Annex 9

2016 Pacific Bluefin Tuna Stock Assessment[1]

REPORT OF THE PACIFIC BLUEFIN TUNA WORKING GROUP

International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean

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2016 Pacific Bluefin Tuna Stock Assessment

ISC PBFWG

EXECUTIVE SUMMARY

1. Stock Identification and Distribution

Pacific bluefin tuna (*Thunnus orientalis*) has a single Pacific-wide stock managed by both the Western and Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC). Although found throughout the North Pacific Ocean, spawning grounds are recognized only in the western North Pacific Ocean (WPO). A portion of each cohort makes trans-Pacific migrations from the WPO to the eastern North Pacific Ocean (EPO), spending up to several years of its juvenile life stage in the EPO before returning to the WPO.

2. Catch History

While Pacific bluefin tuna (PBF) catch records prior to 1952 are scant, there are some PBF landings records dating back to 1804 from coastal Japan and to the early 1900s for U.S. fisheries operating in the EPO. Catch of PBF was estimated to be high from 1929 to 1940, with a peak catch of approximately 47,635 t (36,217 t in the WPO and 11,418 t in the EPO) in 1935; thereafter catches of PBF dropped precipitously due to World War II. PBF catches increased significantly in 1949 as Japanese fishing activities expanded across the North Pacific Ocean. By 1952, a more consistent catch reporting process was adopted by most fishing nations. Estimates indicate that annual catches of PBF fluctuated widely from 1952-2014 (Figure 1). During this period reported catches peaked at 40,383 t in 1956 and reached a low of 8,653 t in 1990. While a suite of fishing gears have been used to catch PBF, the majority is currently caught in purse seine fisheries (Figure 2). Catches during 1952-2014 were predominately composed of juvenile PBF, but since the early 1990s, the catch of age 0 PBF has increased significantly (Figure 3).

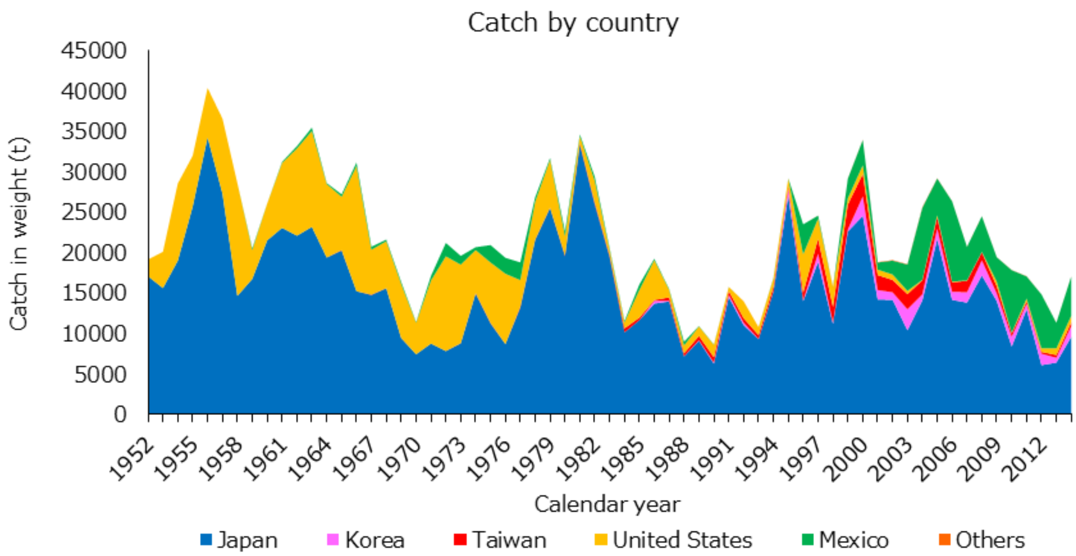


Figure 1. Annual catch of Pacific bluefin tuna (*Thunnus orientalis*) by country from 1952 through 2014 (calendar year).

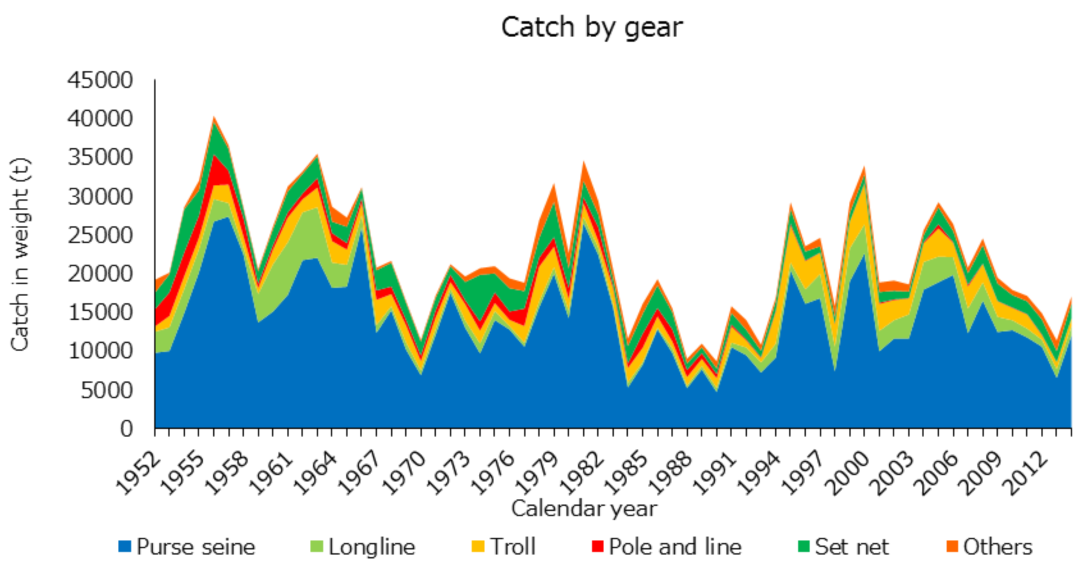


Figure 2. Annual catch of Pacific bluefin tuna (*Thunnus orientalis*) by gear type from 1952 through 2014 (calendar year).

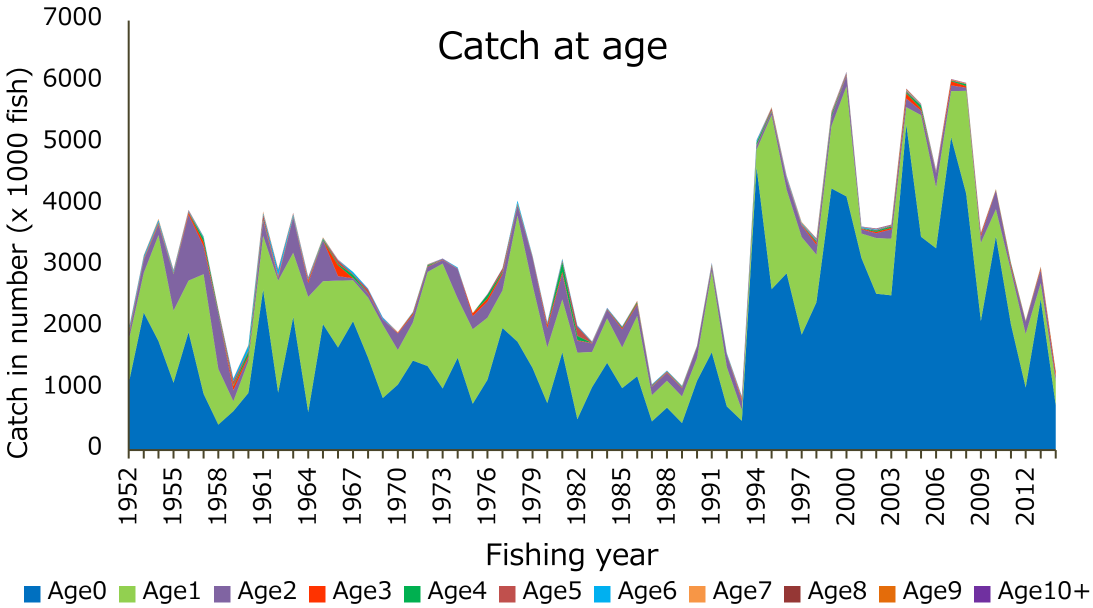


Figure 3. Annual catch-at-age of Pacific bluefin tuna (*Thunnus orientalis*) by fishing year (1952-2014).

3. Data and Assessment

Population dynamics were estimated using a fully integrated age-structured model (Stock Synthesis (SS) v3.24f) fitted to catch, size-composition and catch-per-unit of effort (CPUE) data from 1952 to 2015, provided by Members of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC), Pacific Bluefin Tuna Working Group (PBFWG) and non-ISC countries. Life history parameters included a length-at-age relationship from otolith-derived ages, and natural mortality estimates from a tag-recapture study and empirical-life history methods.

A total of 19 Fleets were defined for use in the stock assessment model based on country/gear/season/region stratification. Quarterly observations of catch and size compositions, when available, were used as inputs to the model to describe the removal processes. Annual estimates of standardized CPUE from the Japanese distant water, off-shore and coastal longline, the Taiwanese longline and the Japanese troll fleets were used as measures of the relative abundance of the population. The assessment model was fitted to the input data in a likelihood-based statistical framework. Maximum likelihood estimates of model parameters, derived outputs and their variances were used to characterize stock status and to develop stock projections.

In the previous assessments, it was found that conflicts existed among data in the model. However, stock biomass trends were consistent among tested model runs and conservation advice based on those results was provided. The 2016 assessment model was developed and refined in the intervening three years based on improvements made by PBFWG scientists. The improvements include: more accurate historical catch data, a better estimate of size composition by fleet, improved standardization of abundance indices, a revised growth curve based on additional otolith information and standardization of aging techniques, and improved model settings to represent the best input data.

4. Stock Status and Conservation Advice accepted at ISC16 Plenary

Stock Status

The PBFWG conducted a benchmark assessment (base-case model) using the best available fisheries and biological information. For data considered reliable, the base-case model fits the data well and is internally consistent among most of the other sources of data. The model is a substantially improved from the 2014 assessment. The base-case model indicates: (1) spawning stock biomass (SSB) fluctuated throughout the assessment period (fishing years 1952-2014) and (2) the SSB steadily declined from 1996 to 2010; and (3) the decline appears to have ceased since 2010, although the stock remains near the historic low. The model diagnostics suggest that the estimated biomass trend for the last 30 years is considered robust although SSB prior to the 1980s is uncertain due to data limitations.

Using the base-case model in the 2016 assessment, the 2014 (terminal year) SSB was estimated to be around 17,000 t (Figure 7-4), which is about 9,000 t below the terminal year estimated in the 2014 assessment (26,000 in 2012). This is because of improvements to the input data and refinements to the assessment model which scaled down the estimated value of SSB, and not because the SSB declined from 2012 to 2014.

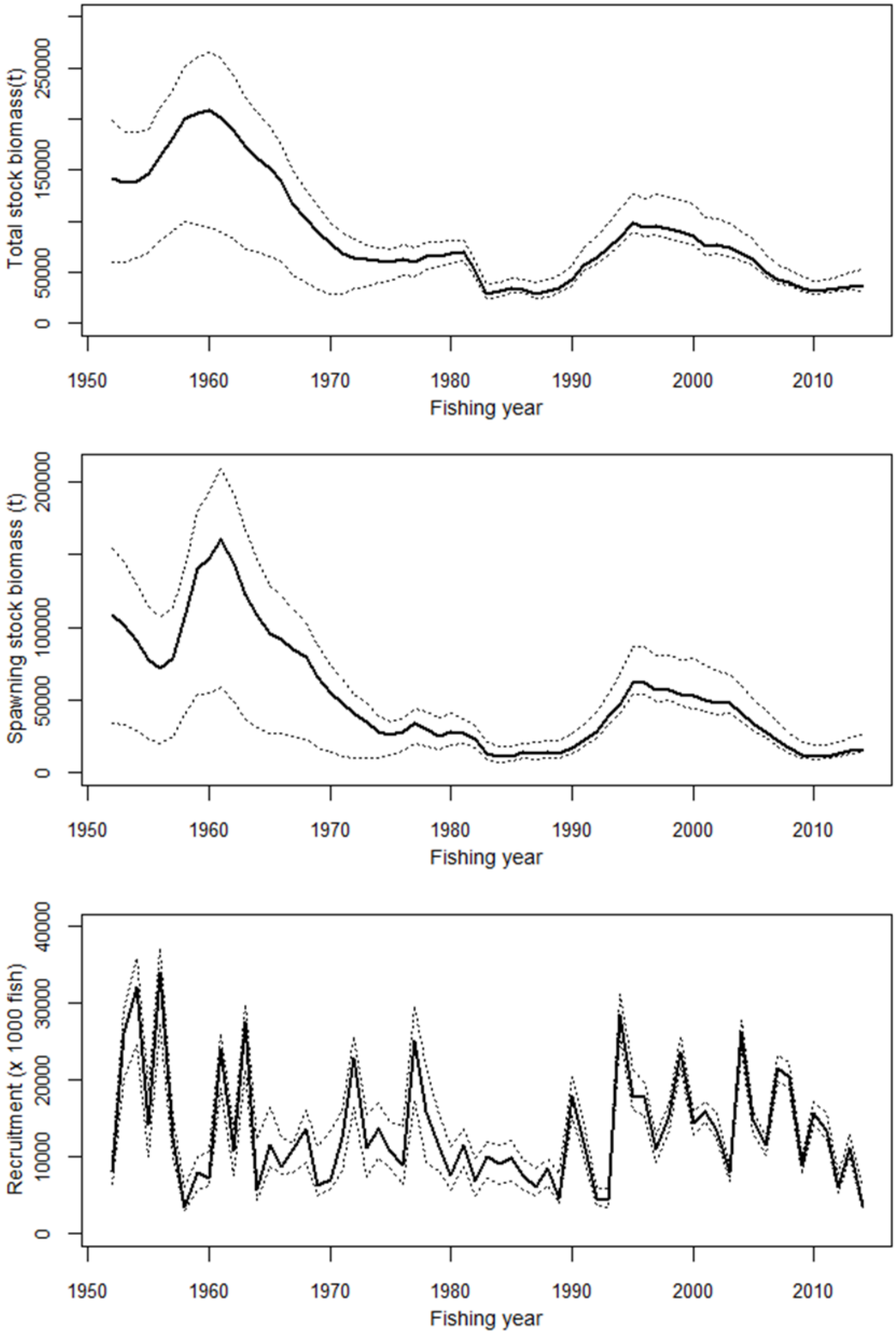


Figure 7-4 Total stock biomass (top), spawning stock biomass (middle) and recruitment (bottom) of PBF from the base-case model. The solid line indicates point estimate and dashed lines indicate the 90% confidence interval.

Recruitment estimates fluctuate widely without an apparent trend. The 2014 recruitment was relatively low, and the average recruitment for the last five years may have been below the historical average level (Figure 7-4). It should be noted that recruitment in terminal years of any assessment are highly uncertain due to limited information on the cohorts and this holds true for the 2016 assessment. However, two of the last three data points from the Japanese troll CPUE-based index of recruitment, which was consistent with other data in the model, are at their lowest level since the start of the index (1980). Estimated age-specific fishing mortalities on the stock during 2011-2013 and 2002-2004 (the base period for WCPFC CMM 2015-04) are presented in Figure 7-5. Most age-specific fishing mortalities (F) for intermediate ages (2-10 years) are substantially above F2002-2004 while those for age 0, as well as ages 11 and above are lower (Table 7-1).

Table 7-1. Percent change of estimated age-specific fishing mortalities of PBF from 2002-2004 to 2011-2013.

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
change from F2002-2004 to F2011-2013	-28%	-1%	+96%	+4%	+86%	+43%	-9%	+81%	+21%	+23%	+5%	-5%	-7%	-8%	-9%	-10%	-10%	-10%	-11%	-11%	-11%

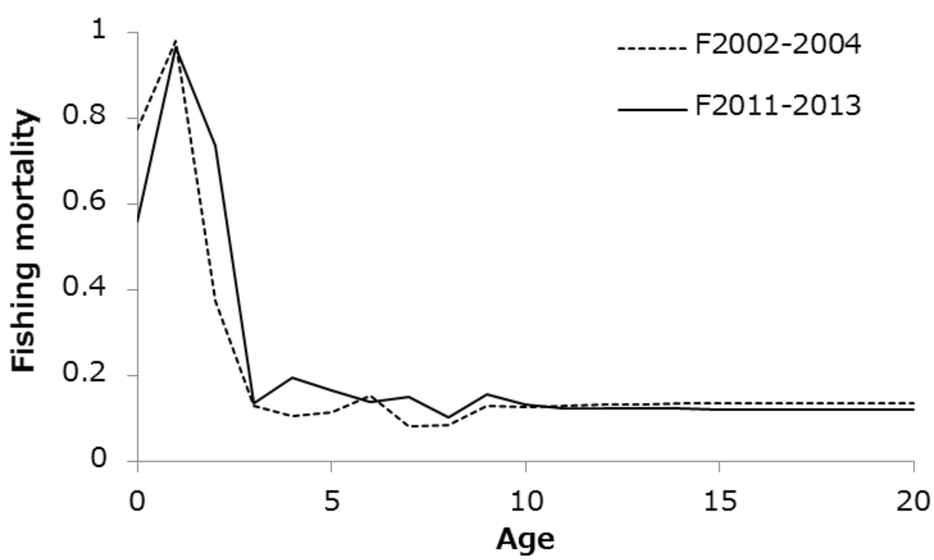


Figure 7-5. Geometric means of annual age-specific (years) fishing mortalities of PBF for 2002-2004 (dashed line) and 2011-2013 (solid line).

Although no limit reference points have been established for the PBF stock under the auspices of the WCPFC and IATTC, the F2011-2013 exceeds all calculated biological reference points except for FMED and FLOSS despite slight reductions to F in recent years

(Table 7-2). The ratio of SSB in 2014 relative to the theoretical unfished[2] SSB (SSB2014/SSBF=0, the depletion ratio) is 2.6%[3] and SSB2012/SSBF=0 is 2.1% indicating a slight increase from 2012 to 2014. Although the SSB2014/SSBF=0 for this assessment (2.6%) is lower than SSB2012/SSBF=0 from the 2014 assessment (4.2%), this difference is due to improvements in the input data and model structure rather than a decline in SSB from 2012 to 2014. Note that potential effects on Fs as a result of the measures of the WCPFC and IATTC starting in 2015 or by other voluntary measures are not yet reflected in the data used in this assessment.

Since no reference points for PBF have yet been agreed to at present, two examples of Kobe plots (Figure 7-6: plot A based on SSBMED and FMED, plot B based on SSB20% and SPR20%) are presented. These versions of the Kobe plot represent two interpretations of stock status in an effort to prompt further discussion. In summary, if these were the reference points, the stock would be approaching overfishing status in the case of FMED and the stock would be considered overfished. Plot B shows that the stock has remained in overfished and being-overfished status for the vast majority of the assessment period if F20% and SSB20% were chosen as reference points. The ISC notes that the SSB estimates before 1980 are more uncertain and that the reason why the fishing mortality is estimated to be so high right after the WWII is not well understood. The low biomass level at the beginning of the assessment period could potentially be the result of relatively high catches prior to the assessment period of PBF.

Table 7-2. Ratios of the estimated fishing mortalities F2002-2004, F2009-2011 and F2011-2013 relative to computed F-based biological reference points and SSB (t) and depletion ratio for the terminal year of the reference period for PBF.

	F_{max}	$F_{0.1}$	F_{med}	F_{loss}	$F_{10\%}$	$F_{20\%}$	$F_{30\%}$	$F_{40\%}$	Estiamted SSB for terminal year of each reference period	Depletion ratio for terminal year of each reference period
2002-2004	1.86	2.59	1.09	0.80	1.31	1.89	2.54	3.34	41,069	0.064
2009-2011	1.99	2.78	1.17	0.85	1.41	2.03	2.72	3.58	11,860	0.018
2011-2013	1.63	2.28	0.96	0.70	1.15	1.66	2.23	2.94	15,703	0.024

[2] "Unfished" refers to what SSB would be had there been no fishing.

[3] The unfished SSB is estimated based upon equilibrium assumptions of no environmental or density-dependent effects.

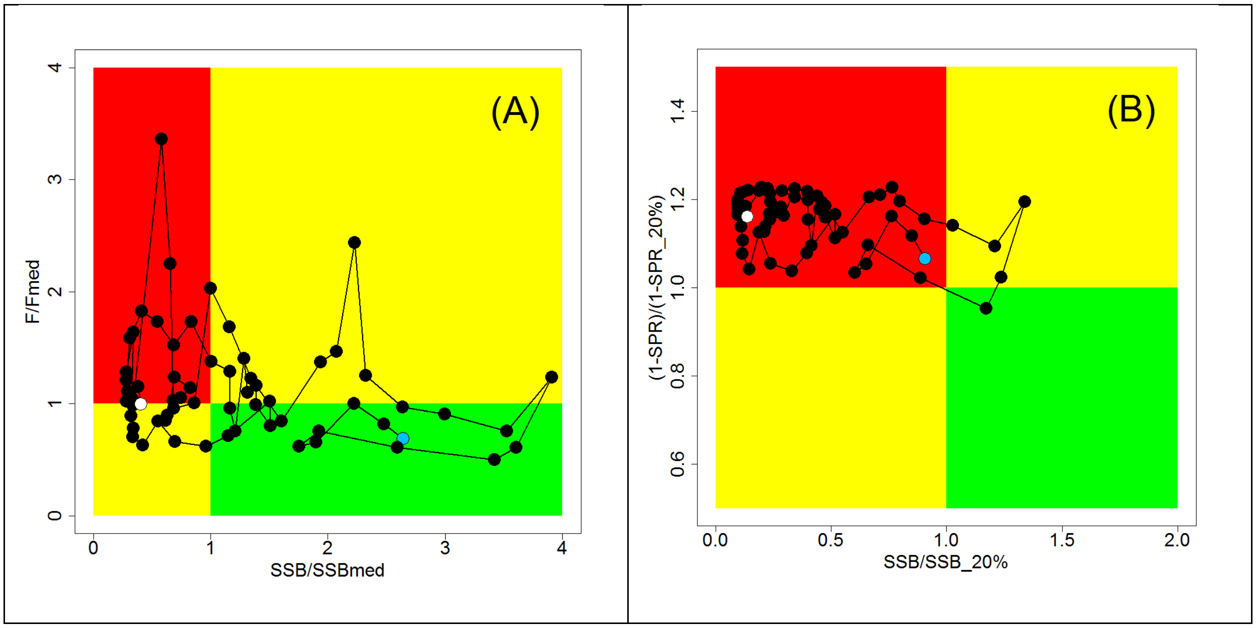


Figure 7-6 Kobe plots for PBF. (A) SSBMED and FMED; (B) SSB20% and SPR20%. Note that SSBMED is estimated as the median of estimated SSB over whole assessment period (40,944 t) and FMED is calculated as an F to provide SSBMED in long-term, while the plots are points of estimates. The blue and white points on the plot show the start (1952) and end (2014) year of the period modeled in the stock assessment, respectively.

Historically, the WPO coastal fisheries group has had the greatest impact on the PBF stock, but since about the early 1990s the WPO purse seine fleets, in particular those targeting small fish (age 0-1), have had a greater impact, and the effect of these fleets in 2014 was greater than any of the other fishery groups. The impact of the EPO fishery was large before the mid-1980s, decreasing significantly thereafter. The WPO longline fleet has had a limited effect on the stock throughout the analysis period (Figure 7-7). This is because the impact of a fishery on a stock depends on both the number and size of the fish caught by each fleet; i.e., catching a high number of smaller juvenile fish can have a greater impact on future spawning stock biomass than catching the same weight of larger mature fish.

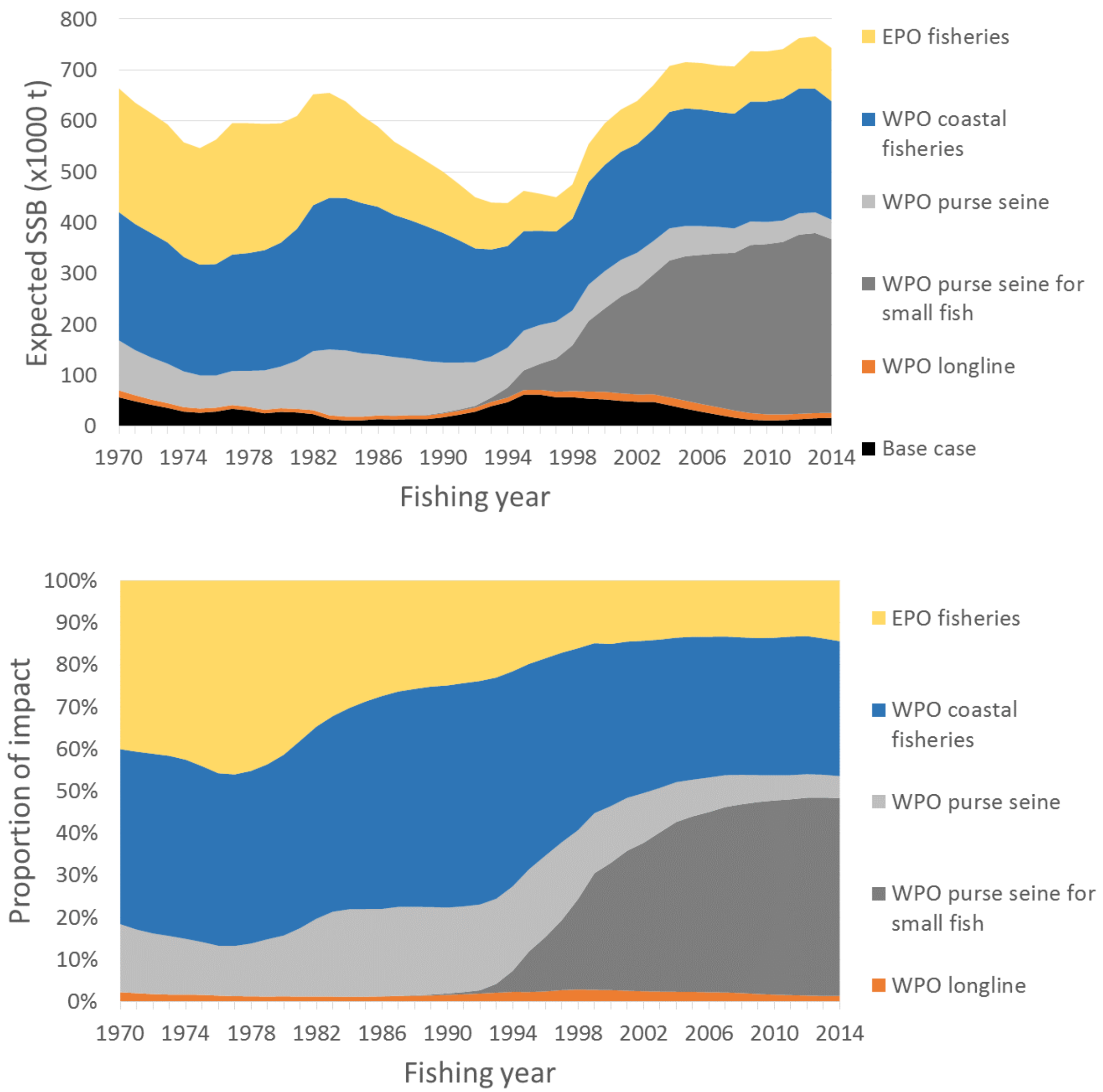


Figure 7-7. Trajectory of the spawning stock biomass of a simulated population of PBF when zero fishing mortality is assumed and recruitment series at F=0 is the same as estimated in the assessment, estimated by the base-case model. (top: absolute impact, bottom: relative impact). Fleet definition; WPO longline: F1, F12, F17. WPO purse seine for small fish: F2, F3, F18. WPO purse seine: F4, F5. WPO coastal fisheries: F6-11, F16, F19. EPO fisheries: F13, F14, F15.

Conservation Advice

The steady decline in SSB from 1996 to 2010 appears to have ceased, although SSB2014 is near the historic low and the stock is experiencing exploitation rates above all calculated biological reference points except for FMED and FLOSS.

The projection results based on the base-case model under several harvest and recruitment scenarios and time schedules are shown in Table 7-3 and Figure 7-8. Under all examined scenarios the initial goal of WCPFC, rebuilding to SSBMED by 2024 with at least 60% probability, is reached and the risk of SSB falling below SSBLOSS at least once in 10 years was low.

The projection results indicate that the probability of SSB recovering to the initial WCPFC target (SSBMED by 2024, 38,000 t, calculated in the same manner as the previous assessment) is 69% or above the level prescribed in the WCPFC CMM if low recruitment scenario is assumed and WCPFC CMM 2015-04 and IATTC Resolution C-14-06 continue in force and are fully implemented (Table 4: Scenario 2 with low recruitment).

The ISC notes that there are technical inconsistencies in the calculation of SSBMED in the assessment and projection. The ISC also notes that the current calculation of SSBMED in the projection incorporates the most recent estimates of SSB and unless a fixed period of years is specified to calculate SSBMED, its calculation (SSBMED) could be influenced by future trends in spawning biomass. The ISC therefore recommends defining SSBMED as the median point estimate for a fixed period of time, either, 1952-2012 or 1952-2014. If 1952-2012 is chosen, then SSBMED is estimated to be 41,069 t, and if 1952-2014 is chosen, SSBMED is 40,994 t. The probabilities of achieving 41,000 t under various scenarios are provided in Table 7-3. The probabilities of achieving 43,000 t, where WCPFC CMM2015-04's initial rebuilding target is specified as 42,592 t, are also provided in Table 7 3, although this value is derived from the previous assessment and is higher than the SSBMED calculated in the current assessment. The ISC recommends that in the future absolute values should not be used for the initial rebuilding target, as the calculated values of reference points would change from assessment to assessment.

Scenario 2 with low recruitment has the lowest prospect of recovery among the examined harvest scenarios. The probability of achieving the WCPFC's initial target (SSBMED by 2024) would increase if more conservative management measures were implemented as shown in Table 7-3 and Figure 7-8. The projection results indicate that a 10% reduction in the catch limit for fish smaller than the weight threshold in CMM 2015-04 would have a larger effect on recovery than a 10% reduction in the catch limit for fish larger than the weight threshold. (Figure 7-8 (D)). The ISC further notes that the current assessment model uses a maturity ogive that assumes 20%, 50% and 100% maturity in age 3 (weight on July 1: 34kg), 4 (weight on July 1: 58kg) and 5 (weight on July 1: 85kg), respectively, while the WCPFC CMM 2015-04 specifies that catches of fish smaller than 30kg should be reduced. The weight threshold in the CMM needs to be increased to 85kg (weight of age 5) if the intent is to reduce catches on all juveniles according to the maturity ogive in the assessment.

The projections results assuming a stronger stock-recruitment relationship (where h=0.9) than in the assessment model (0.999) are not necessarily more pessimistic than the low recruitment scenario.

The projection results assume that the CMMs are fully implemented and are based on certain biological or other assumptions. In particular, the ISC noted the implementation of size based management measures need to be monitored carefully. If conditions change, the projection results would be more uncertain. Given the low SSB, the uncertainty in future recruitment, and the influence of recruitment has on stock biomass, monitoring recruitment and SSB should be strengthened so that the recruitment trends can be understood in a timely manner.

Harvesting Scenario #	Fishing mortality	Catch limit *		Threshold of Small/Large	Recruitment scenario **	Probability that SSB exceeds 38,000 tons (SSB median of Bootstrap analysis runs)			Probability that SSB exceeds 41,000 tons (SSB median of Basecase model) ***			Probability that SSB is more than 43,000 tons (SSBmed@last assessment)			Probability that SSB is more than 10%SSB0			Probability that SSB is more than 20%SSB0			Average Catch	
		Small	Large			2024	2029	2034	2024	2029	2034	2024	2029	2034	2024	2029	2034	2024	2029	2034	2019	2024
Scenario1	F2002-2004	scenario 6 in 2014 assessment		30 kg	Low recruitment	77.0%	88.8%	89.9%	69.7%	83.3%	85.2%	64.3%	79.3%	81.9%	14.7%	28.0%	31.8%	0.0%	0.0%	0.1%	11619.2	13574.9
Scenario2		50% of 2002-2004 average catch for WPO fisheries 3,300 tons for EPO commercial fisheries	2002-2004 average catch for WPO fisheries		Low recruitment	69.3%	83.7%	86.6%	61.5%	77.8%	82.3%	56.1%	73.9%	79.0%	13.6%	29.3%	35.4%	0.1%	0.4%	0.6%	11749.7	12994.2
					Average recruitment	99.6%	100%	100%	99.3%	100%	100%	99.3%	100%	100%	96.3%	99.8%	100%	73.8%	95.0%	98.0%	12958.4	14750.8
					Stock Recruit Relationship w/ h=0.9	98.2%	99.8%	99.9%	97.7%	99.8%	99.9%	97.5%	99.7%	99.9%	93.5%	99.4%	99.9%	72.0%	97.3%	99.6%	13087.3	15020.1
Scenario3		50% of 2002-2004 average catch		50 kg	Low recruitment	80.5%	91.5%	94.0%	73.8%	87.9%	90.7%	69.1%	85.1%	88.5%	22.2%	43.6%	51.7%	0.2%	0.9%	1.3%	11404.4	12672.3
Scenario4				80 kg	Low recruitment	86.4%	94.6%	96.5%	80.6%	91.9%	94.7%	76.6%	90.0%	93.0%	27.8%	51.8%	61.3%	0.2%	1.1%	1.6%	11292.6	12542.7
Scenario5		90% of scenario 2	same as Scenario 2	30 kg	Low recruitment	90.0%	96.5%	98.1%	85.3%	94.8%	97.0%	81.5%	93.4%	95.9%	35.0%	61.7%	70.4%	0.3%	2.5%	3.7%	11306.4	12881.3
					Average recruitment	99.9%	100%	100%	99.9%	100%	100%	99.9%	100%	100%	98.4%	100%	100%	82.2%	97.8%	99.3%	12442.0	14126.3
					Stock Recruit Relationship w/ h=0.9	99.4%	100%	100%	99.2%	100%	100%	99.1%	100%	100%	97.0%	99.8%	100%	81.8%	99.0%	99.9%	12576.4	14448.2
Scenario6		same as Scenario 2	90% of scenario 2		Low recruitment	75.3%	88.2%	90.2%	67.2%	82.9%	86.5%	61.7%	78.6%	83.4%	15.7%	32.5%	38.7%	0.1%	0.5%	0.7%	11496.2	12632.4
					Average recruitment	99.7%	100%	100%	99.6%	100%	100%	99.5%	100%	100%	96.8%	99.9%	100%	73.1%	95.2%	98.1%	12686.3	14071.5
					Stock Recruit Relationship w/ h=0.9	98.9%	99.9%	100%	98.6%	99.9%	100%	98.4%	99.9%	100%	95.0%	99.7%	100%	75.5%	98.0%	99.9%	12761.0	14379.7
Scenario7		90% of scenario 2			Low recruitment	90.3%	96.8%	98.3%	86.2%	95.4%	97.6%	82.7%	94.2%	96.8%	39.4%	68.0%	77.4%	0.5%	3.5%	5.6%	11231.0	12607.1
					Average recruitment	99.9%	100%	100%	99.9%	100%	100%	99.9%	100%	100%	98.5%	100%	100%	83.5%	98.1%	99.6%	12139.4	13461.7
					Stock Recruit Relationship w/ h=0.9	99.2%	100%	100%	99.1%	100%	100%	99.0%	99.9%	100%	96.9%	99.8%	100%	81.6%	99.0%	99.9%	11227.3	12461.8
Scenario8		80% of scenario 2	same as Scenario 2		Low recruitment	97.5%	99.6%	99.9%	96.1%	99.3%	99.7%	94.8%	98.9%	99.5%	65.4%	89.2%	94.0%	1.9%	14.5%	22.8%	10922.8	12688.4
Scenario9		same as Scenario 2	80% of scenario 2		Low recruitment	78.1%	89.9%	92.5%	70.4%	85.6%	88.8%	65.0%	81.9%	86.3%	18.4%	37.1%	44.7%	0.2%	0.6%	0.9%	11327.0	12329.9
Scenario10		80% of scenario 2			Low recruitment	98.3%	99.8%	99.9%	97.4%	99.6%	99.9%	96.3%	99.5%	99.8%	73.2%	93.8%	97.5%	3.1%	22.4%	34.1%	10585.9	11586.4
					Average recruitment	100%	100%	100%	100%	100%	100%	100%	100%	100%	99.7%	100%	100%	91.0%	99.5%	100%	11194.1	12104.9
					Stock Recruit Relationship w/ h=0.9	99.8%	100%	100%	99.7%	100%	100%	99.7%	100%	100%	98.7%	100%	100%	90.0%	99.7%	100%	11227.3	12461.8
Scenario11	F2011-2013	same as Scenario 2	same as Scenario 2		Low recruitment	82.6%	93.0%	95.0%	75.9%	89.9%	92.1%	71.3%	86.4%	89.9%	23.6%	46.2%	56.0%	0.1%	1.2%	1.6%	12266.8	13587.4

Table 7 3. Future projection scenarios for PBF and their probability of achieving various target levels by various time schedules based on the base-case model.

* Catch limits for EPO commercial fisheries is applied for all the catch (small and large fish) made by the Fleets.
** Average recruitment refers to the recruitment for the whole assessment period while low recruitment refers to that of 1980-1989.
*** Probability that SSB exceeds 41,000 tons (SSB median of Basecase model) developed by PBFWG at ISC16 Plenary.

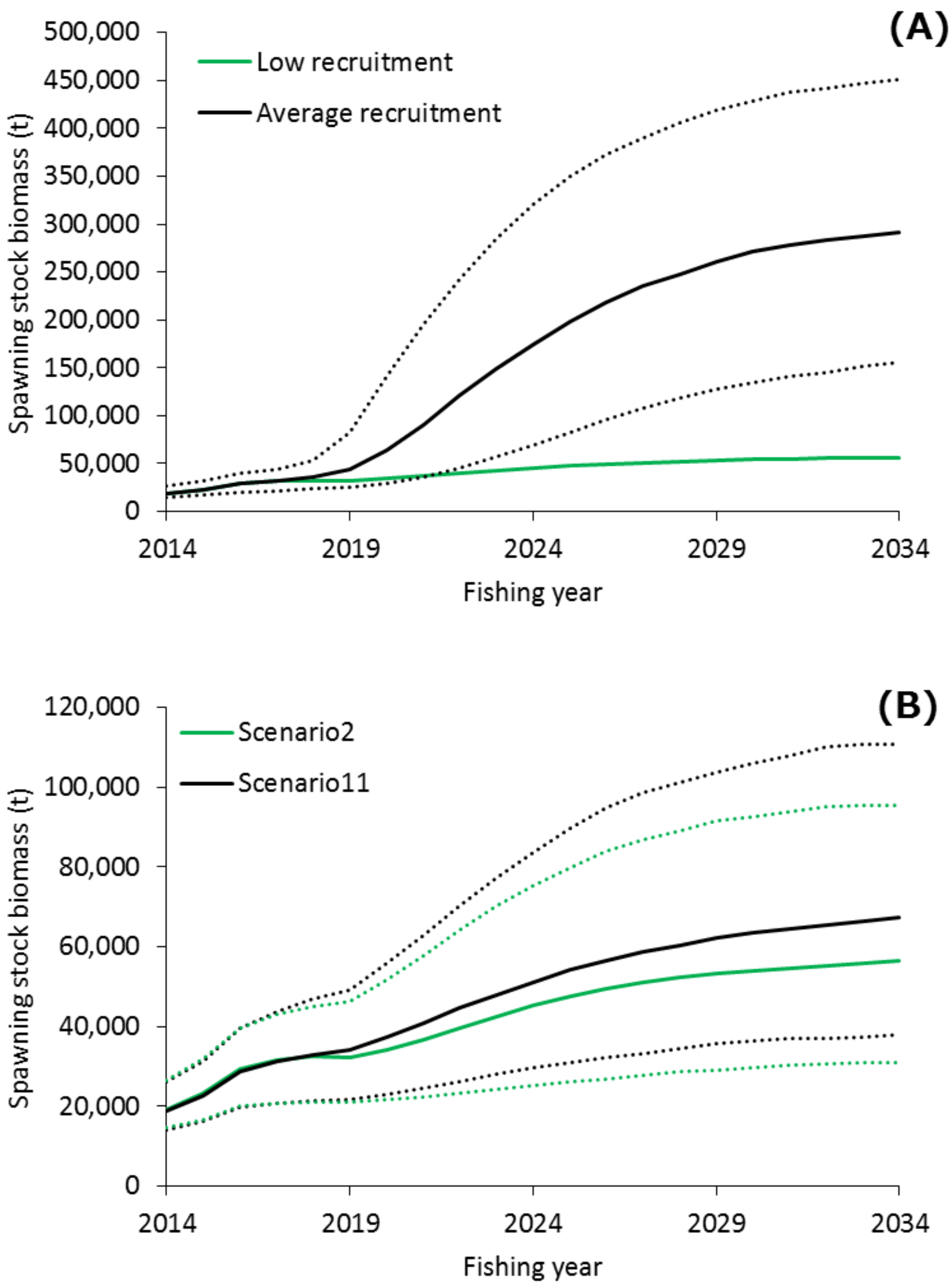


Figure 7-8. Comparisons of various projection results for PBF. (A) low recruitment vs. historical average recruitment (Scenario 2). (B) current CMMs (Scenario 2) vs. current F (Scenario 11) (low recruitment). The solid lines indicate median of bootstrapped projection results and dotted lines indicate 90% confidence interval.

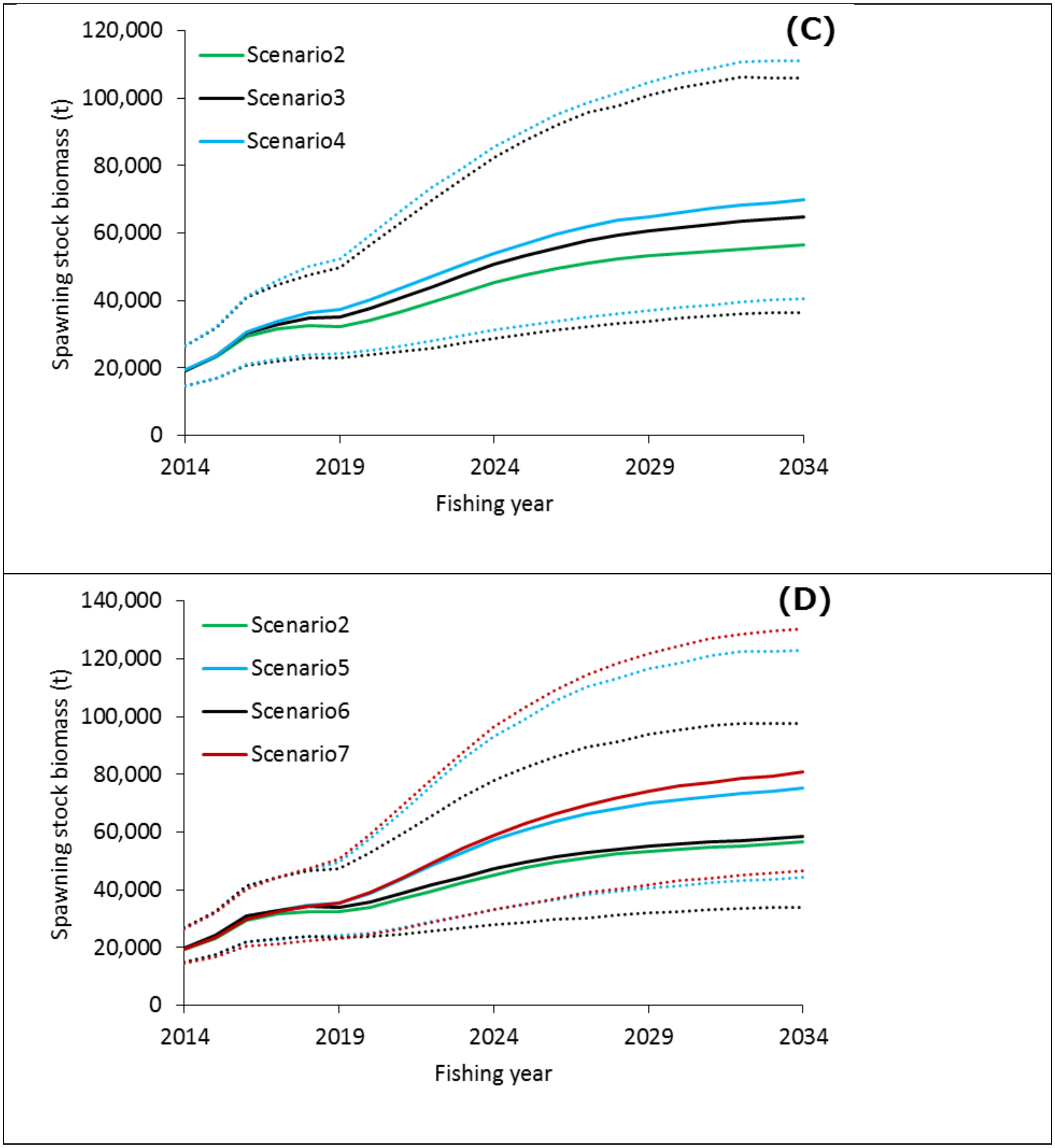


Figure 7-8 (cont.) Comparisons of various projection results for PBF. (C) different definition of small fish (30kg (Scenario 2) vs. 50kg (Scenario 3) vs. 80kg (Scenario 4)) (low recruitment). (D) current CMMs (Scenario 2) vs. additional 10% catch limit reduction for small fish (Scenario 5), for large fish (Scenario 6) and for all fish (Scenario 7) (low recruitment). The solid lines indicate median of bootstrapped projection results and dotted lines indicate 90% confidence interval.

1.0 INTRODUCTION

Pacific bluefin tuna (*Thunnus orientalis*) (PBF) is a highly migratory species of great economic importance found primarily in the North Pacific Ocean. The PBF Working Group (PBFWG) of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) established in 1996 has been tasked with conducting regular stock assessments to assemble fishery statistics and biological information, estimate population parameters, summarize stock status, and develop conservation advice. The results are submitted to Pacific tuna regional fisheries management organizations (RFMOs), in particular the Western Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC) for review and used as basis of management actions (the Conservation and Management Measures (CMMs) of WCPFC and IATTC resolutions).

The PBFWG completed the last stock assessment in 2014 using fishery data from 1952 through 2012 (ISC 2014) and concluded that the terminal biomass were at or near historical low and stock experienced high exploitation rates. Based on the results, the WCPFC and the IATTC both amended their management measures in 2014, which became effective in 2015 (WCPFC CMM 2014-04 and IATTC Resolution C-14-06).

In the years since the last assessment, there have been considerable advances in knowledge of growth curve based on additional otolith information and ageing techniques (Shimose and Takeuchi 2012, Shimose and Ishihara 2015, Fukuda et al. 2015b), fishery data (Oshima et al. 2014, Sakai et al. 2016), developing abundance indices, and modeling selectivity to deal with age-based availability due to movement and length-based selectivity due to gear contact (Lee et al. 2015a, Lee et al. 2016). These advances were incorporated into 2016 assessment model.

The 2016 assessment of Pacific bluefin tuna was conducted during 29 February - 11 March at the Southwest Fisheries Science Center, La Jolla, USA. This report presents the assessment results using updated seasonal fishery data through 2015 in an annual time-step length-based, age-structured, and forward-simulation population model.

In this report, “years” denotes fishing years unless otherwise specified. A fishing year starts on 1 July and ends on the following 30 June, and 1 July is also assumed to be the date of birth for PBF in the models. Thus, the 2014 fishing year corresponds to 1 July 2014 to 30 June 2015. Relationships between calendar year, fishing year, and year class are shown in Table 1-1.

2.0 BACKGROUND ON BIOLOGY, FISHERIES AND PREVIOUS ASSESSMENT

2.1 Biology

2.1.1 Stock Structure

Bluefin tuna in the Pacific and Atlantic Oceans were once considered a single species (*Thunnus thynnus*) with two subspecies (*Thunnus thynnus orientalis* and *Thunnus thynnus thynnus*, respectively), but are now considered separate species (*Thunnus orientalis* and *Thunnus thynnus*, respectively) on the basis of genetic information and morphometric studies (Collette 1999). This taxonomy is accepted by the relevant tuna RFMOs, the Food and Agriculture Organization of the United Nations (FAO), and ISC.

Major spawning areas of PBF are located in the western North Pacific Ocean (WPO) in waters between the Ryukyu Islands in Japan and the east of Taiwan, and in the southern portion of the Sea of Japan (Schaefer 2001). Genetics and tagging information (e.g., Bayliff 1994, Tseng and Smith 2012) also suggests that PBF comprise a single stock. This hypothesis is used in the PBF assessment within ISC and accepted by the RFMOs (WCPFC and IATTC).

