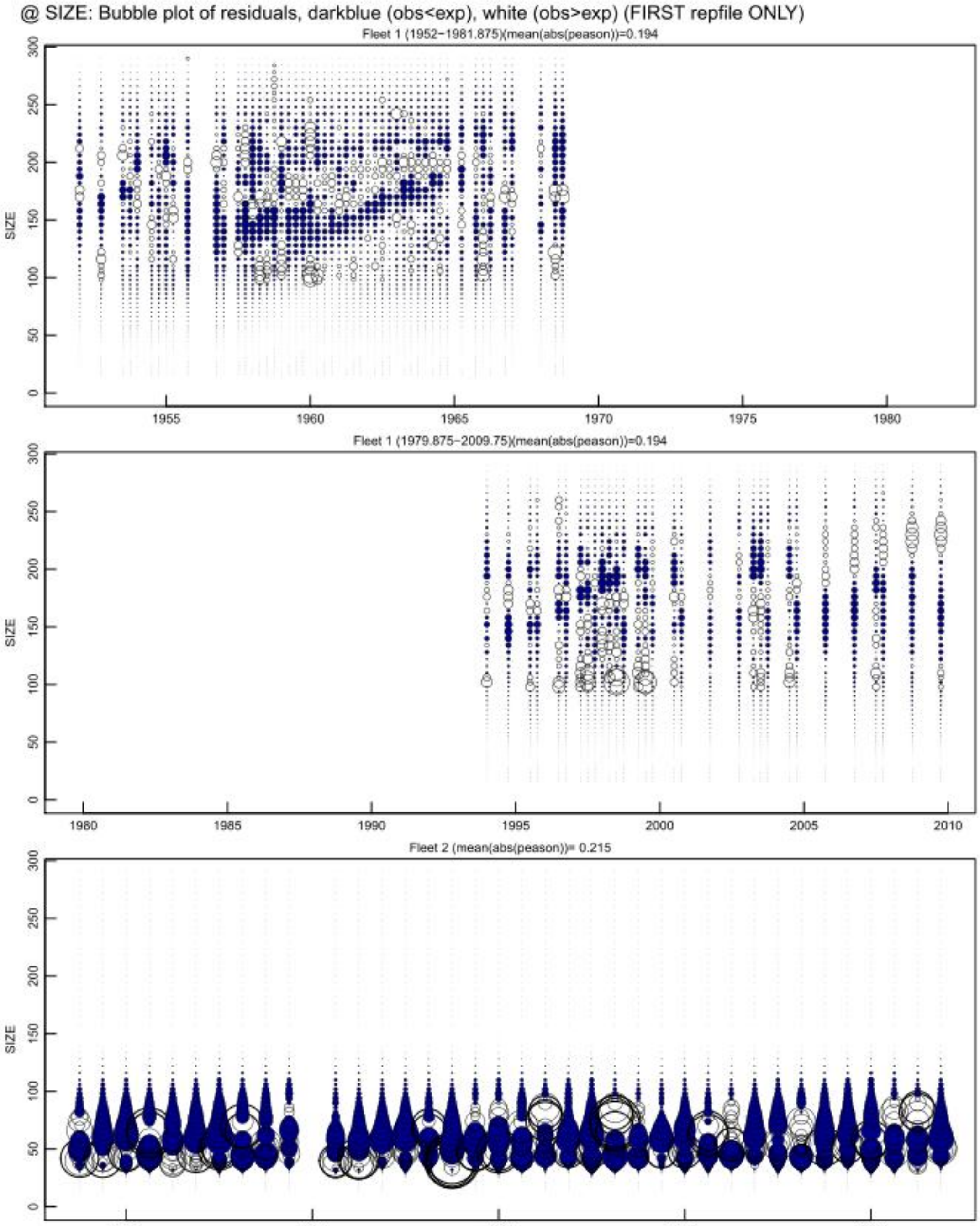


Figure 6. The model fits to the length composition data. Dark blue circle (observation value < expected value), white circle (expected value > observation value)

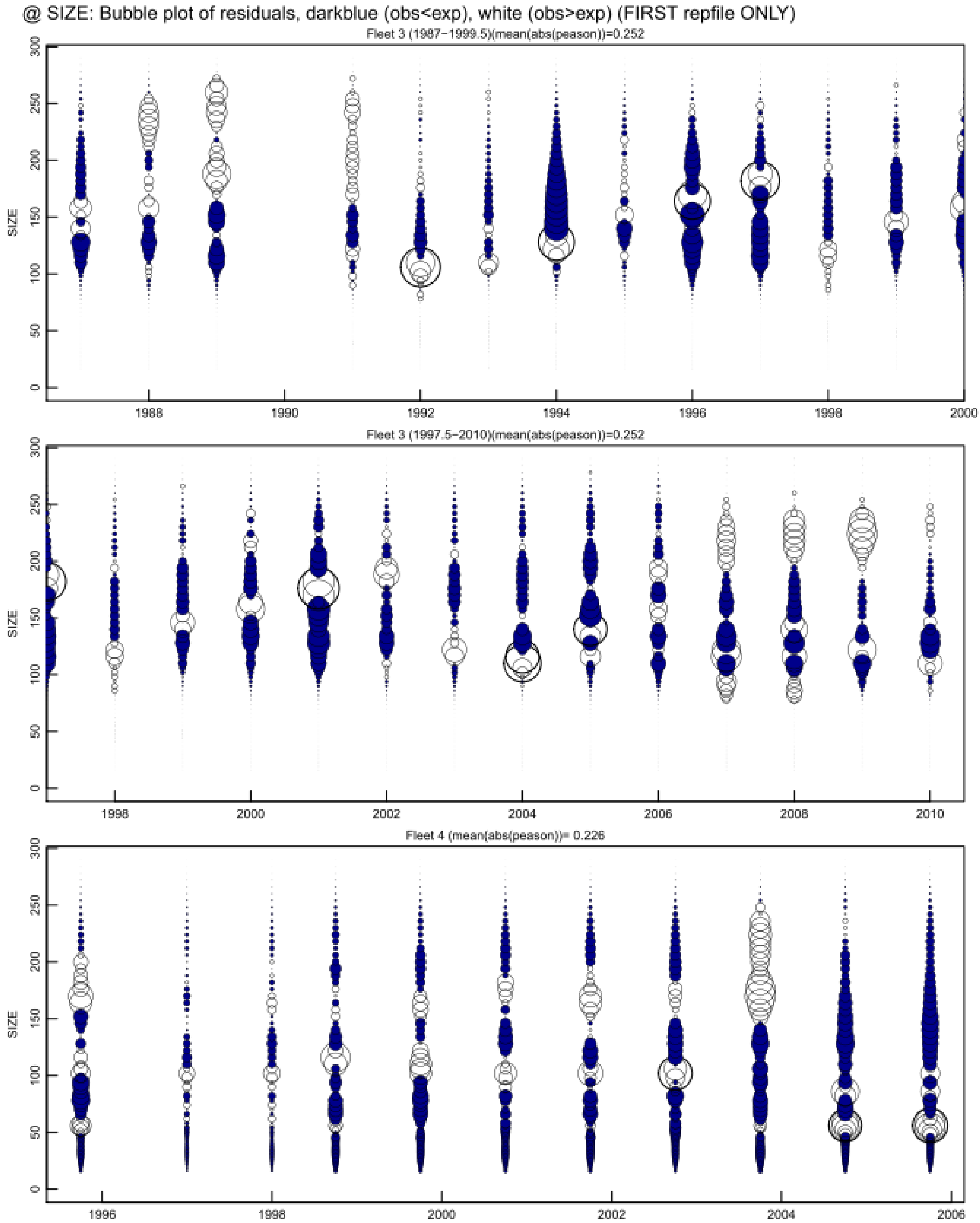


Figure 6 (cont'd). The model fits to the length composition data. Dark blue circle (observation value < expected value), white circle (expected value > observation value).

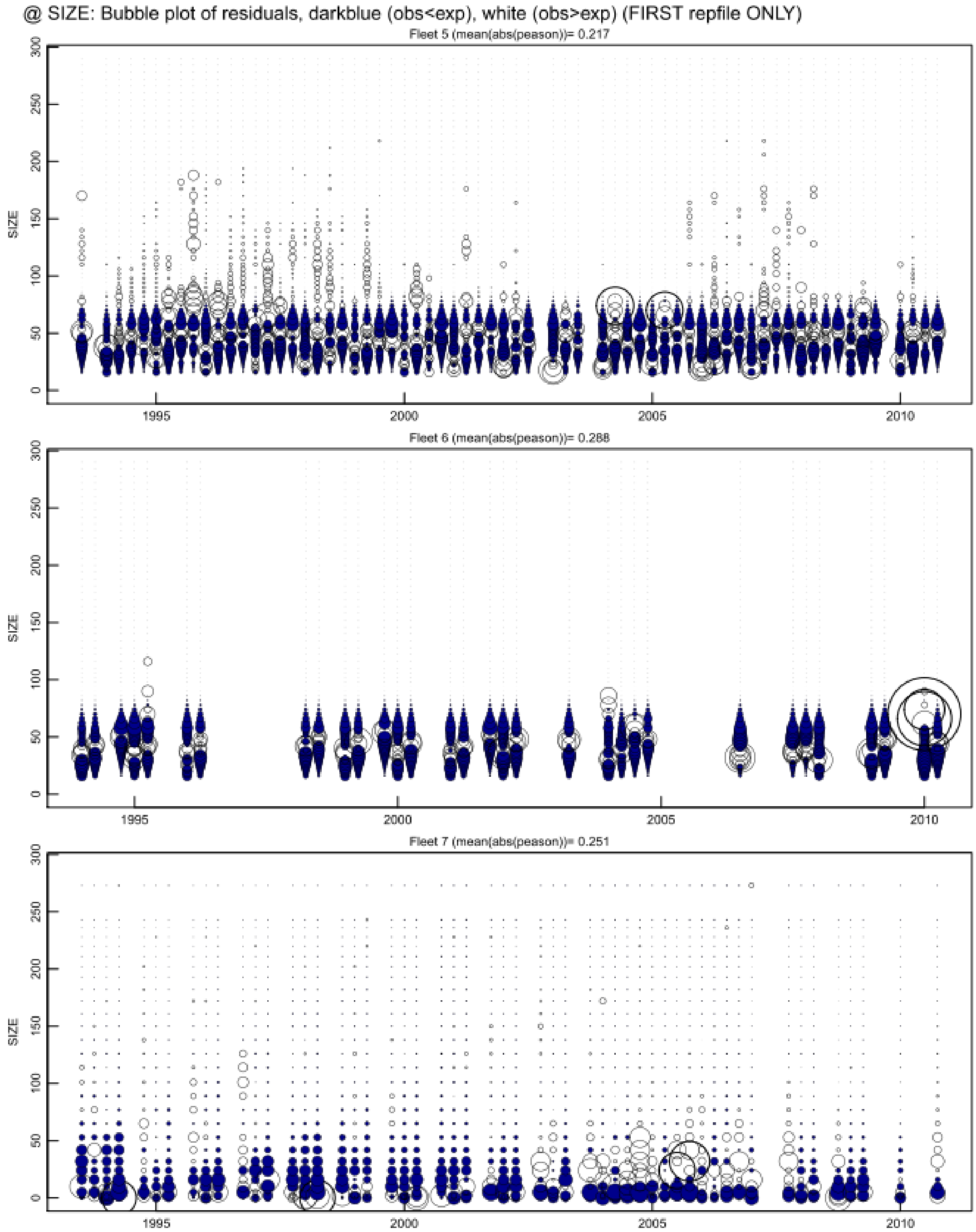


Figure 6 (cont'd). The model fits to the length composition data. Dark blue circle (observation value < expected value), white circle (expected value > observation value).