2.1.2 Reproduction

PBF are iteroparous spawners, i.e., they spawn more than once in their lifetime. Spawning generally occurs from April to July in the waters around the Ryukyu Islands and off eastern Chinese Taipei, and from July to August in the Sea of Japan (Yonemori 1989, Ashida et al. 2015) (Figure 2-1). A recent histological study showed that 80% of the fish ca. 30 kg (corresponding to age 3) caught in the Sea of Japan from June to August were mature (Tanaka 2006, Okochi et al. 2016). Almost all of the fish caught off the Ryukyu Islands and east of Taiwan were above 60 kg (> 150 cm fork length (FL)). These fish are at least 5 years old, and are all mature.

2.1.3 Distribution and Movements

PBF are mainly distributed in sub-tropical and temperate latitudes between 20^{o} N and 50°N, but are occasionally found in tropical waters and in the southern hemisphere (Figure 2-2).

Although there are large inter-annual variations of movement (numbers of migrants, timing of migration and migration routes), ages 0-1 fish tend to migrate north along the Japanese and Korean coasts in the summer and south in the winter (Inagake et al. 2001, Itoh et al. 2003, Yoon et al. 2012). Depending on ocean conditions, an unknown portion of immature ages 1-3 fish in the WPO make a seasonal clockwise eastward migration across the North Pacific Ocean, spending up to several years as juveniles in the EPO before returning to the WPO (Inagake et al. 2001). It has been suggested that this migration has been driven by inter-annual changes in the abundance of PBF due to the limitation of food sources in the WPO as well as the oceanographic factors (Polovina 1996), however the migration rates have not been quantified. While PBF in the EPO, the juveniles make seasonal north-south migrations along the west coast of North America

(Kitagawa et al. 2007, Boustany et al. 2010). In the spring, PBF are resident off the southern coast of Baja California and as the waters warms, PBF move northwest into southern California bight in summer. By fall, PBF are off of central California.

After spending 3-4 years in EPO, PBF move westward presumably for purposes of spawning as no spawning grounds have been observed outside of WPO. This westward migration has been observed from December to March as PBF begin their southward migration along the coast of California (Boustany et al. 2010). Mature adults in the WPO generally migrate north to feeding grounds after spawning, although a small proportion of fish move to south or eastwards (Itoh 2006).

2.1.4 Growth

In the past assessments, the growth curve was based on Shimose et al. (2009) and updated in 2012 (Shimose and Takeuchi 2012). It was pointed out that 1) this growth curve is inconsistent with the growing modes of observed size composition data, and 2) the study did not include data of age-0 fish. In 2014, a 'Pacific Bluefin and North Pacific Albacore Tuna Age Determination Workshop' was held to standardize age determination techniques among the ISC members and a manual for age determination of PBF was produced (Shimose and Ishihara 2015). In addition to otolith samples used in the Shimoses' analyses (Shimose et al. 2009), the annuli rings of otolith samples collected from the fish landed at Japan and Taiwan between 1992 and 2014 and the daily rings of otolith samples collected from west coast of Japan between 2011 and 2014 were examined.

Fukuda et al. (2015b), then, estimated alternative growth curves by integrating these annuli data for fish aged 1-28 and daily increment data for fish aged 51-453 days after hatching (18.6-60.1 cm in folk length (FL)). Their analyses indicated that a simple von-Bertalanffy growth function (VBGF) applied to fish aged 0-28 could not fit length at age 0 well due to seasonal pattern in age-0 growth (growing very rapidly from July to December but then hardly growing during winter) (Fukuda et al. 2015a). The other approaches using the 2-stanza VBGFs model could fit length at age 0 better than a simple von-Bertalanffy model. These externally estimated growth parameters from the otoliths were to be considered as fixed parameters in the integrated assessment model.

In addition to these traditional VB estimation methods that treat the paired age-length data obtained from annuli and daily rings data as random at age, the age-length data were also treated as random at length (length-conditional method) and incorporated into the integrated stock assessments models to simultaneously estimate growth parameters with underlying population dynamics (Piner et al. 2016). Fukuda et al. (2016) implemented both traditional VB estimation methods (a simple VBGF, a 2-stanza model, a two growth patterns model each for different birth date) and length-conditional method (a seasonal growth model) in the earlier integrated model runs and found that the simple VBGF and the seasonal growth model fit the length/age compositions better than other growth models. The PBFWG also further explored the length-conditional method and concluded that it was difficult to have a reliable estimate due to seasonal nature of PBF fisheries. The PBFWG decided to use a simple VBGF proposed by Fukuda et al. (2015b) and address the misfit of length compositions by adding modeling process and/or data weighting in the section 4.3.2.

The variance of length composition data for all fisheries were reviewed during the stock assessment workshop meeting. The possible causes of variance of growth could be from seasonal growth, different birth date, different growth patterns among years, etc. and the actual variance could be the result of mix of many factors. The estimated variance of length data generally constant over ages suggesting that coefficient of variation (CV) of length at age decreases with age 0-3 and seems to be stable from age 3 and above. This CV at age was externally estimated from the daily and annuli rings.

The growth curve assumed in this assessment was generally consistent with the previous studies (Shimose et al. 2009, Shimose and Takeuchi 2012); grows rapidly to age 5 (approximately 160 cm FL), after which slows down (Figure 2-3). At age 12, the fish reach 226 cm FL, corresponding to 90% of the maximum FL of this species. Fish larger than 250 cm FL are primarily older than age 20, indicating that the potential lifespan of this species is at least 20 years. Fish larger than 300 cm FL are rarely found in commercial catches. Length-weight relationship of PBF based on the von Bertalanffy growth curve used in this stock assessment are shown in Table 2-1 and Figure 2-4.

2.1.5 Natural Mortality

Estimates and schedules of instantaneous natural mortality coefficient (natural mortality or *M*) used for southern bluefin tuna (*T. maccoyii*) and Atlantic bluefin tuna (*T. thynnus*) stock assessments were compared to *M* used for Pacific Bluefin tuna stock assessments using cohort survival analyses (ISC 2008, Aires-da-Silva et al. 2008). The results suggested that usage of *M* schedules and estimates for southern bluefin tuna and Atlantic bluefin tuna to represent *M* for PBF may not be appropriate due to the difference of life history and longevity assumptions among these species. The *M* schedule used for PBF was evaluated (Aires-da-Silva et al. 2008). Natural mortality was assumed to be age-specific: high at a young age, decrease as fish grow, and constant afterwards (Figure 2-5). Natural mortality for age 0 fish was based on results obtained from PBF conventional tagging studies (Takeuchi and Takahashi 2006, Iwata et al. 2012a, Iwata et al. 2014). In the absence of direct estimates of *M* beyond age 0, natural mortality for age 1 fish was based on length-adjusted *M* estimated from conventional tagging studies on southern bluefin tuna (Polacheck et al. 1997, ISC 2009). This adjustment incorporated the difference of life-history between PBF and southern bluefin tuna. Natural mortality was further derived from the median value obtained across a suite of empirical and life-history based methods to represent age 2+ fish (Aires-da-Silva et al. 2008, ISC 2009). Whitlock et al. (2012) estimated *M* for age 2 and older PBF based on tagging data, however several issues wit h regard to the analysis were noted by the PBFWG so it was then decided not to change *M*. This stock assessment used the same *M* schedule as the 2012 and 2014 stock assessments. See 4.2.5 for the actual model setting for *M*.

2.2 Review of Fishery

While PBF catch records prior to 1952 are scant, there are some PBF landings records dating back to 1804 from coastal Japan and to the early 1900s for U.S. fisheries operating in the EPO. Catch of PBF was estimated to be high from 1929 to 1940, with a peak catch of approximately 47,635 t (36,217 t in the WPO and 11,418 t in the EPO) in 1935; thereafter catches of PBF dropped precipitously due to World War II. PBF catches increased significantly in 1949 as Japanese fishing activities expanded across the North Pacific Ocean (Muto et al., 2008).

By 1952, a more consistent catch reporting process was adopted by most fishing nations. Estimates indicate that annual catches of PBF by country fluctuated widely from 1952-2014

(Figure 2-6). Five countries mainly harvest these fish but Japan catches the majority, followed by Mexico, the USA, Korea and Chinese Taipei. Catches in tropical waters and in the southern hemisphere are small and sporadic. During this period reported catches peaked at 40,383 t in 1956 and reached a low of 8,653 t in 1990. While a suite of fishing gears has been used to catch PBF, the majority is currently caught in purse seine fisheries (Figure 2-7).

The fisheries of the main PBF fishing nations are reviewed in this section. However, the input data for the assessment are organized by fishery rather than by country. Therefore, the characteristics of the input data are discussed in detail in Sections 3.3 (fishery definitions), 3.4 (catch), 3.5 (abundance indices), 3.6 (size composition data) and 4.3 (selectivity).

The most important PBF fisheries currently active in Japan use longlines, purse seines, trolling, and set nets, but other gear types such as pole-and-line, drift net and hand-line can and did take considerable catches. The fishing grounds are generally in coastal or nearshore waters, extending from Hokkaido to the Ryukyu Islands. The distant-water longline fishery also catches PBF but in relatively small numbers.

Total annual catches by Japanese fisheries have fluctuated between a maximum of 34,000 t in 1956 and a minimum of 6,000 t in 1990 (calendar year). Yamada (2007) provided a general review of Japanese fisheries taking PBF. Changes in the longline fishery are described in Section 3.5.3; changes in the purse seine fishery are covered in Section 3.5.4, Section 3.5.7, Section 3.5.8, 3.6.3, 3.6.4, and 3.6.5.

In the USA, two main types of fisheries, purse seine and recreational fisheries, catch PBF off the west coast of North America. The US purse seine fishery targeting PBF mainly for canning was fully developed and operated in the traditional PBF fishing grounds off Baja California until the early 1980s. In 1976, Mexico established its Exclusive Economic Zone (EEZ) and by the early 1980s the US fishery had abandoned its traditional fishing grounds in Mexican waters. After 1983, the US purse seine fishery targeting PBF basically ceased operations with only opportunistic catches of this species thereafter (Aires-da-Silva et al. 2007). The US recreational fleet also catches relatively small amounts of PBF, typically while fishing in Mexican waters.

The Mexican purse seine fishery is the most important large pelagic fishery in Mexico. This fishery developed rapidly after Mexico established its EEZ in 1976. This fishery is monitored by an at-sea observer program with 100% coverage, as well as captains' logbooks and Vessel Monitoring Systems (VMS) and more recently through stereoscopic cameras at some of the rearing facilities (Dreyfus and Aires-da-Silva 2015). Most of the purse seine sets target yellowfin tuna (the dominant species in the catch) in tropical waters; PBF are caught near Baja California. The Mexican PBF catch history recorded three large annual catches (above 7,000 t) in the years 2004, 2006 and 2010.

In Korean waters, PBF are mostly caught by the offshore large purse seine fleet (OLPS) but there is a small amount of catch reported by the coastal troll fleet in recent years. The catch of the OLPS fleet was below 500 t until the mid-1990s, increased thereafter with a peak of 2,601 t in 2003, and fluctuated in recent years from 670 t in 2011 to 1,421 t in 2012. The catch of the coastal troll fleet was 0.1 t in 2011 and 1.1 t in 2012, respectively. The main fishing ground of the OLPS fleet is off Jeju Island, but it occasionally expands to the Yellow Sea and the southeastern waters of Korea (Yoon et al. 2014).

Since 1993, the majority of catch by Taiwanese fleets derived from a small-scale longline fleet (<100 gross registered tonnage (GRT)) that targets PBF. Landing records indicate that small amounts (<300 t) of PBF have been harvested by small-scale longline, purse seine, large-scale pelagic driftnet, set net, offshore and coastal gillnet and bottom longline gear since the 1960s. Since 1984, the landings started to increase gradually to over 300 t, mostly due to the increased catch by small-scale longline vessels fishing in the eastern spawning grounds from April to June. The highest observed catch of 3,000 t was in 1999 but this declined rapidly to less than 1,000 t in 2008 and to their lowest level of about 200 t in 2012. The decline ceased and the landing started to increase thereafter. Preliminary estimate of PBF landing in 2015 was 542 t.

3.0 STOCK ASSESSMENT INPUT DATA

3.1 Spatial Stratification

As discussed in the Section 2.1.1, PBF are distributed across the North Pacific Ocean and considered to be a single stock. Juvenile PBF move between the WPO and the EPO (Itoh et al. 2003, Boustany et al. 2010), but incorporation of this movement process into the stock assessment model is difficult due to lack of information of movement rates. Thus the stock assessments of PBF have been assumed an instantaneously mixed population and incorporated regional selection patterns to account for spatial effects ("areas-as-fleets approach", Waterhouse et al. 2014). A simulation study on how to deal with movement in PBF stock assessment suggested that although the use of alternative model processes are not as effective as the spatially explicit model with estimation of movement rates, some management quantities are less biased in the model using fishery selection to account for availability (spatial patterns) as well as contact gear selectivity (Lee et al. 2015a).

3.2 Temporal Stratification

The time period modeled in the assessment of PBF is 1952-2014 (fishing year), with catch and size composition data compiled quarterly as follows;

Season 1: July-September,

Season 2: October-December,

Season 3: January-March, and

Season 4: April-June.

Although fisheries catching PBF have been operated since at least the beginning of the 20th century in the EPO (Bayliff 1991) and for several centuries in the WPO (Ito 1961), the detailed fishery statistics prior to 1952—especially from the WPO—were not available. Therefore, the fishing year 1952 has been used as the starting year of the stock assessments because catch-and-effort data from Japanese longline and EPO commercial purse seine fleets were available from that year onward. Data sources and temporal coverage of the available datasets are summarized in Figure 3-1.

3.3 Fishery Definitions

A total of 19 Fleets were defined for the use in the stock assessment of PBF based on stratification of country, gear type, season, area, and size of fish caught (Table 3-1). Representative fisheries for each Fleet are as follows;

Fleet 1: Japanese longline fisheries (JPLL),

Fleet 2: Japanese small pelagic fish purse seine fishery in the East China Sea (JPSPPS) for seasons 1, 3, and 4,

Fleet 3: Korean offshore large purse seine fishery (KROLPS),

Fleet 4: Japanese tuna purse seine fishery in the Sea of Japan (JPTPSJS),

Fleet 5: Japanese tuna purse seine fishery off the Pacific coast of Japan (JPTPSPO),

Fleet 6: Japanese troll fishery (JPTroll) for seasons 2-4,

Fleet 7: Japanese pole and line fishery (JPPL),

Fleet 8-10: Japanese set-net fisheries (JPSetNet),

Fleet 11: Japanese other fisheries (JPOthers), mainly small-scale fisheries in the Tsugaru Strait,

Fleet 12: Taiwanese longline fishery (TWLL) in southern fishing ground,

Fleet 13: Eastern Pacific Ocean commercial purse seine fishery of USA (USCOMM),

Fleet 14: Eastern Pacific Ocean commercial purse seine fishery of Mexico (MXCOMM),

Fleet 15: Eastern Pacific Ocean sports fishery (EPOSP),

Fleet 16: Japanese troll fishery for farming (JPTroll for Pen),

Fleet 17: Taiwanese longline fishery (TWLL) in northern fishing ground,

Fleet 18: Japanese small pelagic fish purse seine fishery in the East China Sea (JPSPPS) for season 2, and,

Fleet 19: Japanese troll fishery (JPTroll) for season 1.

Representative fisheries of both fleets 2 and 18 are Japanese purse seiners for PBF operated in the East China Sea and the western Sea of Japan. Whereas fleet 18 corresponds to the operations in season 2 when age 0 and 1 fish may be caught, fleet 2 corresponds to the operations mainly catching age 0 fish in seasons 1, 3, and 4. Fleet 3 corresponds to Korean purse seiners operated in the neighboring waters of Japanese purse seiners. Both Japanese and Korean purse seine fisheries were treated as one fleet in the previous assessments, but in this assessment, they are separated into two fleets due to management purpose (ISC 2015a, ISC 2016). Both of fleets 4 and 5 are also Japanese tuna purse seine fisheries, but their fishing grounds are different; fleet 4 operates in the Sea of Japan, whereas fleet 5 operates off the Pacific coast of Japan. They were defined as separate fleets because of differences in the length compositions of the catch (Abe et al. 2012). Fleets 6, 16, and 19 are Japanese troll fisheries targeting age 0 and 1 PBF, fish caught by fleet 16 are used for "farming". Fleets 6 and 16 are "conventional" troll, and their fishing seasons are seasons 2-4 and season 1, respectively. The fish size caught by these fleets differ among each other—age 0 fish are preferred for the fish farming (Fleet 16), and length compositions in season 1 (Fleet 19) are smaller than those in the other seasons (Fleet 6). Thus the PBFWG agreed to use them as separate fleets (ISC 2015a, ISC 2016). Fleets 8-10 are Japanese set-net fisheries, which are separated based on the availability of length (fleets 8 and 9) or weight measurements (fleet 10) and seasonal changes of size compositions (seasons 1-3 of the quarter of fishing year for fleet 8 and season 4 for fleet 9) (Sakai et al. 2015a). Most of catch for fleet 11 (JP Others) are from the small-scale fisheries in the Tsugaru Strait such as handliners and longliners. Taiwanese longline fishery is treated as two separate fleets based on their fishing grounds; fleet 12 for the southern area and fleet 17 for the northern area (ISC 2016). Both fleets 13 and 14 are purse seine fisheries in the EPO, but separated by the time period in 2002: During the early period (before 2002), US purse seine fishery was dominant while Mexican fishery was being developed (fleet 13). Then, since 2002, fully developed Mexican purse seine fishery has been dominant (fleet 14) (Aires-da-Silva and Dreyfus 2012).

Fisheries with small amount of PBF catch were also considered in the stock assessment. As the previous stock assessment (ISC 2014), their catch amounts were included in the fleet with similar catch-at-size, fishing grounds, and seasons. For example, Korea reported small catch amount caught by trawl, set-net, and troll fisheries, and these catch were included in fleet 3. Taiwanese purse seine catch were included in fleet 4, the driftnet catch of both Japan and Taiwan were included in season 1 of fleet 7, and the other Taiwanese catch were included in season 4 of fleet 7. Japanese miscellaneous catches for seasons 1-3 and season 4 were included in Japanese set-net fleets, fleet 8 and 9, respectively. The other Japanese catch (by trawl and other small longline fisheries other than those from the Tsugaru Strait) were included in fleet 11. Non-ISC members' catch (i.e. by New Zealand, Australia, etc.) were included in fleet 12.

3.4 Catch

Purse seine fisheries continued to occupy a large portion of the total catch throughout the assessment period (Figure 3-2(a)). The Japanese tuna purse seine fishery operating off the Pacific coast of Japan (Fleet 5) accounted for a large portion of the catch until the 1990s. However, catches of the Japanese small pelagic fish purse seine fishery operating in the East China Sea (Fleet 2 and 18) and the Japanese tuna purse seine fishery in the Sea of Japan (Fleet 4) have become relatively larger since the mid-2000s. The largest catches in the EPO came from the US and Mexican commercial purse seine fisheries (Fleet 13 and 14). Catch data for stock assessment were expressed in tonnes for all fleets except for Fleet 15 and 16, whose catches were expressed in thousands of fish (Figure 3-2(b)).

For almost all fleets, the time series of quarterly catch data from 1952 through 2014 (fishing year) has been developed (Table 3-2). For some of fisheries, the quarterly catches for the early period were estimated using recent quarterly catch proportions applied to annual catch data; e.g. Fleets 8 and 9 before fishing year 1994 (Kai 2007a), Fleet 5 before fishing year 1971 (Takeuchi 2007), etc.. For other Fleets, recent quarterly catches were directly derived from logbook or landing statistics. Fleet 11 included small-scaled Japanese fisheries (e.g. trawl, small longline, etc.), and their annual total catch was placed in Season 2 of fishing year for the input data of assessment model. Size composition data for Fleets 10 and 11 were combined and shared the estimated selectivity information (see section 3.6), thus catches by Fleet 10 were also placed in Season 2 of fishing year aggregating their quarterly catch data.

3.5 Abundance Indices

3.5.1 Overview

CPUE-based Abundance indices of PBF available for this assessment are listed in Table 3-3. These series were derived from fishery-specific catch and effort data which were standardized with appropriate statistical methods (Figure 3-3 and Table 3-4).

Indices S1-3 were derived from the Japanese longline fisheries (Fleet 1), S4, 13, and 14 were derived from the Japanese tuna purse seine fishery in the Sea of Japan (Fleet 4), S5-8 were derived from the Japanese troll fisheries (Fleet 6), S9 and 12 were derived from the Taiwanese longline fishery (Fleet 12 and 17), and S10 and 11 were derived from EPO commercial purse seine fisheries (Fleet 13 and 14).

The PBFWG decided to use four longline CPUE series as the adult abundance indices (S1, S2, S3, and S9), and a Japanese troll index (S5) as the recruitment index for the base-case model of stock assessment (ISC 2015b, ISC 2016). The other indices were prepared for the sensitivity analysis etc. (Table 3-3 and Table 3-4).

3.5.2 CV for the CPUE Series

The PBFWG agreed to set 0.2 as the input CV values in the assessment model if the estimated value was less than 0.2, which is the same approach as used in the previous assessment (ISC 2014). Since all of the estimated CV values for updated abundance indices were below 0.2, the base-case model used 0.2 as input CV value for all the abundance indices.

3.5.3 Japanese Longline CPUE (S1, S2 & S3)

Until the mid-1960s, PBF longline catches in Japanese coastal waters were made by offshore and distant-water longline vessels larger than 20 GRT. Since the mid-1960s, the coastal longline fleet has consisted of coastal longline vessels smaller than 20 GRT. A logbook system was not established until 1993 for the coastal longline fleet, whereas aggregated logbook data from 1952 onward are available for the offshore and distant-water longline fleets.

Japanese longline CPUE is based on the logbook data, thus recent CPUE series for the coastal longline fishery is only available from fishing year 1993 to 2014 (S1). Before fishing year 1993, offshore and distant water longline CPUE is available, but the indices to input the stock assessment has to be split up into two time series; fishing year 1952-1973 (S2; Fujioka et al. 2012a) and 1974-1992 (S3; Yokawa 2008). The reason for the separation is that the operational patterns of this fishery changed in the mid-1970s (e.g. the super-freezer was developed and targeting shifted from yellowfin tuna and albacore to bigeye tuna), in addition, hooks-per-basket information, which was used to standardize for these targeting changes, has only been collected since the mid-1970s (Yokawa et al. 2007).

The standardization method of S1 CPUE was revised after the previous stock assessment, which used the result of cluster analysis as an explanatory variable of Zero-Inflated Negative Binomial model (ZINB). This is an effective approach to address the target shift of longliner (Sakai et al. 2015b), thus the PBFWG agreed that the increased CV for recent year to take into account the target shift in the previous assessment is no longer necessary (ISC 2015b).

3.5.4 Japanese Troll CPUE (S5, S6, S7 & S8)

Catch-and-effort data for coastal troll fisheries targeting age 0 PBF in Kochi, Wakayama and Nagasaki Prefectures have been collected primarily from six, four and five fishing ports in these Prefectures, respectively (Ichinokawa et al. 2012). The unit of effort in the catch-and-effort data is the cumulative daily number of unloading troll vessels, which is nearly equivalent to the total number of trolling trips because most troll vessels make one-day trips. The effort data in Kochi and Wakayama Prefectures include unloading without PBF catch (zero-catch data), thus a ZINB model was used to standardize CPUE for these prefectures. On the other hand, the effort data in Nagasaki Prefecture doesn't include the unloading without PBF catch: no zero-catch data was available. Therefore a log normal model was applied for standardization of the CPUE in Nagasaki Prefecture.

Based on these standardized CPUE series, four indices had been prepared in the previous stock assessment (S5 from Nagasaki Prefecture, S6 from weighted average CPUE of Kochi and Nagasaki Prefecture, S7 from Kochi Prefecture, and S8 from Wakayama Prefecture), however, only S5 CPUE series from Nagasaki Prefecture since fishing year 1980 was fitted in the assessment model due to representativeness as the recruitment index (ISC 2014): The troll fishery in Nagasaki Prefecture has dominant share in Japanese troll catch, and they can fish age 0 PBF from both two spawning grounds (around Ryuku Islands and the Sea of Japan) because of the geographical location of their fishing ground (Ichinokawa et al. 2012).

For this stock assessment, only S5 CPUE was updated. The CPUE had a record-low value in 2014 fishing year (Sakai and Oshima 2015). Japanese troll fisheries were separated into 2 Fleets by season (Fleet 6 and 19) in the assessment model. The catch and effort for S5 CPUE contains very few data from Season 1, thus Fleet 6 was used as the correspondence Fleet for the selectivity setting of S5 CPUE (ISC 2016).

3.5.5 Taiwanese Longline CPUE in Southern area (S9) and Northern area (S12)

Taiwanese new longline CPUE series for PBF from 2001 to 2014 fishing year, which was standardized using Delta lognormal model, was available. This CPUE series misses the oldest two years' data which was included in the previous series because of the difference of data set. But this new standardized series addressed the effect of fishing area (Chang et al. 2015a), thus the PBFWG considered it to be an improvement (ISC 2015b).

This CPUE was developed by the following process; (1) Estimating PBF catch in number from landing weight for 2001-2003 based on an MCMC simulation, (2) Deriving fishing days for 2007-2009 from data of vessel monitoring system (VMS) and voyage data recorder (VDR), (3) Deriving fishing days for 2001-2006 from vessels trip information based on linear relationships between fishing days and at-sea days for a trip, by vessel size and fishing port, during 2007-2014, and (4) Estimating and standardizing the CPUE (catch number per fishing days) for fishing year 2001-2014 (Chang and Liu 2016).

As a result of the discussion during the PBFWG meeting, the Taiwanese longline CPUE was separated into two series by fishing area; S9 for southern area and S12 for northern area. The CPUE in the south area (S9) showed little increase in the terminal years while the one in the north area (S12) showed a large increase in the terminal two years. The south area has been the main fishing ground for Taiwanese longline fishery, thus the PBFWG decided to use S9 CPUE for the base-case model of this stock assessment (ISC 2016).

3.5.6 US Purse Seine CPUE (S10)

Standardized CPUEs for PBF are available for two periods of the US purse seine fishery: (1) the developed phase targeting PBF (1960-1982); and (2) the decline phase (post-1982). Jackknifing was used to estimate the CV (Aires-da-Silva et al. 2012). The availability of PBF in the EPO depends on migration of PBF from the WPO but the rate is likely variable and unknown. Due to unresolved issues concerning the representativeness of these data to reflect abundance, this index was not used in the assessment.

3.5.7 Mexican Purse Seine CPUE (S11)

Mexican standardized CPUEs for PBF are available for two periods of the fishery: (1) the Mexican opportunistic fishery (1960-1998); and (2) the Mexican fishery that has targeted PBF since 1999. This fishery supplies PBF for pen rearing operations. Jackknifing was used estimate the CV (Aires-da-Silva et al. 2012). As mentioned above, the availability of the PBF in the EPO depends on the migration from the WPO at an unknown but likely variable rate. Therefore, this index was not used in the assessment.

3.5.8 Japanese Purse Seine in the Sea of Japan CPUE (S4, S13, & S14)

Japanese purse seine CPUE in the Sea of Japan had been provided by Kanaiwa et al. (2012, 2014). For this CPUE series, there were two concerns as follows; (1) the flat annual trend of CPUE of purse seiners in the Sea of Japan may have reflected specific problems with purse-seine CPUE indices rather than abundance trends, and (2) fishing effort used in the CPUE calculation did not consider search time for the fish schools. Hence, changes in the CPUE might represent only the size of a school of fish, which may not be proportional to the abundance of the stock. Due to these issues this index (S4) was not used in the base-case model in the previous stock assessment (ISC 2014).

During the intersessional working group meeting, age separated standardized CPUE using “Random Forests” were proposed as S12 (for age 4) and S14 (for age 5) as a solution to the problems in S4 CPUE (Kanaiwa et al. 2015). These new CPUE series addressed the area, environment, and age factors. There was no problem on the standardization statistically, but the trend of standardized CPUE had conflict with other information (ISC 2015a). Therefore the ISC PBFWG decided not to use these new CPUE series for the base-case model as with the old one (ISC 2015b).

3.6 Size Composition Data

3.6.1 Overview and Input Sample Size

Quarterly size composition (both length and weight) data for PBF from 1952 to 2014 (fishing year) were used for this assessment. The size composition data for Fleets 5, 7, 13, and 15 were not updated after 2010 (Oshima et al. 2014). Length composition data were available for Fleets 1-9, 12-15, and 17-19, while weight composition data were available for Fleets 10 and 11. Of these, the size compositions for Fleets 2-3 and Fleets 10-11 were combined to simplify the assessment model (Table 3-5).

All length data in the model was "fork length (FL)" measured to the nearest cm. Length composition bins of 2, 4, and 6 cm width were used for 16-58, 58-110, and 110-290 cm FL fish, respectively. Weight composition bins were of variable width, ranging from 1 kg to 30 kg (0, 1, 2, 5, 10, 16, 24, 32, 42, 53, 65, 77, 89, 101, 114, 126, 138, 150, 161, 172, 182, 193, 202, 211, 220, 228, 236, 243, and 273 kg), which set two bins for each age between 0 to 15 to minimize the misinterpretation of the data (Fujioka et al. 2012b). The lower boundary of each bin was used to define the bin.

Figure 3-4 shows the aggregated size compositions, and Figure 3-5 shows the quarterly size compositions for each Fleet. The source of input sample sizes for the size composition data are summarized in Table 3-6. Depending on the corresponding fisheries, the information of sample size was based on four different criteria; "Number of fish measured", "Number of landing well measured", "Number of total month of well sampled port", and "Number of haul well measured". Table 3-5 also summarizes the relative size-sampling quality of each fleet's catch-at-size data.

3.6.2 Japanese Longline (Fleet 1)

Length-composition data from the Japanese longline fishery (Fleet 1) are available for the periods of fishing year 1952-1968 and 1994-2014 (Figure 3-5). Until 1960s, the data were collected mainly from the Tsukiji Market. Since the 1990s, size sample and market data have been collected at the major PBF unloading ports, e.g., Okinawa, Miyazaki and Wakayama Prefectures. Length measurements were relatively sparse from 1969 to 1993 (Mizuno et al. 2012), and were not included in this assessment.

Length compositions for fishing year 1952-1968 were estimated based on the aggregated catch and length measurement data by year, month, and area (5x5 degree cells). Using this stratification, length composition was raised by catch number (Mizuno et al. 2012). Since fishing year 1993, the length compositions were estimated based on the quarterly landing amount and length measurement in each prefecture. Using quarter and prefecture strata, length composition was raised by landing weight (Sakai et al. 2015c).

3.6.3 Japanese Purse Seines in the East China Sea (Fleet 2 and 18) and Korean Purse Seine (Fleet 3)

Length-composition data for PBF from the Japanese purse seine fishery in the East China Sea has been developed from length measurements taken at Fukuoka and Matsuura, which were the major landing ports for this fishery. The data is separated into two Fleets by season (Fleet 2 and 18). The available period for Fleet 2 (Seasons 1, 3, 4) was fishing year 2002-2014, whereas that for Fleet 18 (Season 2) was fishing year 2003-2012 and 2014. The data in Seasons 3-4 of 2014 for Fleet 2 were not used in the assessment model because presumably only the different (larger) size range of PBF than the previous years were measured whereas small fish (same size range with the previous years) caught by this fishery for farming might not be measured in this year (ISC 2015b).

Length composition data from the Korean purse seine fishery was also available for fishing year 2010-2014 (Kim et al. 2015). The size of fish caught by Korean fleet was similar to the Japanese fleet which was fishing in neighboring waters. Thus the PBFWG agreed to share the size composition by Fleet 2 and 3 after the inclusion the size data of Korean fleet into that of Japanese fleet (ISC 2015b: Figures 3-5).

3.6.4 Japanese Purse Seine in the Sea of Japan (Fleet 4)

Length-composition data for PBF from the Japanese purse seine fleet in the Sea of Japan (Fleet 4) has been collected by port samplers in Sakai-minato and available in fishing years 1987-2014, except for 1990 when there was no catch (Figure 3-5). Size measurement coverage has been high and most of the landings were sampled (in average 98% landings were covered). This fleet catches mainly PBF older than age 3 (Fukuda et al. 2012). There was no new information which suggests the change of operation of this fishery, thus the PBFWG agreed on a simple update of the length composition for this stock assessment (ISC 2015b).

3.6.5 Japanese Purse Seine off the Pacific Coast of Japan (Fleet 5)

Size composition data for PBF from Japanese purse seiners operating off the Pacific coast of Japan were collected at the Tsukiji Market and several unloading ports in the Tohoku region between the 1950s and 1993. Since 1994, length and weight composition data have been collected at Shiogama and Ishinomaki ports (Abe et al. 2012).

Although length measurements for this fishery had been made since 1980s, an appropriate method to create catch-at-size data has not yet been established for the entire period. The size composition data for this fishery is highly variable (from 50 cm to very large) and further research especially for smaller fish is needed for this dataset. The PBFWG decided to use the length-composition data for only fishing year 1995-2006 for this stock assessment, which is the same approach taken in the previous assessment (Figure 3-5).

3.6.6 Japanese Troll and Pole-and-Line (Fleet 6, 7, and 19)

Length-composition data for PBF from Japanese troll fishery (Fleet 6 and 19) and pole-and-line fishery (Fleet 7) have been collected comprehensively at their main unloading ports since 1994. Until then, the size measurements were very limited in both the number of sampling ports and number of fish (Oshima et al. 2007; Fukuda and Oshima 2012).

Length-composition data for Japanese troll fishery (Fleet 6 and 19) was estimated by revised method: The length measurement data was pooled by “Area” and “Month” as the minimum spatial and temporal strata, and then raised by catch number in corresponding strata (Fukuda et al. 2015a). In order to improve the fitting of the length-composition data to the assessment model, this fishery was separated into two fleets by season (ISC 2016), because the length composition in Season 1 (Fleet 19) is smaller than that of the other Seasons (Fleet 6).

The size sampling for Fleet 7 was considered to be relatively poor compared to the numerous troll vessels. Both troll and pole-and-line fisheries operate catch similar-sized fish (primarily age 0 fish), thus the PBFWG decided not to fit the length-composition of Fleet 7 in the assessment model (mirror the selectivity information of Fleet 6), which is the same approach taken in the previous assessments (ISC 2015b: Figure 3-5).

3.6.7 Japanese Set Net fishery except for Hokkaido and Aomori Prefectures (Fleets 8 and 9)

Size measurement data for PBF from Japanese set-net fleets have been collected since 1993. The catch-at-size data were estimated based on the multi-stratified raising using the catch weight. The method was revised after the previous stock assessment; excessive estimation was avoided by the introduction of broad size category stratum (i.e. Small/Medium/Large) and limitation of over-strata calculation (Hiraoka et al. 2015, Sakai et al. 2015a). The length-composition data was available for the set-net fisheries except for Hokkaido and Aomori Prefectures (see section 3.6.8). The catch by set-net is largely influenced by the environmental conditions and migration (Kai 2007a), thus the catch-at-size is highly variable (Figure 3-5). In order to treat the complexity of the dataset, the PBFWG decided to divide the set-net fisheries into 3 fleets: Fleet 8 is the Seasons 1, 2, and 3 of the fisheries in all prefectures except for Hokkaido and Aomori, Fleet 9 is Season 4 from the same areas, and Fleet 10 is all season of set-net fishery in Hokkaido and Aomori (ISC 2015b).

3.6.8 Japanese Set Net fishery for Hokkaido and Aomori Prefectures (Fleets 10) and Other Fisheries (Fleet 11)

Size measurement data for PBF from the set-net fishery in Hokkaido and Aomori Prefectures (Fleet 10) is based on the weight measurement data (Sakai et al. 2015a). Fleet 11 also has weight-composition data, which includes Japanese hand line and small-scaled longline fisheries in the Tsugaru Strait and its adjacent waters. The estimation method for the weight composition data for Fleet 11 was revised after the previous stock assessment (Nishikawa et al. 2015). Both Fleets 10 and 11 probably target similar fish in the similar area, thus the PBFWG agreed to combine their size-composition data to estimate and share the selectivity pattern (ISC 2015b; Figure 3-5).

3.6.9 Taiwanese Longline (Fleets 12 and 17)

Length composition data for PBF from the Taiwanese longline fishery (Fleets 12 and 17) were based on the market landing information and port sampling. Since 2010, additional information has been also available from the catch documentation scheme (CDS) program, which provides much more size samples with higher quality (Chang et al. 2015b).

As a result of the discussion during the PBFWG meeting, the Taiwanese longline fishery was separated into two fleets by fishing area; Fleet 12 for southern area and Fleet 17 for northern area.

The southern area has been the main fishing ground for Taiwanese longliners, accounting for more than 75% of catch on average. The length-composition data for the southern area was available in fishing year 1992-2014. Meanwhile, the size composition data in the northern area was not available before fishing year 2009 (ISC 2016).

3.6.10 EPO Commercial Purse Seine of US Dominant Period & Transition Period (Fleet 13) and Mexico Dominant Period (Fleet 14)

Length-composition data for PBF from EPO purse seine fishery are collected by port samplers from IATTC and national/municipal sampling programs (Bayliff 1993, Aires-da-Silva and Dreyfus 2012). Fleet 13 is US dominant & transition period of EPO purse seine fishery until 2001. For this fleet, length composition data for US dominant period from 1952 to 1982 is used to estimate the selectivity pattern for the stock assessment (ISC 2015b). Fleet 14 is Mexico dominant period of EPO purse seine fishery (2002 onwards). The length composition data for Fleet 14 had been obtained by IATTC at-sea observers and port sampling programs. For 2013, size composition data measured by stereoscopic cameras from the largest farming company was available (Dreyfus and Aires-da-Silva 2015).

3.6.11 US Recreational Fishery (Fleet 15)

Size composition data for PBF from the US recreational fishery had been collected by IATTC staff since 1993, however the size sampling program by IATTC ended in 2012. From 2014, NOAA took over the sampling program (Lee et al. 2015b). These size data were not used to estimate the selectivity for Fleet 15 in the stock assessment: the selectivity pattern estimated for Fleet 13 was used for Fleet 15, because both fleets were considered to target the same age fish (ISC 2015b) (Figure 3-5).

3.6.12 Japanese Troll Fishery for Farming (Fleet 16)

In Japan, lengths of PBF caught by troll for farming are apparently smaller than those of fish caught by conventional troll. The PBFWG considered that the troll fishery for farming should be treated targeting age 0 fish specifically (ISC 2015a). There were no size composition data for Fleet 16.

4.0 MODEL DESCRIPTION

4.1 Stock Synthesis

An annual time-step length-based, age-structured, forward-simulation population model, fit to seasonal data (expectations generated quarterly), was used to assess the status of PBF. The model was implemented using Stock Synthesis (SS) Version 3.24F (Methot and Wetzel 2013; http://nft.nefsc.noaa.gov/Stock_Synthesis_3.htm). SS is a stock assessment model that estimates the population dynamics of a stock through use of a variety of fishery dependent and fishery independent information. Although it was developed for coastal pelagic fishes (sardine and anchovy) and used primarily for ground fishes, it has become a standard tool for tunas and other highly migratory species in the Pacific Ocean. The structure of the model allows for both maximum likelihood and Bayesian estimation processes with full integration across parameter space using a Monte Carlo Markov Chain (MCMC) algorithm. This application uses maximum likelihood and normal approximation or bootstrapping to estimate parameter uncertainty.

SS is comprised of three subcomponents: (1) a systems dynamics subcomponent that recreates an estimate of the numbers/biomass at age using estimates of natural mortality, growth, fecundity etc., (2) an observational subcomponent that relates observed (measured) quantities such as CPUE or proportion at length/age to the population dynamics, and (3) a statistical subcomponent that uses likelihoods to quantify the fit of the observations to the recreated population.

4.2 Biological and Demographic Assumptions

4.2.1 Growth

The sex-combined length-at-age relationship was based on reading annual rings from otolith samples (Shimose and Takeuchi 2012, Shimose and Ishihara 2015) and daily rings (Fukuda et al. 2015b). This relationship was then re-parameterized to the von Bertalanffy growth equation used in SS **(**Figure 2-3**)** and adjusted for the birth date used in SS (1 July, i.e. the first day of the fishing year),

$$L_2 = L_\infty + (L_1 - L_\infty)e^{-K\,(A_2 - A_1)}$$

where L_1 and L_2 are the sizes associated with ages near the first (A_1) and second (A_2) ages, L_∞ is the theoretical maximum length, and K is the growth coefficient. K and L_∞ can be solved based on the length at age and L_∞ was thus re-parameterized as:

$$L_\infty = L_1 + \frac{L_2 - L_1}{1 - e^{-K\,(A_2 - A_1)}}$$

The growth parameters K, L_1 and L_2 were fixed in the SS model, with K at 0.188y^{-1} and L_1 and L_2 at 19.05 cm and 118.57 cm for age 0 and age 3, respectively. The process error was modelled as CV=f(length-at-age) with fixed CV =0.259 and 0.044 for ages 0 and 3, respectively. A linear interpolation between 0-3 was used to generate the process error for intervening ages, and ages>3 were assumed the same as age 3.

The parametrization above results in the traditional von Bertalanffy parameters as follows:

$$L_t = 249.917 \times (1 - e^{-0.188\times(t+0.4217)})$$

where

L_t = length at age t;

L_∞ = 249.917 cm = theoretical maximum length;

K = 0.188 y^{-1} = growth coefficient or the rate at which L_∞ is asymptotically reached; and

t_0 = -0.4217 (assumed July 1 as birth day, the first day in fishing year) = theoretical age where length is equal to zero.

4.2.2 Ages Modeled

Ages from age 0 to the maximum age 20 were modeled. Age 20 was treated as an accumulator for all older ages (dynamics are simplified in the accumulator age). To avoid biases associated with the approximation of dynamics in the accumulator age, the maximum was set at an age sufficient to minimize the number of fish in the accumulator bin. Given the *M* schedule, approximately 0.15% of an unfished cohort remains by age 20.

4.2.3 Weight-Length Relationship

A sex-combined weight-length relationship was used to convert fork length (*L*) in cm to weight (W_L) in kg (Kai 2007b). The sex-combined length-weight relationship is:

$$W_L = 1.7117 \times 10^{-5} L^{3.0382}$$

where W_L is the weight at length *L*. This weight-length relationship was assumed time invariant and fixed. (Figure 2-4).

4.2.4 Sex Ratio

This assessment assumes a single sex. Shimose and Takeuchi (2012) previously estimated sex-specific differences in the growth of male and female PBF. However, given the lack of sexual dimorphism and a near total lack of records of sex in the fishery data, a single sex was assumed for this assessment.

4.2.5 Natural Mortality

Natural mortality (*M*) was assumed to be age-specific in this assessment. Age-specific *M* estimates for PBF were derived from a meta-analysis of different estimators based on empirical and life history methods to represent juvenile and adult fish (Aires-da-Silva et al. 2008; see Section 2.1.5). The *M* of age 0 fish was estimated from a tagging study, as discussed in detail in the Section 2.1.5. Age-specific estimates of *M* were fixed in the SS model as 1.6 year^{-1} for age 0, 0.386 year^{-1} for age 1, and 0.25 $year^{-1}$ for age 2 and older fish.

4.2.6 Recruitment and Reproduction

PBF spawn throughout spring and summer (April-August) in different areas in the western Pacific Ocean as inferred from egg and larvae collections and examination of female gonads. In the SS model, spawning was assumed to occur at the beginning of April (Season 4). Based on Tanaka (2006), age-specific estimates of the proportion of mature fish were fixed in the SS model as 0.2 at age 3, 0.5 at age 4, and 1.0 at age 5 and older fish. PBF ages 0-2 fish were assumed to be immature. Recruitment is assumed to occur in season 1.

A standard Beverton and Holt stock recruitment relationship (SR) was used in this assessment. The expected annual recruitment was a function of spawning biomass, a fixed steepness (h), and estimated natural log of unfished recruitment ($\log R_0$). Recruitment deviations from the SR relationship (1953-2014) were estimated and assumed to follow a lognormal distribution with a fixed standard deviation σ (Methot and Taylor 2011, Methot and Wetzel 2013).

Steepness of the stock-recruitment relationship was defined as the fraction of recruitment when the spawning stock biomass is 20% of SSB_0, relative to R_0. Previous studies have indicated that h tends to be poorly estimated due to the lack of information in the data about this parameter (Magnusson and Hilborn 2007, Conn et al. 2010, Lee et al. 2012). Lee et al. (2012) concluded that steepness was estimable from within the stock assessment models when models were correctly specified for relatively low productivity stocks with good contrast in spawning stock biomass. However, the estimate of h may be imprecise and biased for PBF as it is a highly productive species. Independent estimates of steepness that incorporated biological and ecological characteristics of the species (Iwata 2012, Iwata et al. 2012b) reported that mean h was approximately 0.999, close to the asymptotic value of 1.0. Therefore, steepness was fixed at 0.999 in this assessment. It was noted that these estimates were highly uncertain due to the lack of information on PBF early life history stages.

Recruitment variability (σ_r) fixed at 0.6 was approximately the same as the deviate variability estimated by the model. Relatively large σ_r assumes that the estimated recruitment could be decoupled from the predicted to a large degree. This method allows the model to be less sensitive to our assumptions about steepness.

The central tendency that penalizes the log (recruitment) deviations for deviating from zero was assumed to sum to zero over the estimated period. A log-bias adjustment factor was used to assure that the estimated mean log-normally distributed recruitments were mean-unbiased.

4.2.7 Stock Structure

The model assumed a single well-mixed stock for PBF. The assumption of a single stock is supported by previous tagging and genetic studies (see Section 2.1.1).

4.2.8 Movement

PBF is a highly migratory species, with juveniles known to move widely throughout the Pacific Ocean, especially between the EPO and WPO (Section 2.1.3). In this assessment, PBF were assumed to occur in a single, well-mixed area, and explicit spatial dynamics (including regional and seasonal movement rates) were not explicitly modeled. Although the model was not spatially explicit, the collection and pre-processing of data, on which the assessment is based, were fishery specific (i.e. country-gear type) and therefore contain spatial inferences. Instead of explicitly modeling movement, the model used fishery-specific time-varying selectivity and separated length- and age- based selectivity patterns to approximate changes in the movement patterns of the stock (see Section 4.3.2).

4.3 Model Structure

4.3.1 Initial Conditions

When populations are exploited prior to the onset of data collection, stock assessment models must make assumptions about what occurred prior to the start of the dynamic period. Assessment models often make equilibrium assumptions about this pre-dynamic period. Two approaches describe the extreme alternatives for dealing with the influence of equilibrium assumptions on the estimated dynamics. The first approach is to start the dynamic model as far back in time as is necessary to assume that there was no fishing prior to the dynamic period. Usually this entails creating a series of hypothetical catches that both extend backwards in time and diminish in magnitude with temporal distance from the present. The other approach is to estimate (where possible) parameters defining initial conditions.

Because of the significance (in both time and magnitude) of the historical catch, this assessment used the second method (estimate) to develop initial conditions which are described as follows. Equilibrium catch is the catch taken from a stock for which removals and natural mortality are balanced by stable recruitment and growth. This equilibrium catch can be used to estimate the equilibrium fishing mortality rates (*Fs*) in the assessment model. This assessment did not fit to equilibrium catch (no influence on the total likelihood function for deviating from assumed equilibrium catch) therefore freely estimating equilibrium *Fs*. Equilibrium *Fs* were estimated for the Japanese longline (Fleet 1) and Japanese set-net seasons 1-3 (Fleet 8) because they represented fleets that take large and small fish. This parsimonious approach allows for a departure from the virgin age structure implied by *M* for both young and old fish somewhat separately. In addition, an equilibrium offset from the S-R relationship and ten recruitment deviations prior to the start of the dynamic period were estimated to allow more flexibility in the population age-structure to better match size composition information available at the start of the dynamic period.

4.3.2 Selectivity

Selectivity is the observation model process that links composition data to underlying population dynamics. For non-spatial models, this observation model process combines contact selectivity of the gear and population availability to the gear. The former is defined as the probability that a fish of a given size/age is caught by the gear and the latter is the probability that a fish of a given size/age is spatially available to the gear. In the case of PBF, variable trans-Pacific movement rates of juvenile fish cause temporal variability in the availability component of selectivity for those fisheries catching juveniles. The use of time-invariant selection results in poor fits to the composition data which has adverse consequences on fits to other prioritized data.

Our approach to deal with this issue was to use a combination of model process (time varying selectivity) and data weightings to insure adequate fit to fleets that caught high numbers of fish since 1990 and to reduce misfit to size composition which could adversely affect model performance. In general, fleets with large catches of migratory ages, good size composition data, and no CPUE were modelled with time-varying selection (Lee et al. 2015a). Fleets taking only age 0 or adults were treated as time-invariant unless fleet fishing patterns changed and blocks of time-invariant selection were used (e.g. Fleet 1). Fleets with small catches or poor size composition data were either aggregated with similar fleets or given low weights.