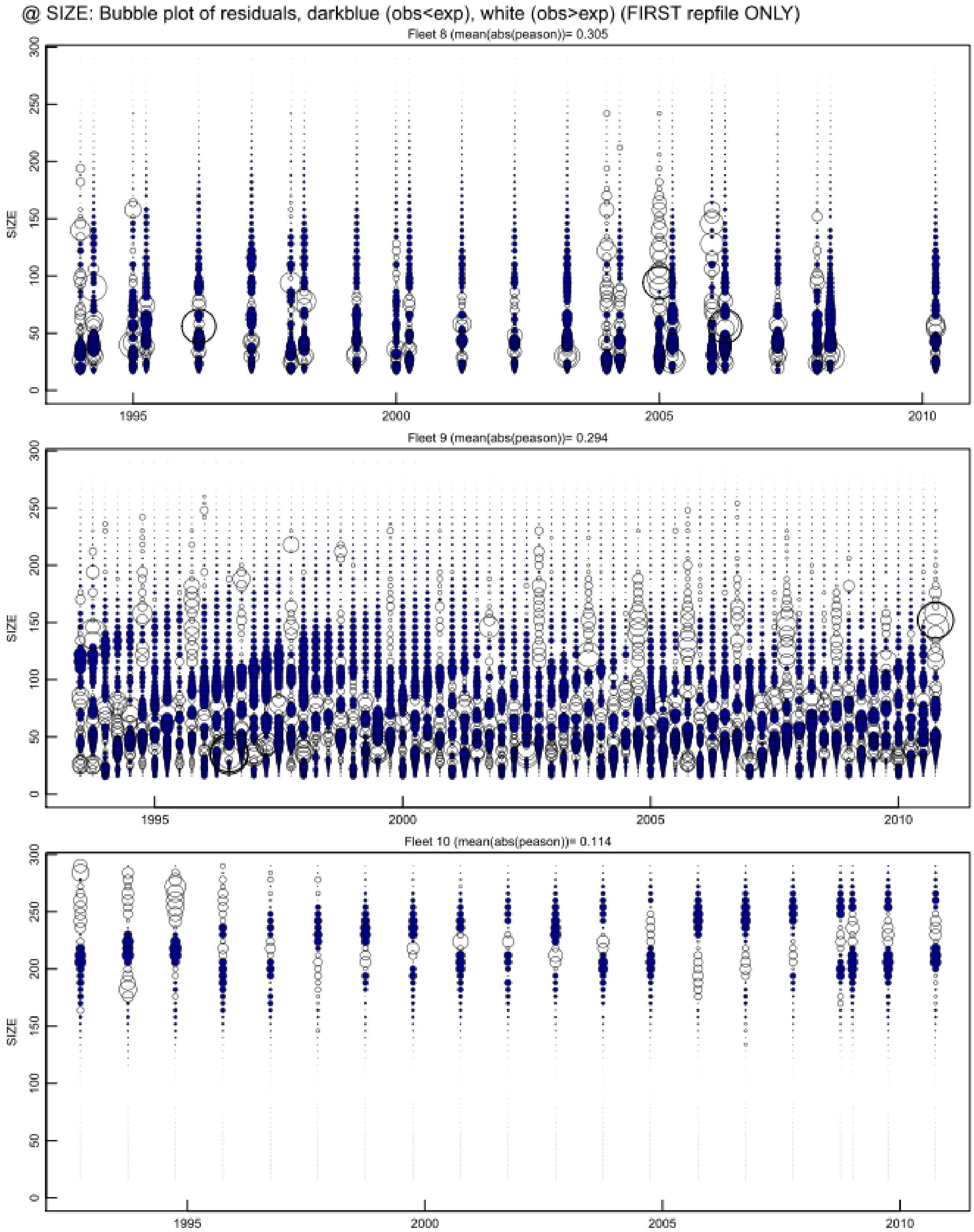


Figure 6 (cont'd). The model fits to the length composition data. Dark blue circle (observation value < expected value), white circle (expected value > observation value).