Fishery-specific selectivity was estimated by fitting length composition data for each fleet except Fleets 3, 7, 11, 15, and 16, whose selectivity patterns were fixed and borrowed from other fleets based on the similarity of size of fish caught of the fleet (Table 4-1). The size composition for Fleets 3 and 11 were combined to Fleets 2 and 10, respectively; however, the size composition data for Fleet 7 were not used to estimate its selectivity due to poor quality of sampling. The selectivity for Fleet 6 was used to represent the selectivity for Fleet 7. The size composition data for Fleets 15 and 16 were not used to estimate their selectivity due to the limited observations. The selectivity for Fleet 13 was used to represent the selectivity for Fleet 15 and the selectivity for Fleet 16 was assumed to be 100% selected at only age 0.

Fleets with CPUE (Fleets 1, 6, and 12) were modeled as time-invariant (within blocks of time as appropriate) length-based selection patterns to account for the gear selectivity. Due to the nature of their size compositions, typically a single well-behaved mode as well as non-migratory ages caught by these fleets (either age 0 fish or spawners), functional forms of logistic or double normal curves were used for the CPUE fleets. The choice of asymptotic (logistic curves) or dome-shaped (double normal curves) selection patterns was based on the assumption that at least one of the fleets sampled from the entire population above a specific size (asymptotic selectivity pattern) to stabilize parameter estimation. This assumption was evaluated in the previous study and it was indicated that the Taiwanese longline fleet (Fleet 12) consistently produced the best fitting model when asymptotic selection was used (Piner 2012). The assumption along with the observed sizes and life history parameters, sets an upper bound to population size. Selection patterns were assumed to be dome-shaped (double normal curves) for Fleets 1 and 6.

Fleets without CPUE were categorized into fleets taking fish of non-migratory ages (age 0 fish or spawners for Fleets 2, 17, and 19) and fleets taking fish of migratory ages (ages 1-5 for Fleets 4, 5, 8, 9, 10, 13, 14, and 18). Non-CPUE fleets taking fish of non-migratory ages were modeled as time-invariant length-based selection patterns to account for the gear contact, assuming that availability was temporally constant. Due to the nature of their size compositions with a single well-behaved mode, functional forms of double normal curves were used. Fleets taking fish of migratory ages and without CPUE, separate length- and age-based selectivity patterns were estimated (Lee et al. 2015a). A time-invariant length-based selection pattern was estimated to account for gear selection and time varying age based selection was estimated to approximate the un-modelled process of age-based movement (Fleets 4, 5, and 18). The length-based selection was modeled as asymptotic or dome-shaped while age-based selection was modeled assuming a separate selection parameter for each age. Separate time-varying age selection parameters were estimated for migratory ages. Selection for each fleet is a product of the age and length based selection patterns. Because of the large number of parameters involved, fleets without significant catch (Fleets 8, 9, and 10), did not include the time-varying age-based component. The two EPO fleets (Fleets 13 and 14) were modelled with time-varying length based selection due to changes in the contact selectivity of the gears.

4.3.3 Catchability

Catchability (*q*) was estimated assuming that each index of abundance is proportional to the vulnerable biomass/numbers with a scaling factor of *q* that was assumed to be constant over time. Vulnerable biomass/numbers depend on the fleet-specific selection pattern and underlying population numbers-at-age.

4.4 Likelihood Components

4.4.1 Observation error structure

The statistical model estimates best-fit model parameters by minimizing a negative log-likelihood value that consists of likelihoods for data and prior information components. The likelihood components consisted of catch, CPUE indices, size compositions, and a recruitment penalty. The observed total catch data assumed a lognormal error distribution. An unacceptably poor fit to catch was defined as models that did not remove >99% of the total observed catch from any fishery. Fishery CPUE and recruitment deviations were fit assuming a lognormal error structure. Size composition data assumed a multinomial error structure.

4.4.2 Weighting of the Data

Three types of weighting were used in the model: (1) weighting among length compositions (effective sample size), (2) weighting catch, and (3) CPUE data.

Weights given to catch data were S.E.=0.1 (in log space) for all fleets, which can be considered as relatively good precision to catches. Weights given to the CPUE series were assumed to be CV=0.2 across years unless the standardization model produced larger uncertainty and that model estimate was used. The weights given to fleet-specific quarterly composition data were done on a relatively ad hoc basis, and might be subjective decisions about the quality of measurements (e.g. weights converted to lengths). Sample sizes were generally low (<15 N) and were set based on the number of well-measured samplings from the number of hauls or daily/monthly landings (Table 4-1) except for the longline fleets. For longline fleets, because only the number of fish measured are available (number of trips or landings measured were not available), sample size was scaled relative to the average sample size and standard deviation of sample size of the all other fisheries based on the number of fish sampled.

4.5 Model Diagnostics

4.5.1 Adequacy of fit

Fit to all data was evaluated by residual analysis and the ratio of inputted sample weights to model estimates of the weights. Residual plots evaluated trends in residuals as well as the magnitude of the residuals. Inputted weights in excess of model estimates of the weight to that data source were considered diagnostic of lack of fit.

4.5.2 Retrospective and R_0 profiling analyses

Two diagnostics were performed to evaluate the influence of residual misfit on model results. Retrospective analysis was performed on the final model via the subsequent removal of the terminal year of data. 9-year retrospective analysis was evaluated for temporal trends in spawning biomass. Model without significant one-way bias would be considered as a positive diagnostic.

A likelihood profile across the population scale estimate of $\log(R_0)$ was used to evaluate which data sources were providing information on global scale (Lee et al. 2014). Data components with a large amount of information on population scale will show significant degradation in fit as population scale was changed from the best estimate. A model with global scale estimated that was consistent with the information provided by the primary tuning indices would be considered as a positive diagnostic.

4.5.3 Convergence Criteria

A model was not considered converged unless the hessian was positive definite. Convergence to a global minimum was further examined by randomly perturbing the starting values of all parameters by 10%, and randomly changing the ordering of phases of global parameters used in the optimization of likelihood components prior to refitting the model. These analyses were conducted as a quality control procedure to ensure that the model was not converging on a local minimum.

4.5.4 Sensitivity analysis

The effect of model assumptions that could not be incorporated with the base-case model fitting were evaluated via sensitivity analysis. In each sensitivity run an assumption of the model was changed and the model re-run to examine effects on derived quantities. Sensitivity runs include the changes to the base-case model of the followings:

1. Natural Mortality

2. Steepness

3. Variance of Length at Age

4. Time-varying selectivity for JPLL

5. Data-weighting of size composition data

4.6 Projections and Biological Reference Points

4.6.1 Projections

Projections were conducted outside the integrated model using forecasting software described by Akita et al. (2015, 2016). This projection was based on the results of the base-case model. Each projection was conducted from 300 bootstrap replicates followed by 20 stochastic simulations. The base-case model replicates were derived by estimating parameters using SS and fishery data generated with parametric resampling of residuals from the expected values. The same error distributions were assumed with the stock assessment using SS. These projections could include parameter uncertainty of the stock assessment model because of the bootstrap runs, which included estimation of model parameters.

Future recruitment is randomly resampled from the whole stock assessment period (1952-2014) for the average recruitment scenario, and also resampled from the relatively low recruitment period (1980-1989) for the assumed low recruitment scenario. The PBFWG decided to also examine a future population dynamics under an assumption of possible stronger stock-recruitment relationship (with a steepness value of 0.9) than that assumed in the stock assessment. For this analysis, Akita et al. (2016) enabled to resample deviations from around a specified spawner recruit relationship. The SR option assumed a steepness=0.9 and fit $\log(R_0)$ to the model estimates of recruitment and spawning biomass, then those deviations were resampled from the whole stock assessment period for computing future recruitment.

Several alternative harvest scenarios were examined using both recruitment states of nature (resample recruitment or deviations around the SR relationship) (Table 4-2). Harvesting scenario 1 approximates the scenario which formed the basis of the conservation advice in the last stock assessment (scenario 6 at that assessment). Harvesting scenario 2 approximates the conservation and management measures which are currently in force in the WCPFC convention area (WCPFC CMM15-04) and IATTC convention area (IATTC Resolution C14-06). For the EPO commercial fishery, since the IATTC Resolution apply only a catch limit, constant catch limit of 3,300 tons with maximum F level twice as much as that in 2002-2004 are assumed in this future projection to consume all the quota. Scenarios 3 and 4 were examined to investigate the effects of the different thresholds of small and large fish than currently defined in the WCPFC CMM. For these analyses, average catch of PBF under the different definition of small fish and large fish (50 and 80 kg) were calculated from the catch and size composition data, and catch limits for each fishery was re-defined based on the management measures of WCPFC and IATTC. Scenarios 5-10 were examined to assess the effects of more conservative management measures which are depicted as the further reduction of catch limit in certain percentage (10% and 20%) for either small fish only or large fish only or all sized fish. Scenario 11 approximates the “Status Quo” which assumed the most current fishing mortality estimates (F2011-2013 average) will continue in the future with keeping catch limits prescribed in the management measures of WCPFC and IATTC.

4.6.2 Biological Reference Points

Because there is no adopted F-based biological reference points, a suit of alternative F-based reference points were evaluated: (1) growth overfishing reference points (F_{max}, $F_{0.1}$), (2) historical time series reference points (F_{MED}, F_{loss}), and (3) spawning potential ratio reference points ($F_{20\%}$, $F_{30\%}$ and $F_{40\%}$). . Two biomass-based reference points were calculated: (1) equilibrium depletions (terminal SSB/unfished SSB from the base-case model) was used to characterize current stock status and (2) SSB_{MED} (historical median SSB) was used as the interim rebuilding target to evaluate success of projection scenarios.

5.0 STOCK ASSESSMENT MODELLING RESULTS

5.1 Model Convergence

All estimated parameters in the base-case model were within the boundaries and the final gradient of the model was 0.00046. The model hessian was positive-definite and the variance-covariance matrix could be estimated. Based on the results from 120 model runs with the random perturbations of initial values and phasing, the base-case model likely converged to a global minimum with no evidence of further improvements on the total likelihood (Figure 5-1 and Figure 5-2).

5.2 Model Diagnostics

5.2.1 Likelihood Profiles on fixed log-scale Unfished Recruitment (log R_0)

Results of the profile of total and component likelihoods over fixed log(R_0) for the base-case model are shown in Figure 5-3. Relative likelihood values represent the degradation in model fit (for each component, negative log-likelihood for each profile run minus the minimum component negative log-likelihood across profiles). A relative likelihood value = 0 indicates that data component was the most consistent with that fixed population scale. The smallest values of log(R_0) for recruitment penalty, all combined CPUEs component, and all combined size composition were 9.60, 9.50, and 9.50, respectively, which were consistent with the smallest values of log(R_0) (9.53) for the total likelihood (Figure 5-3 (A)).

The main data components which strongly influence the global scaling of log(R_0) were the recruitment penalty (low side), size compositions (both low and high side), and abundance indices (high side); however, catch component did not have much impact on log(R_0). The relative likelihood values of combined size composition data were larger than those of abundance indices. The strong influence of recruitment penalty on the low side of log(R_0) could be resulted from large negative recruitment deviations in some years in the runs when log(R_0) was fixed at low values.

As for the size composition components, Taiwanese longline composition data (fleet 12) had the greatest influence (high side) on log(R_0) due to its strong assumption (asymptotic) about the selection (Lee et al. 2014) (Figure 5-3 (B)). In addition, the purse seine fleets (fleets 4, 13, and 14), which contributed large amount of catch for age 1-7 PBF, had strong impact on the low side of log(R_0) profile. Fleets 1, 9, and 10 were relatively important for the scaling of log(R_0) although these fleets did not contribute as large amount of catch as purse seine fleets. The rest of the size composition components did not have much influence on the scaling of log(R_0).

All of the abundance indices provided consistent information on population scale except CPUE for S2 (Japanese longline early period) (Figure 5-3 (C)). The influence of this CPUE to the log(R_0) was on the low side of scale, while the rest of the CPUEs affected mainly on the high side or both sides.

In general, the base-case model resulted in an internally consistent model regarding population scale, demonstrated by relative likelihood values for composition component < 5 units and those for index component < 1 unit at the log(R_0) when estimated.

5.2.2 Goodness-of-fit to Abundance Indices

Predicted and observed abundance indices with variation (section 3.5.2) by fishery for the base-case model are shown in Figure 5-4. The fits were generally within 95% CI for all of the abundance indices. In particular, the base-case model fit very well to the S2, S3 (Japanese longline early and middle periods), and S5 (Japanese troll) indices; the root-mean-squared-error (RMSE) between observed and predicted abundance indices for these indices were close to or less than 0.2, which was the input CVs for these indices.

The model also fit well to the terminal indices of S1 and S9, which were Japanese and Taiwanese longline CPUEs (RMSE < 0.3). In the 2014 stock assessment, the model did not fit well to both indices (RMSE > 0.4) due to the conflicting trends (ISC 2014). The improvement of the CPUE standardization for both Japanese and Taiwanese longline CPUEs minimize the conflict given the 2016 based-case model structure.

5.2.3 Goodness-of-fit to Size Compositions

The model fits the size modes in data aggregated by fishery and season fairly well given the estimated effective sample sizes (effN) in the base-case model (Figure 5-5 and Table 5-1), where the average effNs are larger than the average input sample sizes indicating precise estimates for the base-case model.

However, it should be noted that although the aggregated fits were reasonable, the residual plots showed large misfit in some years (e.g. Fleet 6) (Figure 5-6). In addition, some size composition data still showed residual patterns with additional time-varying process (e.g. Fleet 4). The model misfits to the size composition data occurred for fisheries that predominantly caught juvenile or small adult. The size composition data for these fleets were relatively variable seasonally and inter-annually, which may be due to variability in the growth pattern or un-modelling migration patterns. The base-case model may not be able to incorporate those biological processes sufficiently. The PBFWG noted that further work on growth is needed for the improvement of model fits to the size composition data in future assessment (ISC 2016).

The 2014 model did not fit well to most of the size compositions due to conflicting scale among data sources (ISC 2014). In comparison, additional selectivity process added in the 2016 base-case model minimizes the conflict and improves the size composition data fits.

5.2.4 Retrospective Analysis

The retrospective analyses showed no substantial pattern of overestimating or underestimating SSB for recent 9 terminal years (Figure 5-7). The PBFWG concluded that the 2016 base-case model is internally consistent among the data source.

5.3 Model Parameter Estimates

5.3.1 Recruitment Deviations

A Beverton-Holt relationship based on a steepness value of h=0.999 was used for the base-case model, and stock and recruitment plots are presented in Figure 5-8. The estimated recruitment deviations were relatively precise after 1990 indicating that these periods were well informed by data. Since the predicted variability of recruitment deviations is lower than assumed recruitment variability ($\sigma R = 0.6$, RMSE between expected recruitment from stock recruitment curve and predicted recruitment for main recruitment period [1953-2014] were 0.53), the estimated population scale and recruitment would not be substantially affected by the recruitment penalty (σR) or assumptions on steepness.

5.3.2 Selectivity

The estimated selectivity curves by fleet for the base-case model are shown in Figures 5-9 and 5-10. In this assessment, both of the length-based and age-based selectivity were estimated for Fleets 4, 5, 8, 9, 10, and 18. The length-based selections were estimated as asymptotic or dome-shaped while age-based selections were estimated for each age. Temporal variations in the age-based selectivity were captured for Fleets 4, 5, and 18. For the rest of the fleets with estimated length-based selectivity (Fleets 1, 2, 6, 12, 13, 14, 17, and 19), dome-shaped patterns were estimated except for Fleet 12 with logistic pattern. Among these fisheries, temporal variations were captured for Fleets 1, 13, and 14. This configuration is newly developed by the PBFWG taking into account traits of each fishery given its importance of catch, gear contact and availability, goodness of fit to size composition data, and minimal impact of misfit on size composition data.

In summary, 259 selectivity parameters were estimated in the base-case model. The most of selectivity parameters were well-estimated with precise estimates, although several parameters still had high uncertainty in their estimation due to the number and/or quality of observations, and/or high correlation among selectivity parameters. As for the dome-shaped length-based selectivity parameters, width of the plateau for Fleet 1 (between 1993 and 2014), Fleet 2, and Fleet 17, ascending slope parameters of Fleet 13 (1955, 1960, 1976) and Fleet 14 (2008, 2011), and descending slope parameters of Fleet 14 (2006) and Fleet 17 had large coefficient of variation (CV ≥ 70%). As for the age-based selectivity parameters, parameters with old-aged fish selected had large coefficient of variation (CV ≥ 70%) such as Fleet 4, Fleet 5, Fleet 8, and Fleet 9.

Japanese longline fisheries (Fleet 1) had dome-shaped selectivity during 1952-1992 with a peak length at around 190 cm. However, Fleet 1 after 1993 selected a portion of large size fish, which reflected the observation of larger size fish in its size data. Fleet 2 had a dome-shaped selectivity with the peak length at around 50 cm. Fleet 4 had logistic length selectivity with full selection from around 130 cm and highly variable age specific selectivity over time mainly caught from age 3 to 7. Fleet 5 had a similar nature with the Fleet 4, although it assumed less temporary variable age specific selection than Fleet 4 for the sake of limiting the number of parameters due to limited observations. Fleet 6 had dome-shaped selectivity with a peak length at around 50 cm. Fleets 8-10 had similar selectivity patterns which selected wider age range of fish mainly from age 0 to 5. Fleet 12 had logistic selectivity which fully selected from about 230 cm fish. Both Fleets 13 and 14 had highly variable selectivity over time which mainly selected 60-130 cm fish, although Fleet 14 selected slightly larger size fish than Fleet 13 possibly due to the change of the nature of fisheries (Aires-da-Silva et al. 2012). Fleet 17 had dome-shaped length selection pattern which caught the largest size range of fish. Fleet 18 had dome-shaped selectivity with the peak length between 50 and 80 cm, although selection of age 0 and 1 fish varied over time. Fleet 19 had dome-shaped length selectivity which selected the smallest range (around 20 cm in peak) of fish.

5.4 Stock Assessment Results

5.4.1 Total and Spawning Stock Biomass

Point estimates of total stock biomass from the base-case model showed long-term fluctuations (Table 5-2 and Figure 5-11) ranging from a low of about 29,300 t in 1983 to a high of about 209,000 t in 1960.

Spawning stock biomass (SSB) estimates also exhibited long term fluctuations which is consistent with that of total stock biomass. Estimates of SSB at the beginning of quarter 4 (April-June) in the first five years (1952-1956) of the assessment period averaged approximately 90,100 t. The highest SSB of about 160,000 t occurred in 1961 while the lowest SSB of about 11,400 t occurred in 1984. In the 1990s, SSB reached its second highest level of about 61,800 t in 1996 and declined to about 11,500 t in 2010. The decline appeared to have ceased since 2010, and showed a tendency of slight increase.

The quadratic approximation to the likelihood function at the global minimum, using the Hessian matrix, indicated that the CV of SSB estimates was about 20% on average for 1980-2014, and 19% for 2014, although that on average for 1952-1979 was about 39%.

The unfished SSB (SSB_0) was estimated by extrapolating the estimated stock recruit relationship under the equilibrium assumptions to be about 650,000 t (R_0 = 13.8 million fish). The depletion ratios (SSB/SSB_0) of the assessment period ranged from 1.8% to 25%. The second peak (1996), a trough in the most recent year (2010) and terminal year (2014) of SSB corresponded 9.6%, 1.8% and 2.6% of the SSB0, respectively.

5.4.2 Recruitment

Recruitment (age 0 fish on July 1st) estimates fluctuated widely without an apparent trend. Recent strong cohorts occurred in 1994 (28.6 million fish), 1999 (23.6 million fish), 2004 (26.4 million fish) and 2007 (21.7 million fish) (Table 5-2 and Figure 5-11). The average estimated recruitment was approximately 13.4 million fish for the entire stock assessment period (1952-2014). The 2014 recruitment was estimated to be relatively low (3.6 million fish) and the average recruitment level for the last five years (10 million fish) may have been below the historical average level. PBFWG acknowledged high uncertainty of the recruitment estimates in terminal years in an assessment due to limited information on the cohort, though two of the last three data points (2012-2014) from the Japanese troll CPUE based index of recruitment, which was consistent with other data in the model, were at their lowest level seen since the start of the index (1980).

Recruitment estimates were less precise at the start of assessment period to 1970's (average CV = 23%, maximum CV = 44%) and became moderately precise from 1980 to 1993 (average CV = 17%, maximum CV = 26%) when CPUE-based recruitment indices from the Japanese troll fishery became available. After 1994, recruitment estimates had further improved in their precision (average CV = 7%) due to the comprehensive size data collection for Japanese fisheries that began in 1994.

5.4.3 Catch at Age

Catch number of PBF at each age was estimated internally in the stock assessment model based on the growth assumption, observed catch, and selectivity estimated by fitting to the size composition data. Because of this nature to estimate the catch in number of PBF in each age, estimated results are usually uncertain if the size composition data are limited. Since there was a big gap in the size information available before and after 1994 (Figure 5-12), PBFWG acknowledged a possible uncertainty in the estimated catch number at age before early 1990's.

Historically, PBF catches were predominately composed of juveniles (age 0-2), and the estimated number of fish caught showed a fluctuations ranging from a low of one million fish in 1959 to a high of 4 million fish in 1978 during 1950's to early 1990's. However, since the early 1990's, the catch of age 0 PBF has increased significantly, and consequently the estimated number of fish caught were fluctuated around the average of 4 million (Figure 5-12). In the recent 3 years (2012-2014), average number of fish caught were lower than that of 1990's and 2000's.

5.4.4 Fishing Mortality at Age

Annual fishing mortality-at-age was calculated externally by solving the Baranov catch equation using the estimated numbers of fish-at-age at the beginning of the first quarter and the estimated annual catch-at-age matrix from the base-case model (Figure 5-13 and Table 5-3). Throughout the stock assessment period (1952-2014), average fishing mortality for age 0-2 juveniles (0.65) was higher than that for age 3+ fish (0.09). The average F of age 1 fish during 1995-2013 was 1.10, while average Fs of age 0, 2 and 3 fish were 0.62, 0.54, and 0.14, respectively. The average F of age 4+ fish during the same period was 0.15.

5.5 Sensitivity Analysis

5.5.1 Natural Mortality

Both of the high and low alternative natural mortality scenarios only showed difference in the first and second peaks of SSB (Figure 5-14) and the terminal SSB was not affected substantially by the mortality scenarios. The PBFWG concluded that the base-case model is not sensitive to different assumptions for natural mortality.

5.5.2 Steepness

The base-case model could not converge for lower steepness, indicating that the model is fine-tuned to explain data under current assumption of steepness. Note that this result does not imply a justness of the current setting of high steepness, thus the PBFWG considered the issue needs to be further investigated in future.

5.5.3 Variance of Length at Age

Estimation of the standard deviation of the variation of length at age was problematic resulting in convergence issues. Estimating the two parameters of the variation of length at age resulted in a substantial improvement in fit (45 log-likelihood units). The trend in the spawning biomass was similar, but the spawning biomass was estimated to be moderately larger. Changing the upper reference age for the relationship between the standard deviation of the variation of length at age and mean length, while estimating the standard deviation parameters, provided a worse fit to the data and the estimates of biomass were similar to those estimated with fixed parameters. Given the size composition data as well as length at age data, the PBFWG recognized that the current approach of the base-case model on growth and its variability are not unreasonable and decided to use these growth function and CVs as function of age. Nevertheless, the PBFWG prioritized the improvement of knowledge about PBF growth to better estimate of the right number of fish caught at right age for a future assessment.

5.5.4 Time-varying selectivity for JPLL

A sensitivity run which assumed time varying selectivity for Japanese longline (TVS_JLL_run) (Fleet 1) fits better to the Fleet 1 size composition data than the base-case. The difference in the component likelihood for Fleet 1 was not very large (about 15), even though this sensitivity run estimated 60 more parameters than the base-case. TVS_JLL_run also fits well to the terminal longline CPUEs (S1 and S9). The age-structure of the TVS_JLL model in 2014 differs somewhat from the base-case model with higher abundance for ages3-11 (Figure 5-15). SSB estimates were similar among runs except for the most recent couple of years where the TVS_JLL run showed a more rapid recovery than that of the base-case (Figure 5-16).

The PBFWG acknowledged the possibility of time varying selection by the Japanese longline fleet due to a change of fisherman's operation and/or size/age dependent migration of fish. However, since this selectivity is associated with the Japanese longline CPUE (S1), assuming time-varying selectivity will reduce the information of the relative abundance and the PBFWG chose the base-case model. The WG concluded that there is a need to further study the fishing processes of the Japanese longline fleet especially the spatio-temporal variation of size of the available PBF as well as its relative abundance.

5.5.5 Data-weighting of size composition data

An alternative scenario of the data re-weighting for the size composition data did not substantially affect to the estimated spawning biomass as well as the recruitment (Figure 5-17). Although the fits to the size composition data might be better in the re-weighting model than the base-case model, the base-case model showed better fit to the abundance indices. The WG considered that the specific method for re-weighting among the size composition data and then with the abundance indices requires further study and discussion. The base-case results were not sensitive to the alternative assumption of relative data weighting and the PBFWG chose the base-case model with prioritizing the fit to the abundance indices.

6.0 Future Projection

SSB_{MED} is defined as the historical median spawning stock biomass and is used by the WCPFC as the interim rebuilding target. However, the SSB_{MED} calculated for the projections and used to evaluate rebuilding strategy is not the same as the one used as one of the potential biological reference points. Point estimates of year-specific SSB from the base-case model, especially during 1950s-1970s, were generally above the median estimators from the bootstrap. This discrepancy between point estimates from the assessment and the bootstrap medians were also observed in previous stock assessments. In the projections reported in this document, the projection SSB_{MED} (38,000 t) is the median of the 300 individual SSB_{MED} calculated for each bootstrap simulation. The projection SSB_{MED} of 38,000 t is less than the base-case model SSB_{MED} (41,000 t), which is used as a potential biological reference point, and less than that used in WCPFC CMM (43,000 t). Probabilities of rebuilding to both 38,000 and 43,000 t are reported. Additional considerations regarding the calculation of SSB_{MED} include that point estimates of SSB in the base-case model are more uncertain during 1950s-1970s (Figure 5-11) due to the paucity of data prior to 1990 (Figure 3-1). The differential uncertainty in the estimated spawning biomass in the calculation of SSB_{MED} may need to be considered. The PBFWG also notes that the calculation of SSB_{MED} is not based on a fixed set of years. The calculation of SSB_{MED} included the addition of SSB estimated for the most recent years which were not available in prior assessments. Without a fixed range of years, the calculated value of SSB_{MED} will be influenced by the long-term trend in SSB.

Table 6-1 summarizes the results for the future projections in each harvesting and recruitment scenario. Within the first ten year simulation period (start from 2015 to 2024), the projection results indicated that the probability of SSB recovering to the interim rebuilding target at 2024 is 69% or above the level prescribed in the WCPFC CMM if recruitment is low (60% of average recruitment) and WCPFC CMM and IATTC resolution (C-14-06) continue in force and are fully implemented (Table 6-1: Scenario 2 with low recruitment, Figure 6-1).

Scenario 2, which assumed the largest catch limits, had the lowest prospect of recovery. This scenario with assumed future low recruitment indicates a low probability of reaching 10% of SSB0 by 2034. However, the prospect of recovery is highly dependent on the recruitment scenario, since the same scenario 2 with average recruitment has a high probability of achieving 20%SSB0 within a couple of decades (Figure 6-2).

The projection results assuming a stronger stock-recruitment relationship (where steepness h=0.9; namely SRR scenario) than in the assessment model are not necessarily more pessimistic than that of the low recruitment scenario (Figure 6-3). Under the harvesting scenario 2, predicted recruitment from S-R relationship with h=0.9 were relatively low due to the very low depletion level at the start of projection (Figure 6-4). However, those recruitments were still above the assumed low recruitment scenario, even though the lower 90% confidence interval were lower during the first 5 years of projection than those of the low recruitment scenario. The WG was yet to conclude the reasons for the relatively low recruitment estimations for the recent some years, but the projection result suggested that the current CMMs were robustly performed for the stock recovery in case there are stronger stock-relationship of h=0.9.

The probability of achieving the WCPFC's interim rebuilding target would increase if stricter management measures were implemented (Table 6-1). The projection results indicate that an additional 10% reduction in catch limit (Scenario 7) would provide a higher probability of reaching the interim target as well as a higher biomass by 2034 than scenario 2 (Figure 6-5). A 20% additional reduction in catch limit (scenario 10) is projected to provide an even higher probability of rebuilding to the interim target and larger biomass levels than Scenario 7, although if recruitment remains low only a 34% probability of achieving 20% SSB0 by 2034. The results of scenarios 5-10 also indicated that a reduction in the catch limit for small fish would have a larger effect on recovery than a reduction in the catch limit for large fish (Figure 6-6).

The change of the definition of “small fish” from the current definition used in WCPFC (30 kg) to the larger size affect generally positive regarding the stock recovery (Figure 6-7). Those effects would be brought by the lager reduction of catch due to a stricter catch limit for “small fish” compared with “large fish”, consequently providing a higher yield per a recruit ratio and F_{SPR} ratio such as $F_{10\%}$.

Scenario 11 (catch limits approximated current CMMs and F2011-2013) with low recruitment performed better than scenario 2, although average current (2011-2013) fishing mortality for intermediate ages (2-10 years) were higher than those of 2002-2004 (Figure 6-8). Good performance of scenario 11 was considered to be brought by the lower fishing mortality for age 0 fish than the 2002-2004 (Figure 5-13).

In summary, in the all scenarios explored, the probability of achieving the WCPFC’s interim rebuilding target were estimated to be above the level prescribed in the WCPFC CMM. The probability of rebuilding to the interim management target and biomass levels in the future will be higher with stricter catch management measures.

7.0 Stock Status and Conservation Advice accepted at ISC16 Plenary

7.1 Stock Status

The PBFWG conducted a benchmark assessment (base-case model) using the best available fisheries and biological information. For data considered reliable, the base-case model fits the data well and is internally consistent among most of the other sources of data. The model is a substantially improved from the 2014 assessment. The base-case model indicates: (1) spawning stock biomass (SSB) fluctuated throughout the assessment period (fishing years 1952-2014) and (2) the SSB steadily declined from 1996 to 2010; and (3) the decline appears to have ceased since 2010, although the stock remains near the historic low. The model diagnostics suggest that the estimated biomass trend for the last 30 years is considered robust although SSB prior to the 1980s is uncertain due to data limitations.

Using the base-case model in the 2016 assessment, the 2014 (terminal year) SSB was estimated to be around 17,000 t (Figure 7-4), which is about 9,000 t below the terminal year estimated in the 2014 assessment (26,000 in 2012). This is because of improvements to the input data and refinements to the assessment model which scaled down the estimated value of SSB, and not because the SSB declined from 2012 to 2014.

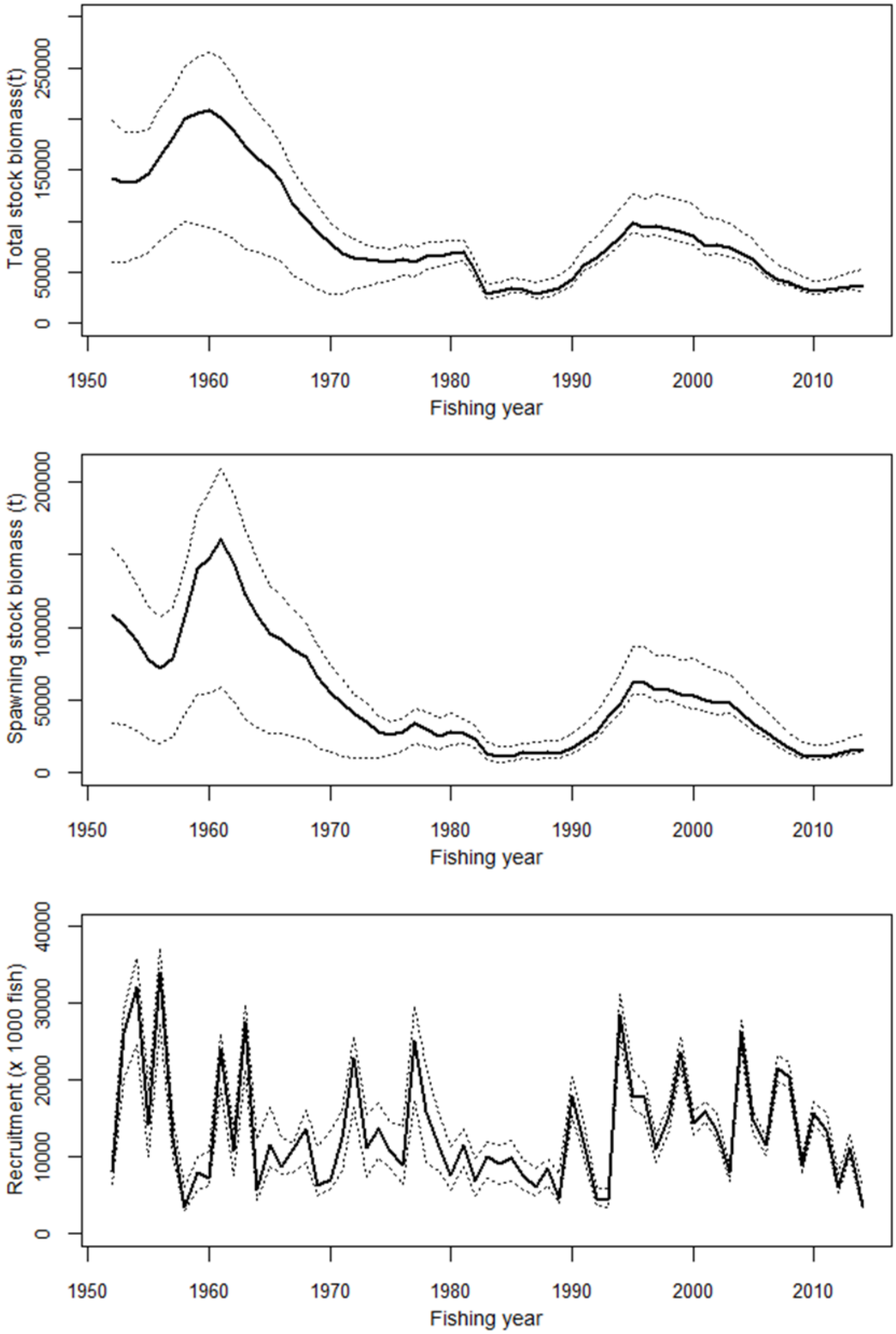


Figure 7-4 Total stock biomass (top), spawning stock biomass (middle) and recruitment (bottom) of PBF from the base-case model. The solid line indicates point estimate and dashed lines indicate the 90% confidence interval.

Recruitment estimates fluctuate widely without an apparent trend. The 2014 recruitment was relatively low, and the average recruitment for the last five years may have been below the historical average level (Figure 7-4). It should be noted that recruitment in terminal years of any assessment are highly uncertain due to limited information on the cohorts and this holds true for the 2016 assessment. However, two of the last three data points from the Japanese troll CPUE-based index of recruitment, which was consistent with other data in the model, are at their lowest level since the start of the index (1980). Estimated age-specific fishing mortalities on the stock during 2011-2013 and 2002-2004 (the base period for WCPFC CMM 2015-04) are presented in Figure 7-5. Most age-specific fishing mortalities (F) for intermediate ages (2-10 years) are substantially above F2002-2004 while those for age 0, as well as ages 11 and above are lower (Table 7-1).

Table 7-1. Percent change of estimated age-specific fishing mortalities of PBF from 2002-2004 to 2011-2013.

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
change from F2002−2004 to F2011−2013	−28%	−1%	+96%	+4%	+86%	+43%	−9%	+81%	+21%	+23%	+5%	−5%	−7%	−8%	−9%	−10%	−10%	−10%	−11%	−11%	−11%

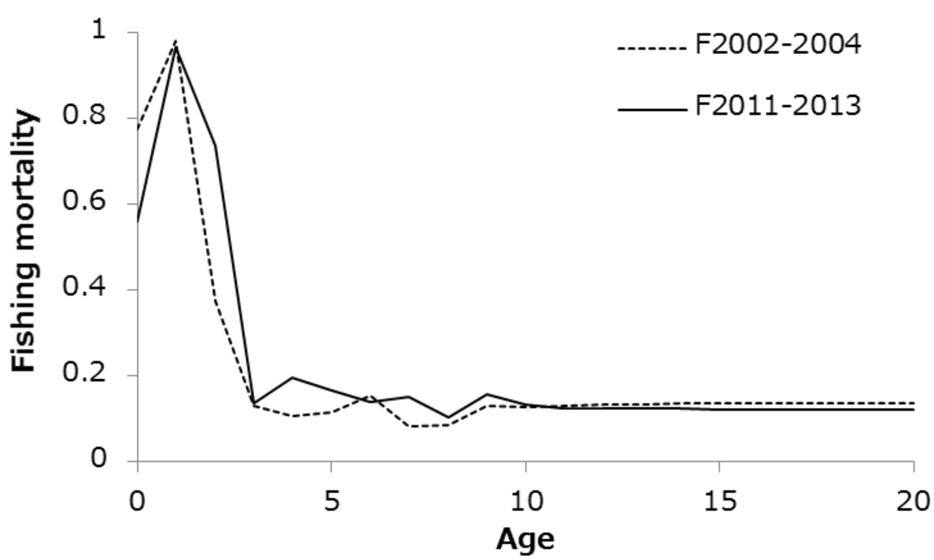


Figure 7-5. Geometric means of annual age-specific (years) fishing mortalities of PBF for 2002-2004 (dashed line) and 2011-2013 (solid line).

Although no limit reference points have been established for the PBF stock under the auspices of the WCPFC and IATTC, the F2011-2013 exceeds all calculated biological reference points except for FMED and FLOSS despite slight reductions to F in recent years

(Table 7-2). The ratio of SSB in 2014 relative to the theoretical unfished[4] SSB (SSB2014/SSBF=0, the depletion ratio) is 2.6%[5] and SSB2012/SSBF=0 is 2.1% indicating a slight increase from 2012 to 2014. Although the SSB2014/SSBF=0 for this assessment (2.6%) is lower than SSB2012/SSBF=0 from the 2014 assessment (4.2%), this difference is due to improvements in the input data and model structure rather than a decline in SSB from 2012 to 2014. Note that potential effects on Fs as a result of the measures of the WCPFC and IATTC starting in 2015 or by other voluntary measures are not yet reflected in the data used in this assessment.

Since no reference points for PBF have yet been agreed to at present, two examples of Kobe plots (Figure 7-6: plot A based on SSBMED and FMED, plot B based on SSB20% and SPR20%) are presented. These versions of the Kobe plot represent two interpretations of stock status in an effort to prompt further discussion. In summary, if these were the reference points, the stock would be approaching overfishing status in the case of FMED and the stock would be considered overfished. Plot B shows that the stock has remained in overfished and being-overfished status for the vast majority of the assessment period if F20% and SSB20% were chosen as reference points. The ISC notes that the SSB estimates before 1980 are more uncertain and that the reason why the fishing mortality is estimated to be so high right after the WWII is not well understood. The low biomass level at the beginning of the assessment period could potentially be the result of relatively high catches prior to the assessment period of PBF.

Table 7-2. Ratios of the estimated fishing mortalities F2002-2004, F2009-2011 and F2011-2013 relative to computed F-based biological reference points and SSB (t) and depletion ratio for the terminal year of the reference period for PBF.

	F_{max}	$F_{0.1}$	F_{med}	F_{loss}	$F_{10\%}$	$F_{20\%}$	$F_{30\%}$	$F_{40\%}$	Estiamted SSB for terminal year of each reference period	Depletion ratio for terminal year of each reference period
2002-2004	1.86	2.59	1.09	0.80	1.31	1.89	2.54	3.34	41,069	0.064
2009-2011	1.99	2.78	1.17	0.85	1.41	2.03	2.72	3.58	11,860	0.018
2011-2013	1.63	2.28	0.96	0.70	1.15	1.66	2.23	2.94	15,703	0.024

[4] "Unfished" refers to what SSB would be had there been no fishing.

[5] The unfished SSB is estimated based upon equilibrium assumptions of no environmental or density-dependent effects.

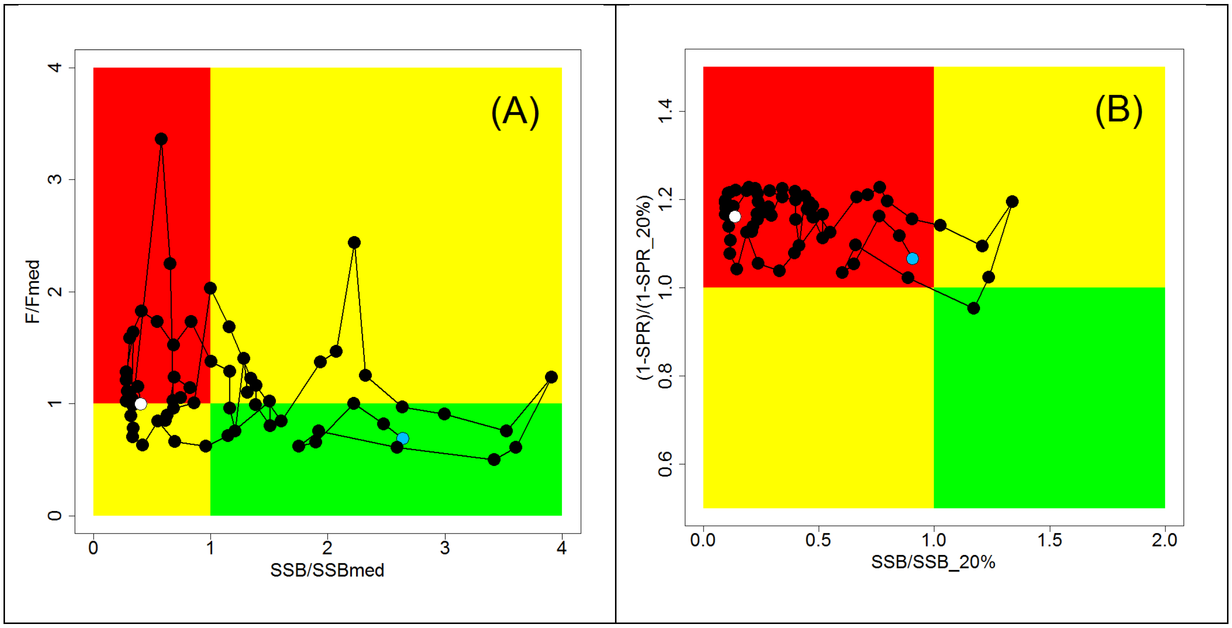
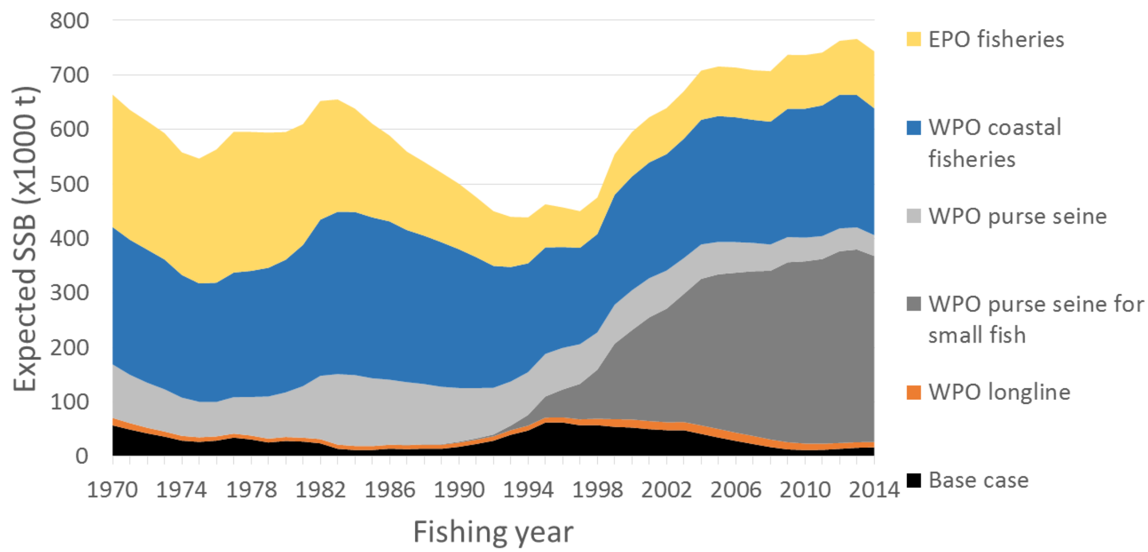


Figure 7-6 Kobe plots for PBF. (A) SSBMED and FMED; (B) SSB20% and SPR20%. Note that SSBMED is estimated as the median of estimated SSB over whole assessment periods (40,944 t) and FMED is calculated as an F to provide SSBMED in long-term, while the plots are points of estimates. The blue and white points on the plot show the start (1952) and end (2014) year of the period modeled in the stock assessment, respectively.

Historically, the WPO coastal fisheries group has had the greatest impact on the PBF stock, but since about the early 1990s the WPO purse seine fleets, in particular those targeting small fish (age 0-1), have had a greater impact, and the effect of these fleets in 2014 was greater than any of the other fishery groups. The impact of the EPO fishery was large before the mid-1980s, decreasing significantly thereafter. The WPO longline fleet has had a limited effect on the stock throughout the analysis period (Figure 7-7). This is because the impact of a fishery on a stock depends on both the number and size of the fish caught by each fleet; i.e., catching a high number of smaller juvenile fish can have a greater impact on future spawning stock biomass than catching the same weight of larger mature fish.



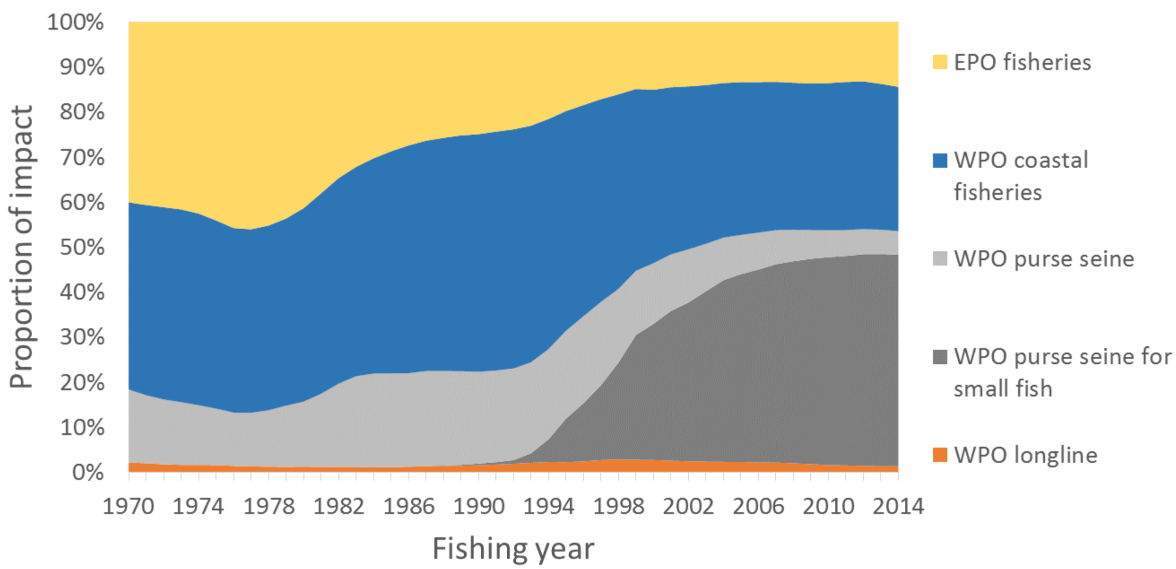


Figure 7-7. Trajectory of the spawning stock biomass of a simulated population of PBF when zero fishing mortality is assumed and recruitment series at F=0 is the same as estimated in the assessment, estimated by the base-case model. (top: absolute impact, bottom: relative impact). Fleet definition; WPO longline: F1, F12, F17. WPO purse seine for small fish: F2, F3, F18. WPO purse seine: F4, F5. WPO coastal fisheries: F6-11, F16, F19. EPO fisheries: F13, F14, F15

7.2 Conservation Advice

The steady decline in SSB from 1996 to 2010 appears to have ceased, although SSB2014 is near the historic low and the stock is experiencing exploitation rates above all calculated biological reference points except for FMED and FLOSS.

The projection results based on the base-case model under several harvest and recruitment scenarios and time schedules are shown in Table 7-3 and Figure 7-8. Under all examined scenarios the initial goal of WCPFC, rebuilding to SSBMED by 2024 with at least 60% probability, is reached and the risk of SSB falling below SSBLOSS at least once in 10 years was low.

The projection results indicate that the probability of SSB recovering to the initial WCPFC target (SSBMED by 2024, 38,000 t, calculated in the same manner as the previous assessment) is 69% or above the level prescribed in the WCPFC CMM if low recruitment scenario is assumed and WCPFC CMM 2015-04 and IATTC Resolution C-14-06 continue in force and are fully implemented (Table 4: Scenario 2 with low recruitment).

The ISC notes that there are technical inconsistencies in the calculation of SSBMED in the assessment and projection. The ISC also notes that the current calculation of SSBMED in the projection incorporates the most recent estimates of SSB and unless a fixed period of years is specified to calculate SSBMED, its calculation (SSBMED) could be influenced by future trends in spawning biomass. The ISC therefore recommends defining SSBMED as the median point estimate for a fixed period of time, either, 1952-2012 or 1952-2014. If 1952-2012 is chosen, then SSBMED is estimated to be 41,069 t, and if 1952-2014 is chosen, SSBMED is 40,994 t. The probabilities of achieving 41,000 t under various scenarios are provided in Table 7-3. The probabilities of achieving 43,000 t, where WCPFC CMM2015-04's initial rebuilding target is specified as 42,592 t, are also provided in Table 7 3, although this value is derived from the previous assessment and is higher than the SSBMED calculated in the current assessment. The ISC recommends that in the future absolute values should not be used for the initial rebuilding target, as the calculated values of reference points would change from assessment to assessment.

Scenario 2 with low recruitment has the lowest prospect of recovery among the examined harvest scenarios. The probability of achieving the WCPFC's initial target (SSBMED by 2024) would increase if more conservative management measures were implemented as shown in Table 7-3 and Figure 7-8. The projection results indicate that a 10% reduction in the catch limit for fish smaller than the weight threshold in CMM 2015-04 would have a larger effect on recovery than a 10% reduction in the catch limit for fish larger than the weight threshold. (Figure 7-8 (D)). The ISC further notes that the current assessment model uses a maturity ogive that assumes 20%, 50% and 100% maturity in age 3 (weight on July 1: 34kg), 4 (weight on July 1: 58kg) and 5 (weight on July 1: 85kg), respectively, while the WCPFC CMM 2015-04 specifies that catches of fish smaller than 30kg should be reduced. The weight threshold in the CMM needs to be increased to 85kg (weight of age 5) if the intent is to reduce catches on all juveniles according to the maturity ogive in the assessment.

The projections results assuming a stronger stock-recruitment relationship (where h=0.9) than in the assessment model (0.999) are not necessarily more pessimistic than the low recruitment scenario.

The projection results assume that the CMMs are fully implemented and are based on certain biological or other assumptions. In particular, the ISC noted the implementation of size based management measures need to be monitored carefully. If conditions change, the projection results would be more uncertain. Given the low SSB, the uncertainty in future recruitment, and the influence of recruitment has on stock biomass, monitoring recruitment and SSB should be strengthened so that the recruitment trends can be understood in a timely manner.

Harvesting Scenario #	Fishing mortality	Catch limit *		Threshold of Small/Large	Recruitment scenario **	Probability that SSB exceeds 38,000 tons (SSB median of Bootstrap analysis runs)			Probability that SSB exceeds 41,000 tons (SSB median of Basecase model) ***			Probability that SSB is more than 43,000 tons (SSBmed@last assessment)			Probability that SSB is more than 10%SSB0			Probability that SSB is more than 20%SSB0			Average Catch	
		Small	Large			2024	2029	2034	2024	2029	2034	2024	2029	2034	2024	2029	2034	2024	2029	2034	2019	2024
Scenario1	F2002-2004	scenario 6 in 2014 assessment		30 kg	Low recruitment	77.0%	88.8%	89.9%	69.7%	83.3%	85.2%	64.3%	79.3%	81.9%	14.7%	28.0%	31.8%	0.0%	0.0%	0.1%	11619.2	13574.9
Scenario2		50% of 2002-2004 average catch for WPO fisheries 3,300 tons for EPO commercial fisheries	2002-2004 average catch for WPO fisheries		Low recruitment	69.3%	83.7%	86.6%	61.5%	77.8%	82.3%	56.1%	73.9%	79.0%	13.6%	29.3%	35.4%	0.1%	0.4%	0.6%	11749.7	12994.2
					Average recruitment	99.6%	100%	100%	99.3%	100%	100%	99.3%	100%	100%	96.3%	99.8%	100%	73.8%	95.0%	98.0%	12958.4	14750.8
					Stock Recruit Relationship w/ h=0.9	98.2%	99.8%	99.9%	97.7%	99.8%	99.9%	97.5%	99.7%	99.9%	93.5%	99.4%	99.9%	72.0%	97.3%	99.6%	13087.3	15020.1
Scenario3		50% of 2002-2004 average catch		50 kg	Low recruitment	80.5%	91.5%	94.0%	73.8%	87.9%	90.7%	69.1%	85.1%	88.5%	22.2%	43.6%	51.7%	0.2%	0.9%	1.3%	11404.4	12672.3
Scenario4				80 kg	Low recruitment	86.4%	94.6%	96.5%	80.6%	91.9%	94.7%	76.6%	90.0%	93.0%	27.8%	51.8%	61.3%	0.2%	1.1%	1.6%	11292.6	12542.7
Scenario5		90% of scenario 2	same as Scenario 2	30 kg	Low recruitment	90.0%	96.5%	98.1%	85.3%	94.8%	97.0%	81.5%	93.4%	95.9%	35.0%	61.7%	70.4%	0.3%	2.5%	3.7%	11306.4	12881.3
					Average recruitment	99.9%	100%	100%	99.9%	100%	100%	99.9%	100%	100%	98.4%	100%	100%	82.2%	97.8%	99.3%	12442.0	14126.3
					Stock Recruit Relationship w/ h=0.9	99.4%	100%	100%	99.2%	100%	100%	99.1%	100%	100%	97.0%	99.8%	100%	81.8%	99.0%	99.9%	12576.4	14448.2
Scenario6		same as Scenario 2	90% of scenario 2		Low recruitment	75.3%	88.2%	90.2%	67.2%	82.9%	86.5%	61.7%	78.6%	83.4%	15.7%	32.5%	38.7%	0.1%	0.5%	0.7%	11496.2	12632.4
					Average recruitment	99.7%	100%	100%	99.6%	100%	100%	99.5%	100%	100%	96.8%	99.9%	100%	75.1%	95.2%	98.1%	12686.3	14071.5
					Stock Recruit Relationship w/ h=0.9	98.9%	99.9%	100%	98.6%	99.9%	100%	98.4%	99.9%	100%	95.0%	99.7%	100%	75.5%	98.0%	99.9%	12761.0	14379.7
Scenario7		90% of scenario 2			Low recruitment	90.3%	96.8%	98.3%	86.2%	95.4%	97.6%	82.7%	94.2%	96.8%	39.4%	68.0%	77.4%	0.5%	3.5%	5.6%	11231.0	12607.1
					Average recruitment	99.9%	100%	100%	99.9%	100%	100%	99.9%	100%	100%	98.5%	100%	100%	83.5%	98.1%	99.6%	12139.4	13461.7
					Stock Recruit Relationship w/ h=0.9	99.2%	100%	100%	99.1%	100%	100%	99.0%	99.9%	100%	96.9%	99.8%	100%	81.6%	99.0%	99.9%	11227.3	12461.8
Scenario8		80% of scenario 2	same as Scenario 2		Low recruitment	97.5%	99.6%	99.9%	96.1%	99.3%	99.7%	94.8%	98.9%	99.5%	65.4%	89.2%	94.0%	1.9%	14.5%	22.8%	10922.8	12688.4
Scenario9		same as Scenario 2	80% of scenario 2		Low recruitment	78.1%	89.9%	92.5%	70.4%	85.6%	88.8%	65.0%	81.9%	86.3%	18.4%	37.1%	44.7%	0.2%	0.6%	0.9%	11327.0	12329.9
Scenario10		80% of scenario 2			Low recruitment	98.3%	99.8%	99.9%	97.4%	99.6%	99.9%	96.3%	99.5%	99.8%	73.2%	93.8%	97.5%	3.1%	22.4%	34.1%	10585.9	11586.4
					Average recruitment	100%	100%	100%	100%	100%	100%	100%	100%	100%	99.7%	100%	100%	91.0%	99.5%	100%	11194.1	12104.9
					Stock Recruit Relationship w/ h=0.9	99.8%	100%	100%	99.7%	100%	100%	99.7%	100%	100%	98.7%	100%	100%	90.0%	99.7%	100%	11227.3	12461.8
Scenario11	F2011-2013	same as Scenario 2	same as Scenario 2		Low recruitment	82.6%	93.0%	95.0%	75.9%	89.9%	92.1%	71.3%	86.4%	89.9%	23.6%	46.2%	56.0%	0.1%	1.2%	1.6%	12266.8	13587.4

Table 7 3. Future projection scenarios for PBF and their probability of achieving various target levels by various time schedules based on the base-case model.

* Catch limits for EPO commercial fisheries is applied for all the catch (small and large fish) made by the Fleets.
** Average recruitment refers to the recruitment for the whole assessment period while low recruitment refers to that of 1980-1989.
*** Probability that SSB exceeds 41,000 tons (SSB median of Basecase model) developed by PBFWG at ISC16 Plenary.

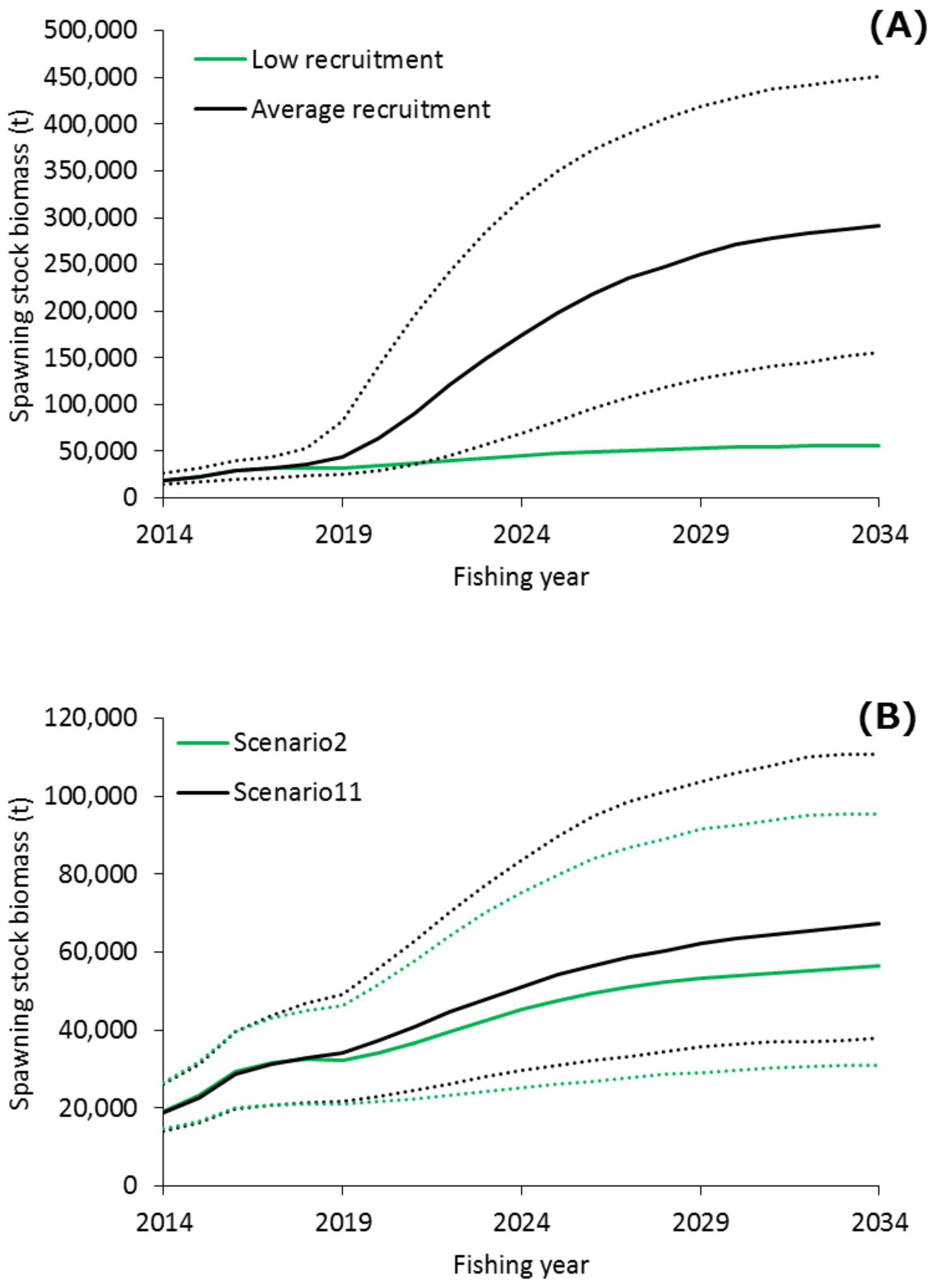


Figure 7-8. Comparisons of various projection results for PBF. (A) low recruitment vs. historical average recruitment (Scenario 2). (B) current CMMs (Scenario 2) vs. current F (Scenario 11) (low recruitment). The solid lines indicate median of bootstrapped projection results and dotted lines indicate 90% confidence interval.

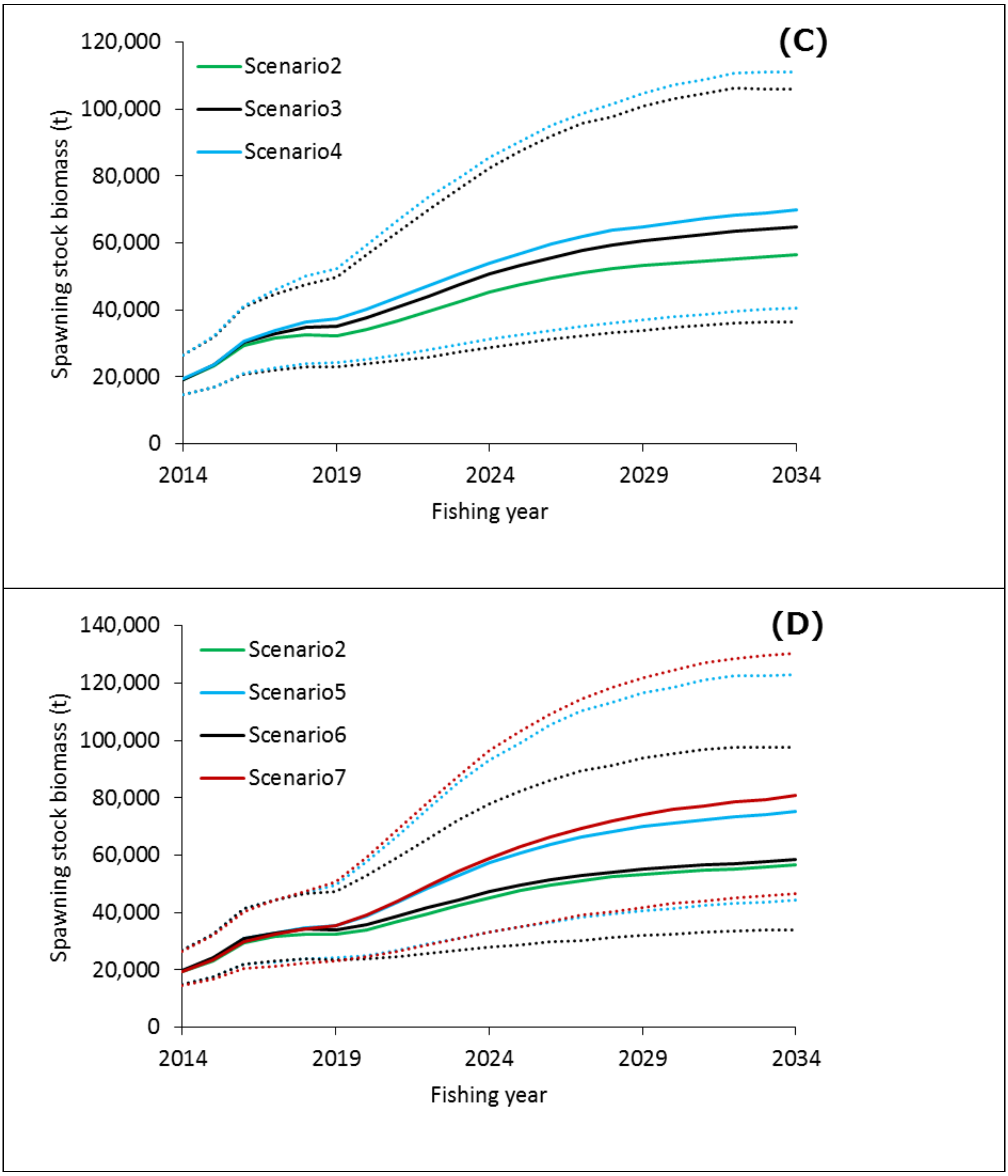


Figure 7-8 (cont.) Comparisons of various projection results for PBF. (C) different definition of small fish (30kg (Scenario 2) vs. 50kg (Scenario 3) vs. 80kg (Scenario 4)) (low recruitment). (D) current CMMs (Scenario 2) vs. additional 10% catch limit reduction for small fish (Scenario 5), for large fish (Scenario 6) and for all fish (Scenario 7) (low recruitment). The solid lines indicate median of bootstrapped projection results and dotted lines indicate 90% confidence interval.

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9.0 Table and Figure

Table 1-1. Definition of calendar year, fishing year, and year class used in the Pacific bluefin tuna (*Thunnus orientalis*) stock assessment.

Fishing year	2012				2013				2014				2015	
Season	Season 1	Season 2	Season 3	Season 4	Season 1	Season 2	Season 3	Season 4	Season 1	Season 2	Season 3	Season 4	Season 1	Season 2
SSB				SSB in 2012				SSB in 2013				SSB in 2014		
Day of birth in SS	Birthday of 2012 yr class				Birthday of 2013 yr class				Birthday of 2014 yr class				Birthday of 2015 yr class	
Recruitment	Recruitment in 2012				Recruitment in 2013				Recruitment in 2014				Recruitment in 2015	
Year class	2012 yr class				2013 yr class				2014 yr class				2015 yr class	
Calender year	2012		2013				2014				2015			
Month	7 8 9	10 11 12	1 2 3	4 5 6	7 8 9	10 11 12	1 2 3	4 5 6	7 8 9	10 11 12	1 2 3	4 5 6	7 8 9	10 11 12

Table 2-1. Age-length-weight relation derived from the von Bertalanffy growth curve and length-weight relationship used in the Pacific bluefin tuna (*Thunnus orientalis*) stock assessment.

Age	Length (cm)	Lt + SD	L t- SD	Weight (kg)
0	19.1	24.1	14.0	0.2
1	58.6	68.9	48.3	4.4
2	91.4	100.9	81.9	16.1
3	118.6	123.9	113.3	34.5
4	141.1	147.4	134.8	58.4
5	159.7	166.9	152.6	85.2
6	175.2	183.0	167.4	112.8
7	188.0	196.4	179.6	139.8
8	198.6	207.4	189.8	165.1
9	207.4	216.6	198.2	188.4
10	214.7	224.2	205.1	209.2
11	220.7	230.5	210.9	227.6
12	225.7	235.8	215.7	243.6
13	229.9	240.1	219.7	257.5
14	233.3	243.7	222.9	269.3
15	236.2	246.6	225.7	279.5
16	238.5	249.1	227.9	288.0
17	240.5	251.1	229.8	295.3
18	242.1	252.8	231.3	301.4
19	243.4	254.2	232.6	306.5
20	245.7	256.6	234.8	315.1

Table 3-1. Definition of fleets in the stock assessment of Pacific bluefin tuna (*Thunnus orientalis*).

Fleet #	Fleet name	Unit of Catch	Gears included				Catch-at-size data (Size bin definition)	Abundance index
			Representative component	Component 2	Component 3	Component 4		
Fleet 1	JPLL	Weight	JP Longline				Length bin	S1, S2, S3
Fleet 2	JPSPPS (Seas1, 3, 4)	Weight	JP SPPS (Season 1, 3, 4)				Length bin	
Fleet 3	KROLPS	Weight	KR OLPS	KR Trawl*1	KR Setnet*1	KR Troll*1	Length bin	
Fleet 4	JPTPSJS	Weight	JP TPSJS	TW PS*2			Length bin	S4, S13, S14
Fleet 5	JPTPSPO	Weight	JP TPSPO				Length bin	
Fleet 6	JPTroll (Seas2-4)	Weight	JP Troll (Season 2-4)				Length bin	S5, S6, S7, S8
Fleet 7	JPPL	Weight	JP Pole-and-Line	JP Driftnet*3	TW Driftnet*3	TW Others*4	Length bin	
Fleet 8	JPSetNet (Seas1-3)	Weight	JP Setnet (Season 1-3)	JP Miscellaneous (Season 1-3)			Length bin	
Fleet 9	JPSetNet (Seas4)	Weight	JP Setnet (Season 4)	JP Miscellaneous (Season 4)			Length bin	
Fleet 10	JPSetNet_HK_AM	Weight	JP Setnet in Hokkaido and Aomori				Weight bin	
Fleet 11	JPOthers	Weight	JP Handline & Tsugaru Longline	JP Trawl	JP OtherLL		Weight bin	
Fleet 12	TWLL (South)	Weight	TW Longline (South area)	Out of ISC PBFWG members (NZ, AUS, etc.)*5			Length bin	S9
Fleet 13	USCOMM (-2001)	Weight	US Commercial Fisheries (PS, Others)	MX Commercial Fisheries (PS, Others)			Length bin	S10
Fleet 14	MXCOMM (2002-)	Weight	MX Commercial Fisheries (PS, Others)	US Commercial Fisheries (PS, Others)			Length bin	S11
Fleet 15	EPOSP	Number	US Recreational Fisheries				Length bin	
Fleet 16	JPTroll4Pen	Number	JP Troll for Farming				Age (age-0 only)	
Fleet 17	TWLL (North)	Weight	TW Longline (North area)				Length bin	S12
Fleet 18	JPSPPS (Seas2)	Weight	JP SPPS (Season 2)				Length bin	
Fleet 19	JPTroll (Seas1)	Weight	JP Troll (Season 1)				Length bin	

*1 Catch for Korean Trawl, Korean Setnet and Korean Troll are **not included** in the input data used for the 2014 stock assessment.

*2 Annual catches for Taiwanese PS are put into the Season 1 in the input data for the 2014 stock assessment.

*3 Annual catches for Japanese and Taiwanese Driftnets are put into the Season 1 in the input data for the 2014 stock assessment.

*4 Annual catches for Japanese and Taiwanese Others are put into the Season 4 in the input data for the 2014 stock assessment.

*5 Annual catches of out of ISC PBFWG members are put into the Season 1 in the input data for the 2014 stock assessment.

Table 3-2. Quarterly catch of Pacific bluefin tuna (*Thunnus orientalis*) by fleet and fishing year for 1952-2014.

Fishing year	Season	Weight (t)																	Number (x 1000 fish)	
		Fleet1	Fleet2	Fleet3	Fleet4	Fleet5	Fleet6	Fleet7	Fleet8	Fleet9	Fleet10	Fleet11	Fleet12	Fleet13	Fleet14	Fleet17	Fleet18	Fleet19	Fleet15	Fleet16
1952	1	1073	0	0	0	4936	0	713	736	0	236	0	0	1951	0	0	0	23	0	0
1952	2	132	0	0	0	0	498	505	537	0	170	172	0	24	0	0	0	0	0	0
1952	3	145	0	0	0	0	282	796	503	0	0	0	0	0	0	0	0	0	0	0
1952	4	1898	0	0	0	1990	39	907	0	568	17	0	0	0	0	0	0	0	0	0
1953	1	764	0	0	0	3580	0	650	371	0	255	0	0	3843	0	0	0	51	3	0
1953	2	241	0	0	0	0	1098	706	458	0	186	131	0	590	0	0	0	0	1	0
1953	3	263	0	0	0	0	318	609	430	0	2	0	0	0	0	0	0	0	0	0
1953	4	1578	0	0	0	1917	44	815	0	1427	107	0	0	2289	0	0	0	0	0	0
1954	1	1096	0	0	0	3448	0	744	1109	0	861	0	0	6845	0	0	0	58	1	0
1954	2	178	0	0	0	0	1236	923	1032	0	613	219	0	403	0	0	0	0	0	0
1954	3	177	0	0	0	0	289	569	612	0	1	0	0	483	0	0	0	0	0	0
1954	4	1310	0	0	0	5008	40	761	0	1334	43	0	0	3131	0	0	0	0	1	0
1955	1	1172	0	0	0	9008	0	665	788	0	364	0	0	2467	0	0	0	53	4	0
1955	2	311	0	0	0	0	1125	862	889	0	260	101	0	93	0	0	0	0	0	0
1955	3	124	0	0	0	0	338	813	903	0	1	0	0	0	0	0	0	0	0	0
1955	4	1104	0	0	0	7496	47	1087	0	1180	38	0	0	0	0	0	0	0	0	0
1956	1	1521	0	0	0	13483	0	953	636	0	262	0	0	4753	0	0	0	62	30	0
1956	2	161	0	0	0	0	1316	1232	1134	0	185	192	0	974	0	0	0	0	2	0
1956	3	163	0	0	0	0	459	359	506	0	3	0	0	0	0	0	0	0	0	0
1956	4	905	0	0	0	6036	64	481	0	935	98	0	0	141	0	0	0	0	0	0
1957	1	566	0	0	0	12111	0	425	558	0	74	0	0	8779	0	0	0	84	6	0
1957	2	98	0	0	0	0	1785	545	830	0	25	194	0	296	0	0	0	0	0	0
1957	3	135	0	0	0	0	287	468	286	0	0	0	0	0	0	0	0	0	0	0
1957	4	384	0	0	0	3937	40	626	0	394	14	0	0	2635	0	0	0	0	0	0
1958	1	113	0	0	0	4650	0	541	189	0	10	0	0	11188	0	0	0	52	1	0
1958	2	211	0	0	0	0	1117	709	316	0	4	183	0	112	0	0	0	0	0	0
1958	3	371	0	0	0	0	141	117	365	0	1	0	0	0	0	0	0	0	0	0
1958	4	1573	0	0	0	4431	20	157	0	509	39	0	0	1278	0	0	0	0	0	0
1959	1	841	0	0	0	5565	0	135	227	0	29	0	0	2487	0	0	0	26	1	0
1959	2	916	0	0	0	0	550	178	408	0	10	153	0	0	0	0	0	0	0	0
1959	3	642	0	0	0	0	362	120	457	0	0	0	0	103	0	0	0	0	0	0
1959	4	4029	0	0	0	3475	50	161	0	562	15	0	0	1492	0	0	0	0	0	0
1960	1	706	0	0	0	7066	0	204	302	0	113	0	0	2912	0	0	0	66	0	0
1960	2	729	0	0	0	0	1407	182	504	0	80	302	0	40	0	0	0	0	0	0
1960	3	781	0	0	0	0	613	133	683	0	0	0	0	0	0	0	0	0	0	0
1960	4	3940	0	0	0	3356	85	177	0	863	16	0	0	1164	0	0	0	0	0	0
1961	1	1472	0	0	0	5768	0	170	430	0	12	0	0	6755	0	0	0	112	2	0
1961	2	597	0	0	0	0	2383	201	701	0	4	580	0	217	0	0	0	0	0	0
1961	3	800	0	0	0	0	323	149	566	0	1	0	0	108	0	0	0	0	0	0
1961	4	4331	0	0	0	3981	45	200	0	561	32	0	0	2376	0	0	0	0	0	0
1962	1	593	0	0	0	6677	0	176	744	0	71	0	0	8578	0	0	0	59	2	0
1962	2	459	0	0	0	0	1256	227	527	0	43	288	0	1	0	0	0	0	0	0
1962	3	541	0	0	0	0	488	251	528	0	2	0	0	72	0	0	0	0	0	0
1962	4	5130	0	0	0	3485	68	336	0	702	73	0	0	2428	0	0	0	0	0	0
1963	1	600	0	0	0	6301	0	305	406	0	240	0	0	9718	0	0	0	89	1	0
1963	2	255	0	0	0	0	1897	381	689	0	158	276	0	53	0	0	0	0	0	0
1963	3	313	0	0	0	0	534	208	598	0	1	0	0	17	0	0	0	0	0	0
1963	4	2321	0	0	0	3175	74	278	0	992	30	0	0	1768	0	0	0	0	0	0
1964	1	360	0	0	0	5798	0	246	562	0	49	0	0	7420	0	0	0	97	1	0
1964	2	260	0	0	0	0	2078	315	726	0	27	366	0	13	0	0	0	0	0	0
1964	3	322	0	0	0	0	377	229	518	0	1	0	0	26	0	0	0	0	0	0
1964	4	1945	0	0	0	4024	52	242	0	857	32	0	54	545	0	0	0	0	0	0
1965	1	160	0	0	0	7471	0	213	711	0	37	0	0	5400	0	0	0	69	0	0
1965	2	336	0	0	0	0	1465	200	690	0	18	313	0	918	0	0	0	0	0	0
1965	3	122	0	0	0	0	310	145	299	0	1	0	0	1	0	0	0	0	0	0
1965	4	862	0	0	0	3058	43	189	0	382	46	0	0	4873	0	0	0	0	0	0
1966	1	285	0	0	0	7025	0	188	161	0	57	0	0	11021	0	0	0	56	2	0
1966	2	275	0	0	0	0	1204	133	291	0	29	81	0	2	0	0	0	0	0	0
1966	3	218	0	0	0	0	628	285	847	0	2	0	0	16	0	0	0	0	0	0
1966	4	387	0	0	0	2376	87	373	0	570	61	0	53	3064	0	0	0	0	0	0
1967	1	246	0	0	0	4085	0	330	273	0	84	0	0	2768	0	0	0	114	3	0
1967	2	73	0	0	0	0	2443	261	728	0	44	259	0	40	0	0	0	0	0	0
1967	3	179	0	0	0	0	301	221	631	0	3	0	0	50	0	0	0	0	0	0
1967	4	140	0	0	0	3741	42	307	0	819	130	0	33	789	0	0	0	0	0	0
1968	1	135	0	0	0	5527	0	255	456	0	177	0	0	4812	0	0	0	55	1	0
1968	2	54	0	0	0	0	1171	206	755	0	93	206	0	325	0	0	0	0	0	0
1968	3	75	0	0	0	0	426	160	375	0	3	0	0	11	0	0	0	0	0	0
1968	4	661	0	0	0	1176	59	197	0	433	141	0	23	1608	0	0	0	0	0	0
1969	1	109	0	0	0	2061	0	184	294	0	319	0	0	5258	0	0	0	78	1	0
1969	2	54	0	0	0	0	1656	213	426	0	196	160	0	49	0	0	0	0	0	0
1969	3	37	0	0	0	0	230	178	232	0	3	0	0	14	0	0	0	0	0	0
1969	4	524	0	0	0	1274	32	204	0	433	140	0	0	1416	0	0	0	0	0	0
1970	1	23	0	0	0	1633	0	210	282	0	190	0	0	2534	0	0	0	42	1	0
1970	2	35	0	0	0	0	894	194	398	0	99	161	0	2	0	0	0	0	1	0
1970	3	181	0	0	0	0	286	234	163	0	4	0	0	31	0	0	0	0	0	0
1970	4	505	0	0	0	2835	40	269	0	284	171	0	1	4039	0	0	0	0	0	0
1971	1	19	0	0	0	887	0	230	200	0	340	0	0	3349	0	0	0	52	1	0
1971	2	43	0	0	0	0	1114	240	261	0	202	212	0	939	0	0	0	0	0	0
1971	3	47	0	0	0	0	162	297	199	0	3	0	0	3	0	0	0	0	0	0
1971	4	446	0	0	0	2049	23	78	0	215	111	0	14	2879	0	0	0	0	0	0
1972	1	15	0	0	0	2163	0	449	127	0	164	0	0	8861	0	0	0	29	1	0
1972	2	31	0	0	0	0	629	159	233	0	89	124	0	1603	0	0	0	0	0	0
1972	3	57	0	0	0	0	405	73	485	0	2	0	0	11	0	0	0	0	0	0
1972	4	799	0	0	0	464	56	160	0	501	70	0	33	2043	0	0	0	0	2	0

Table 3-2. Cont.

Fishing year	Season	Weight (t)																	Number (x 1000 fish)	
		Fleet1	Fleet2	Fleet3	Fleet4	Fleet5	Fleet6	Fleet7	Fleet8	Fleet9	Fleet10	Fleet11	Fleet12	Fleet13	Fleet14	Fleet17	Fleet18	Fleet19	Fleet15	Fleet16
1973	1	21	0	0	0	1803	0	419	359	0	277	0	0	8690	0	0	0	74	4	0
1973	2	25	0	0	0	0	1573	183	514	0	186	286	0	0	0	0	0	0	0	0
1973	3	30	0	0	0	0	318	450	1313	0	4	0	0	0	0	0	0	0	0	0
1973	4	1037	0	0	0	416	44	246	0	1403	155	0	47	1227	0	0	0	0	0	0
1974	1	105	0	0	0	3690	0	483	865	0	546	0	0	4238	0	0	0	58	6	0
1974	2	48	0	0	0	0	1236	363	1424	0	362	368	0	151	0	0	0	0	0	0
1974	3	29	0	0	0	0	198	806	287	0	1	0	0	0	0	0	0	0	0	0
1974	4	891	0	0	0	3415	28	132	0	349	73	0	61	3065	0	0	0	0	0	0
1975	1	121	0	0	0	1077	0	1096	309	0	605	0	0	5748	0	0	0	36	3	0
1975	2	61	0	0	0	0	769	50	378	0	431	132	0	769	0	0	0	0	0	0
1975	3	37	0	0	0	0	159	80	231	0	5	0	0	616	0	0	0	0	0	0
1975	4	298	0	0	0	1122	22	271	0	430	240	0	17	2283	0	0	0	0	0	0
1976	1	54	0	0	0	1026	0	1300	301	0	818	0	0	7250	0	0	0	29	2	0
1976	2	15	0	0	0	0	619	518	431	0	540	152	0	497	0	0	0	0	0	0
1976	3	69	0	0	0	0	416	169	320	0	2	0	0	2	0	0	0	0	0	0
1976	4	244	0	0	0	4063	58	1338	0	411	108	0	131	2015	0	0	0	0	0	0
1977	1	37	0	0	0	1047	0	1258	222	0	485	0	0	3094	0	0	0	76	2	0
1977	2	12	0	0	0	0	1617	377	378	0	331	168	0	348	0	0	0	0	0	0
1977	3	58	0	0	0	0	867	51	377	0	2	0	0	86	0	0	0	0	0	0
1977	4	243	0	0	0	10346	121	426	0	527	107	0	66	704	0	0	0	0	0	0
1978	1	340	0	0	3	78	0	2329	282	0	441	0	0	4403	0	0	0	158	1	0
1978	2	16	0	0	0	0	3372	380	512	0	298	246	0	21	0	0	0	0	0	0
1978	3	55	0	0	0	0	510	454	733	0	2	0	0	11	0	0	0	0	0	0
1978	4	580	0	0	0	11145	71	211	0	1011	115	0	58	2331	0	0	0	0	0	0
1979	1	104	0	0	0	2736	0	1720	527	0	768	0	0	3539	0	0	0	93	1	0
1979	2	24	0	0	0	0	1982	406	861	0	541	888	0	227	0	0	0	0	0	0
1979	3	43	0	0	0	0	294	572	363	0	3	0	0	0	0	0	0	0	0	0
1979	4	749	0	0	0	6168	41	195	0	379	140	0	114	1435	0	0	0	0	0	0
1980	1	20	0	0	0	5159	0	1641	322	0	574	0	0	1439	0	0	0	54	1	0
1980	2	41	0	0	0	0	1143	468	353	0	387	474	0	59	0	0	0	0	0	0
1980	3	185	0	0	0	0	283	85	406	0	1	0	0	0	0	0	0	0	0	0
1980	4	336	0	0	0	6344	0	115	0	404	54	0	179	356	0	0	0	0	0	0
1981	1	56	0	0	1297	17781	0	2382	271	0	352	0	0	742	0	0	0	68	1	0
1981	2	41	0	0	0	0	1426	302	393	0	248	523	0	1	0	0	0	0	0	0
1981	3	63	0	8	0	0	435	336	277	0	2	0	0	0	0	0	0	0	0	0
1981	4	583	0	12	0	5410	53	671	0	341	69	0	207	60	0	0	0	0	0	0
1982	1	73	0	6	1615	12209	0	1905	198	0	300	0	0	2682	0	0	0	5	1	0
1982	2	20	0	5	0	0	370	444	277	0	204	132	0	406	0	0	0	0	0	0
1982	3	38	0	3	0	0	81	31	189	0	1	0	0	91	0	0	0	0	0	0
1982	4	161	0	5	0	11951	0	107	0	207	35	0	175	8	0	0	0	0	0	0
1983	1	8	0	3	570	2262	0	897	143	0	113	0	0	631	0	0	0	21	1	0
1983	2	15	0	2	0	0	1925	131	210	0	74	310	0	125	0	0	0	0	1	0
1983	3	41	0	1	0	0	287	33	380	0	3	0	0	72	0	0	0	0	0	0
1983	4	94	0	2	0	2448	0	116	0	431	138	0	477	144	0	0	0	0	0	0
1984	1	20	0	1	807	1184	0	588	311	0	343	0	0	563	0	0	0	28	3	0
1984	2	9	0	1	0	0	1558	391	413	0	215	336	0	90	0	0	0	0	1	0
1984	3	24	0	0	0	0	538	1011	265	0	3	0	0	62	0	0	0	0	0	0
1984	4	74	0	0	0	2897	135	464	0	358	153	0	210	1572	0	0	0	0	0	0
1985	1	8	0	0	448	889	0	961	229	0	714	0	0	1264	0	0	0	12	5	0
1985	2	8	0	0	0	0	1165	120	352	0	488	447	0	1126	0	0	0	0	0	0
1985	3	19	0	84	0	0	224	74	369	0	3	0	0	109	0	0	0	0	0	0
1985	4	84	0	130	0	6340	0	460	0	547	118	0	70	428	0	0	0	0	0	0
1986	1	8	0	70	16	1072	0	668	375	0	564	0	0	3759	0	0	0	5	1	0
1986	2	5	0	60	0	0	1238	212	553	0	387	403	0	801	0	0	0	0	0	0
1986	3	20	0	22	0	0	354	1089	274	0	2	0	0	93	0	0	0	0	0	0
1986	4	195	0	34	0	4874	15	132	0	299	89	0	365	31	0	0	0	0	0	0
1987	1	20	0	18	250	3550	0	519	193	0	612	0	0	813	0	0	0	6	1	0
1987	2	9	0	15	0	0	505	98	297	0	432	187	0	63	0	0	0	0	1	0
1987	3	19	0	8	0	0	89	146	94	0	1	0	0	0	0	0	0	0	0	0
1987	4	123	16	12	0	1027	0	357	0	113	45	0	108	221	0	0	0	0	0	0
1988	1	35	0	7	742	2010	0	796	87	0	228	0	0	974	0	0	0	15	0	0
1988	2	10	0	6	0	0	1020	42	118	0	157	127	0	227	0	0	6	0	0	0
1988	3	27	3	17	0	0	259	68	86	0	0	0	0	7	0	0	0	0	0	0
1988	4	190	3	27	0	2134	27	356	0	125	24	0	205	0	0	0	0	0	0	0
1989	1	20	88	15	580	3623	0	411	81	0	186	0	0	988	0	0	0	88	5	0
1989	2	4	0	12	0	0	529	146	114	0	132	110	0	130	0	0	20	0	1	0
1989	3	21	0	32	0	0	166	17	165	0	1	0	0	16	0	0	0	0	0	0
1989	4	280	5	50	0	360	92	213	0	133	26	0	189	1	0	0	0	0	0	0
1990	1	24	32	27	149	2474	0	830	64	0	90	0	0	1311	0	0	0	3	4	0
1990	2	10	0	23	0	0	990	47	179	0	60	199	0	194	0	0	118	0	0	0
1990	3	16	99	65	0	0	636	30	421	0	1	0	0	0	0	0	0	0	0	0
1990	4	193	26	100	0	646	161	79	0	288	49	0	342	86	0	0	0	0	0	0
1991	1	14	182	54	224	3466	0	429	123	0	146	0	2	334	0	0	0	82	5	0
1991	2	14	0	46	0	0	1191	103	363	0	95	414	0	5	0	0	5165	0	0	0
1991	3	36	394	71	0	0	274	18	183	0	2	0	0	0	0	0	0	0	0	0
1991	4	462	2061	109	0	1677	0	35	0	332	68	0	464	11	0	0	0	0	0	0
1992	1	10	255	59	469	2183	0	944	173	0	116	0	0	1650	0	0	0	0	8	0
1992	2	20	0	50	0	0	642	65	269	0	66	193	0	328	0	0	198	0	0	0
1992	3	15	582	10	0	0	145	12	102	0	1	0	0	0	0	0	0	0	0	0
1992	4	708	751	15	0	1243	34	38	0	280	27	0	471	45	0	0	0	0	0	0
1993	1	62	99	8	83	3831	0	204	161	0	32	0	6	525	0	0	0	48	10	0
1993	2	37	0	7	0	0	320	36	230	0	16	207	0	113	0	0	12	0	0	0
1993	3	42	25	12	0	0	67	0	70	0	1	0	0	2	0	0	0	0	0	0
1993	4	1085	562	19	0	2677	15	17	0	481	16	0	559	4	0	0	0	0	0	0

Table 3-2. Cont.

Fishing year	Season	Weight (t)																	Number (x 1000 fish)	
		Fleet1	Fleet2	Fleet3	Fleet4	Fleet5	Fleet6	Fleet7	Fleet8	Fleet9	Fleet10	Fleet11	Fleet12	Fleet13	Fleet14	Fleet17	Fleet18	Fleet19	Fleet15	Fleet16
1994	1	77	14	10	694	3973	0	206	168	0	36	0	3	967	0	0	0	458	2	0
1994	2	22	0	9	0	0	3570	65	356	0	31	272	0	58	0	0	185	0	0	0
1994	3	11	406	202	0	0	2475	9	132	0	0	0	0	0	0	0	0	0	0	0
1994	4	616	254	309	0	2040	733	136	0	256	23	0	335	0	0	0	0	0	0	0
1995	1	35	4055	168	496	2798	0	143	243	0	213	0	2	716	0	0	0	440	16	0
1995	2	25	0	142	0	0	1130	94	788	0	205	476	0	0	0	0	8860	0	0	0
1995	3	31	1355	25	0	0	136	5	84	0	0	0	0	0	0	0	0	0	0	0
1995	4	827	140	38	0	3124	57	1	0	253	16	0	956	757	0	0	0	0	2	0
1996	1	25	451	21	450	1967	0	90	129	0	142	0	4	7652	0	0	0	256	1	0
1996	2	26	0	18	0	0	3191	66	416	0	110	503	0	0	0	0	158	0	0	0
1996	3	27	594	259	0	0	846	1	114	0	0	0	0	1	0	0	0	0	0	0
1996	4	1215	1113	397	0	1402	550	4	0	199	6	0	1814	61	0	0	0	0	3	0
1997	1	27	3000	215	708	4027	0	113	165	0	20	0	15	2638	0	0	0	224	5	0
1997	2	44	0	183	0	0	1120	25	246	0	53	702	0	41	0	0	2309	0	0	0
1997	3	18	559	46	0	0	605	2	158	0	1	0	0	4	0	0	0	0	0	0
1997	4	1150	518	71	0	13	515	2	0	131	15	0	1910	8	0	0	0	0	1	0
1998	1	53	549	38	326	2376	0	108	114	0	29	0	23	2017	0	0	0	131	21	47
1998	2	46	0	33	0	0	1613	64	359	0	68	609	0	24	0	0	1049	0	1	0
1998	3	33	686	63	0	0	798	10	317	0	1	0	0	0	0	0	0	0	0	0
1998	4	1076	986	96	0	5592	360	2	0	329	32	0	3089	2280	0	0	0	0	1	0
1999	1	25	2228	52	579	5448	0	65	133	0	16	0	26	442	0	0	0	129	35	214
1999	2	41	0	44	0	0	2101	17	391	0	46	482	0	49	0	0	653	0	1	0
1999	3	39	651	747	0	0	1456	1	168	0	0	0	0	0	0	0	0	0	0	0
1999	4	893	2380	1597	0	3403	770	83	0	164	5	0	2780	669	0	0	0	0	8	0
2000	1	15	3214	30	747	4042	0	66	154	0	87	0	29	3204	0	0	0	117	13	382
2000	2	12	0	27	0	0	2780	6	475	0	72	638	0	0	0	0	2048	0	0	0
2000	3	8	898	963	0	0	934	0	358	0	1	0	0	0	0	0	0	0	0	0
2000	4	749	2914	179	0	981	464	4	0	189	45	0	1834	382	0	5	0	0	1	0
2001	1	13	409	9	239	1918	0	167	73	0	174	0	57	821	0	0	0	83	21	549
2001	2	26	0	37	0	0	1847	113	293	0	232	683	0	0	0	0	261	0	1	0
2001	3	76	62	160	0	0	988	17	113	0	0	0	0	0	0	0	0	0	0	0
2001	4	671	2126	175	0	556	697	51	0	117	6	0	1513	0	275	10	0	0	1	0
2002	1	45	959	509	599	2767	0	224	157	0	235	0	61	0	1497	0	0	37	31	716
2002	2	56	0	88	0	0	706	24	231	0	251	409	0	0	0	0	1835	0	2	0
2002	3	95	99	238	0	0	520	11	84	0	0	0	0	0	0	0	0	0	0	0
2002	4	992	1771	394	0	185	824	34	0	87	54	0	1832	0	590	0	0	0	1	0
2003	1	78	783	88	571	200	0	58	96	0	291	0	84	0	2704	0	0	80	21	884
2003	2	85	0	1881	0	0	416	6	156	0	71	403	0	0	0	0	2159	0	1	0
2003	3	116	38	53	0	0	182	5	109	0	3	0	1	0	0	0	0	0	0	0
2003	4	1380	1144	556	0	609	54	15	0	266	47	0	1698	0	3620	0	0	0	1	0
2004	1	154	10	59	2100	2225	0	114	136	0	81	0	93	0	5285	0	0	78	3	1051
2004	2	205	0	105	0	0	1868	94	186	0	68	421	0	0	0	0	2131	0	0	0
2004	3	122	586	720	0	0	1173	164	379	0	15	0	0	0	0	0	0	0	0	0
2004	4	1602	1888	264	0	264	906	321	0	572	217	0	1287	0	1986	43	0	0	0	0
2005	1	106	3280	222	3694	77	0	171	414	0	137	0	71	0	2764	0	0	293	5	908
2005	2	108	0	121	0	0	1034	30	346	0	102	413	0	0	0	0	3029	0	0	0
2005	3	81	59	220	0	0	513	68	284	0	7	0	0	0	640	0	0	0	0	0
2005	4	873	2412	339	0	940	85	23	0	356	135	0	1078	0	4714	49	0	0	5	0
2006	1	115	252	354	2012	692	0	315	148	0	328	0	48	0	4573	0	0	251	2	1265
2006	2	62	0	102	0	0	695	17	229	0	69	331	0	0	1	0	2513	0	0	0
2006	3	61	485	376	0	0	228	32	253	0	10	0	0	0	0	0	0	0	0	0
2006	4	1022	1059	13	0	479	70	15	0	270	127	0	1261	0	1424	95	0	0	0	0
2007	1	66	363	121	2123	364	0	238	150	0	381	0	58	0	2723	4	0	101	1	1753
2007	2	71	0	776	0	0	1985	105	314	0	52	1013	0	0	44	0	1968	0	0	0
2007	3	99	214	581	0	0	619	12	268	0	2	0	0	0	0	0	0	0	0	0
2007	4	802	1610	1003	0	1	220	30	0	844	239	0	784	0	1794	175	0	0	1	0
2008	1	33	3007	62	3028	0	0	287	389	0	186	0	35	0	2613	2	0	72	10	1214
2008	2	40	0	230	0	0	1163	14	455	0	95	797	0	0	1	0	2361	0	0	0
2008	3	39	702	518	0	0	868	1	449	0	1	0	0	0	0	0	0	0	0	0
2008	4	662	2177	213	0	1	241	13	0	1031	276	0	625	0	1209	186	0	0	1	0
2009	1	26	2891	97	1299	828	0	108	180	0	181	0	82	0	2221	3	0	62	12	512
2009	2	23	0	112	0	0	703	43	143	0	106	677	0	0	3	0	181	0	0	0
2009	3	35	718	617	0	0	264	0	342	0	1	0	0	0	0	0	0	0	0	0
2009	4	400	1390	424	0	35	38	36	0	566	264	0	260	0	2447	78	0	0	4	0
2010	1	27	123	26	1052	35	0	179	190	0	79	0	45	0	5300	0	0	20	4	1127
2010	2	10	0	145	0	0	979	44	237	0	9	693	0	0	1	0	388	0	1	0
2010	3	25	67	191	0	0	492	29	374	0	4	0	0	0	0	0	0	0	0	0
2010	4	372	3058	429	0	0	298	34	0	380	384	0	197	0	451	76	0	0	2	0
2011	1	49	611	21	1906	320	0	38	158	0	148	0	48	0	2379	0	0	39	29	808
2011	2	32	0	43	0	0	789	22	217	0	36	567	0	0	19	0	2377	0	1	0
2011	3	20	9	163	0	0	242	70	360	0	5	0	0	0	1	0	0	0	0	0
2011	4	189	530	674	0	3	7	45	0	500	151	0	148	0	1286	50	0	0	4	0
2012	1	24	261	559	841	199	0	103	205	0	514	0	26	0	5421	0	0	2	35	346
2012	2	13	0	28	0	0	233	0	176	0	54	644	0	0	3	0	620	0	1	0
2012	3	28	9	76	0	0	256	2	273	0	4	0	0	0	0	0	0	0	0	0
2012	4	237	743	493	0	12	19	6	0	372	170	0	192	0	1368	123	0	0	3	0
2013	1	28	10	1	1729	268	0	81	132	0	204	0	40	0	1788	0	0	22	57	519
2013	2	15	0	35	0	0	477	3	217	0	82	895	0	0	8	0	2	0	4	0
2013	3	9	79	516	0	0	789	0	306	0	2	0	0	0	2	0	0	0	0	0
2013	4	311	2459	783	0	0	60	43	0	818	285	0	257	0	4036	216	0	0	1	0
2014	1	21	654	6	2203	47	0	125	92	0	231	0	21	0	1228	1	0	40	26	149
2014	2	26	0	6	0	0	97	1	107	0	110	679	0	0	2	0	14	0	2	0
2014	3	16	246	607	0	0	61	0	81	0	1	0	0	0	1	0	0	0	1	0
2014	4	237	440	5	0	409	21	1	0	395	261	0	248	0	2414	293	0	0	2	0

Table 3-3 (a). Abundance indices (CPUE) used in the base-case stock assessment model for Pacific bluefin tuna (*Thunnus orientalis*).