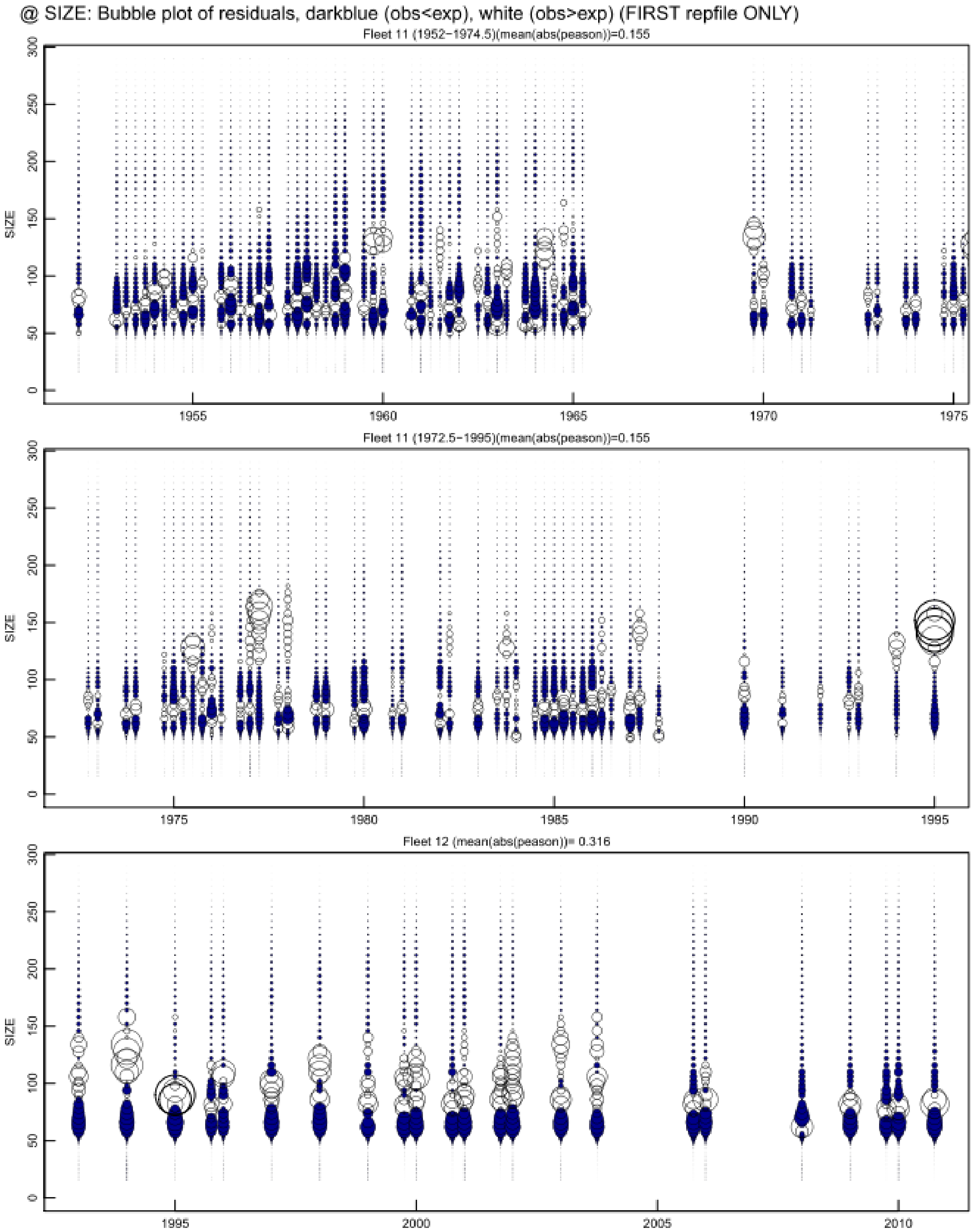


Figure 6 (cont'd). The model fits to the length composition data. Dark blue circle (observation value < expected value), white circle (expected value > observation value).

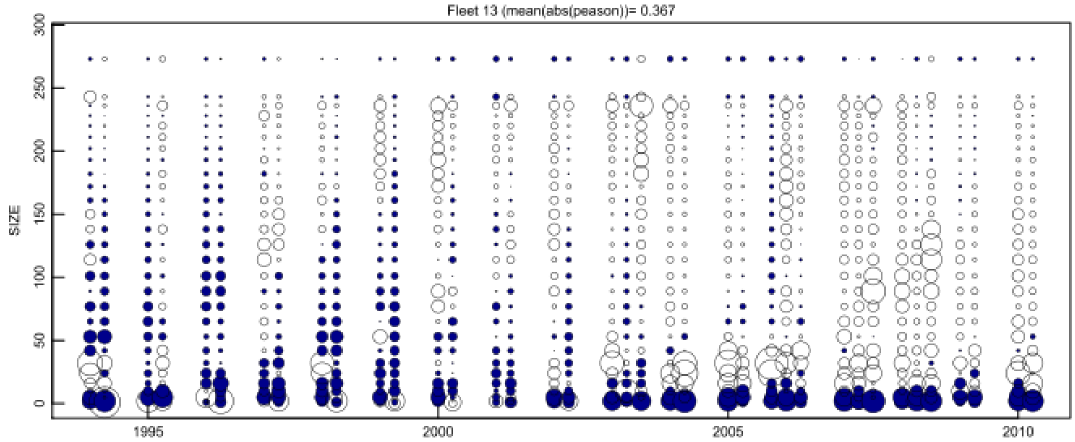


Figure 6 (cont'd). The model fits to the length composition data. Dark blue circle (observation value < expected value), white circle (expected value > observation value).

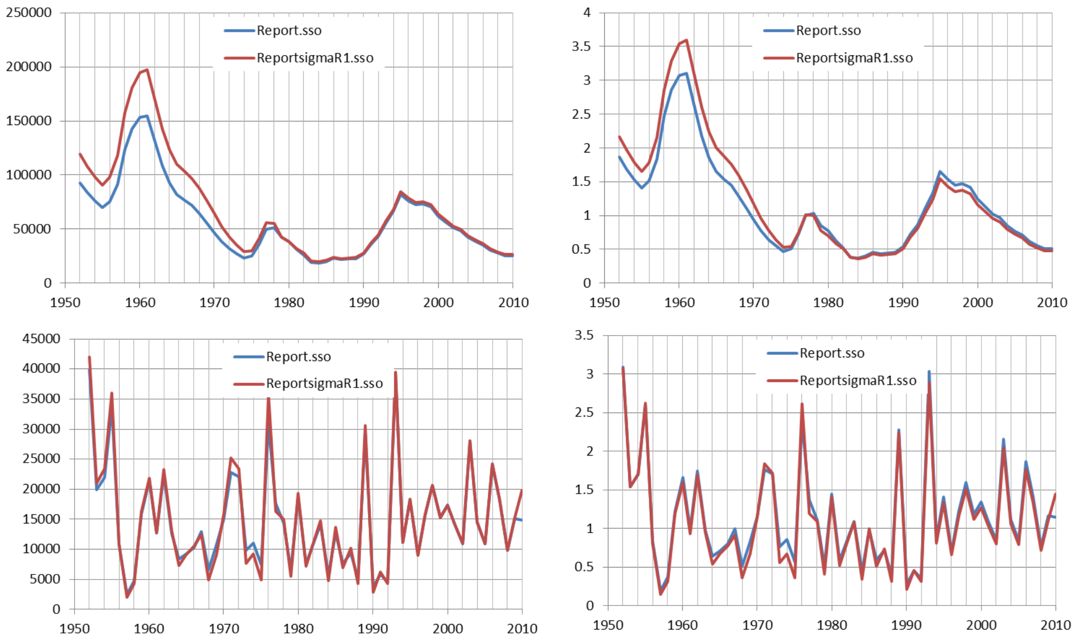


Figure 7. Compare the dynamics of Spawning Stock Biomass (SSB) and recruitment of base case (blue line) and run with sigma R set to be one (red line). (Top: Spawning stock biomass Bottom: Recruitment. left Absolute value, right relative value)

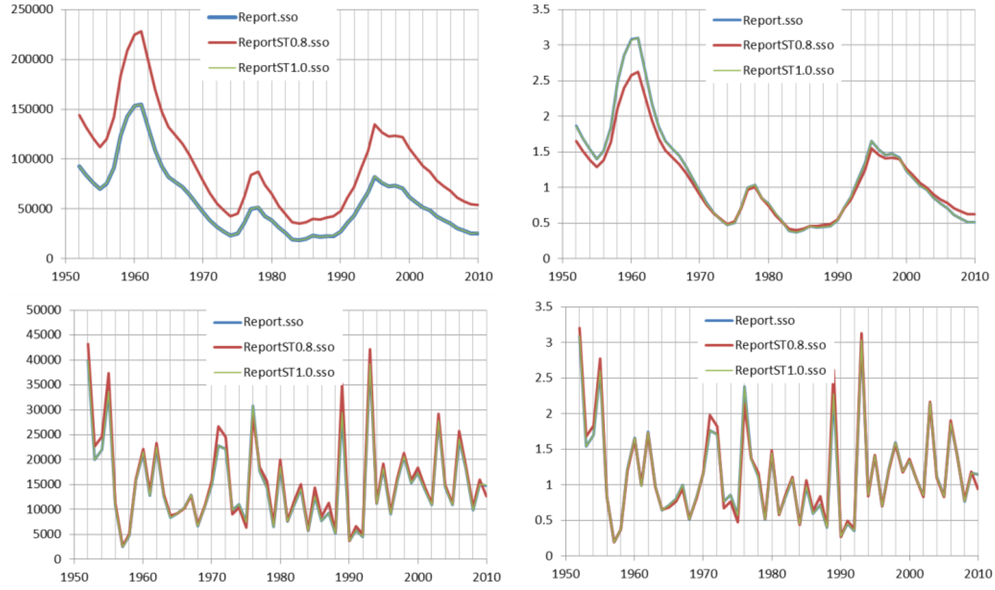


Figure8. Compare the dynamics of Spawning Stock Biomass (SSB) and recruitment of base case (black line), run with steepness0.8 (green line) and run with steepness1.0 (red line). (Top: Spawning stock biomass Bottom: Recruitment.)

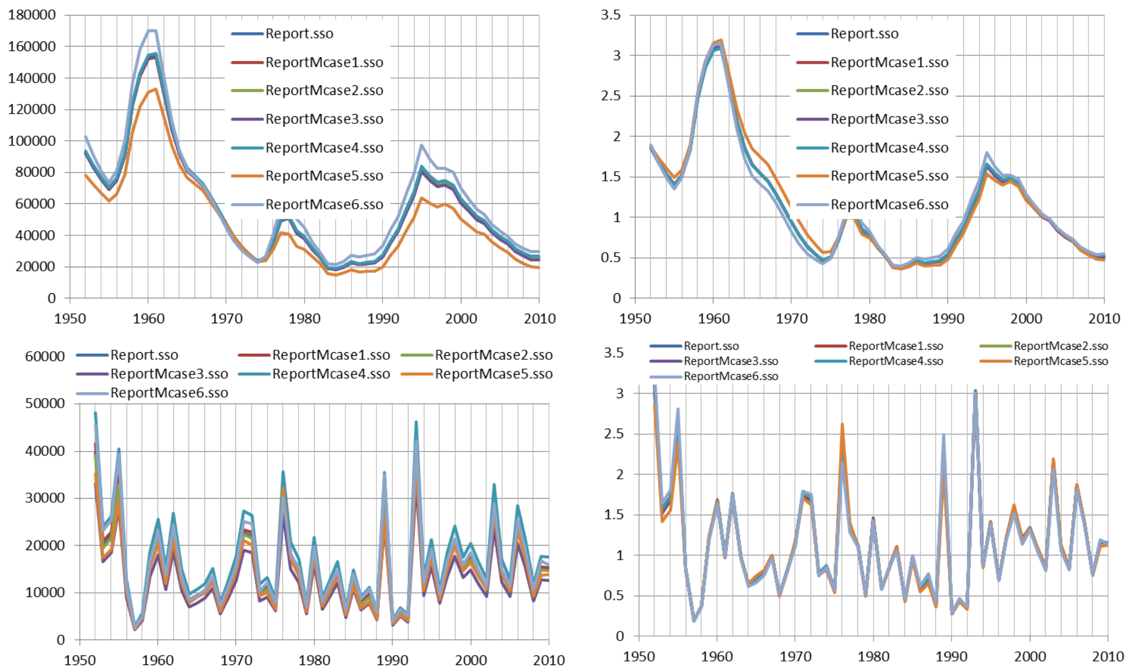


Figure 9. Compare the dynamics of Spawning Stock Biomass (SSB) and recruitment of base case, run for 6 M scenario (see. Table 3). (Top: Spawning stock biomass Bottom: Recruitment.)

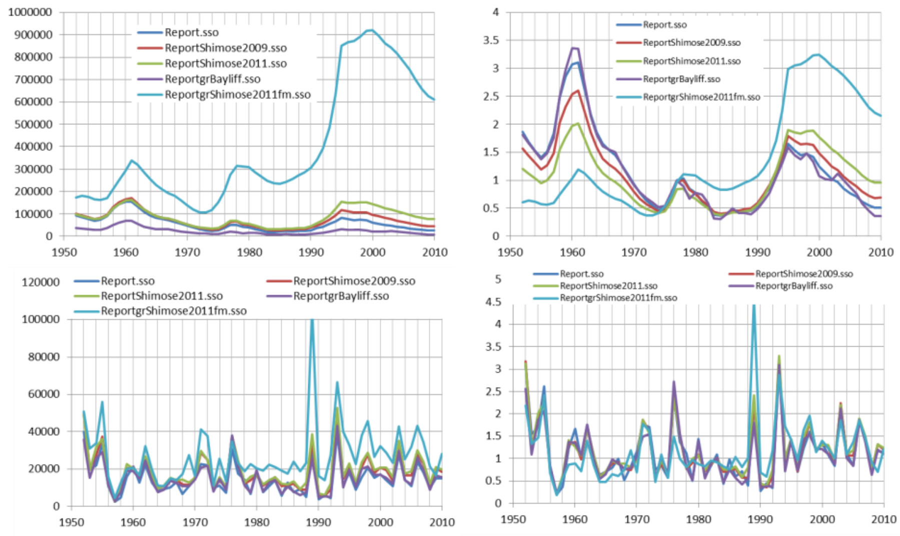


Figure 10. Compare the dynamics of Spawning Stock Biomass (SSB) and recruitment of base case, run using Bayliff's growth curve, run using Shimose (2009)'s growth curve and run using Shimose (2011)'s growth curve. (Top: Spawning stock biomass Bottom: Recruitment.)