CPUE #	Abundance index	Available period (fishing year)	Corresponding fisheries	Corresponding fleet for the selectivity setting	Data quality	Document for reference
S1	Japanese coastal longline CPUE for spawning season.	1993-2014	JP Longline	Fleet 1 (JPLL)	Standardized by ZINB	ISC/16/PBFWG-1/01
S2	Japanese offshore and distant water longliners CPUE	1952-1973	JP Longline	Fleet 1 (JPLL)	Standardized by lognormal model	ISC/12/PBFWG-1/10
S3	Japanese offshore and distant water longliners CPUE	1974-1992	JP Longline	Fleet 1 (JPLL)		ISC/08/PBFWG-1/05
S5	Japanese troll CPUE in Nagasaki prefecture (Sea of Japan and East China sea)	1980-2014	JP Troll	Fleet 6 (JPTroll Seas2-4)	Standardized by lognormal model	ISC/15/PBFWG-2/08
S9	Taiwanese longline CPUE (South area)	2000-2014	TW Longline	Fleet 12 (TWLL South)	Standardized by GLMM	ISC/16/PBFWG-1/02

Table 3-3 (b). Abundance indices (CPUE) **NOT** used in the base-case stock assessment model for Pacific bluefin tuna (*Thunnus orientalis*).

CPUE #	Abundance index	Available period (fishing year)	Corresponding fisheries	Corresponding fleet for the selectivity setting	Data quality	Document for reference
S4	Japanese tuna purse seine CPUE in Sea of Japan (old series)	1987-2010	JP TPSJS	Fleet 4 (JPTPSJS)	Standardized	ISC/12/PBFWG-1/09
S6	Japanese troll CPUE combined with Kochi and Wakayama by catch weighted average	1994-2010	JP Troll	Fleet 6 (JPTroll Seas2-4)	Standardized by ZINB and combined by ad-hoc way	ISC/12/PBFWG-1/11
S7	Japanese troll CPUE in Kochi prefecture (Pacific coast)	1981-2010	JP Troll	Fleet 6 (JPTroll Seas2-4)	Standardized by ZINB	
S8	Japanese troll CPUE in Wakayama prefecture (Pacific coast)	1994-2010	JP Troll	Fleet 6 (JPTroll Seas2-4)		
S10	EPO purse seine CPUE by US target fisheries	1960-1982	US Commercial Fisheries (PS)	Fleet 13 (USCOMM)	Standardized by delta lognormal model	ISC/12/PBFWG-1/18
S11	EPO purse seine CPUE by Mexico target fisheries	1999-2010	MX Commercial Fisheries (PS)	Fleet 14 (MXCOMM)		
S12	Taiwanese longline CPUE (North area)	2000-2014	TW Longline	Fleet 17 (TWLL North)	Standardized by GLMM	ISC/16/PBFWG-1/02
S13	Japanese tuna purse seine CPUE in Sea of Japan (age 4)	2003-2014	JP TPSJS	Using age selectivity	Standardized by random forest	ISC/15/PBFWG-1/05
S14	Japanese tuna purse seine CPUE in Sea of Japan (age 5)					

Table 3-4. Available annual abundance indices (CPUE) of Pacific bluefin tuna (*Thunnus orientalis*). S1, S2, S3, S5, and S9 were fitted to the base-case model (numbers in bold). Numbers in grey indicate that data points were removed.

Fishing year	JLL			JPTroll				TW LL		US COMM	MX COMM	JPTPSJS		
	S1	**S2**	**S3**	**S5**	S6	S7	S8	**S9**	S12	S10	S11	S4	S13	S14
1952		**0.0140**												
1953		**0.0126**												
1954		**0.0112**												
1955		**0.0085**												
1956		**0.0058**												
1957		**0.0067**												
1958		**0.0160**												
1959		**0.0263**												
1960		**0.0197**								1.04				
1961		**0.0193**								1.54				
1962		**0.0175**								1.40				
1963		**0.0123**								1.75				
1964		**0.0128**								1.05				
1965		**0.0100**								1.20				
1966		**0.0128**								1.93				
1967		**0.0062**								1.55				
1968		**0.0056**								0.58				
1969		**0.0065**								0.82				
1970		**0.0046**								0.99				
1971		**0.0029**								0.92				
1972		**0.0028**								1.35				
1973		**0.0019**								0.65				
1974		0.0066	**0.0016**							0.61				
1975			**0.0011**							1.25				
1976			**0.0026**							0.82				
1977			**0.0029**							0.51				
1978			**0.0035**							0.98				
1979			**0.0023**							0.72				
1980			**0.0030**	**0.66**		3.72				0.62				
1981			**0.0035**	**1.16**		0.82				0.34				
1982			**0.0020**	**0.61**		0.25				0.38				
1983			**0.0012**	**0.91**		0.21								
1984			**0.0013**	**0.93**		1.14								
1985			**0.0012**	**0.87**		0.77								
1986			**0.0014**	**0.98**		0.28								
1987			**0.0014**	**0.71**		0.16						709.5		
1988			**0.0016**	**0.82**		0.58						353.9		
1989			**0.0024**	**0.65**		0.32						598.8		
1990			**0.0024**	**1.28**		0.64								
1991			**0.0038**	**1.31**		0.58						289.1		
1992			**0.0041**	**0.58**		0.30						485.5		
1993	**2.00**		0.0051	**0.49**		0.51						600.3		
1994	**1.39**		0.0037	**2.02**	2.36	3.20	1.40					2402.0		
1995	**1.97**		0.0059	**1.08**	0.84	1.05	0.78					1169.3		
1996	**1.72**		0.0066	**1.61**	0.85	0.90	1.26					706.3		
1997	**1.65**		0.0053	**0.95**	0.46	0.48	0.71					459.5		
1998	**1.33**		0.0045	**0.83**	1.11	1.54	0.55					550.6		
1999	**1.06**		0.0039	**1.52**	0.25	0.33	0.18				20.47	766.1		
2000	**0.84**		0.0032	**1.16**	0.32	0.32	0.53	**2.40**	0.59		0.56	754.8		
2001	**1.06**		0.0030	**1.16**	1.56	2.11	0.94	**0.97**	0.85		0.55	438.6		
2002	**1.30**			**0.75**	0.67	0.83	0.62	**1.77**			0.24	459.7		
2003	**1.50**			**0.65**	0.32	0.40	0.30	**1.82**			2.38	474.9	178.36	175.83
2004	**1.75**			**1.29**	3.17	3.47	4.37	**1.29**	1.02		1.64	752.8	141.50	150.27
2005	**0.80**			**1.42**	0.87	0.99	1.08	**1.45**	1.20		0.51	856.7	131.96	149.53
2006	**0.92**			**0.73**	0.82	0.93	1.04	**1.11**	0.52		0.29	388.4	113.09	134.25
2007	**0.70**			**1.41**	1.27	1.47	1.51	**0.95**	0.87		0.27	865.7	118.06	131.70
2008	**0.37**			**1.43**	0.68	0.66	1.20	**0.76**	0.81		0.41	751.6	118.03	132.95
2009	**0.26**			**1.16**	0.08	0.08	0.13	**0.42**	0.57		1.64	585.1	117.53	132.49
2010	**0.21**			**1.12**	1.35	1.97	0.40	**0.42**	0.70		3.01	603.5	115.11	133.91
2011	**0.18**			**0.96**				**0.30**	0.54		0.48		117.33	146.69
2012	**0.32**			**0.50**				**0.35**	0.96				117.52	148.01
2013	**0.34**			**0.84**				**0.50**	2.17				122.61	147.99
2014	**0.33**			**0.42**				**0.40**	2.20				145.24	148.76

Table 3-5. Characteristics of the size composition data used in the stock assessment for Pacific bluefin tuna (*Thunnus orientalis*).

Fleet #	Fleet name	Unit of Comp data (Size bin definition)	Size data included		Available period (Fishing year)	Source of sample size	Sampling quality
			Component 1	Component 2			
Fleet1	JPLL	Length	JPLL		1952-1968, 1993-2014	Scaled Number of fish measured	Good
Fleet2[*1]	JPSPPS (Seas1, 3, 4)	Length	JPSPPS (Season 1, 3, 4)	KROLPS	2002-2014	Number of landing well measured	Good
Fleet3[*1]	KROLPS	Length	KROLPS		2010-2014		Fair (sampling has been conducted since 2004 opportunistically, systematically from 2010)
Fleet4	JPTPSJS	Length	JP TPSJS		1987-1989, 1991-2014	same velue with the last assessment	Very Good
Fleet5	JPTPSPO	Length	JP TPSPO		1995-2006	Number of landing well measured	Fair
Fleet6	JPTroll (Seas2-4)	Length	JP Troll (Season 2-4)		1994-2014	Total month of well sampled port	Good
Fleet7[*2]	JPPL	Length	JP Pole-and-Line		1994-1996, 1998-2004, 2006-2010		Bad
Fleet8	JPSetNet (Seas1-3)	Length	JP Setnet (Season 1-3)		1993-2014	Total month of well sampled port	Fair
Fleet9	JPSetNet (Seas4)	Length	JP Setnet (Season 4)		1993-2014	Total month of well sampled port	Fair
Fleet10[*3]	JPSetNet_HK_AM	Weight	JP Setnet in Hokkaido and Aomori	JP Handline & Tsugaru Longline	1994-2014	Total month of well sampled port	Good
Fleet11[*3]	JPOthers	Weight	JP Handline & Tsugaru Longline		1994-2014	Total month of well sampled port	Good
Fleet12	TWLL (South)	Length	TWLL (South area)		1992-2014	Scaled Number of fish measured	Very Good
Fleet13	USCOMM (-2001)	Length	US Commercial Fisheries (PS)		1952-1965, 1969-1982	Number of haul well measured	Fair (many samples but not sure)
Fleet14	MXCOMM (2002-)	Length	MX Commercial Fisheries (PS)		2005-2006, 2008-2013	Number of haul well measured	Fair (improvement in the recent years due to the stereo-camera; after 2013 calendar year)
Fleet15[*4]	EPOSP	Length	US Recreational Fisheries		1993-2003, 2005-2006, 2008-2011		Fair (Good samples are aveailable only for recent years)
Fleet16[*5]	Troll4Pen						Size comp data are not available
Fleet17	TWLL (North)	Length	TWLL (North area)		2009-2014	Scaled Number of fish measured	Fair
Fleet18	JPSPPS (Seas2)	Length	JPSPPS (Season 2)		2003-2012, 2014	Number of landing well measured	Good
Fleet19	JPTroll (Seas1)	Length	JP Troll (Season 1)		1994-2004, 2006-2011	Total month of well sampled port	Good

*1 Size composition data of Fleet 2 and 3 were combined. A selectivity pattern was estimated and shared by those two fleets.
*2 Size composition data of Fleet 7 was not used in the assessment model. The selectivity pattern estimated for Fleet 6 was mirrored.
*3 Size composition data of Fleet 10 and 11 were combined. A selectivity pattern was estimated and shared by those two fleets.
*4 Size composition data of Fleet 15 was not used in the assessment model. The selectivity pattern estimated for Fleet 13 was mirrored.
*5 Fleet 16 was assumed the age based selectivity to catch only age-0 fish. Thus size composition data was not used in the assessment model.

Table 4-1. Fishery-specific selectivity and their attributes used in the base-case stock assessment model for Pacific bluefin tuna (*Thunnus orientalis*).

Fleet #	Fleet name	Ages of fish caught	Priority for size data	Type of size data	Sampling quality	CPUE index	Catch in number	Length-based contact selectivity	Age-based availability	Time-varying process
Fleet 1	JPLL	Spawners in WPO	High*	Length	Good	Yes	Low	Dome-shaped (double normal)	None	Constant on length-based
Fleet 2	JSPPS (Seas1, 3, 4)	Age 0 fish in WPO	Medium*	Length	Good	-	High	Dome-shaped (double normal)	None	Constant on length-based
Fleet 3	KROLPS	Age 0 fish in WPO	Medium**	Length	Fair (opportunistically sampling was conducted for 2004-2009, systematically since 2010)	-	Med	Mirror to Fleet 2		
Fleet 4	JPTPSJS	Migratory ages (ages 1-5)	High*	Length	Very Good	-	High	Asymptotic (logistic)	Age-specific (ages 3-9)	Constant on length-based; time-varying on ages 3-7 for 2000-2014
Fleet 5	JPTPSPO	Migratory ages (ages 1-5)	Medium*	Length	Fair	-	High-historic	Asymptotic (logistic)	Age-specific (ages 1-10)	Constant on length-based; time-varying on ages 1, 5-7 for 2004-2005
Fleet 6	JPTroll (Season2-4)	Age 0 fish in WPO	High*	Length	Good	Yes	High	Dome-shaped (double normal)	None	Constant on length- and age-based
Fleet 7	JPPL	Age 0 fish in WPO	Low	Length	Bad	-	Historic	Mirror to Fleet 6		
Fleet 8	JPSetNet (Season1-3)	Migratory ages (ages 1-5)	Low*	Length	Fair	-	Med	Asymptotic (logistic)	Age-specific (ages 1-4)	Constant on length-based;
Fleet 9	JPSetNet (Season4)	Migratory ages (ages 1-5)	Low*	Length	Fair	-	Low	Asymptotic (logistic)	Age-specific (ages 1-5)	Constant on length-based;
Fleet 10	JPSetNet_HK_AM	Migratory ages (ages 1-5)	Medium*	Weight	Good	-	Low	Asymptotic (logistic)	Age-specific (ages 1-3)	Constant on length-based;
Fleet 11	JPOthers	Migratory ages (ages 1-5)	Medium**	Weight	Good	-	Low	Mirror to Fleet 10		
Fleet 12	TWLL (South)	Spawners in WPO	High*	Length	Very Good	Yes	Low	Asymptotic (logistic)	None	Constant on length- and age-based
Fleet 13	USCOMM (-2001)	Migratory ages (ages 1-5)	Medium*	Length	Fair (many samples)	-	High-historic	Dome-shaped (double normal)	None	Time–varying on length-based for 1954-1981
Fleet 14	MEXCOMM (2002-)	Migratory ages (ages 1-5)	High*	Length	Fair (improvement after 2013 due to the stereo-camera)	-	High	Dome-shaped (double normal)	None	Time–varying on length-based for 2006-2014
Fleet 15	EPOSP	Migratory ages (ages 1-5)	Low	Length	Fair (Good samples are available for recent years)	-	Low	Mirror to Fleet 13		
Fleet 16	JPTroll4Pen	Age 0 fish in WPO	Low	Converted length	Catch in # of Age-0 fish are available	-	Med	None	100% selected at age 0	Constant on age-based
Fleet 17	TWLL (North)	Spawners in WPO	Low*	Length	Fair	-	Low	Dome-shaped (double normal)	None	Constant on length-based
Fleet 18	JPSPPS (Season2)	Migratory ages (ages 1-5)	Medium*	Length	Good	-	High	Dome-shaped (double normal)	Age-specific (age 1)	Constant on length-based; Time–varying on age-based for 2004-2012
Fleet 19	JPTroll (Season1)	Age 0 fish in WPO	Medium*	Length	Good	-	High	Dome-shaped (double normal)	None	Constant on length-based

* Fleets whose size data were fitted.

** The size data was combined with another Fleet and was fitted.

Table 4-2. Harvest scenarios used in the projection for Pacific bluefin tuna (*Thunnus orientalis*).

Harvesting Scenario #	Fishing mortality	Catch limit		Threshold of Juv/Adult	Catch limit by country									
					Japan		Korea		Taiwan		EPO commercial		EPO sports	
		Juvenile	Adult		Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult
Scenario1	F2002-2004	scenario 6 in 2014 assessment		30 kg (age-3)	4,007	-	718	-	-	1,700	2,750		-	-
Scenario2		50% of 2002-2004 average catch for WPO fisheries, 3,300 tons for EPO commercial fisheries	2002-2004 average catch		4,007	4,882	718	-	-	1,700	3,300		-	-
Scenario3		50% of 2002-2004 average catch for WPO fisheries,		50 kg (age-4)	4,284	4,327	718	-	-	1,700	2,750		-	-
Scenario4				80 kg (age-5)	4,590	3,718	718	-	-	1,700	2,750		-	-
Scenario5		90% of scenario 2	same as Scenario 2	30 kg (age-3)	3,606	4,882	646	-	-	1,700	2,193	863	-	-
Scenario6		same as Scenario 2	90% of scenario 2		4,007	4,385	718	-	-	1,530	2,437	777	-	-
Scenario7		90% of scenario 2			3,606	4,385	646	-	-	1,530	2,970		-	-
Scenario8		80% of scenario 2	same as Scenario 2		3,206	4,882	574	-	-	1,700	1,950	863	-	-
Scenario9		same as Scenario 2	80% of scenario 2		4,007	3,906	718	-	-	1,360	2,437	690	-	-
Scenario10		80% of scenario 2			3,206	3,906	574	-	-	1,360	2,640		-	-
Scenario11	F2011-2013	same as Scenario 2	same as Scenario 2		4,007	4,882	718	-	-	1,700	3,300		-	-

Table 5-1. Mean input variances (input N after variance adjustment), model estimated mean variance (mean *effN*), and harmonic means of the *effN* by composition data component for the base-case model, where effective sample size (effN) is the models estimate of the statistical precision. A higher ratio of mean *effN* to mean input N indicates a better model fit. Number of observations corresponds to the number of quarters in which size composition data were sampled in a fishery.

Fleet	Number of observations	Mean input N after var adj	Mean *effN*	Harmonic mean *effN*	Mean effN/Mean inputN
Fleet 1	71	8.5	58.3	28.0	10.2
Fleet 2	33	12.1	24.9	13.7	4.4
Fleet 4	27	20.2	37.4	15.9	2.6
Fleet 5	11	9.6	50.4	42.2	9.3
Fleet 6	49	9.9	34.3	15.2	3.7
Fleet 8	64	6.3	18.6	12.1	3.4
Fleet 9	22	7.0	21.0	17.0	3.2
Fleet 10	21	9.2	31.2	17.0	3.6
Fleet 12	23	13.6	112.9	38.2	10.1
Fleet 13	50	14.5	18.5	6.0	2.5
Fleet 14	11	10.2	23.4	15.5	6.7
Fleet 17	6	2.4	59.7	48.4	28.6
Fleet 18	11	11.9	25.0	14.1	4.4
Fleet 19	17	7.5	28.2	13.1	5.1

Table 5-2. Time series estimates of total biomass, spawning stock biomass, recruitment and associated variance from the base-case model for Pacific bluefin tuna (*Thunnus orientalis*).

Fishing year	Total biomass (t)	Spawning stock biomass (t)	Std Dev for SSB	CV for SSB	Recruitment (x1000 fish)	StdDev for R	CV for R
1952	142813	108212	51499	0.48	8179		
1953	137353	101450	46448	0.46	26042	3105	0.12
1954	139364	91087	41170	0.45	32226	4144	0.13
1955	146129	77809	36124	0.46	14217	2513	0.18
1956	163529	71864	32832	0.46	34011	3487	0.10
1957	182294	78794	33194	0.42	12514	1802	0.14
1958	200485	106048	39701	0.37	3465	974	0.28
1959	206403	140043	49517	0.35	7935	1702	0.21
1960	209075	147553	53490	0.36	7357	988	0.13
1961	202076	160005	58187	0.36	24081	1981	0.08
1962	188481	144257	55540	0.39	10908	1918	0.18
1963	173255	122736	50030	0.41	27698	2743	0.10
1964	162393	108050	44642	0.41	5845	1771	0.30
1965	152760	95211	39257	0.41	11670	3763	0.32
1966	139185	91202	36562	0.40	8706	3797	0.44
1967	116884	84992	33830	0.40	11000	4165	0.38
1968	102751	79336	32471	0.41	13737	3327	0.24
1969	89360	65606	28055	0.43	6413	1882	0.29
1970	78444	55050	24126	0.44	6995	2823	0.40
1971	68848	47572	20601	0.43	12485	5302	0.42
1972	64929	40944	17224	0.42	22863	4853	0.21
1973	62646	35166	13932	0.40	11200	3007	0.27
1974	62227	28028	10892	0.39	13638	2299	0.17
1975	60621	25821	8703	0.34	10846	1962	0.18
1976	63393	28298	7469	0.26	8952	2739	0.31
1977	60786	33742	7610	0.23	25189	3803	0.15
1978	65461	30621	6984	0.23	15862	3771	0.24
1979	66308	25123	6404	0.25	11428	2285	0.20
1980	68629	27898	6119	0.22	7618	1943	0.26
1981	70024	26865	4718	0.18	11623	1464	0.13
1982	51827	23696	4267	0.18	6927	1379	0.20
1983	29347	13781	3336	0.24	10103	1513	0.15
1984	31271	11445	3012	0.26	9129	1802	0.20
1985	34365	11482	2756	0.24	9822	1784	0.18
1986	33930	13976	2766	0.20	7645	1405	0.18
1987	29499	13141	2887	0.22	6132	1261	0.21
1988	31410	14055	3082	0.22	8587	1212	0.14
1989	35221	13776	3094	0.22	4637	1196	0.26
1990	42721	17349	3557	0.21	18077	1637	0.09
1991	57036	22503	4217	0.19	12019	1328	0.11
1992	64882	28477	4912	0.17	4562	759	0.17
1993	74219	39327	6210	0.16	4374	775	0.18
1994	84249	47101	7441	0.16	28554	1319	0.05
1995	97759	61686	9579	0.16	17912	1581	0.09
1996	93811	61792	9665	0.16	17806	1114	0.06
1997	95164	56769	9320	0.16	11039	1117	0.10
1998	92261	56831	9052	0.16	15298	1181	0.08
1999	89995	53870	9041	0.17	23646	1143	0.05
2000	86247	52593	9055	0.17	14477	816	0.06
2001	75553	49569	8589	0.17	15923	723	0.05
2002	77575	47783	8125	0.17	13561	774	0.06
2003	74293	47785	7667	0.16	7930	694	0.09
2004	68736	41069	6908	0.17	26359	945	0.04
2005	63621	34266	6130	0.18	14760	852	0.06
2006	50596	28170	5370	0.19	11544	620	0.05
2007	43654	22440	4561	0.20	21658	877	0.04
2008	40843	16909	3792	0.22	20534	865	0.04
2009	34649	12814	2962	0.23	9044	627	0.07
2010	32083	11505	2472	0.21	15791	827	0.05
2011	32774	11860	2337	0.20	13485	1014	0.08
2012	34931	13795	2508	0.18	6112	744	0.12
2013	36485	15703	2805	0.18	11279	801	0.07
2014	35817	16557	3150	0.19	3689	893	0.24

Table 5-3. Geometric means of annual age-specific fishing mortalities of Pacific bluefin tuna (*Thunnus orientalis*) for 2002-2004 and 2011-2013.

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
$F_{2002\text{-}2004}$	0.78	0.98	0.38	0.13	0.11	0.12	0.15	0.08	0.09	0.13	0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.14	0.14	0.14
$F_{2011\text{-}2013}$	0.56	0.97	0.74	0.13	0.20	0.17	0.14	0.15	0.10	0.16	0.13	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12

Table 6-1. Future projection scenarios for Pacific bluefin tuna (*Thunnus orientalis*) and their probability of achieving various target levels by various time schedules based on the base-case model.

Harvesting Scenario #	Fishing mortality	Catch limit		Threshold of Small/Large fish	Recruitment scenario	Probability that SSB is more than SSB median (38,000 tons)			Probability that SSB is more than 43,000 tons (SSBmed@last assessment)			Probability that SSB is more than 10%SSB0			Probability that SSB is more than 20%SSB0			Average Catch	
		Small fish	Large fish			2024	2029	2034	2024	2029	2034	2024	2029	2034	2024	2029	2034	2019	2024
Scenario1	F2002-2004	scenario 6 in 2014 assessment		30 kg	Low recruitment	77.0%	88.8%	89.9%	64.3%	79.3%	81.9%	14.7%	28.0%	31.8%	0.0%	0.0%	0.1%	11619.2	13574.9
Scenario2		50% of 2002-2004 average catch for WPO fisheries, 3,300 tons for EPO commercial fisheries*	2002-2004 average catch for WPO fisheries		Low recruitment	69.3%	83.7%	86.6%	56.1%	73.9%	79.0%	13.6%	29.3%	35.4%	0.1%	0.4%	0.6%	11749.7	12994.2
					Average recruitment	99.6%	100.0%	100.0%	99.3%	100.0%	100.0%	96.3%	99.8%	100.0%	73.8%	95.0%	98.0%	12958.4	14750.8
					Stock Recruit Relationship w/ h=0.9	98.2%	99.8%	99.9%	97.5%	99.7%	99.9%	93.5%	99.4%	99.9%	72.0%	97.3%	99.6%	13087.3	15020.1
Scenario3		50% of 2002-2004 average catch for WPO fisheries, 2,750 tons for EPO commercial fisheries*		50 kg	Low recruitment	80.5%	91.5%	94.0%	69.1%	85.1%	88.5%	22.2%	43.6%	51.7%	0.2%	0.9%	1.3%	11404.4	12672.3
Scenario4				80 kg	Low recruitment	86.4%	94.6%	96.5%	76.6%	90.0%	93.0%	27.8%	51.8%	61.3%	0.2%	1.1%	1.6%	11292.6	12542.7
Scenario5		90% of scenario 2	same as Scenario 2	30 kg	Low recruitment	90.0%	96.5%	98.1%	81.5%	93.4%	95.9%	35.0%	61.7%	70.4%	0.3%	2.5%	3.7%	11306.4	12881.3
					Average recruitment	99.9%	100.0%	100.0%	99.9%	100.0%	100.0%	98.4%	100.0%	100.0%	82.2%	97.8%	99.3%	12442.0	14126.3
					Stock Recruit Relationship w/ h=0.9	99.4%	100.0%	100.0%	99.1%	100.0%	100.0%	97.0%	99.8%	100.0%	81.8%	99.0%	99.9%	12576.4	14448.2
Scenario6		same as Scenario 2	90% of scenario 2		Low recruitment	75.3%	88.2%	90.2%	61.7%	78.6%	83.4%	15.7%	32.5%	38.7%	0.1%	0.5%	0.7%	11496.2	12632.4
					Average recruitment	99.7%	100.0%	100.0%	99.5%	100.0%	100.0%	96.8%	99.9%	100.0%	75.1%	95.2%	98.1%	12686.3	14071.5
					Stock Recruit Relationship w/ h=0.9	98.9%	99.9%	100.0%	98.4%	99.9%	100.0%	95.0%	99.7%	100.0%	75.5%	98.0%	99.9%	12761.0	14379.7
Scenario7		90% of scenario 2			Low recruitment	90.3%	96.8%	98.3%	82.7%	94.2%	96.8%	39.4%	68.0%	77.4%	0.5%	3.5%	5.6%	11231.0	12607.1
					Average recruitment	99.9%	100.0%	100.0%	99.9%	100.0%	100.0%	98.5%	100.0%	100.0%	83.5%	98.1%	99.6%	12139.4	13461.7
					Stock Recruit Relationship w/ h=0.9	99.2%	100.0%	100.0%	99.0%	99.9%	100.0%	96.9%	99.8%	100.0%	81.6%	99.0%	99.9%	11227.3	12461.8
Scenario8		80% of scenario 2	same as Scenario 2		Low recruitment	97.5%	99.6%	99.9%	94.8%	98.9%	99.5%	65.4%	89.2%	94.0%	1.9%	14.5%	22.8%	10922.8	12688.4
Scenario9		same as Scenario 2	80% of scenario 2		Low recruitment	78.1%	89.9%	92.5%	65.0%	81.9%	86.3%	18.4%	37.1%	44.7%	0.2%	0.6%	0.9%	11327.0	12329.9
Scenario10		80% of scenario 2			Low recruitment	98.3%	99.8%	99.9%	96.3%	99.5%	99.8%	73.2%	93.8%	97.5%	3.1%	22.4%	34.1%	10585.9	11586.4
					Average recruitment	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	99.7%	100.0%	100.0%	91.0%	99.5%	100.0%	11194.1	12104.9
					Stock Recruit Relationship w/ h=0.9	99.8%	100.0%	100.0%	99.7%	100.0%	100.0%	98.7%	100.0%	100.0%	90.0%	99.7%	100.0%	11227.3	12461.8
Scenario11	F2011-2013	same as Scenario 2	same as Scenario 2		Low recruitment	82.6%	93.0%	95.0%	71.3%	86.4%	89.9%	23.6%	46.2%	56.0%	0.1%	1.2%	1.6%	12266.8	13587.4

* Catch limits for EPO commercial fisheries is applied for all the catch (small and large fish) made by the Fleets.

** Average recruitment referres to the recruitment for the whole assessment period while low recruitment referres to that of 1980-1989.

Table 7-1. Change of estimated age-specific fishing mortalities (Fs) of Pacific bluefin tuna (*Thunnus orientalis*) from 2002-2004 to 2011-2013.

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Change from $F_{2002-2004}$ to $F_{2011-2013}$	-28%	-1%	+96%	+4%	+86%	+43%	-9%	+81%	+21%	+23%	+5%	-5%	-7%	-8%	-9%	-10%	-10%	-10%	-11%	-11%	-11%

Table 7-2. Ratios of the estimated fishing mortalities $F_{2002\text{-}2004}$, $F_{2009\text{-}2011}$ and $F_{2011\text{-}2013}$ relative to computed F-based biological reference points and SSB and depletion ratio for the terminal year of the reference period for Pacific bluefin tuna (*Thunnus orientalis*).

	F_{max}	$F_{0.1}$	F_{med}	F_{loss}	$F_{10\%}$	$F_{20\%}$	$F_{30\%}$	$F_{40\%}$	Depletion ratio	Estiamted SSB for terminal year (2014)
2002-2004	1.86	2.59	1.09	0.80	1.31	1.89	2.54	3.34	0.026	16,557
2009-2011	1.99	2.78	1.17	0.85	1.41	2.03	2.72	3.58	0.026	16,557
2011-2013	1.63	2.28	0.96	0.70	1.15	1.66	2.23	2.94	0.026	16,557

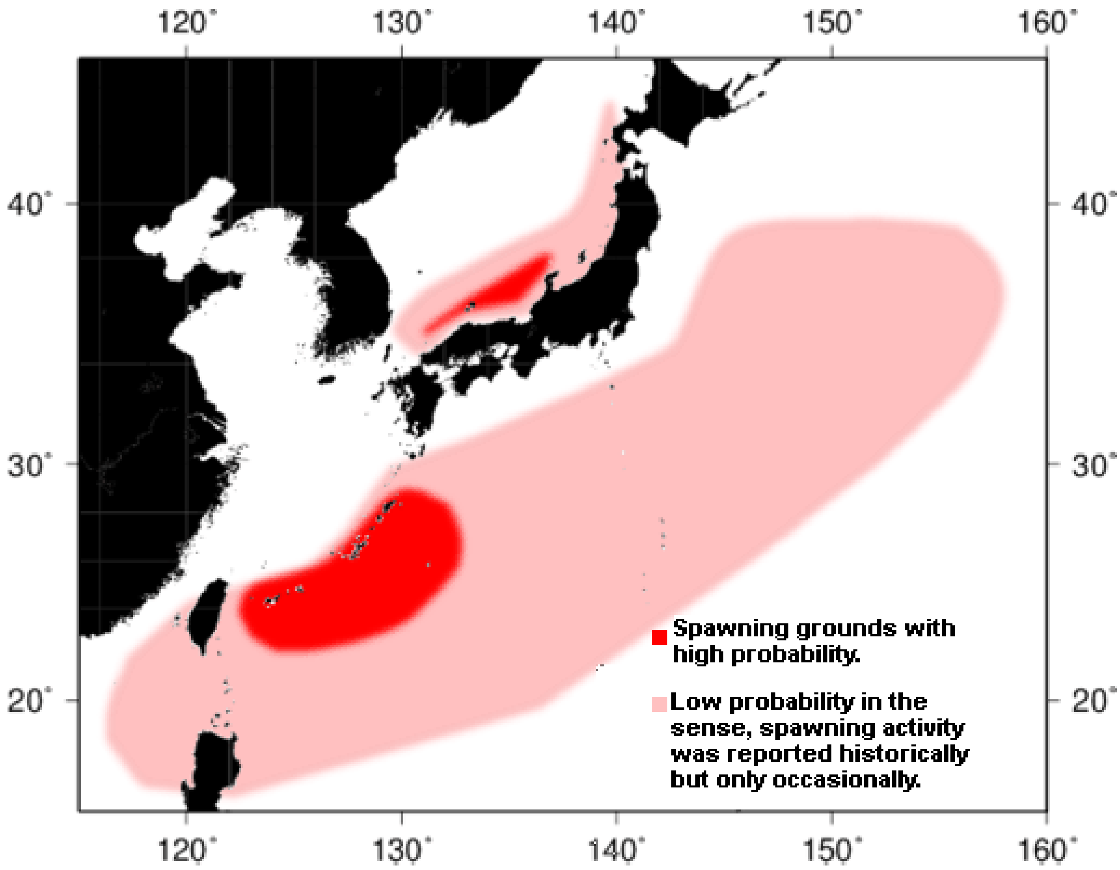


Figure 2-1. Generalized spawning grounds for Pacific bluefin tuna (*Thunnus orientalis*). Red areas represent higher probability of spawning.

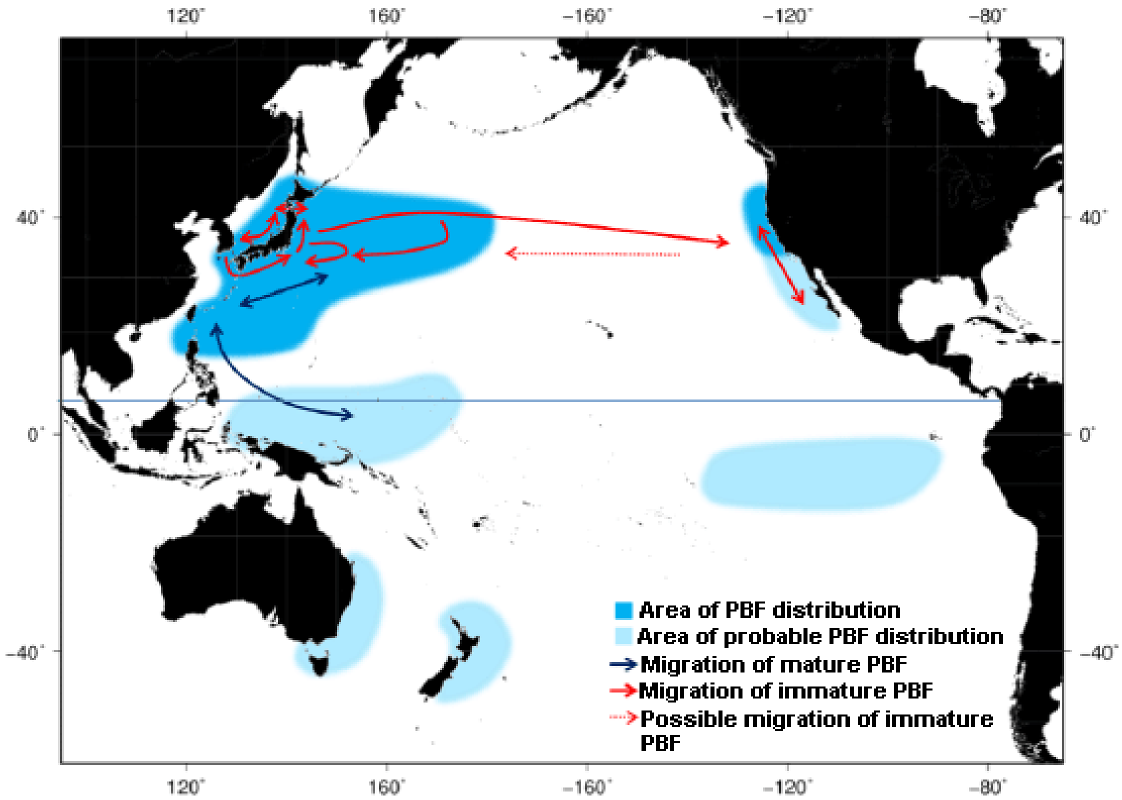


Figure 2-2. Generalized distribution of Pacific bluefin tuna (*Thunnus orientalis*). Darker areas indicate the core habitat.

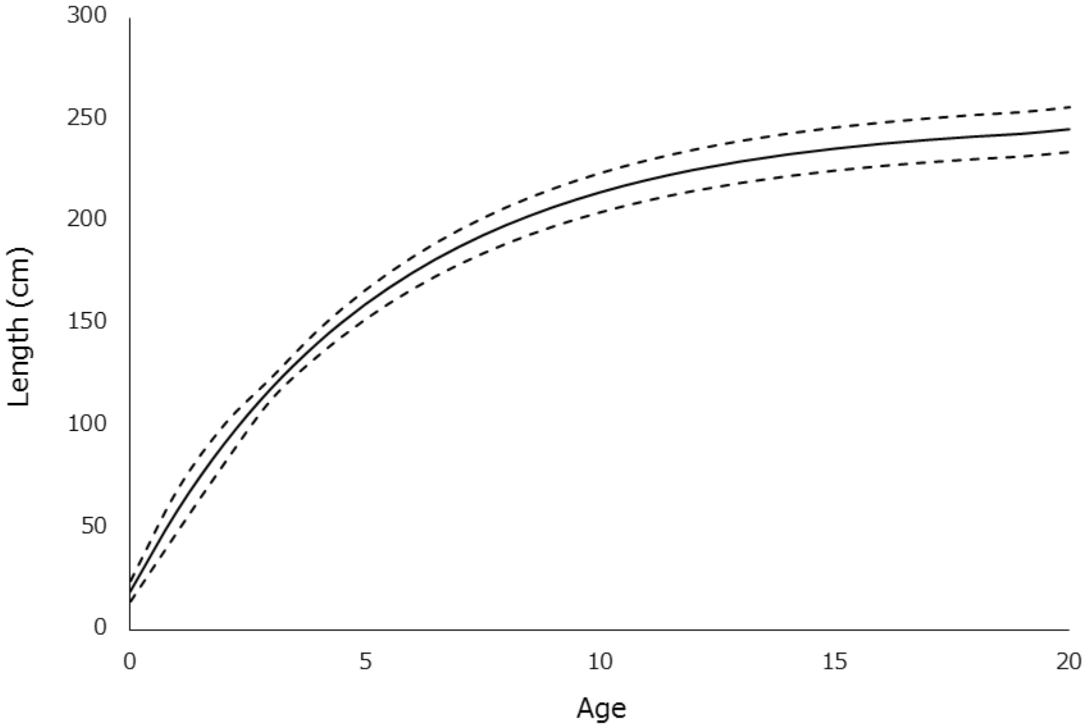


Figure 2-3. The von Bertalanffy growth curve for Pacific bluefin tuna (*Thunnus orientalis*) used in this stock assessment. Integer age (0,1,2,3,…) corresponds to the middle of first quarter 1 of each fishing year (i.e., August 15 in the calendar year).

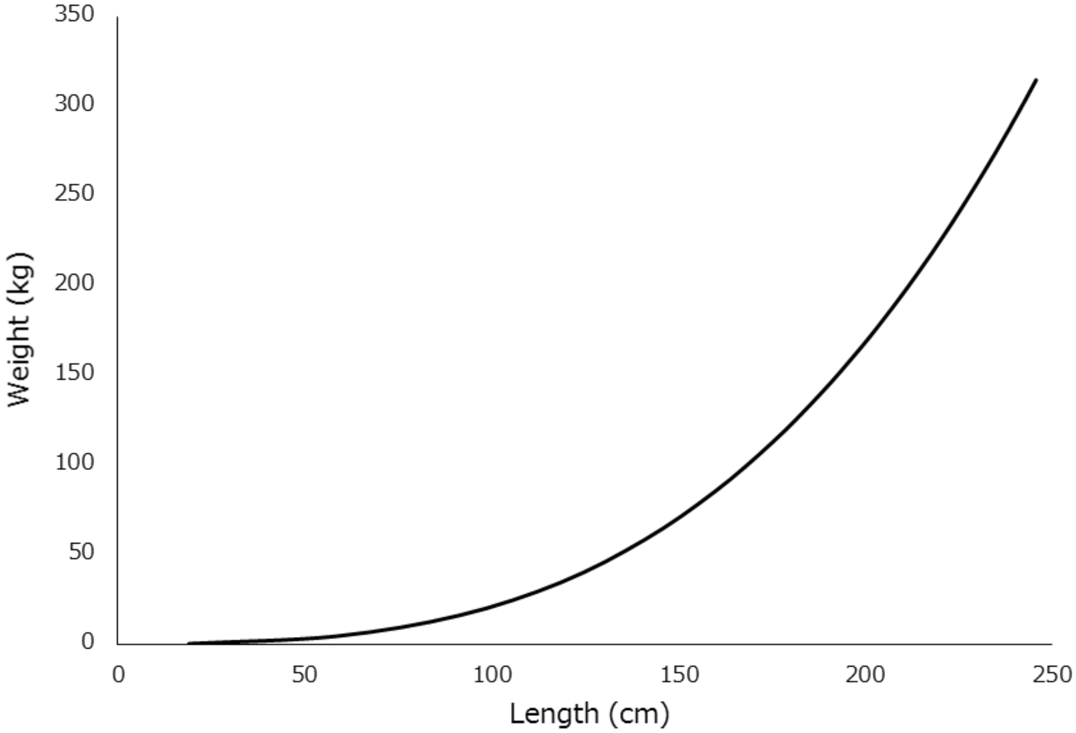


Figure 2-4. Length-weight relationship for Pacific bluefin tuna (*Thunnus orientalis*) used in this stock assessment.

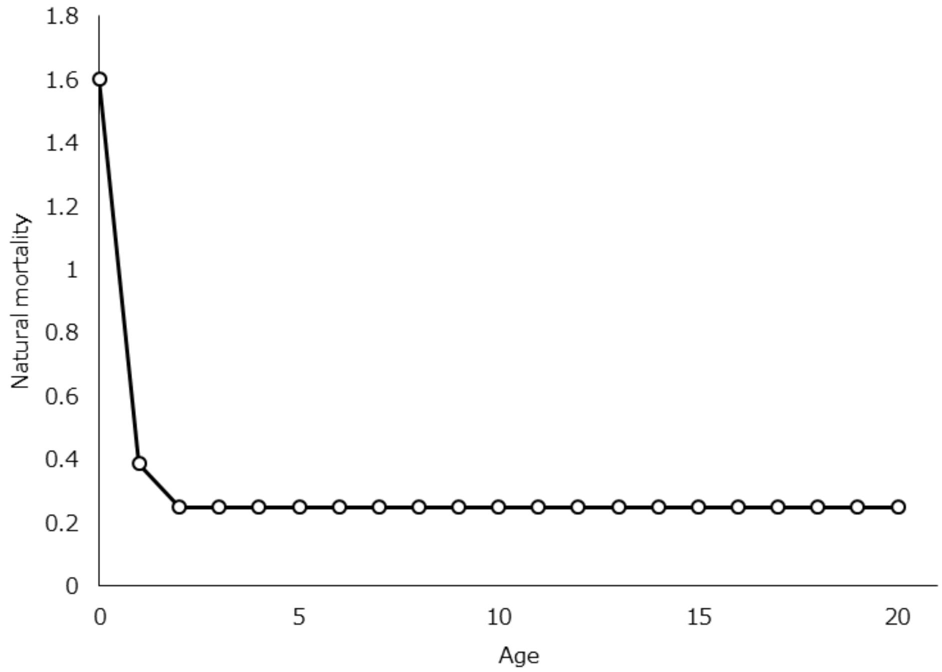


Figure 2-5. Assumed natural mortality (*M*) at age of Pacific bluefin tuna (*Thunnus orientalis*) used in this stock assessment.

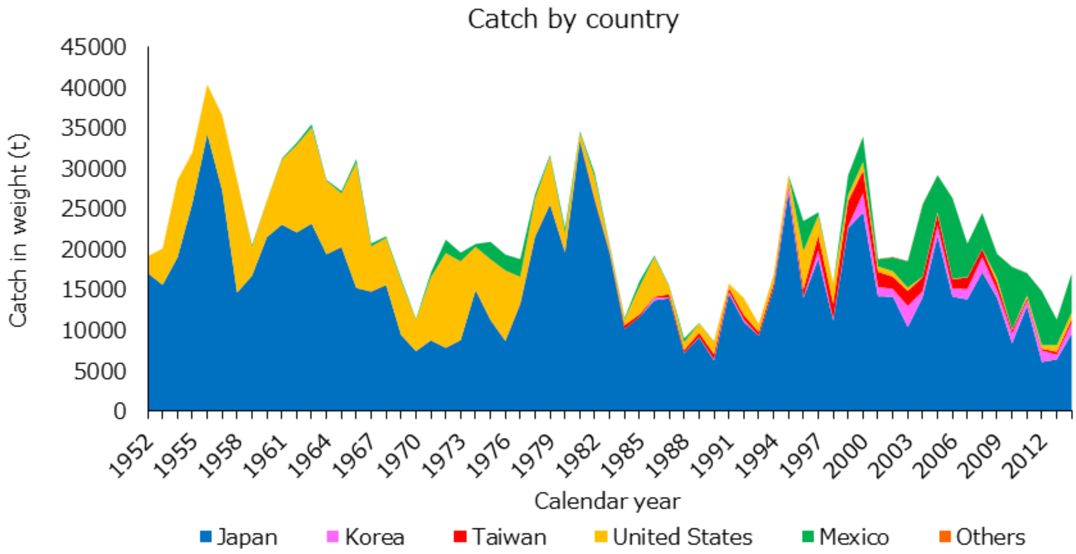


Figure 2-6. Annual catch of Pacific bluefin tuna (*Thunnus orientalis*) by country from 1952 through 2014 (calendar year).