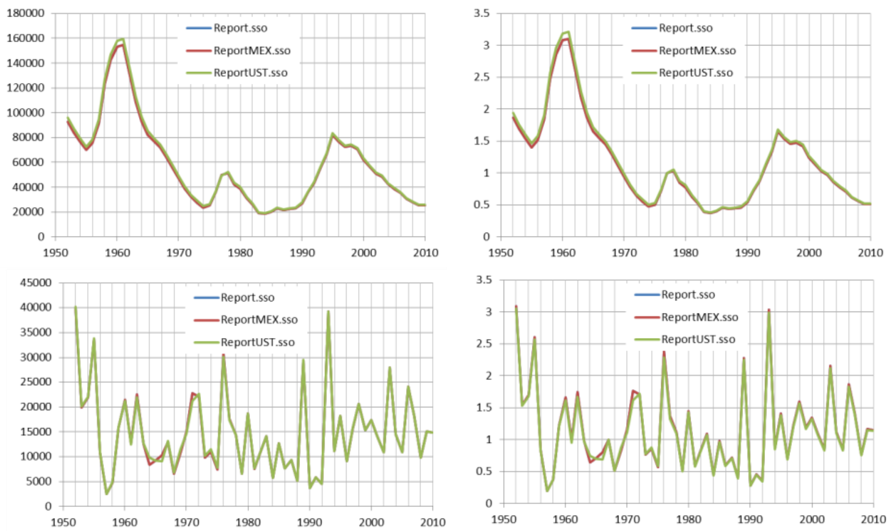
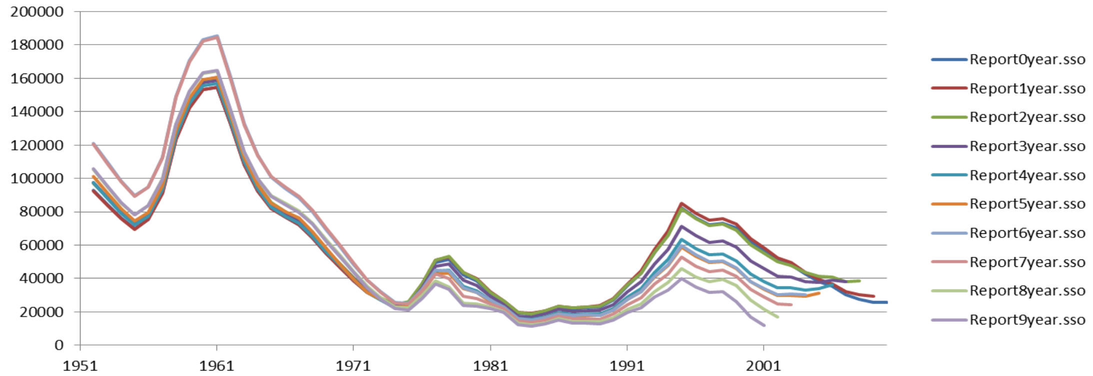
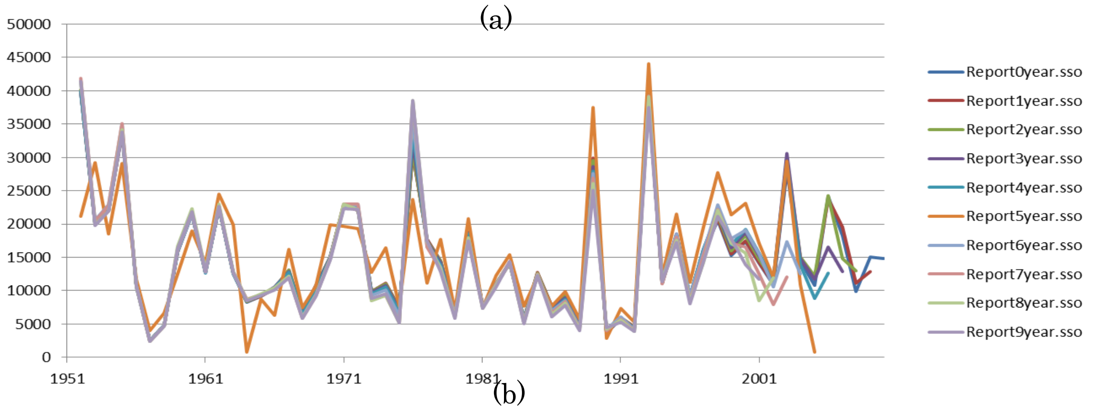


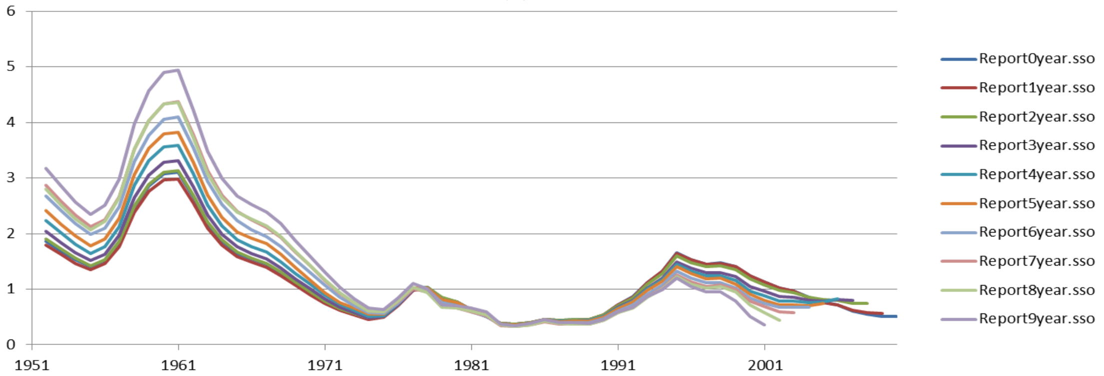
Figure 11. Compare the dynamics of Spawning Stock Biomass (SSB) and recruitment of base case (black line), run using US CPUE (red line), run using MEXICO CPUES (green line). (Top: Spawning stock biomass Bottom: Recruitment.)



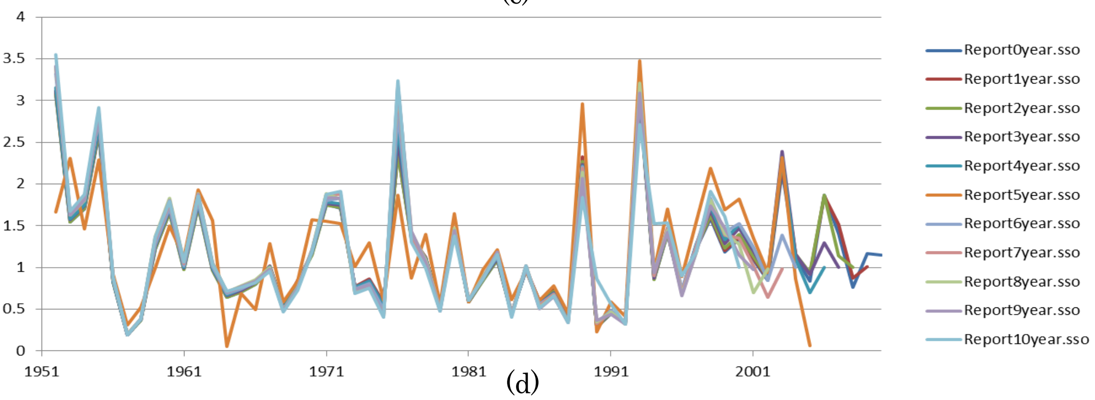
(a)



(b)



(c)



(d)

Figure 12. The result of retrospective analysis (a,c :Spawning stock biomass Bottom: Recruitment. b,d : Absolute value Right : Relative value to the historical median)

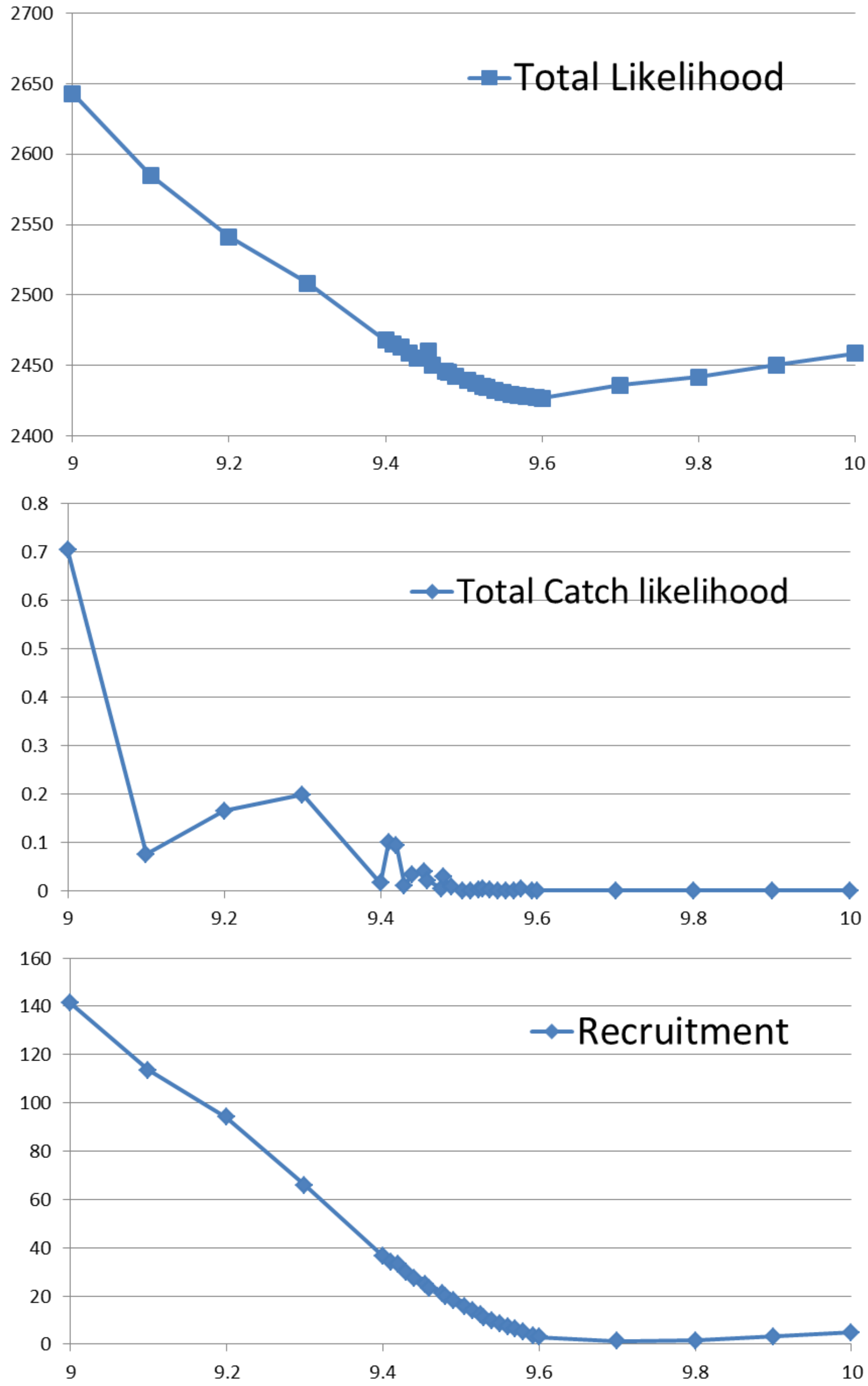


Figure 13. The result of likelihood profile for Total Likelihood, totalcatch Likelihood and Recruitment likelihood for each survey and fleet are shown.