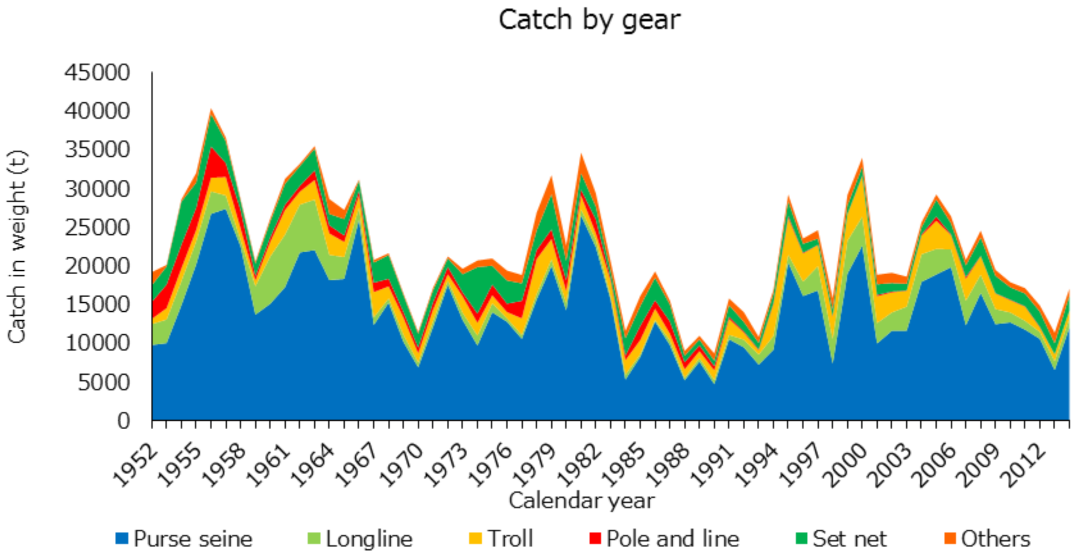


Figure 2-7. Annual catch of Pacific bluefin tuna (*Thunnus orientalis*) by gear type from 1952 through 2014 (calendar year).

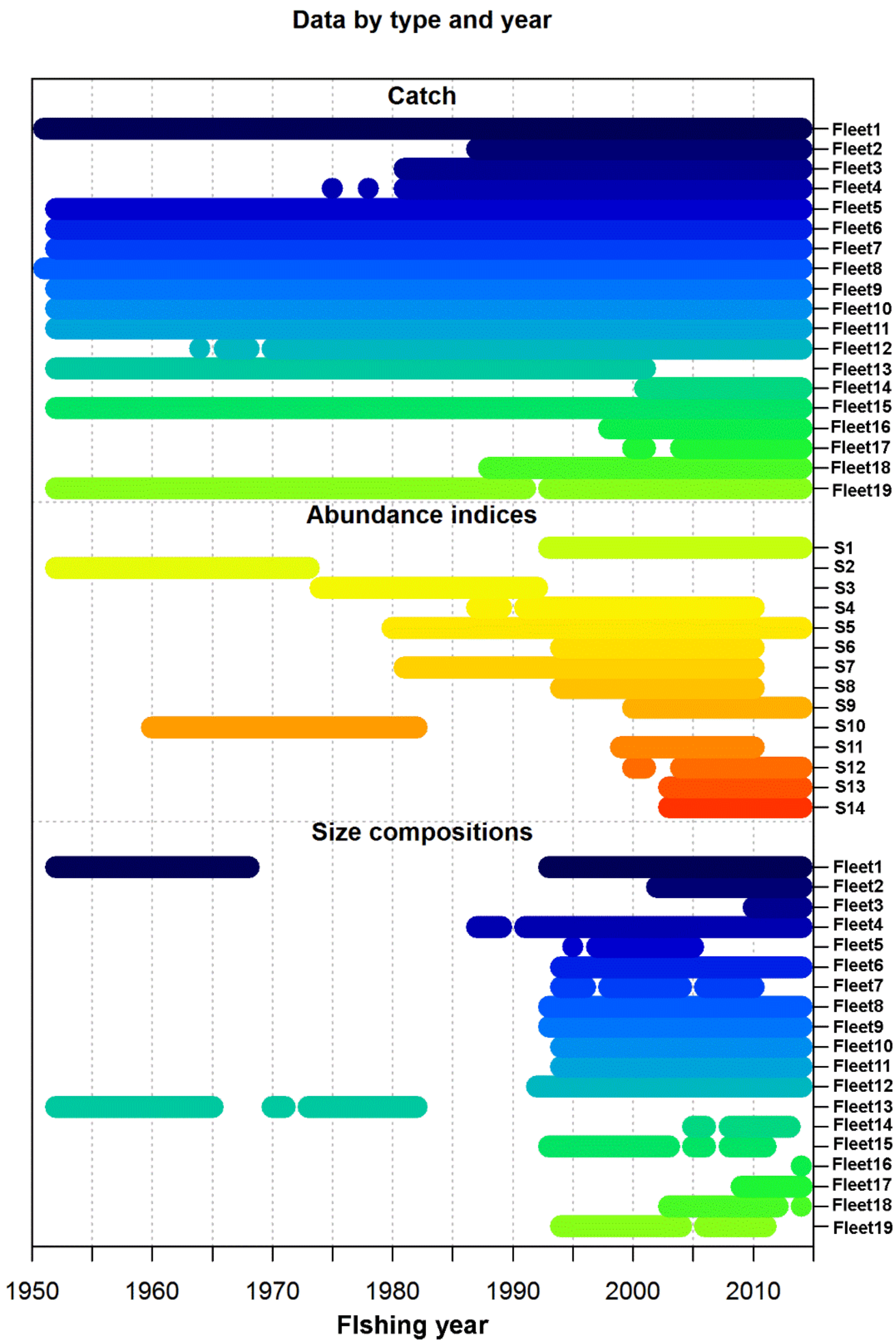
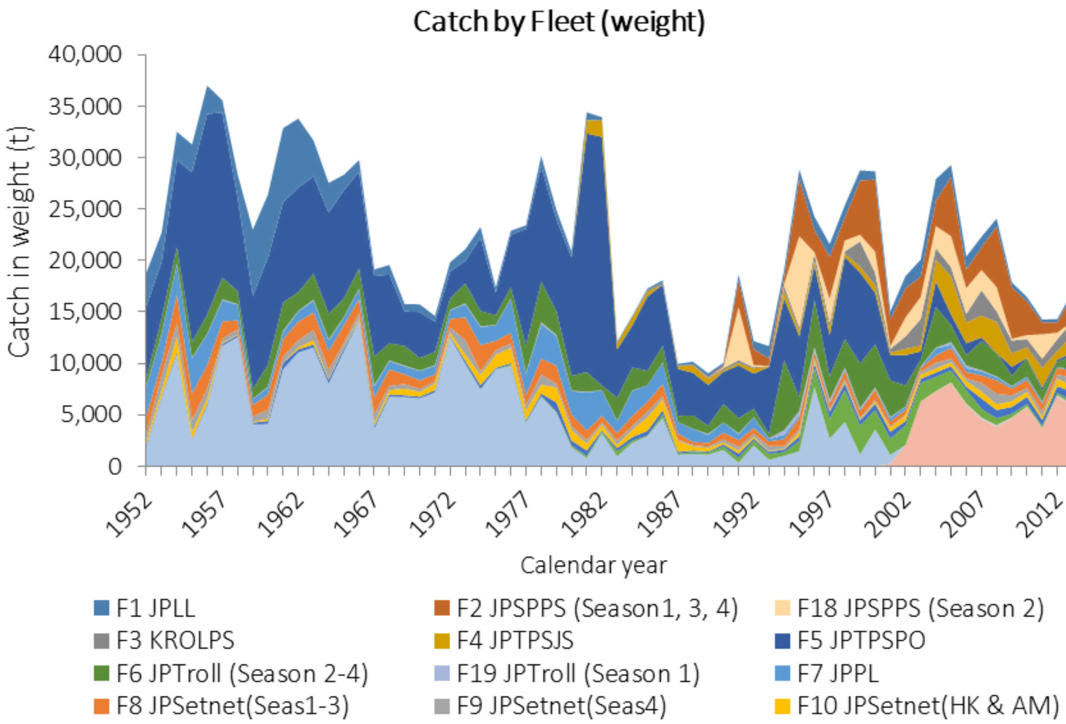


Figure 3-1. Data sources and temporal coverage of catch, abundance indices, and size composition data used in the stock assessment of Pacific bluefin tuna (*Thunnus orientalis*).

(a)



(b)

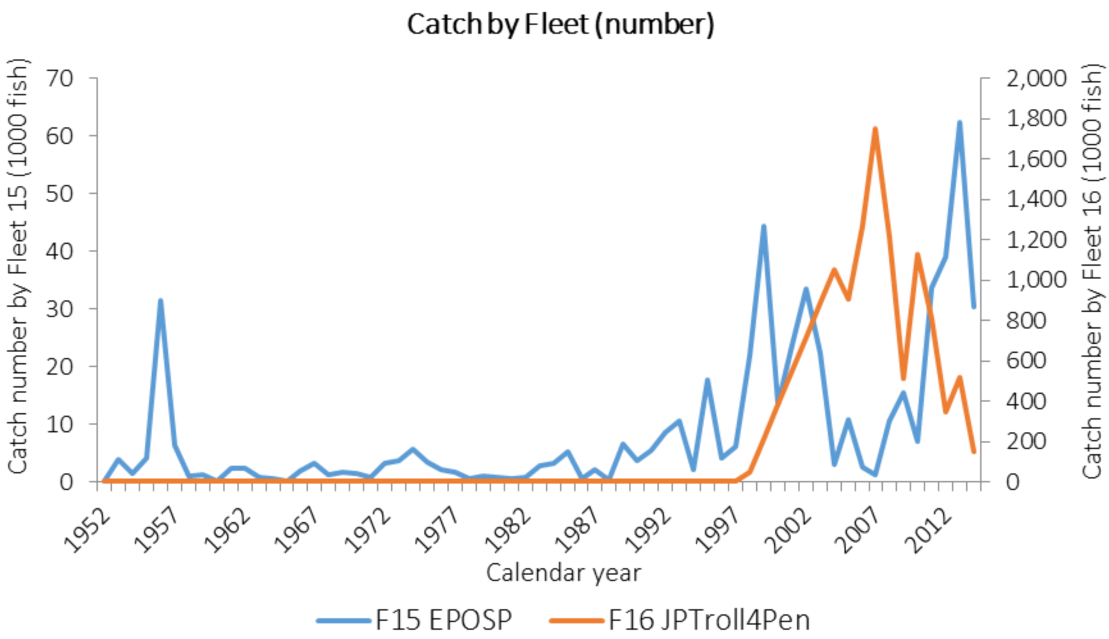


Figure 3-2. Annual catch in (a) weight and (b) number of Pacific bluefin tuna (*Thunnus orientalis*) by fleet from 1952 through 2014 (calendar year).

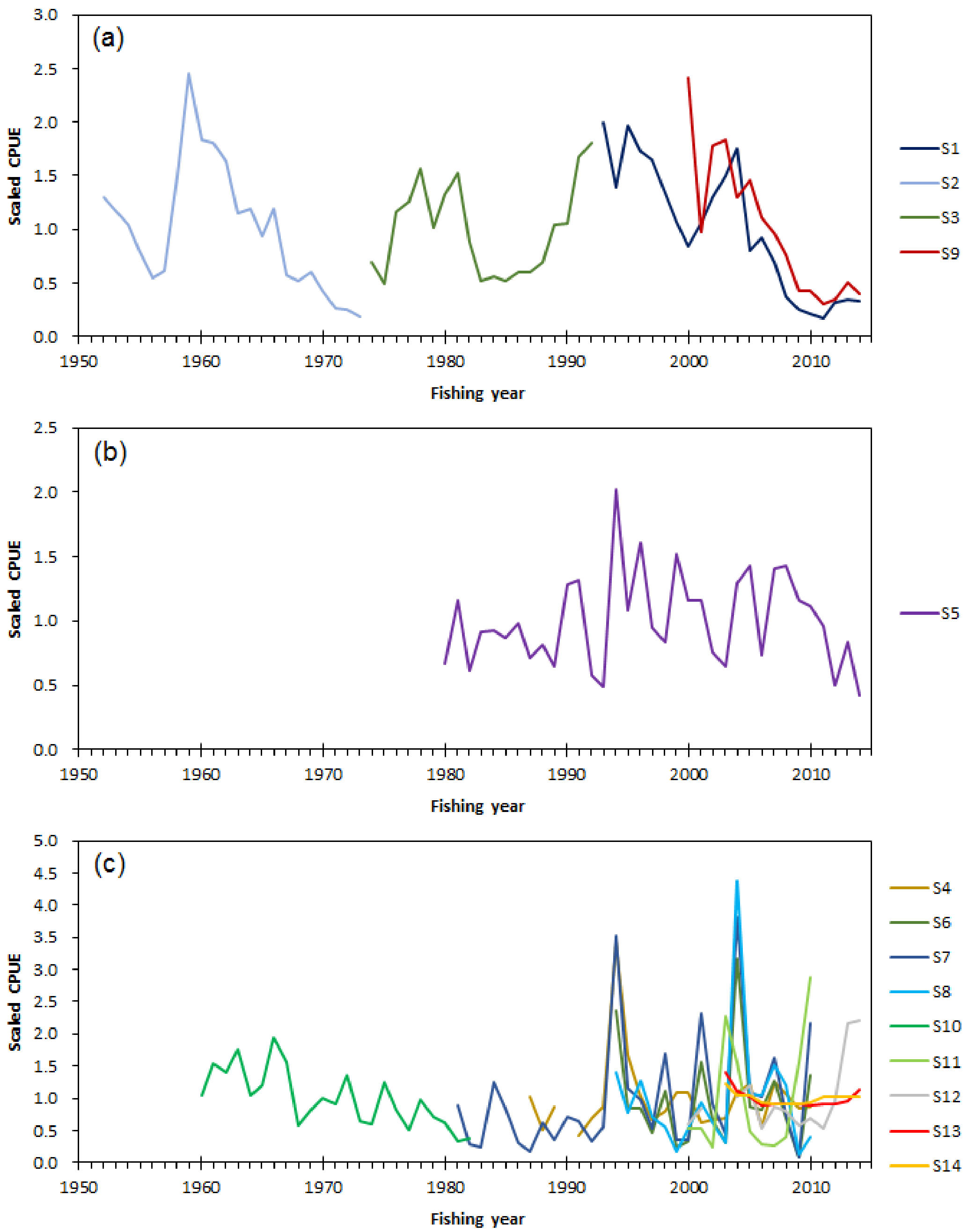


Figure 3-3. Abundance indices of Pacific bluefin tuna (*Thunnus orientalis*) submitted to ISC PBFWG, where (a) the longline indices of Japanese fisheries (S1, S2, and S3) and Taiwanese longline fishery in the southern area (S9) were used to represent adult abundance, (b) the index of Japanese troll fishery (S5) was used to represent recruitment (age 0) abundance, and (c) the other indices were not used in the base-case assessment model; e.g. the indices of Japanese tuna purse seine (S4, S13, S14), Japanese troll fisheries (S6, S7, S8), Taiwanese longline fishery in northern area (S12), and EPO purse seine (S10, S11).

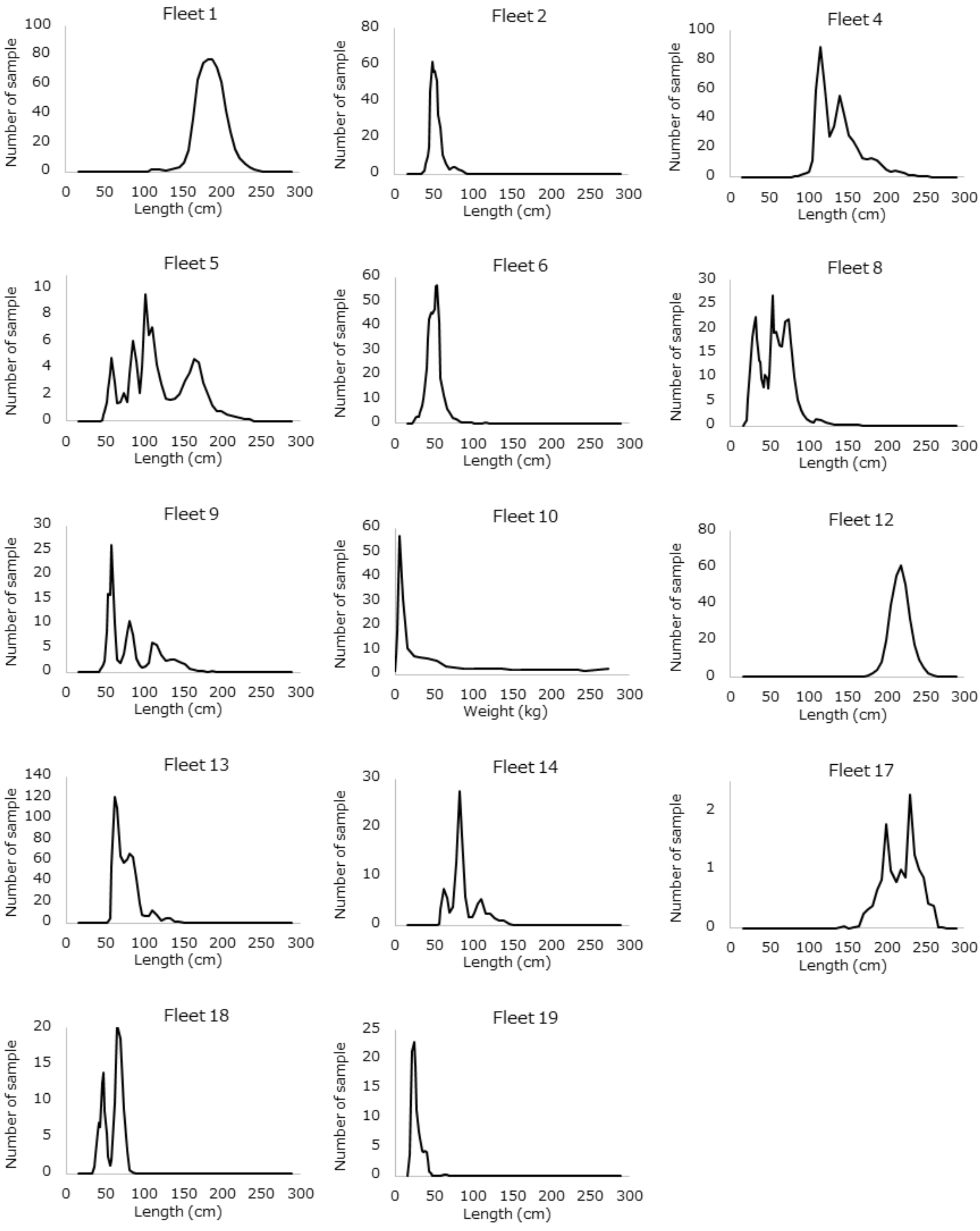


Figure 3-4. Aggregated size compositions of Pacific bluefin tuna (*Thunnus orientalis*) for each fleet used in the stock assessment. The data were aggregated across seasons and years after being scaled by fleet size. The x-axis is in fork length (cm) for all fleets except for Fleet 10 in weight (kg).

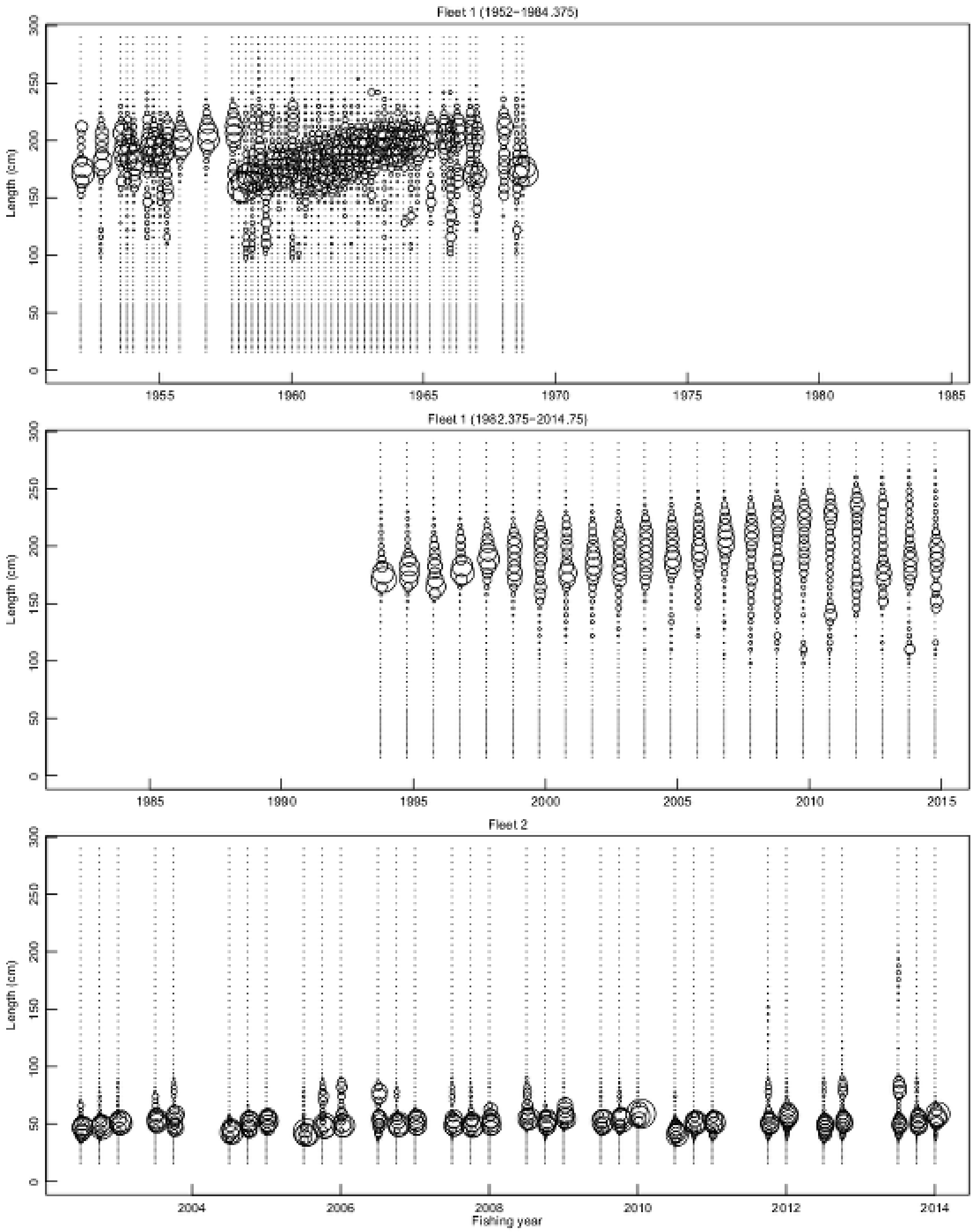


Figure 3-5. Size composition data by fleet and season used in the stock assessment model for Pacific bluefin tuna (*Thunnus orientalis*). Larger circles indicate higher proportions of fish.

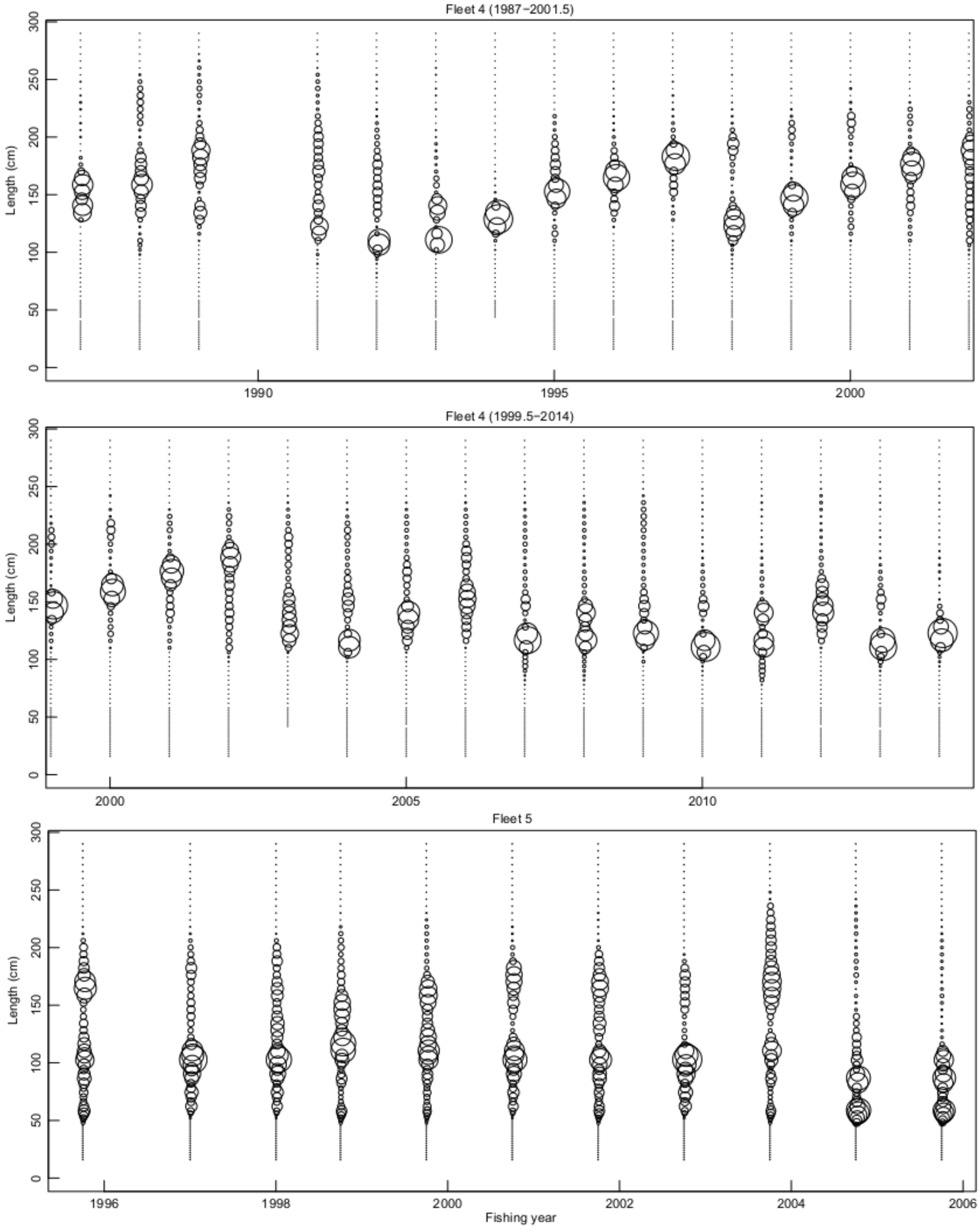
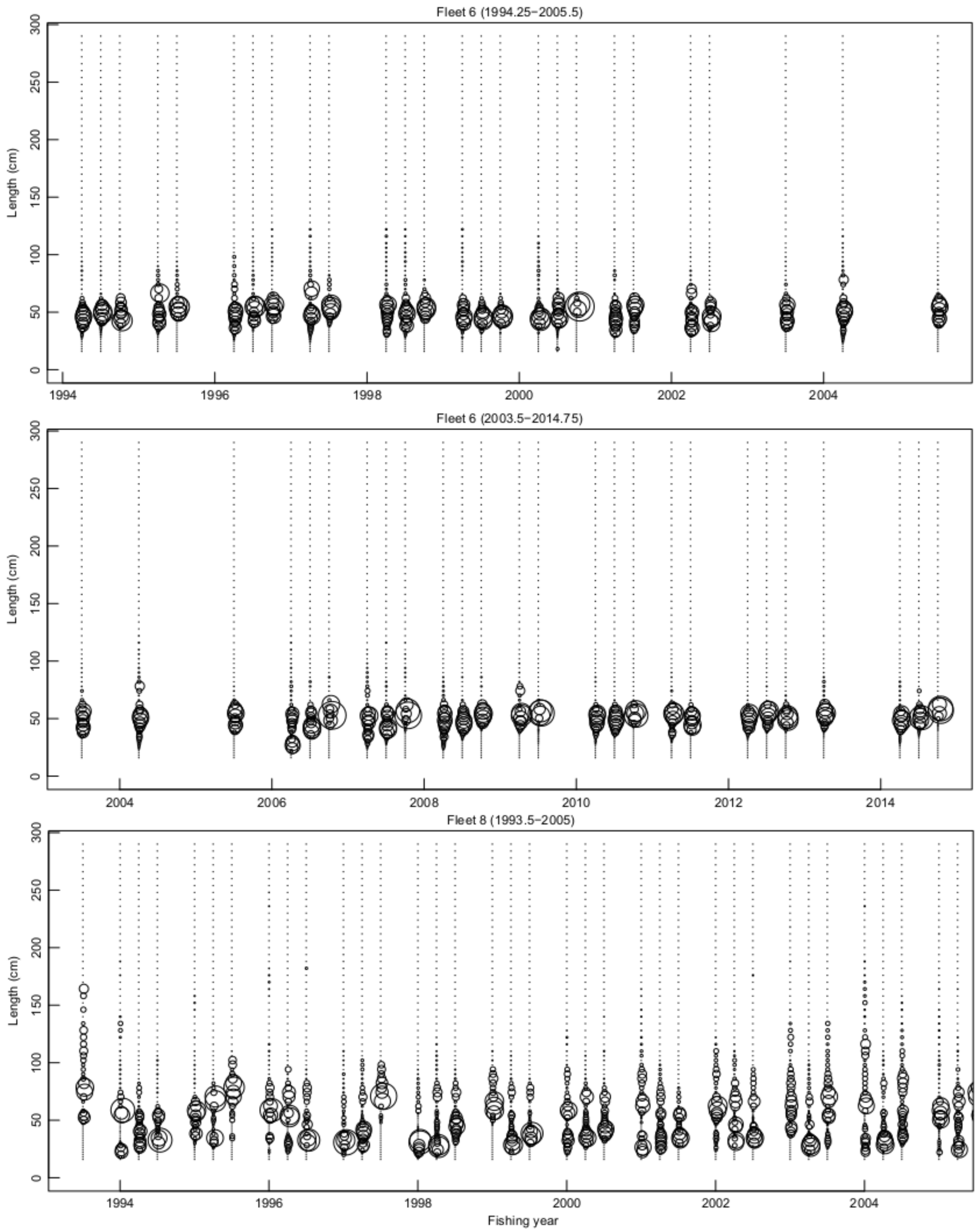


Figure 3-5. Cont.



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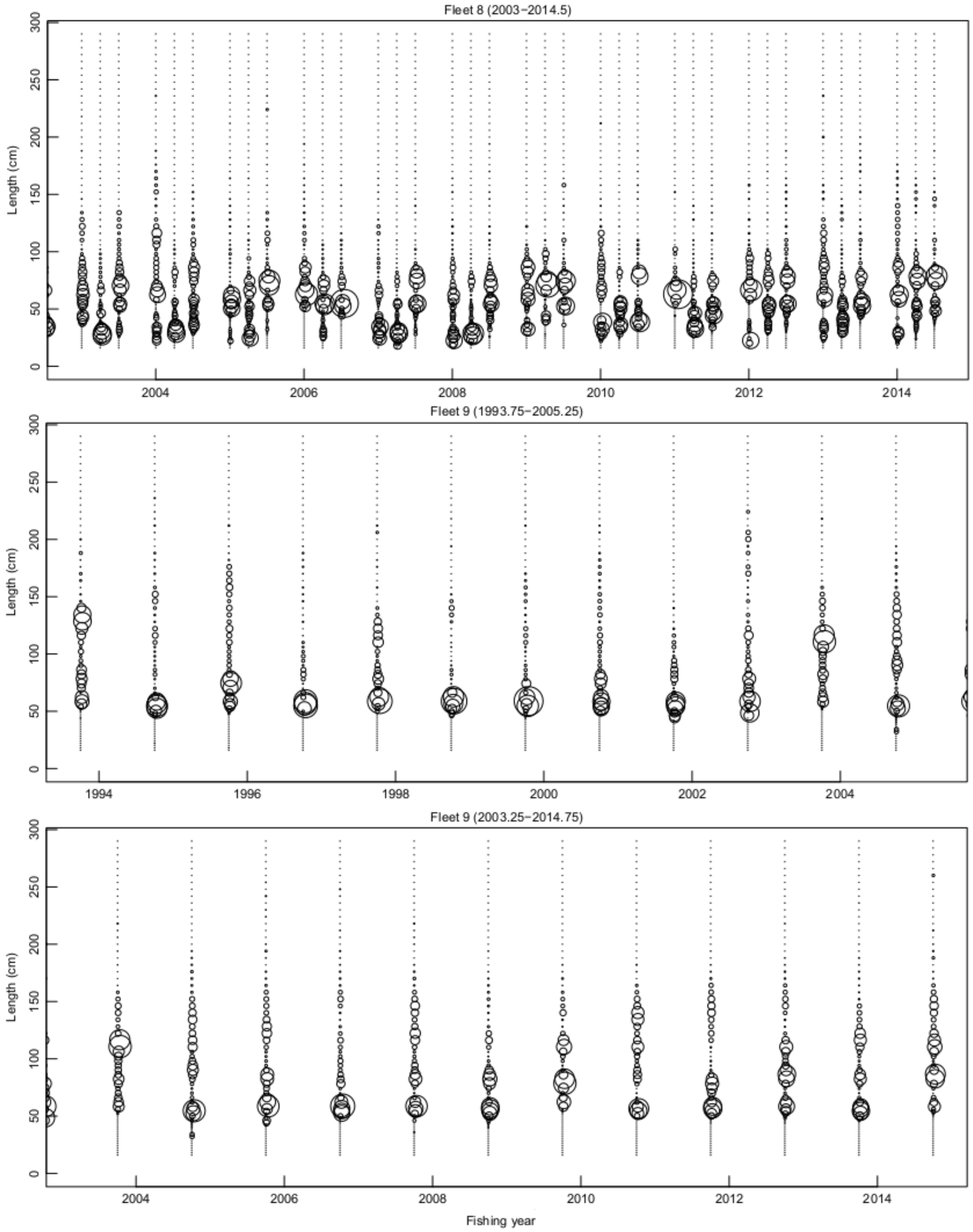

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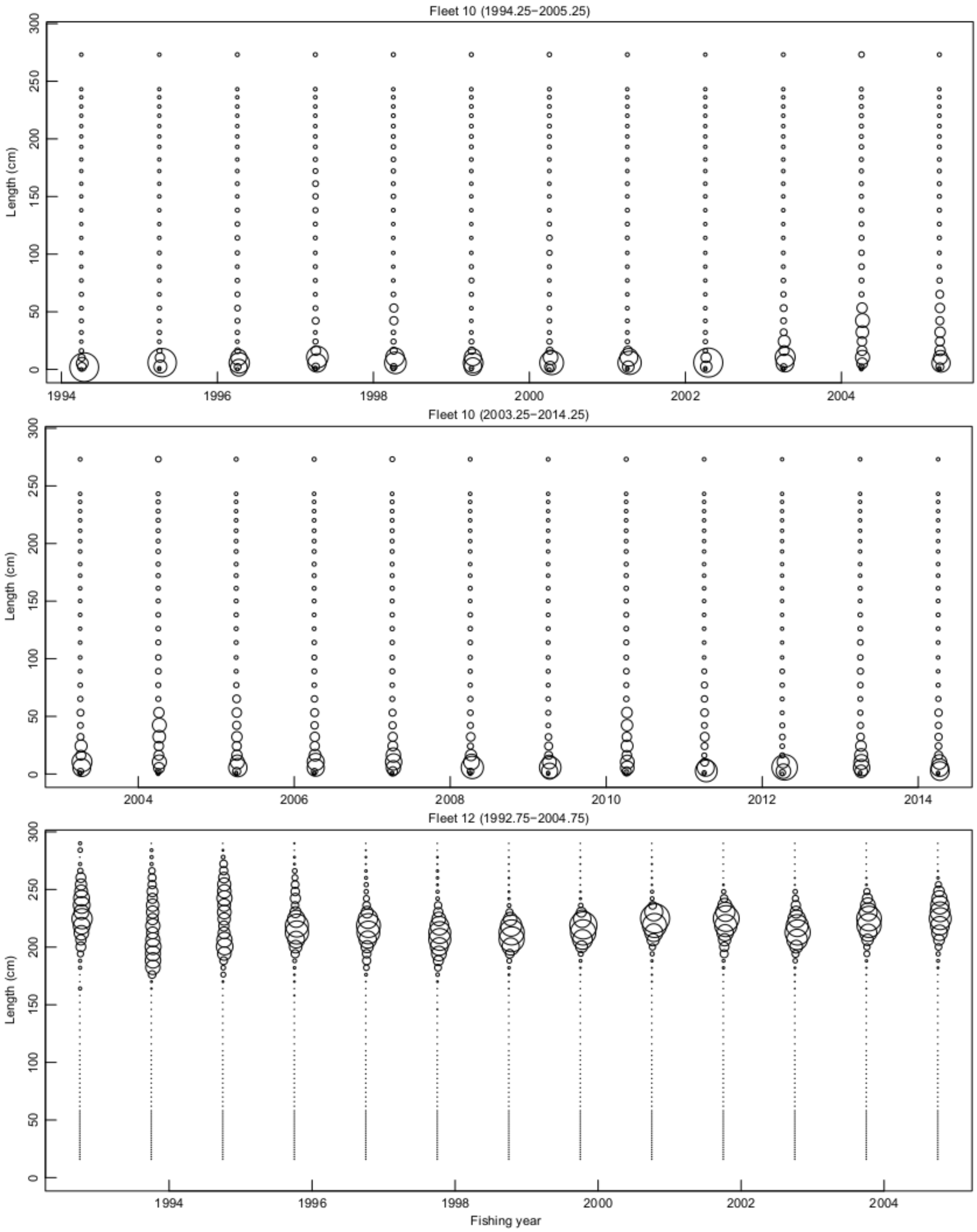

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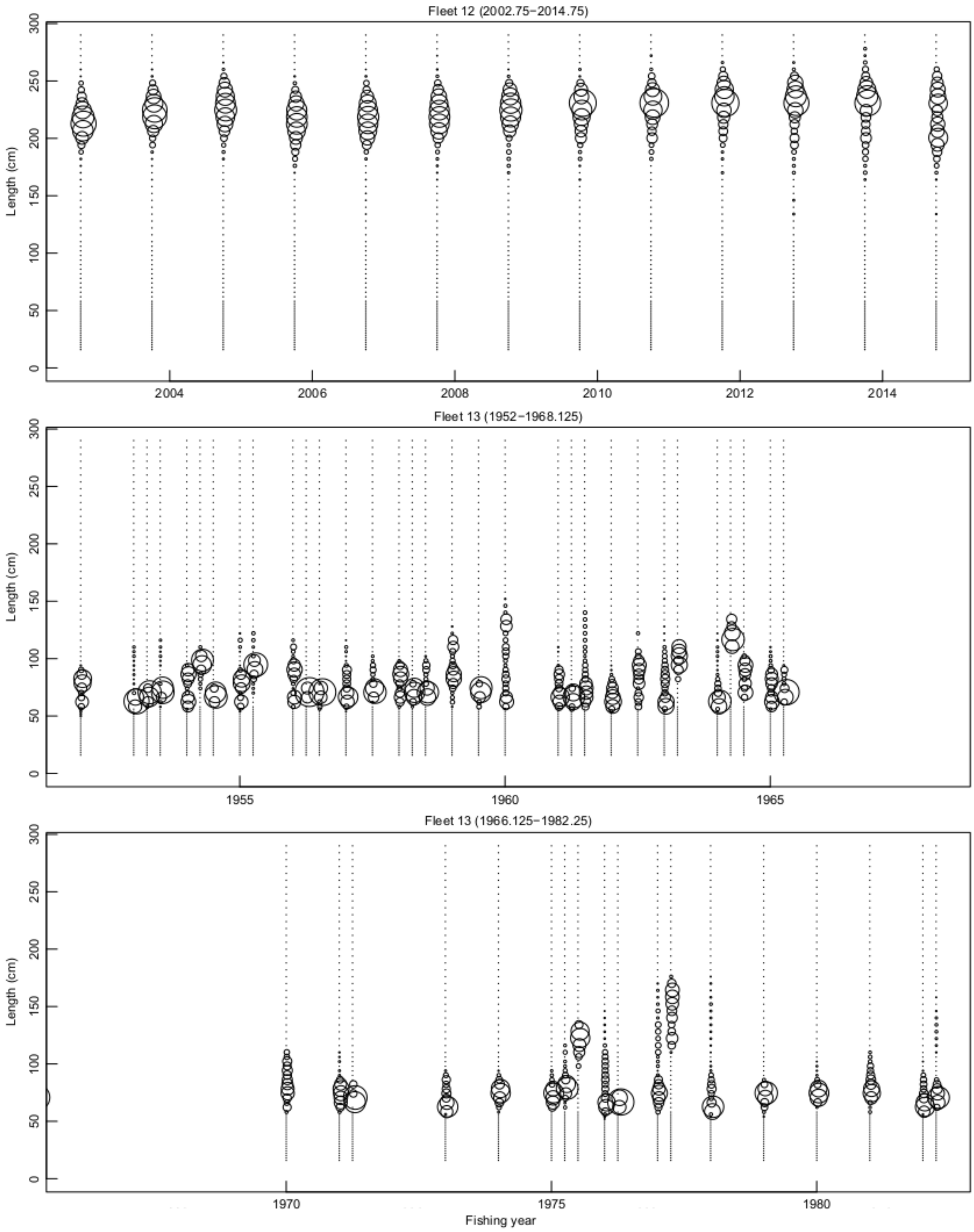

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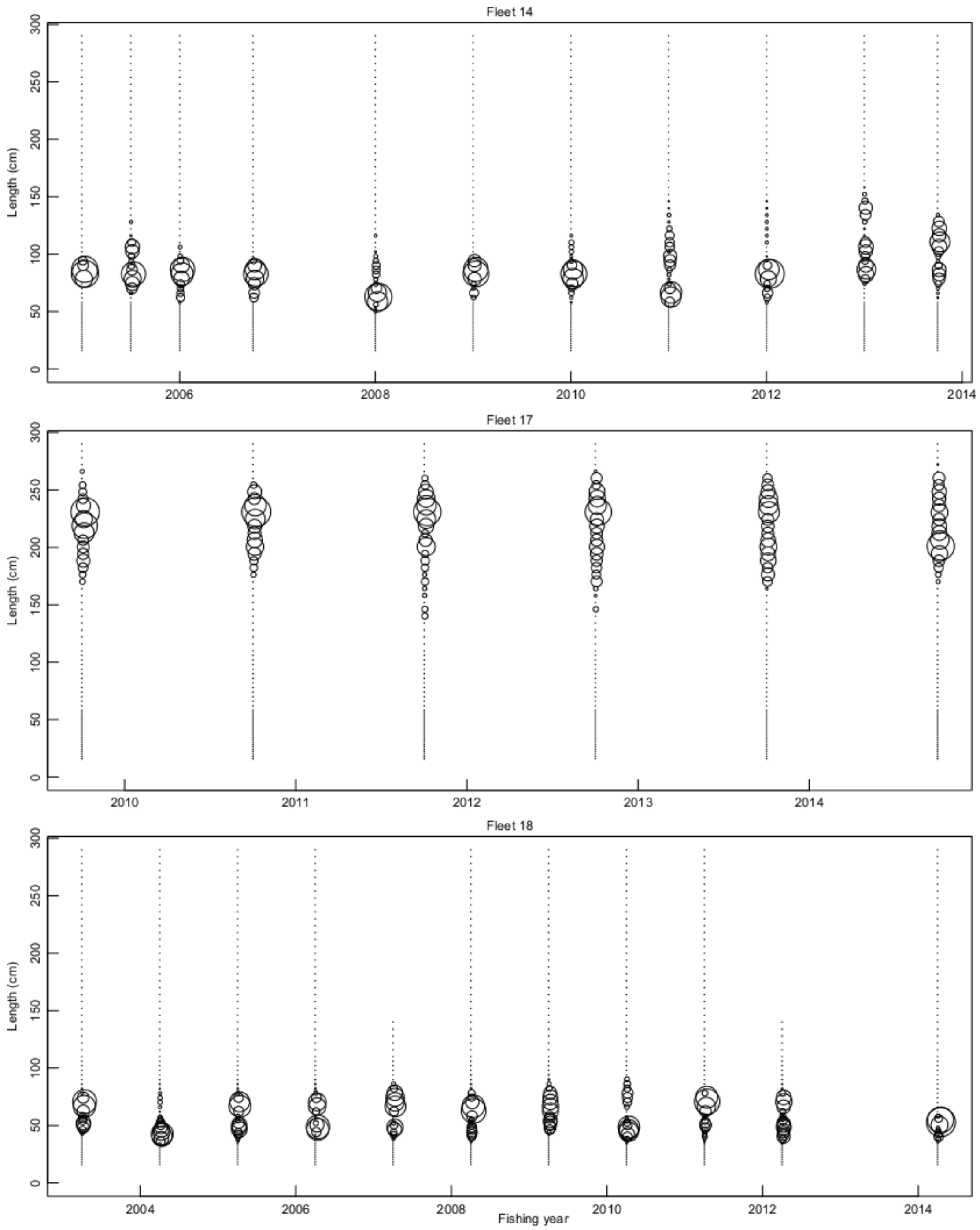

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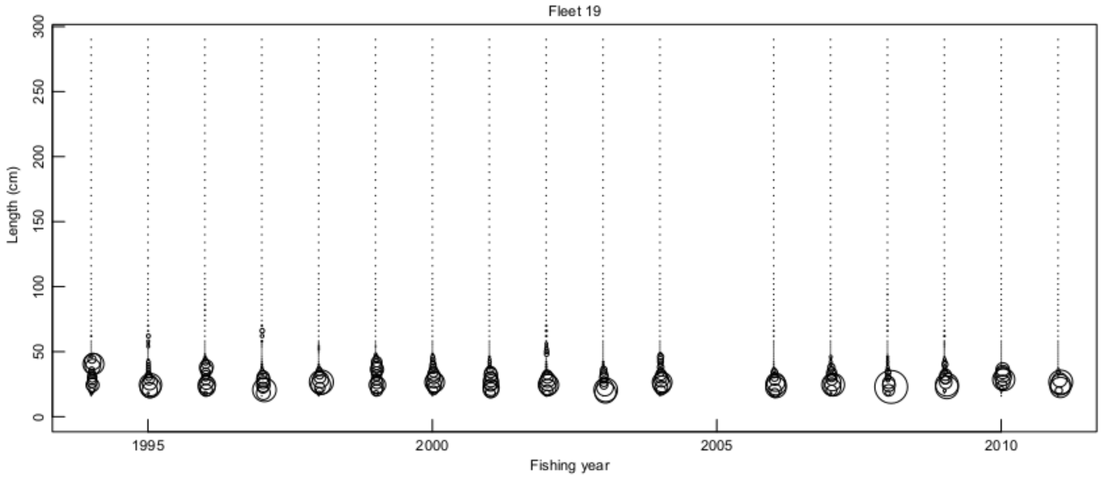

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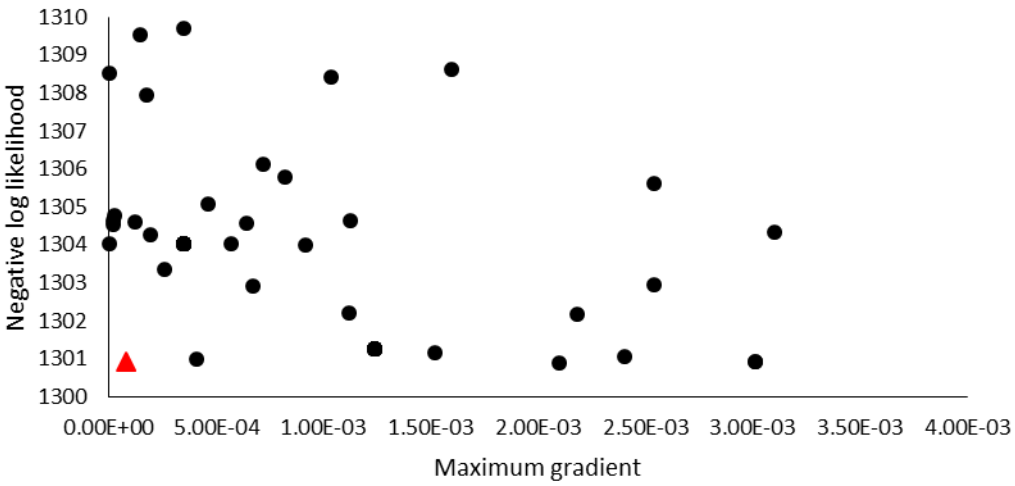


Figure 5-1. Effects of random perturbations of initial values and phasing on maximum gradient and total likelihood by the base-case model for Pacific bluefin tuna (*Thunnus orientalis*). Red triangle represents the value of the base-case model.