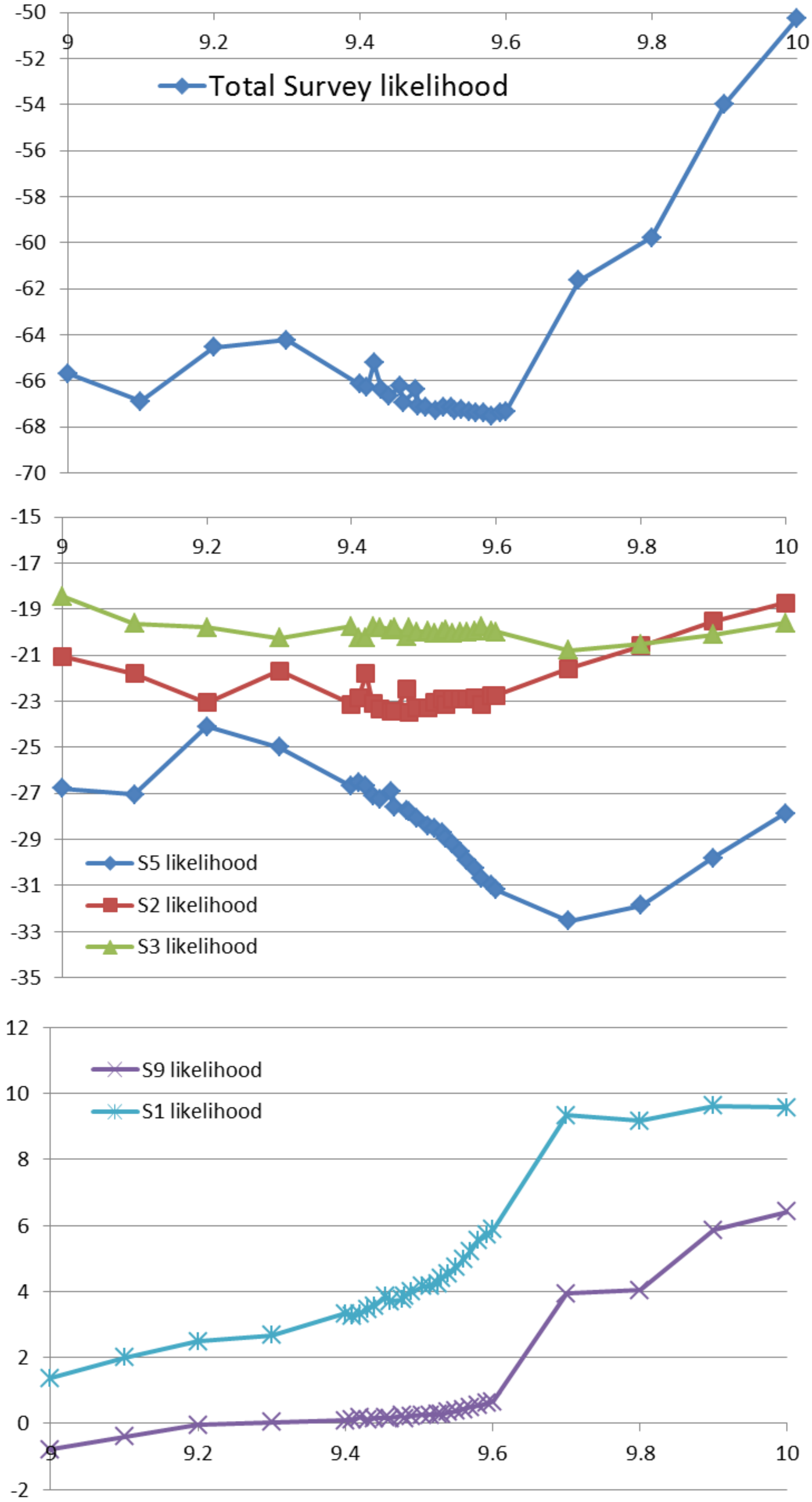


Figure 14. The result of likelihood profile for Survey likelihood and likelihood for each survey are shown.

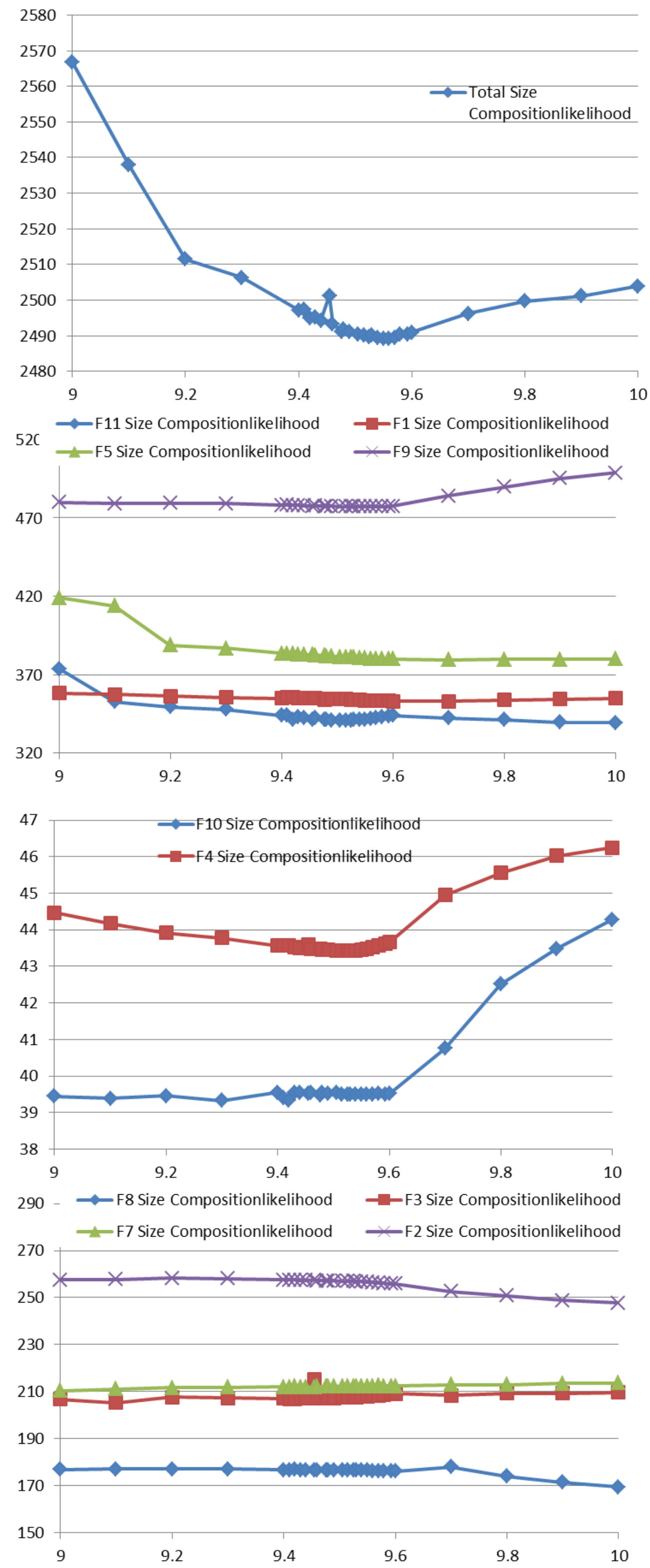


Figure 15. The result of likelihood profile for Size Composition likelihood and likelihood for each fleet are shown.