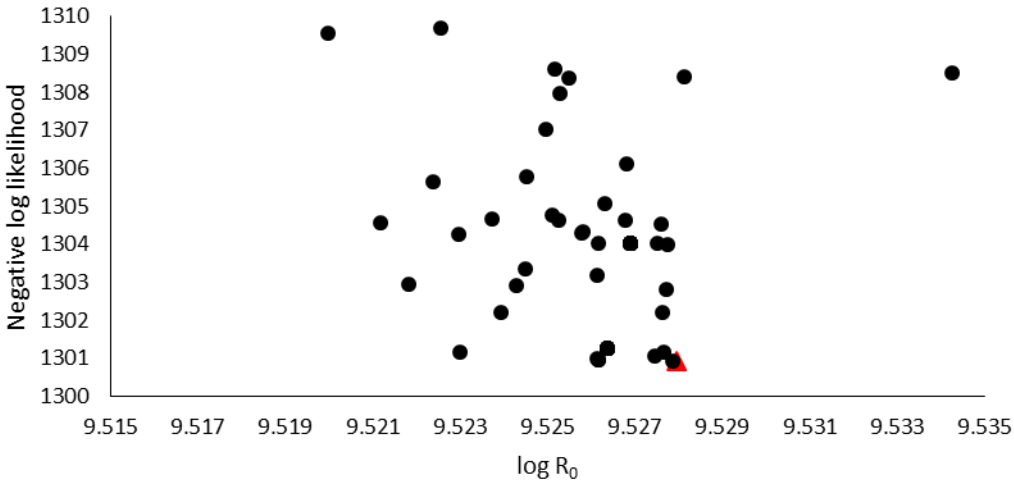


Figure 5-2. Effects of random perturbations of initial values and phasing on log(R_0) and total likelihood by the base-case model for Pacific bluefin tuna (*Thunnus orientalis*). Red triangle represents the value of the base-case model.

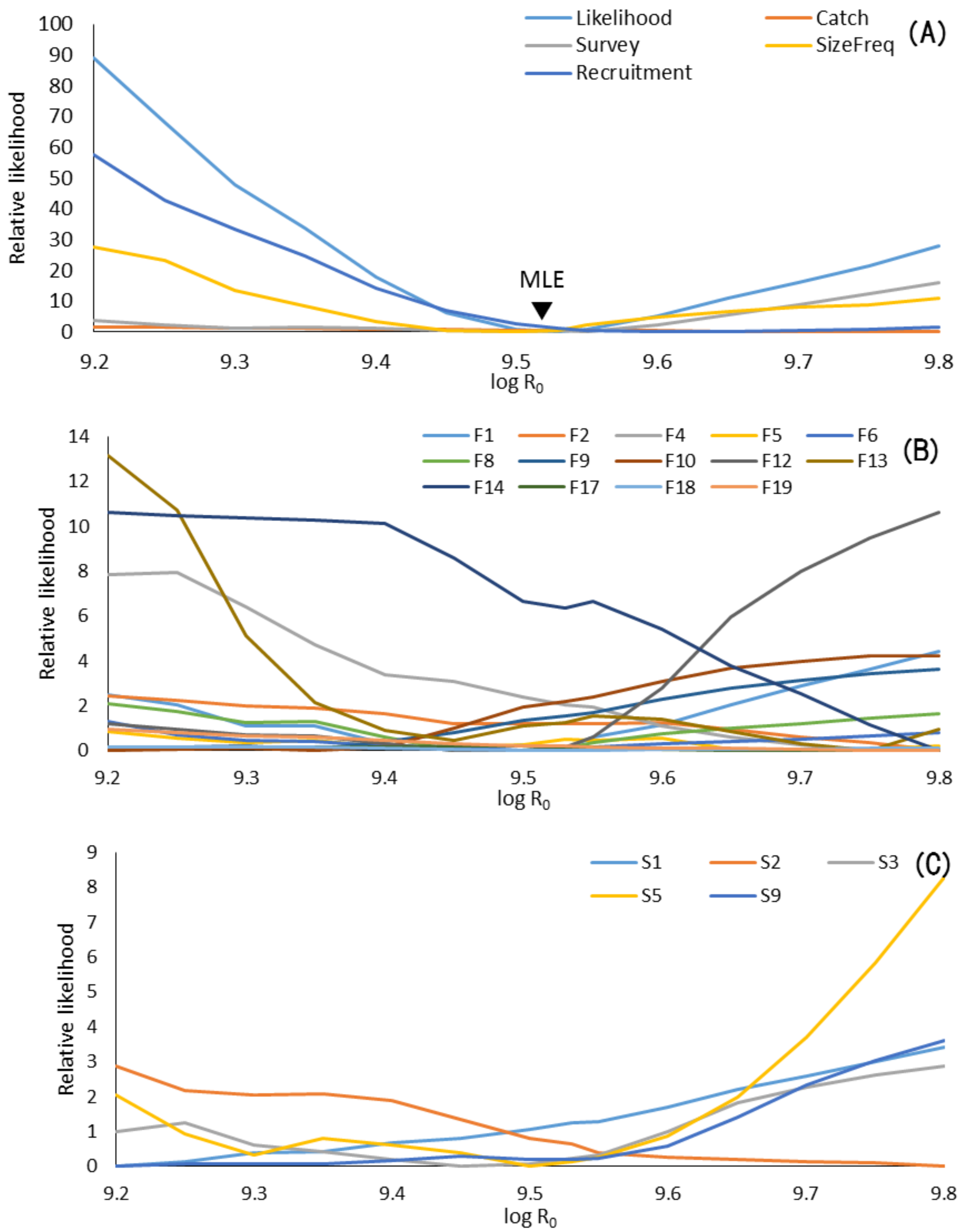


Figure 5-3. Profiles of (A) total and component likelihoods (B) likelihood for each size composition component and (C) likelihood for each index component over fixed log(R_0) for the base-case model of Pacific bluefin tuna (*Thunnus orientalis*).

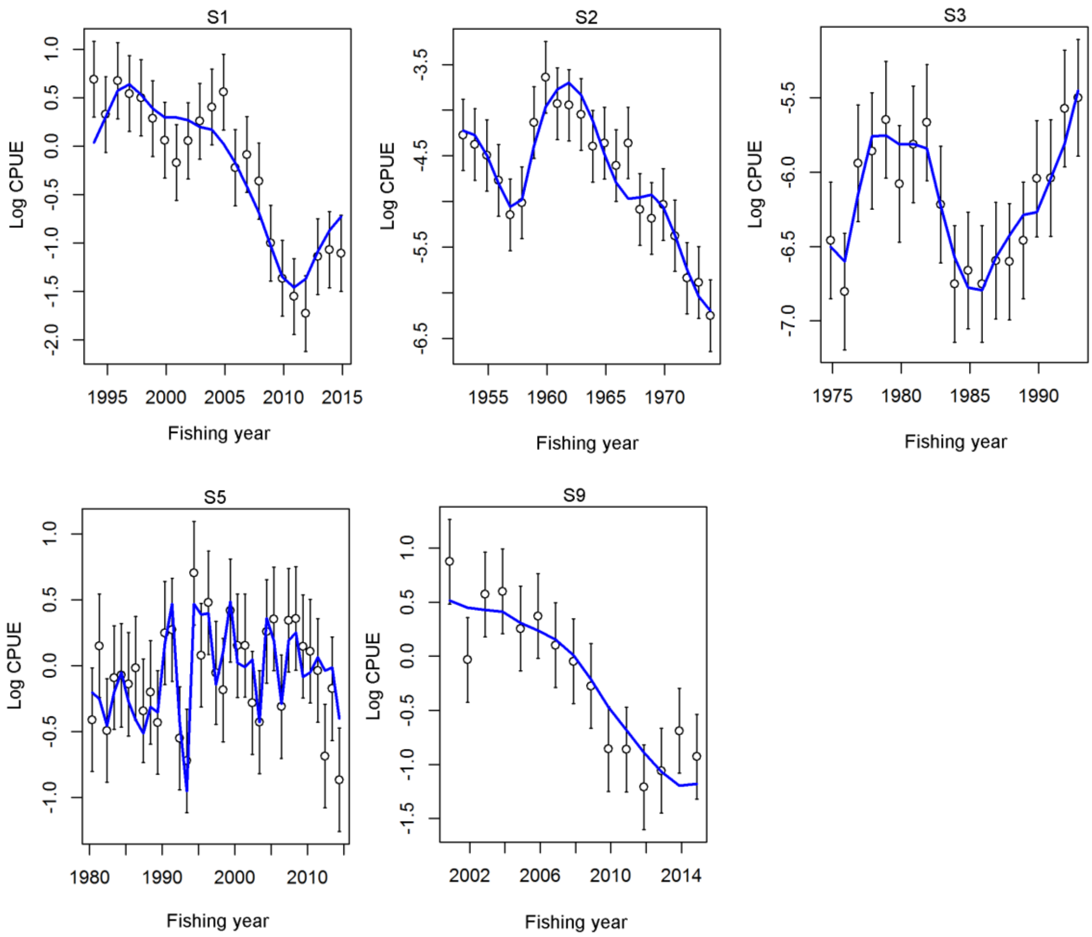


Figure 5-4. Predicted (blue lines) and observed (open dots) abundance indices by fishery for the base-case model of Pacific bluefin tuna (*Thunnus orientalis*), where vertical lines represent the 95% CI of observations.

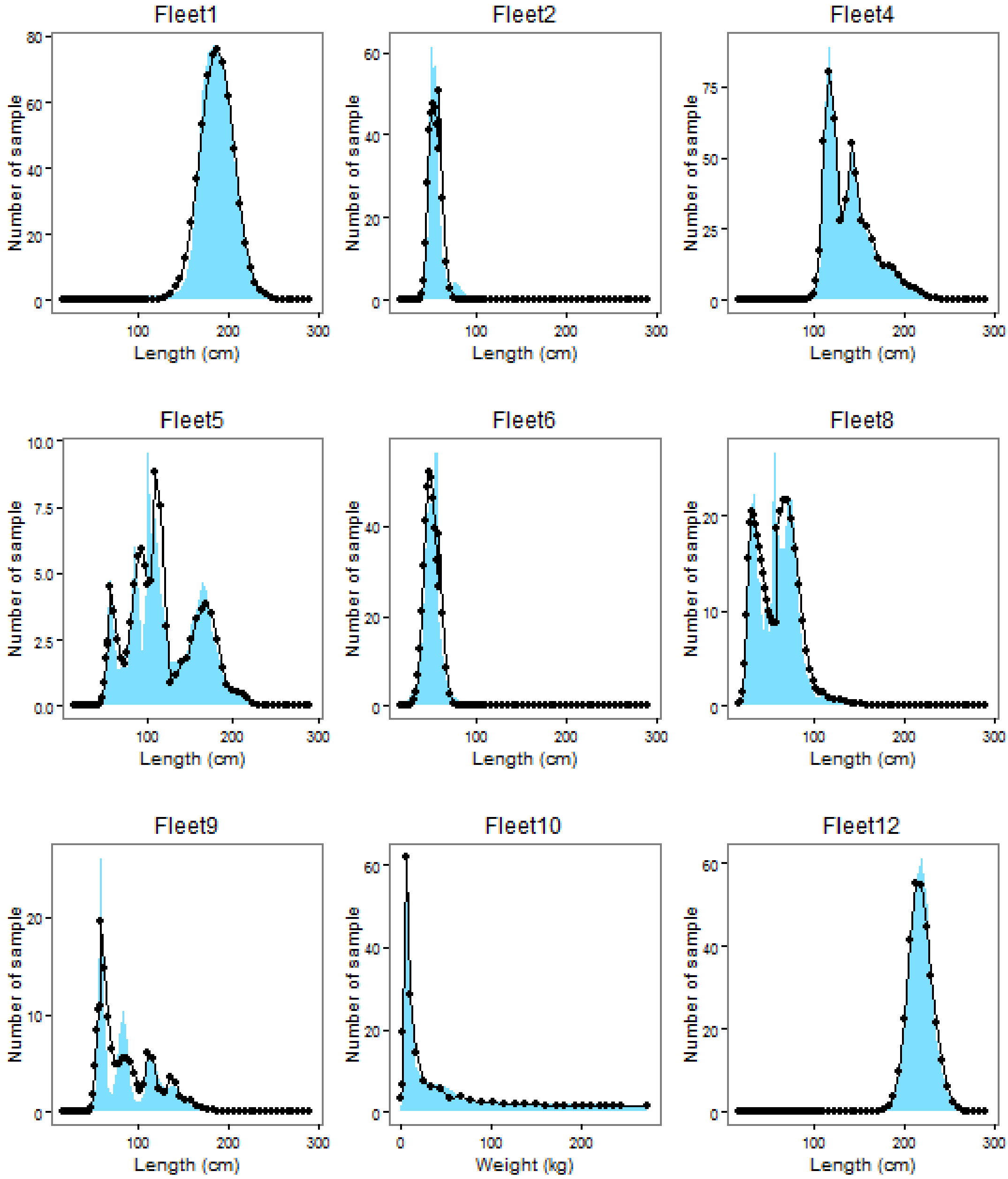


Figure 5-5. Overall fits (black lines with dots) to the size compositions by fleet across seasons in the base-case model for Pacific bluefin tuna (*Thunnus orientalis*), where blue areas indicate the observations.

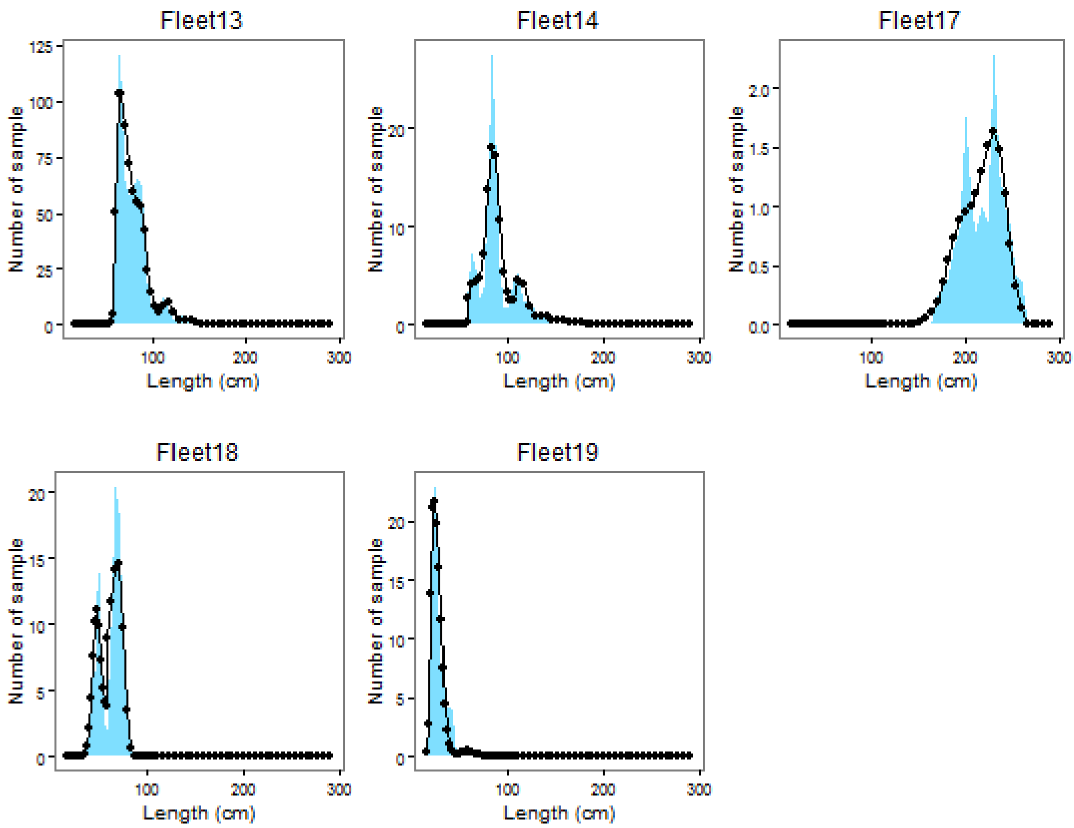


Figure 5-5. Cont.

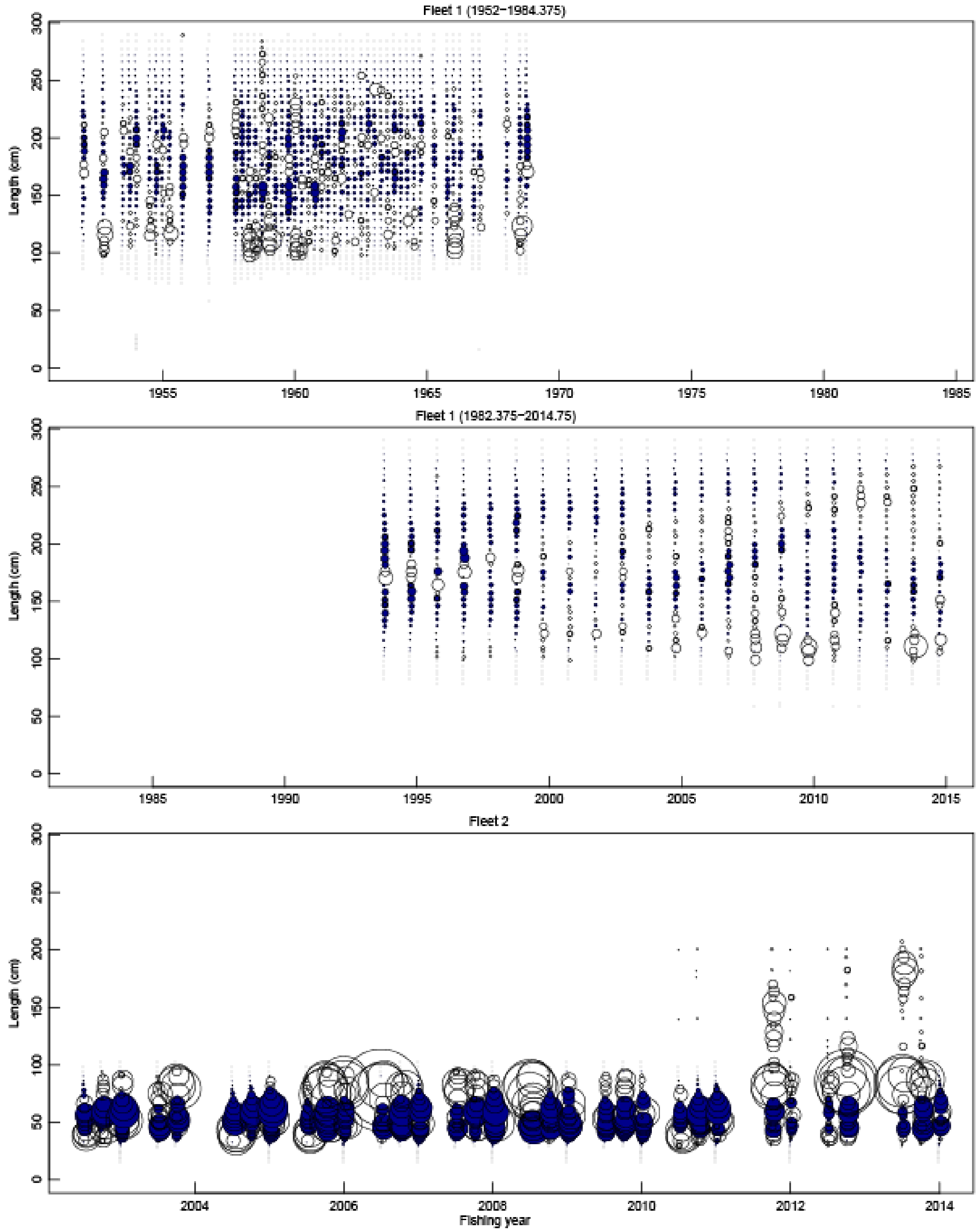
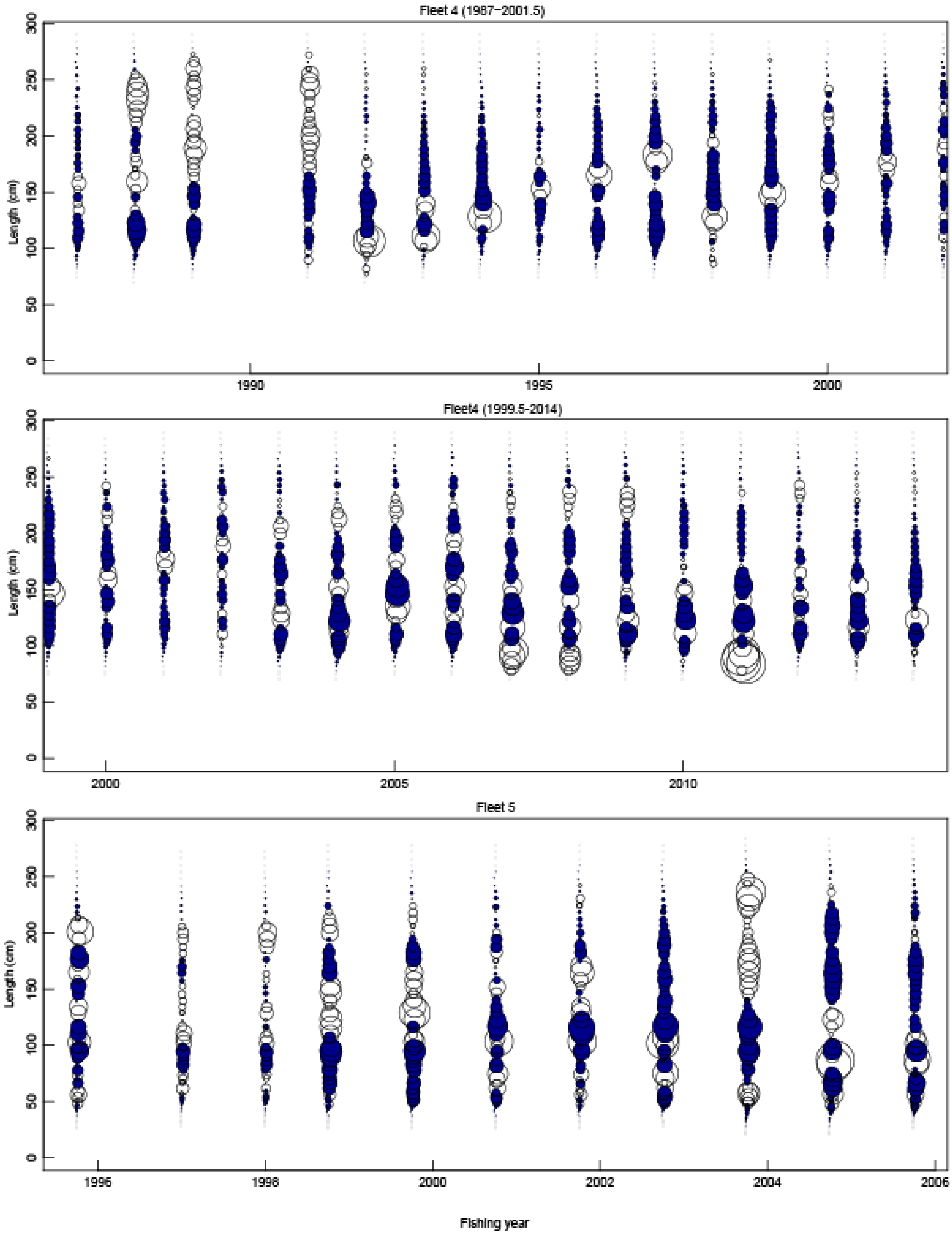


Figure 5-6. Pearson residual plots of model fits to the size composition data of Pacific bluefin tuna (*Thunnus orientalis*) by fishery. The hollow and filled circles represent observations that are higher and lower than the model predictions, respectively. The areas of the circles are proportional to the absolute values of the residuals.



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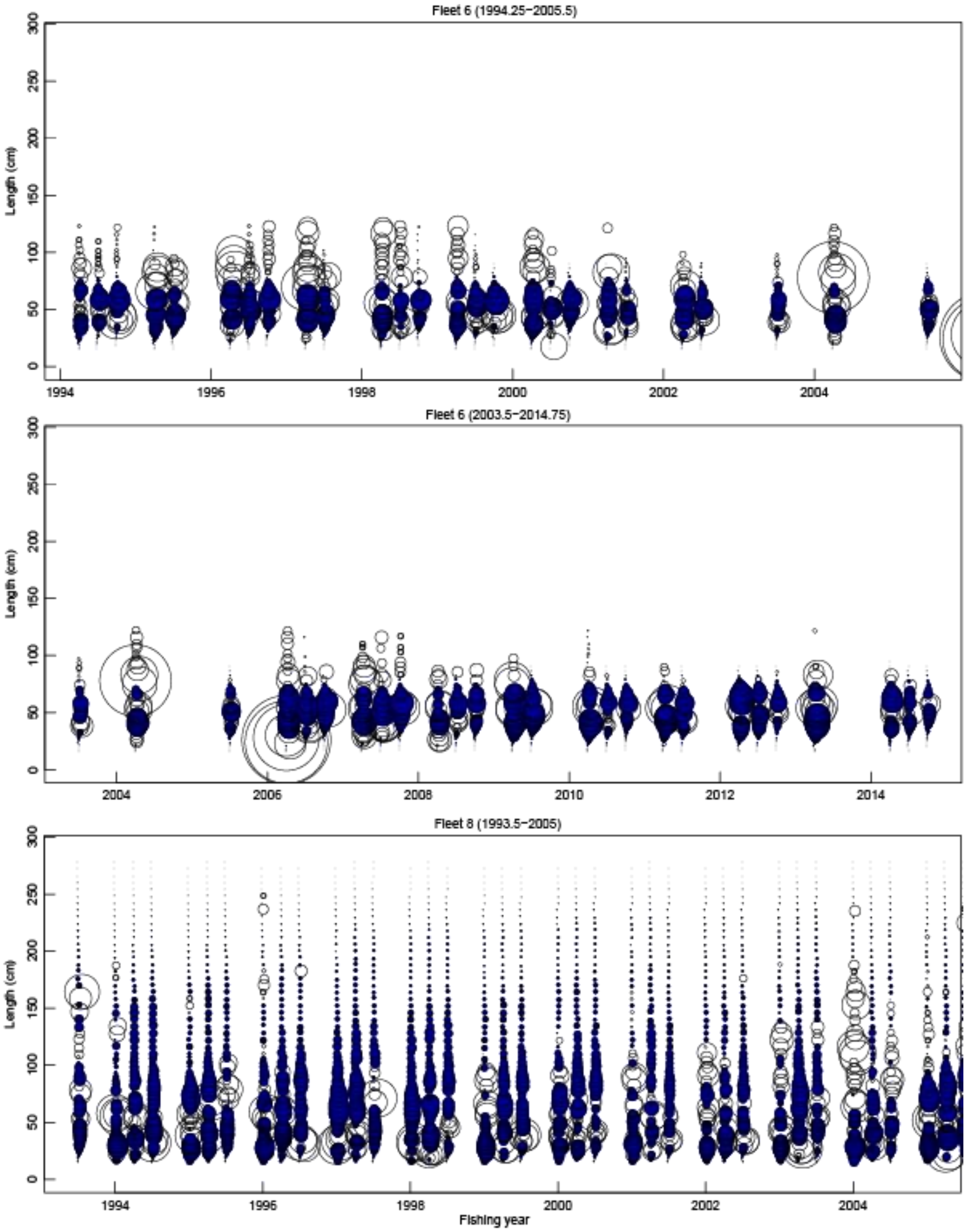

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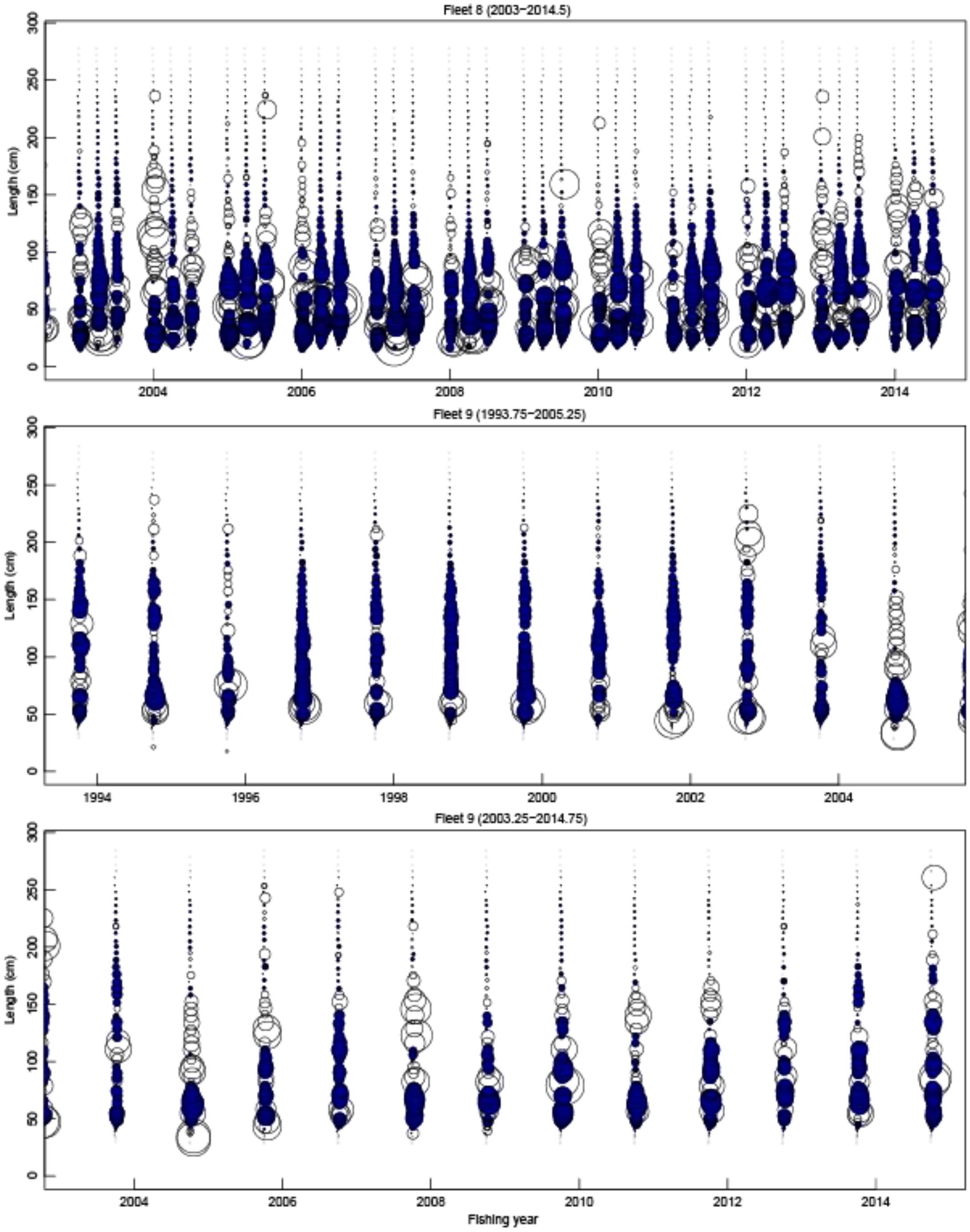

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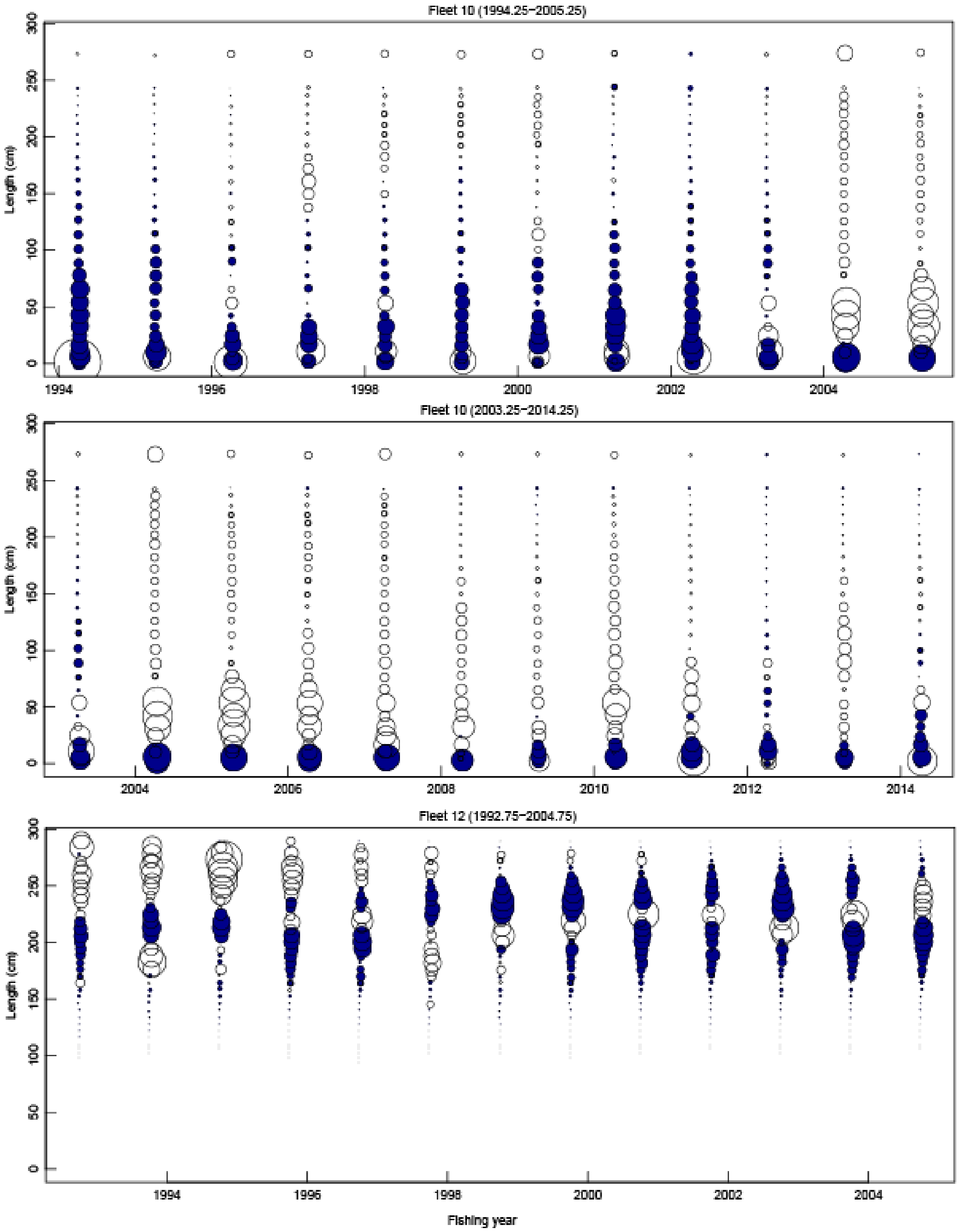

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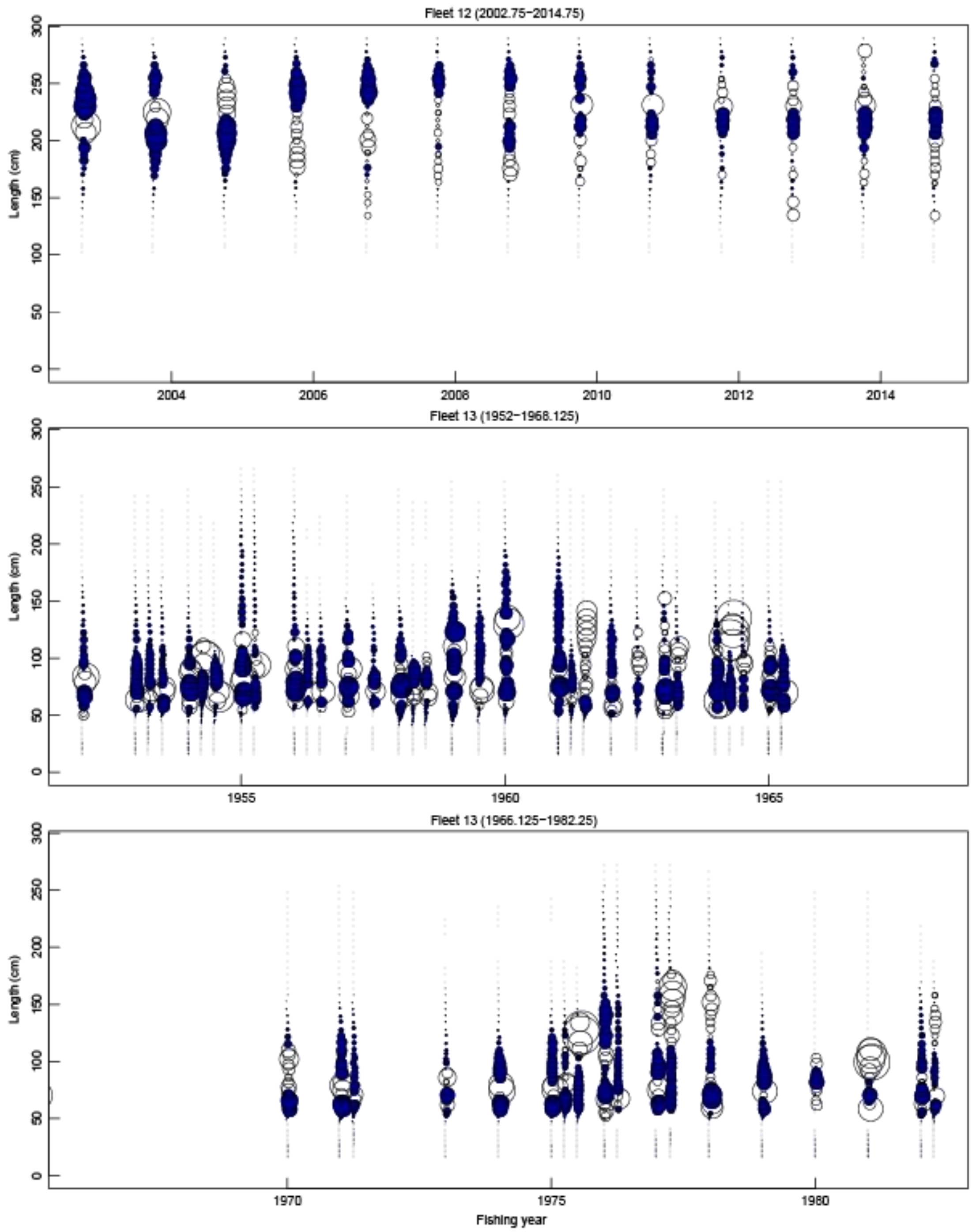

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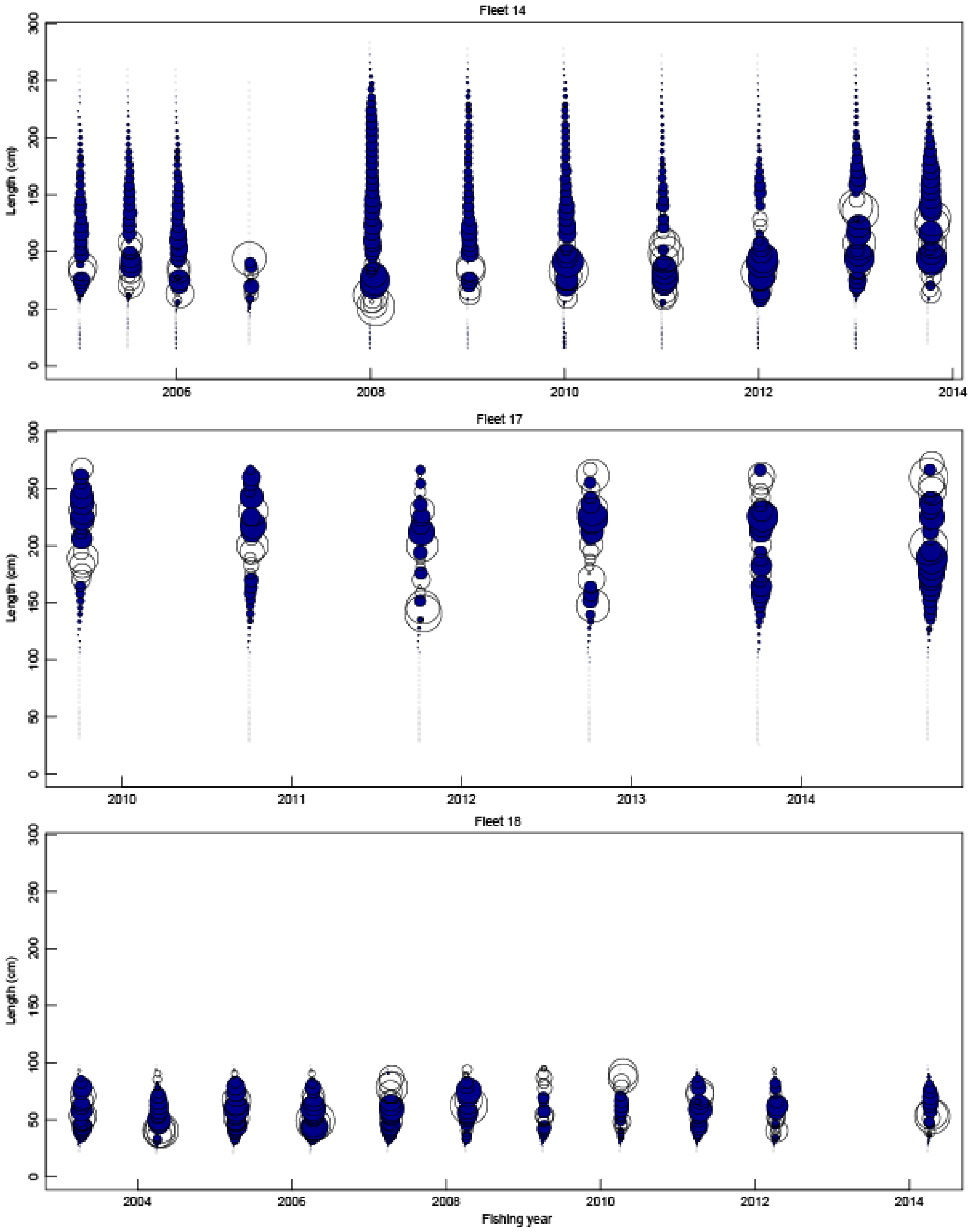

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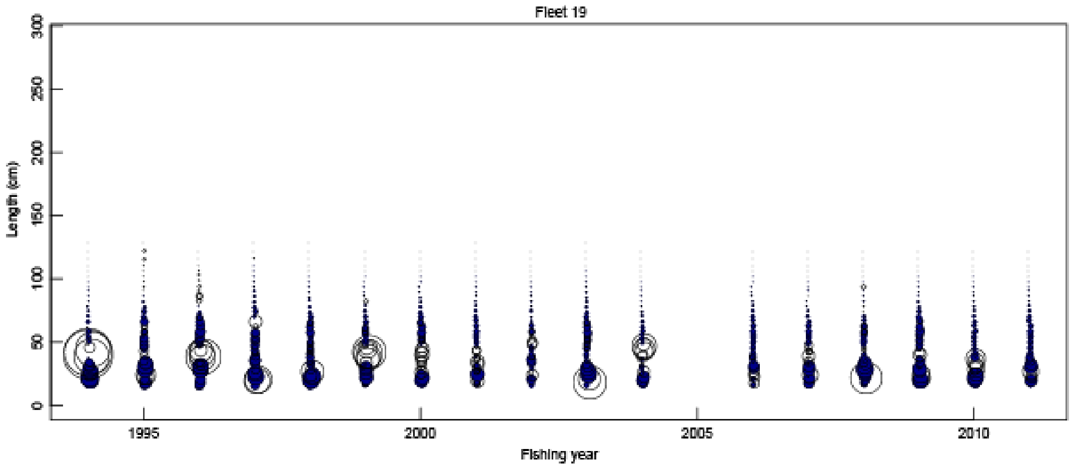

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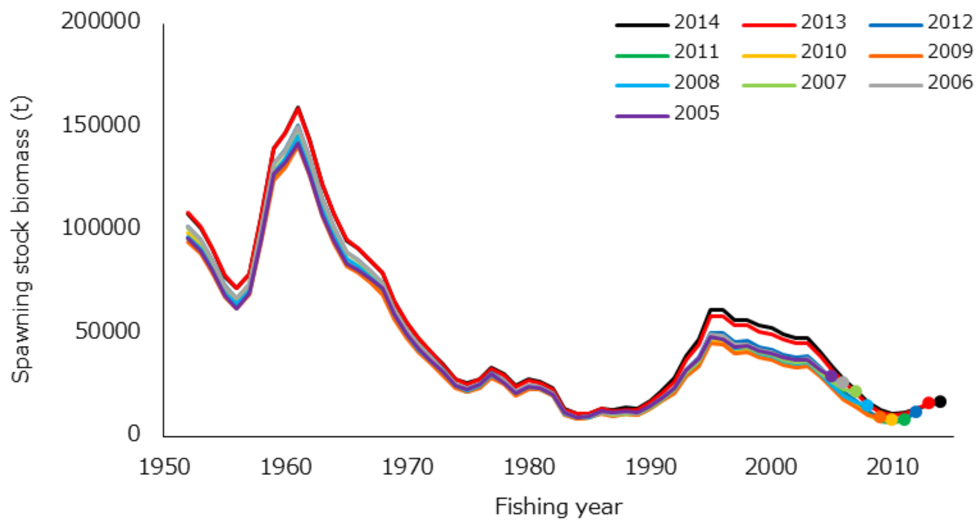

Figure 5-7. Nine-year retrospective analysis of the spawning stock biomass of Pacific bluefin tuna (*Thunnus orientalis*).

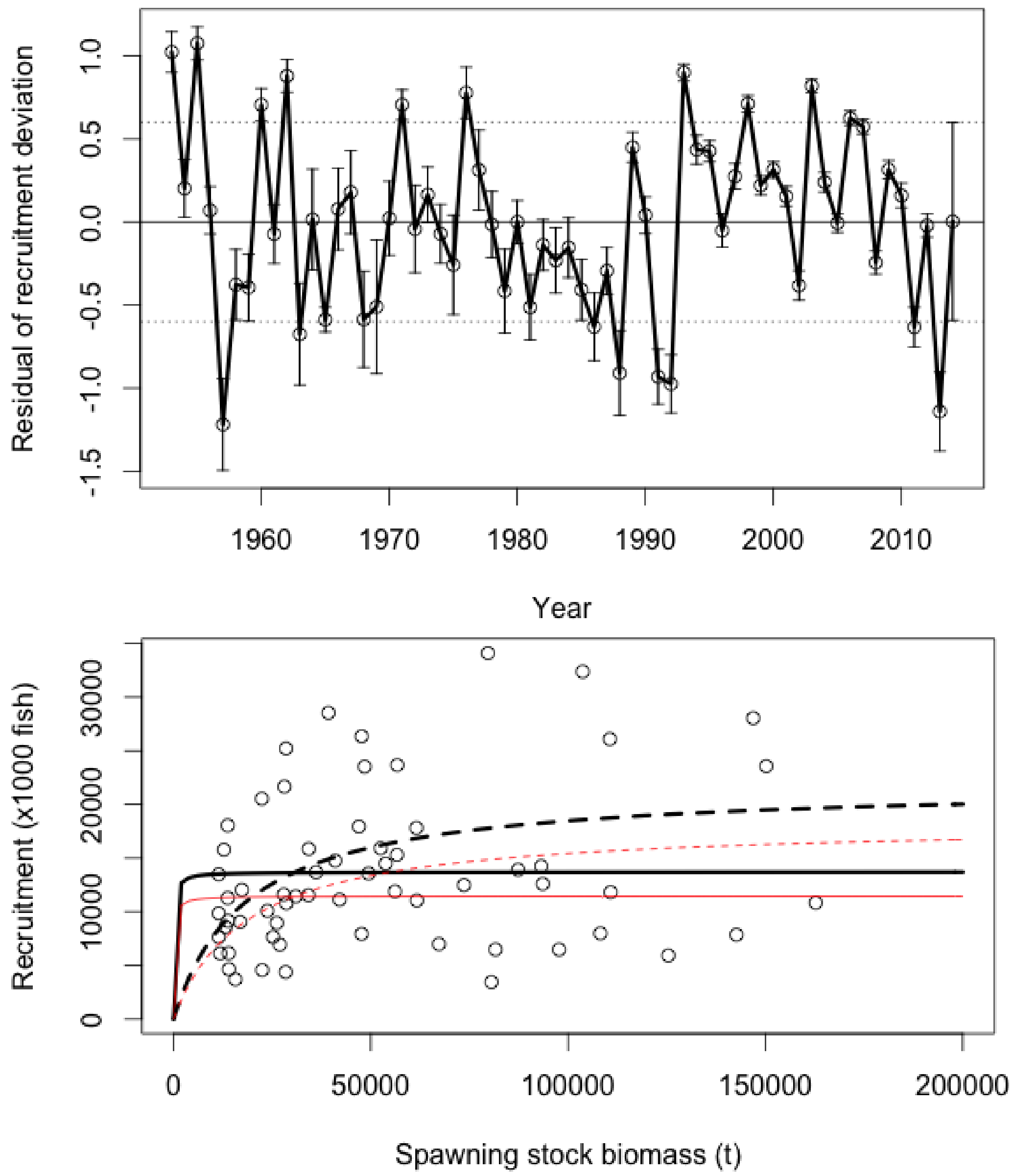

Figure 5-8. Time series of recruitment deviations in log space (upper panel) and spawning stock-recruitment relationship (lower panel) in the base-case stock assessment model for Pacific bluefin tuna (*Thunnus orientalis*). In the upper panel, open circles are the estimated recruitment deviations, vertical lines are the 95% CI of the estimates, and horizontal dotted lines indicate σ_R and -σ_R. In the lower panel, open circles are the paired estimates of spawning stock biomass and recruitment for a given year, black line indicates the Beverton-Holt relationship based on steepness h=0.999 used in the base-case, black dotted line indicates the same relationship based on h=0.9 and estimated R0, which is used in future projections. Both red line and red dotted line indicate expected recruitment after bias adjustment corresponding to above two relationships.

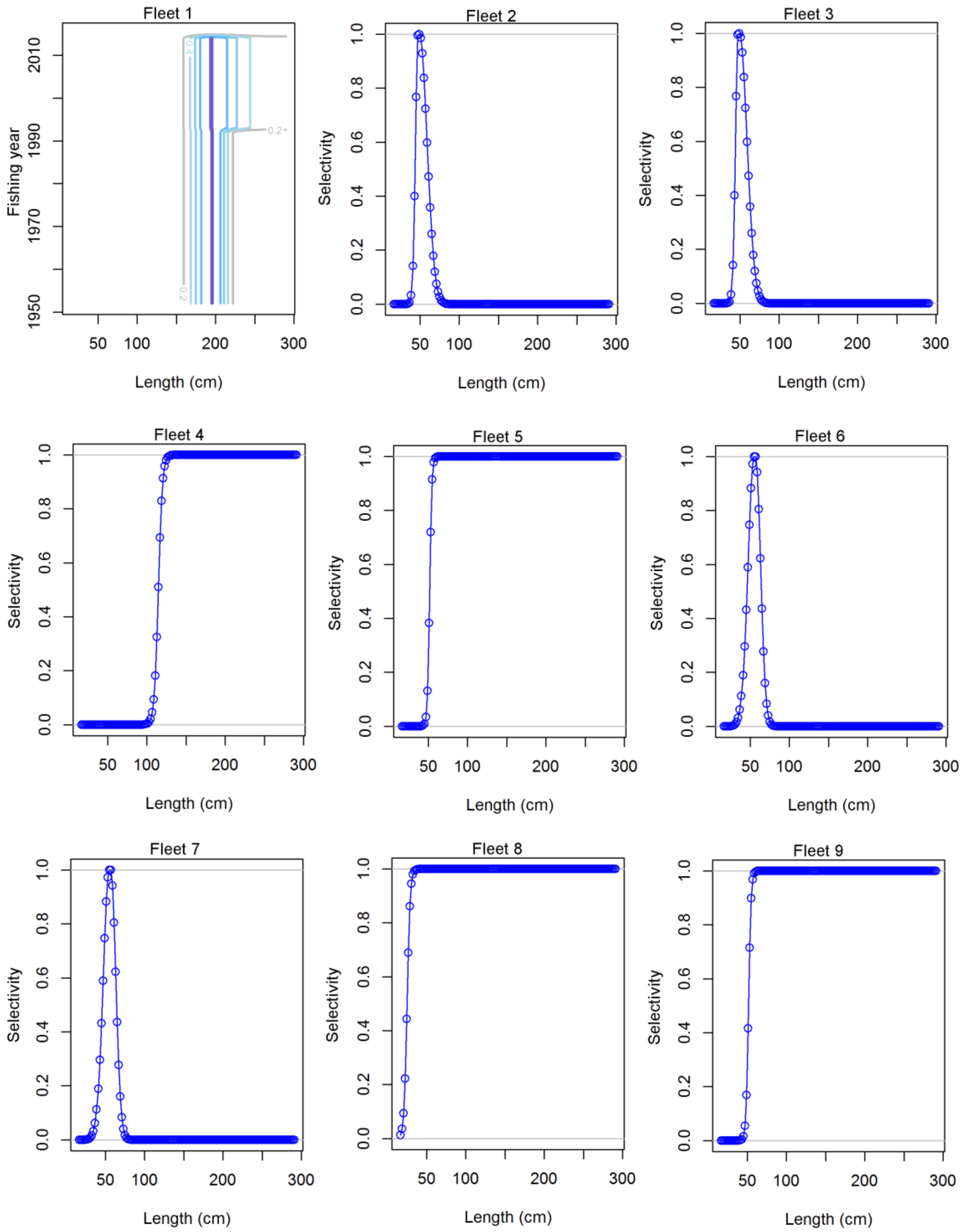

Figure 5-9. Size selectivity for Pacific bluefin tuna (*Thunnus orientalis*) by fishery. Fisheries with time-varying selectivity patterns are displayed in contour plots.

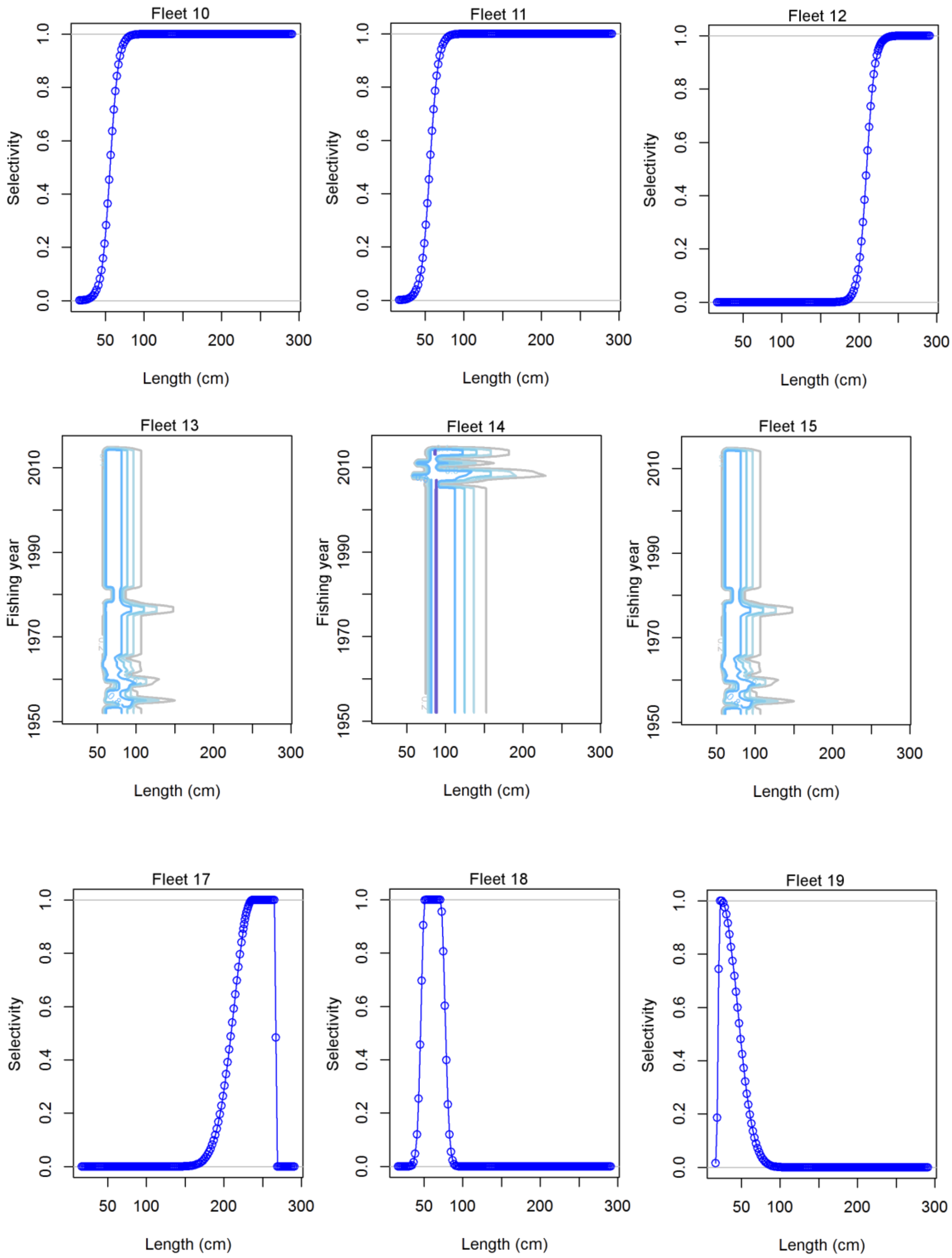

Figure 5-9. Cont.

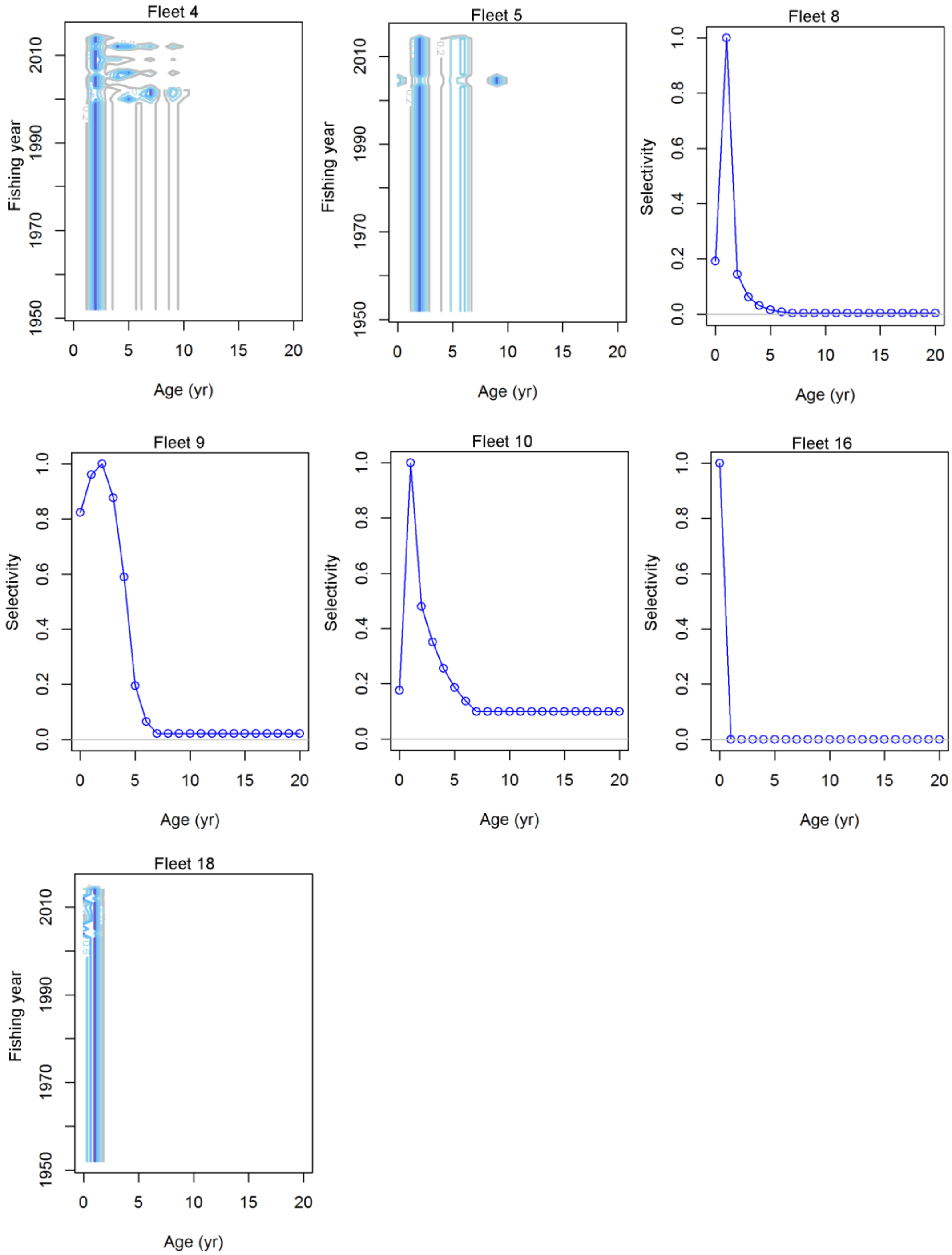

Figure 5-10. Age selectivity for Pacific bluefin tuna (*Thunnus orientalis*) by fishery. Fisheries with time-varying selectivity patterns are displayed in contour plots.

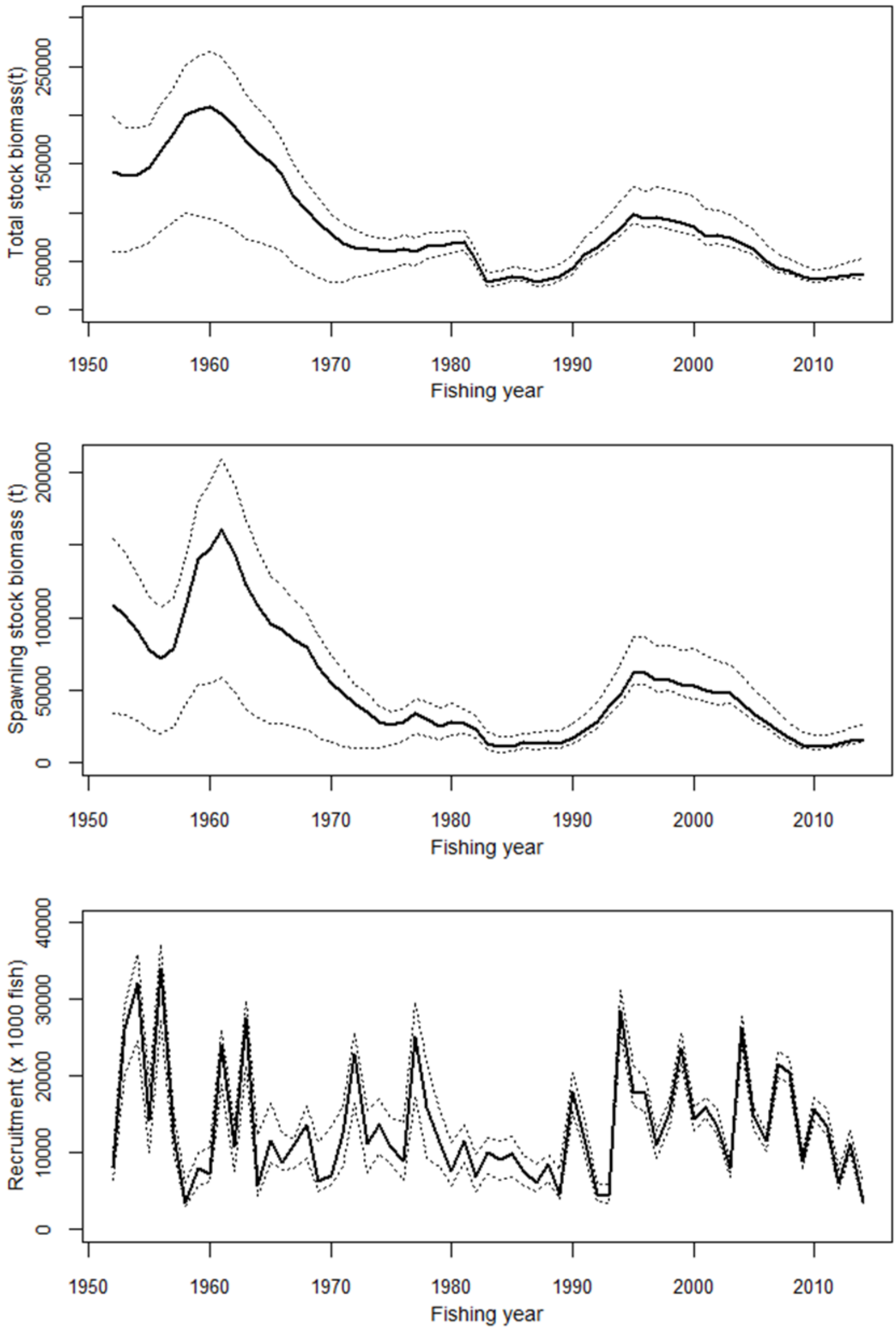

Figure 5-11. Total stock biomass (top), spawning stock biomass (middle) and recruitment (bottom) of Pacific bluefin tuna (*Thunnus orientalis*) from the base-case model. The solid line indicates point estimate and dashed lines indicate the 90% confidence interval.

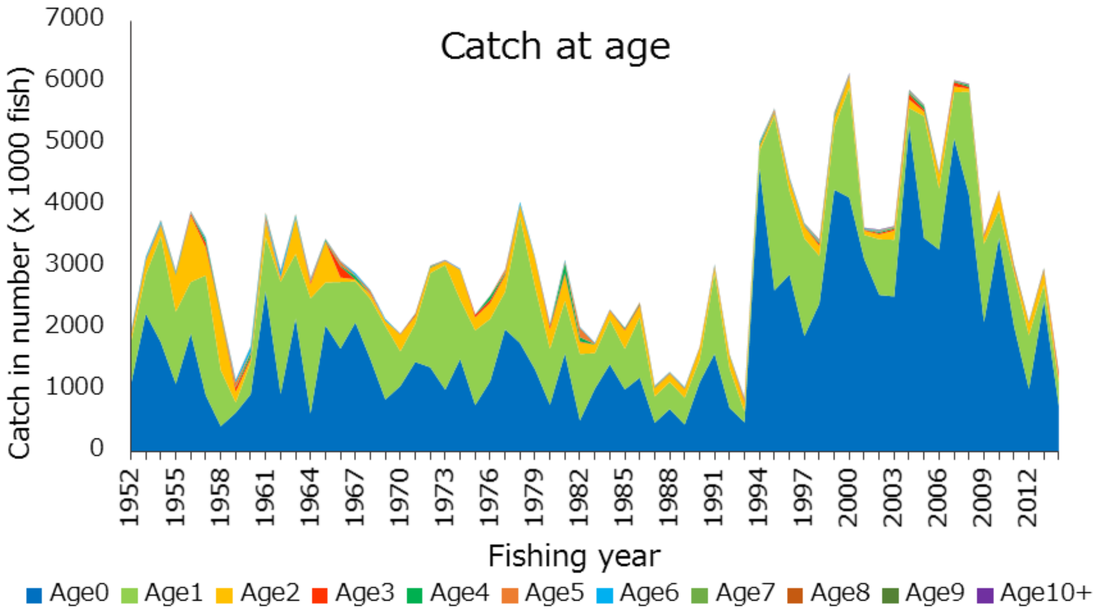

Figure 5-12. Annual catch-at-age (in number) of Pacific bluefin tuna (*Thunnus orientalis*) by fishing year (1952-2014).

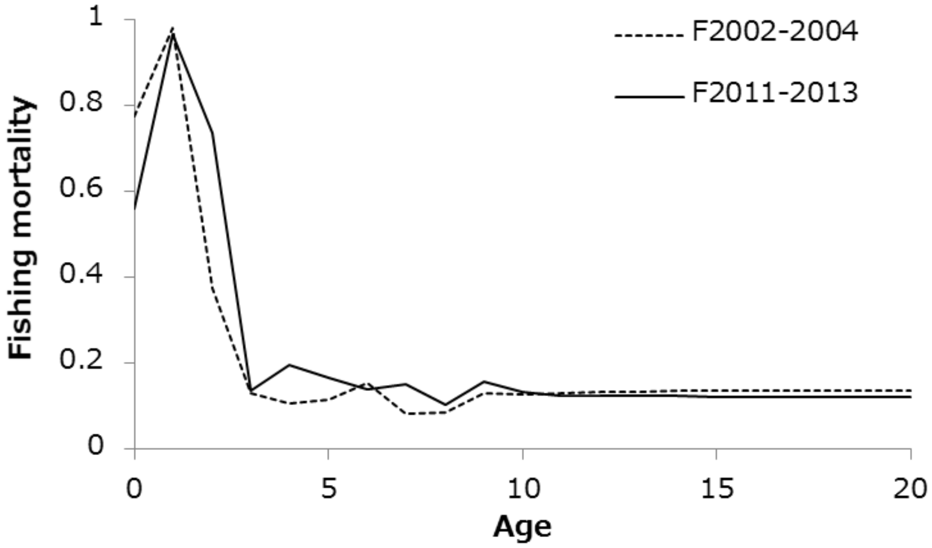

Figure 5-13. Geometric means of annual age-specific fishing mortalities of Pacific bluefin tuna (*Thunnus orientalis*) for 2002-2004 (dashed line) and 2011-2013 (solid line).

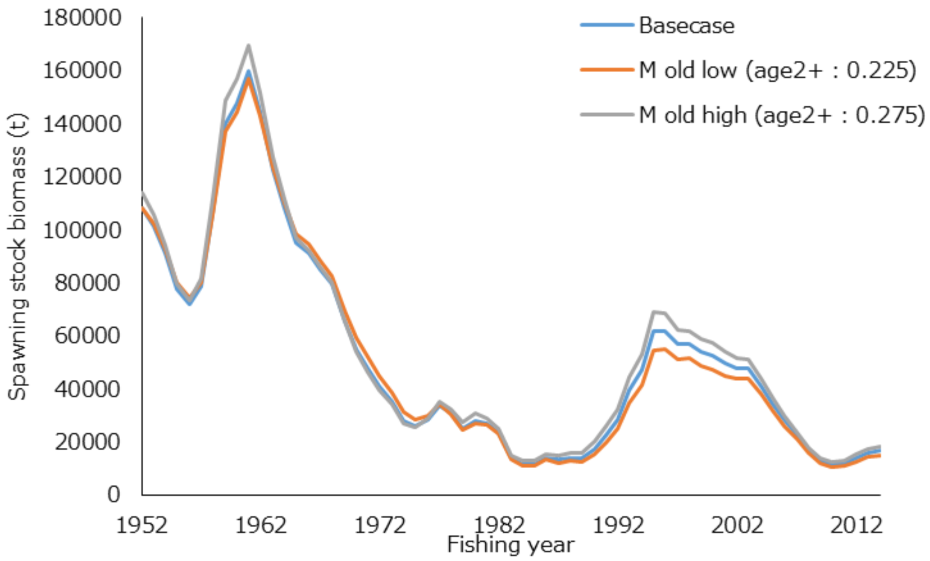

Figure 5-14. Estimated spawning stock biomass of Pacific bluefin tuna (*Thunnus orientalis*) for the base-case model and sensitivity analyses using alternative high and low natural mortality schedules.

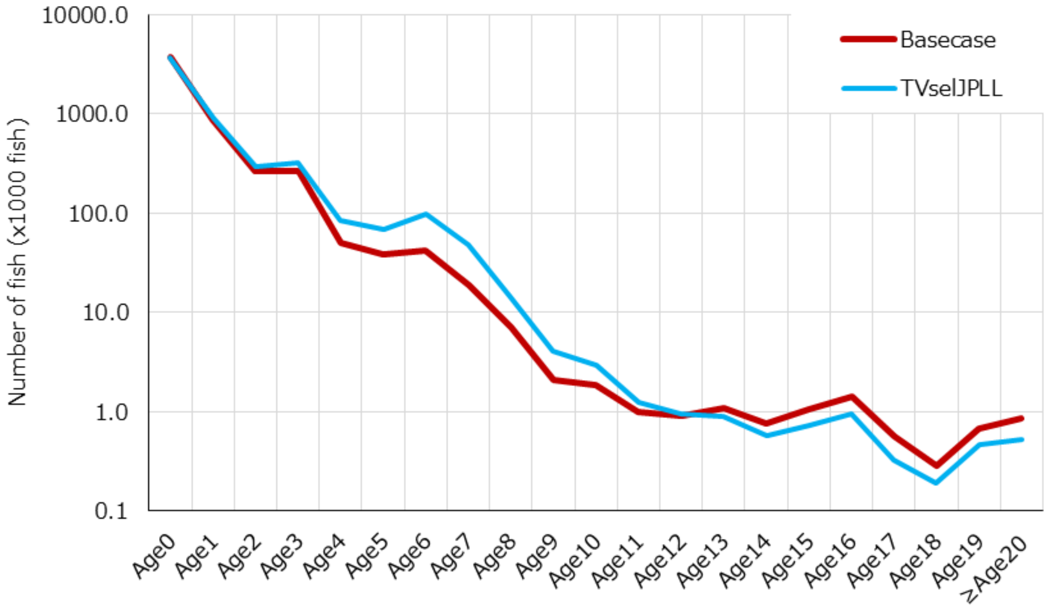

Figure 5-15. Estimated population number of fish of Pacific bluefin tuna (*Thunnus orientalis*) for the base-case model and sensitivity analysis using time-varying selectivity from 2000 to 2014 for Japanese longline fishery (Fleet 1).

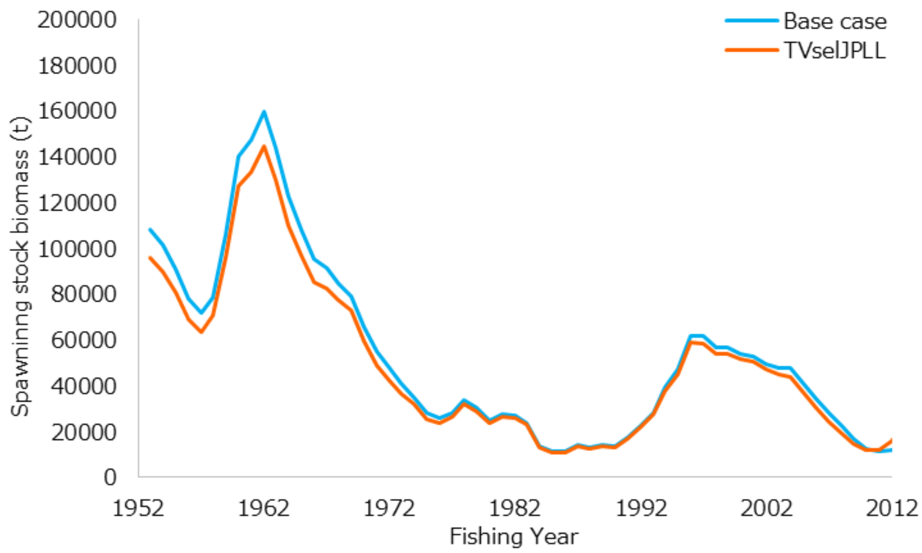

Figure 5-16. Estimated spawning stock biomass of Pacific bluefin tuna (*Thunnus orientalis*) for the base-case model and sensitivity analyses which assumed time-varying selectivity from 2000 to 2014 for Japanese longline fishery (Fleet 1).

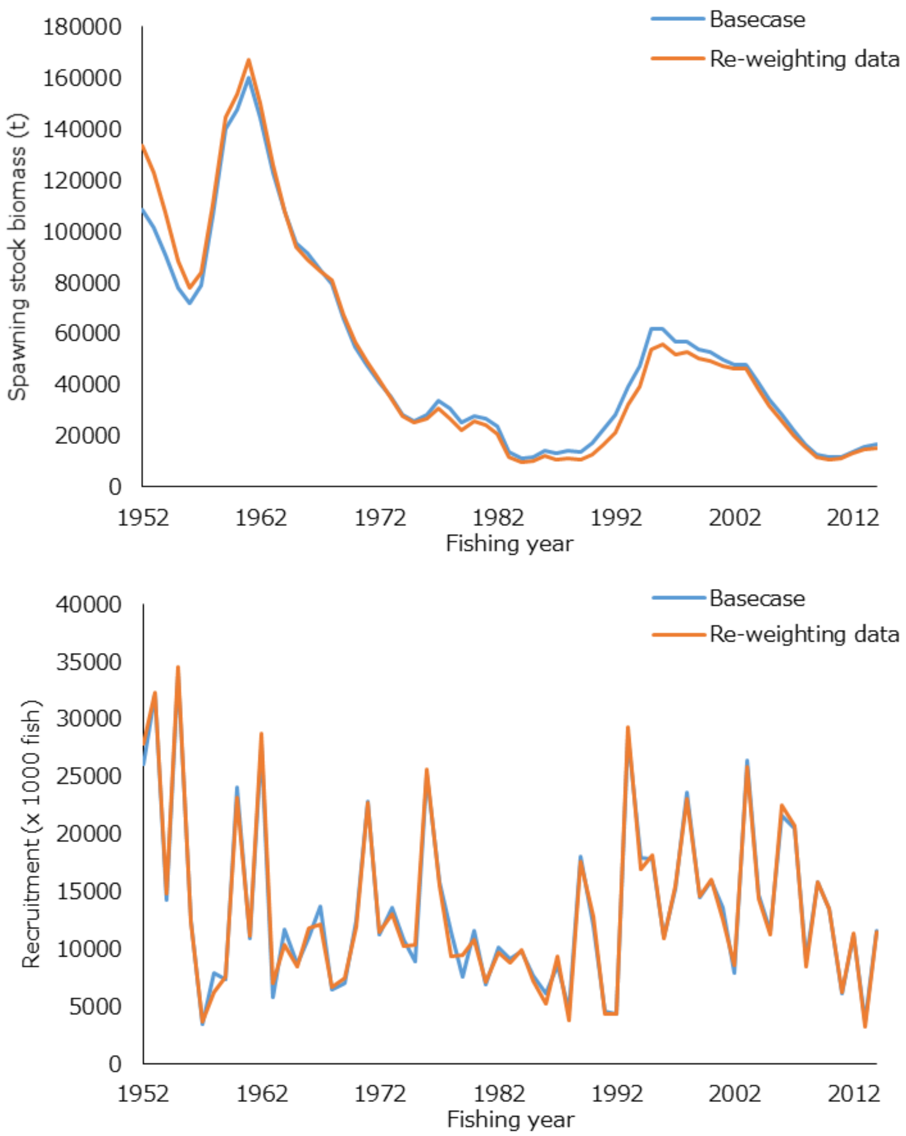

Figure 5-17. Estimated spawning stock biomass (upper panel) and recruitment (lower panel) of Pacific bluefin tuna (*Thunnus orientalis*) for the base-case model and sensitivity analysis using harmonic mean (Table 5-1) as an alternative right-weighting approach on size composition data.

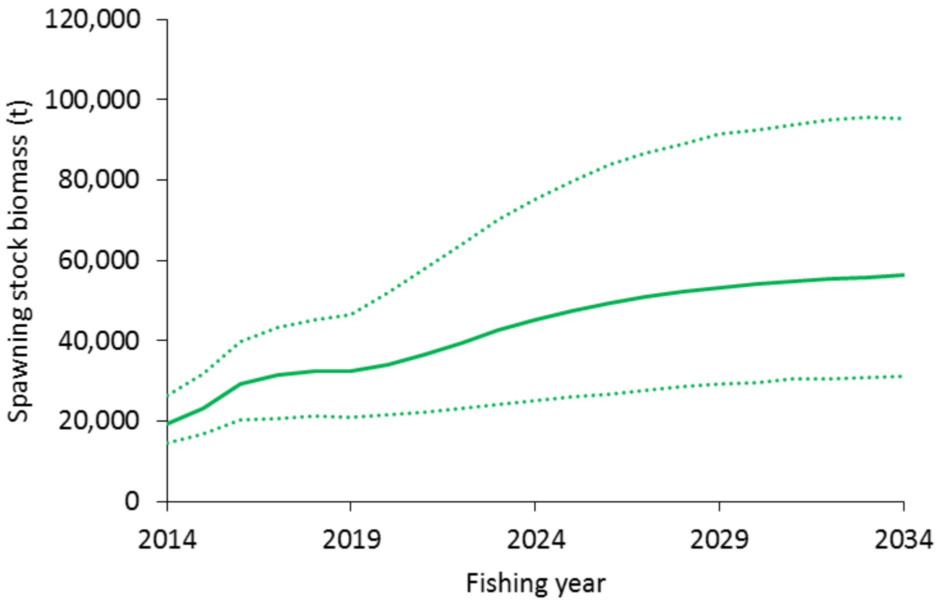

Figure 6-1. Projected trajectories of spawing stock biomass for Pacific bluefin tuna (*Thunnus orientalis*) if the harvest scenario 2 is used and the average recruitment is assumed (Table 6-1). The solid line indicates median of 300 bootstrapped projection results and dotted lines indicate 90% confidence interval.

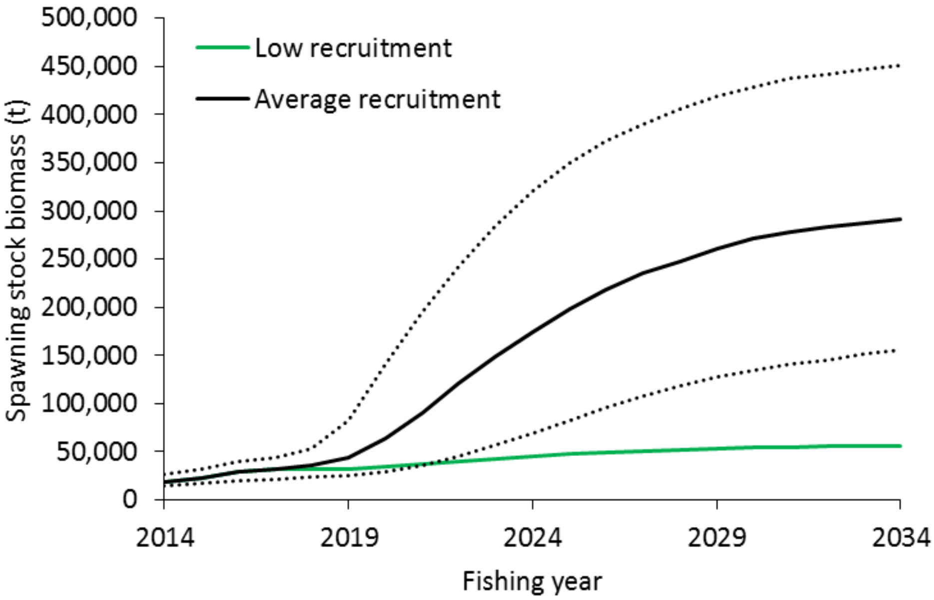

Figure 6-2. Comparisons of various projection results of spawing stock biomass for Pacific bluefin tuna (*Thunnus orientalis*) under the assumptions of low recruitment and average recruitment if the harvest scenario 2 is used (Table 6-1). The solid lines indicate median of 300 bootstrapped projection results and dotted lines indicate 90% confidence interval.

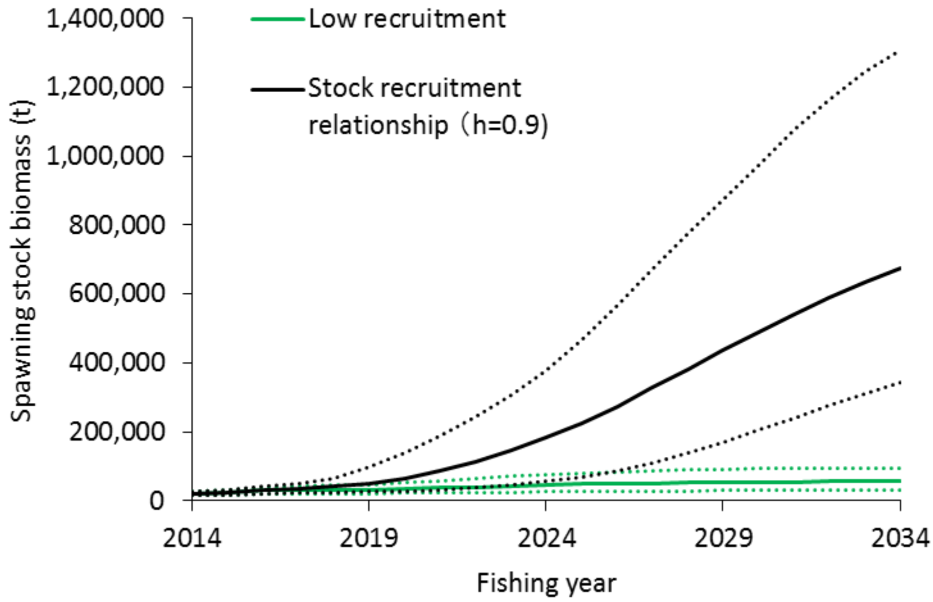

Figure 6-3. Comparisons of various projection results of spawing stock biomass for Pacific bluefin tuna (*Thunnus orientalis*) under the assumptions of low recruitment and the recruitement based on stock-recruitment relationship with h=0.9 (Scenario 2) (Table 6-1). The solid lines indicate median of 300 bootstrapped projection results and dotted lines indicate 90% confidence interval.

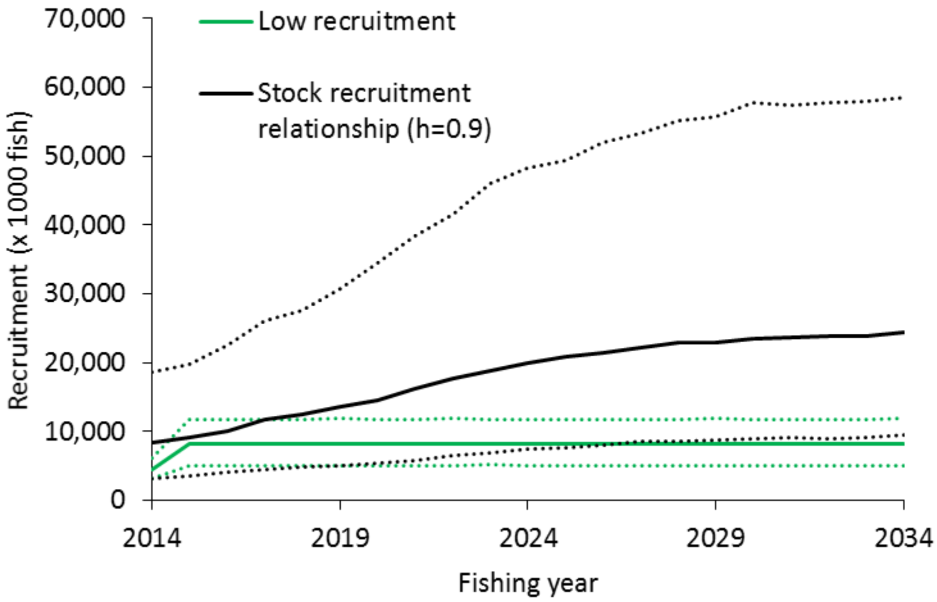

Figure 6-4. Comparisons of projection results of recruitment for Pacific bluefin tuna (*Thunnus orientalis*) under the assumptions of low recruitment and recruitment based on stock-recruitment relationship with h=0.9 (Scenario 2) (Table 6-1). The solid lines indicate median of 300 bootstrapped projection results and dotted lines indicate 90% confidence interval.

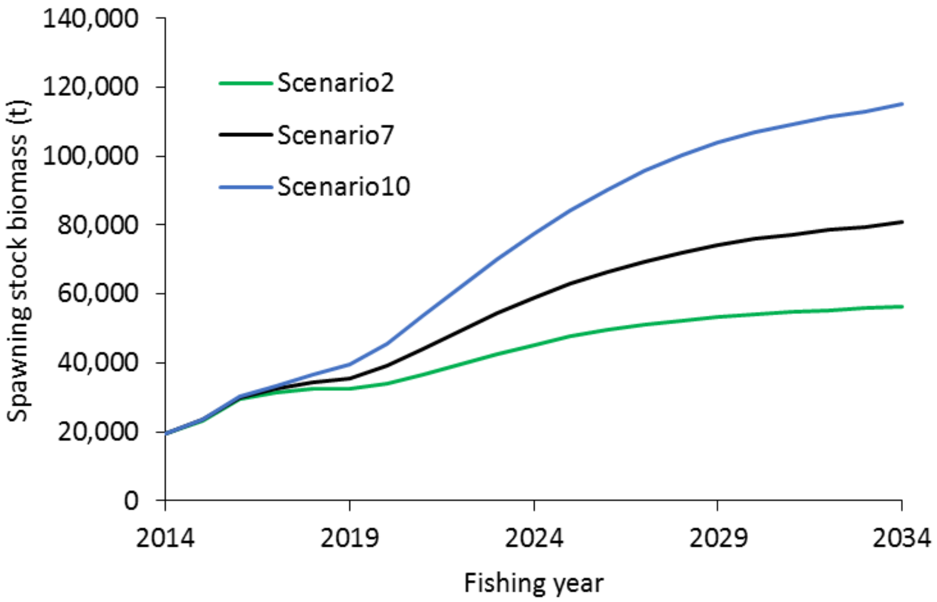

Figure 6-5. Comparisons of various projection results of median of 300 bootstrapped spawning stock biomass for Pacific bluefin tuna (*Thunnus orientalis*) if scenario 2, scenario 7 and scenario 10 is used under the assumption of low recruitment (Table 6-1).

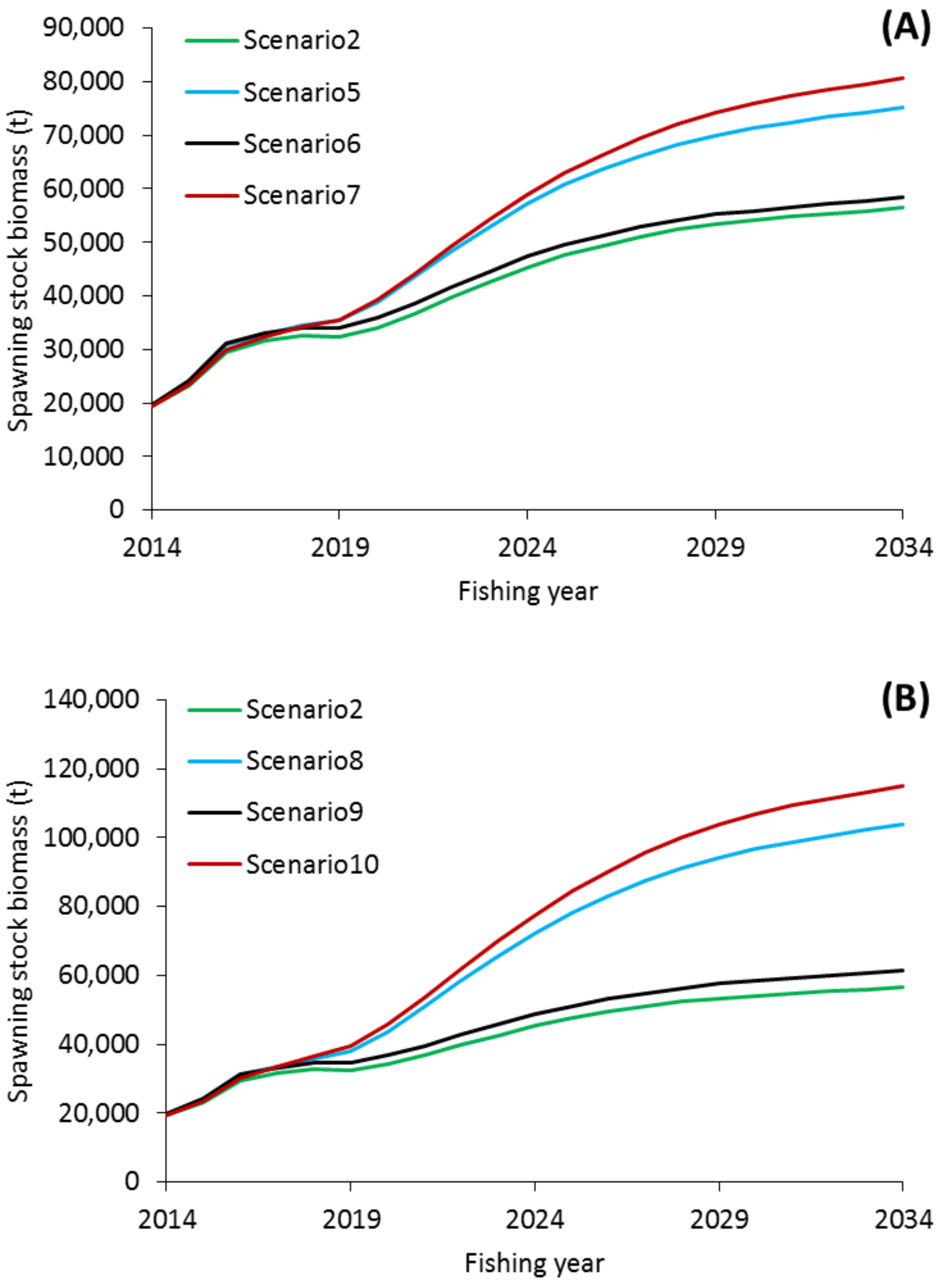

Figure 6-6. Comparisons of various projection results of median of 300 bootstrapped spawning stock biomass for Pacific bluefin tuna (*Thunnus orientalis*). (A) Scenario 2, Scenario 5, Scenario 6 and Scenario 7 under the low recruitment. (B): Scenario 2, Scenario 8, Scenario 9 and Scenario 10 under the assumption of low recruitment (Table 6-1).

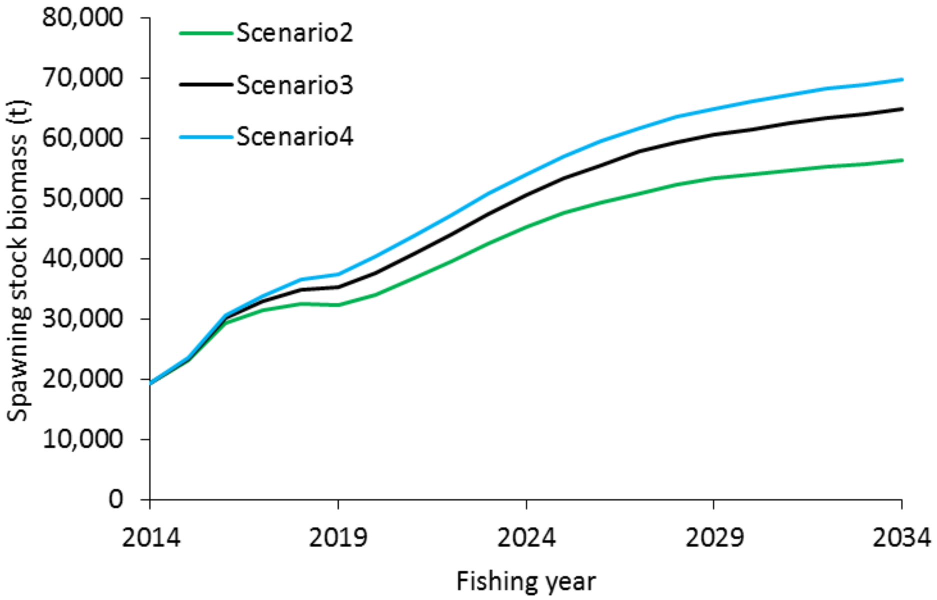

Figure 6-7. Comparisons of various projection results of median of 300 bootstrapped spawning stock biomass for Pacific bluefin tuna (*Thunnus orientalis*). Scenario 2, Scenario 3 and Scenario 4 under the assumption of low recruitment (Table 6-1).

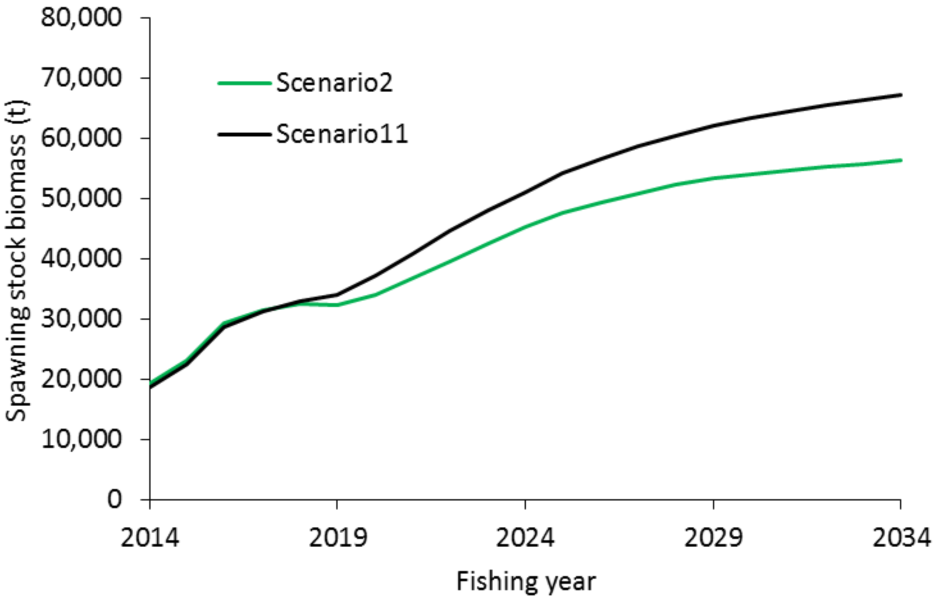

Figure 6-8. Comparisons of various projection results for Pacific bluefin tuna (*Thunnus orientalis*). Current CMMs (Scenario 2) and current F (Scenario 11) under the low recruitment (Table 6-1).

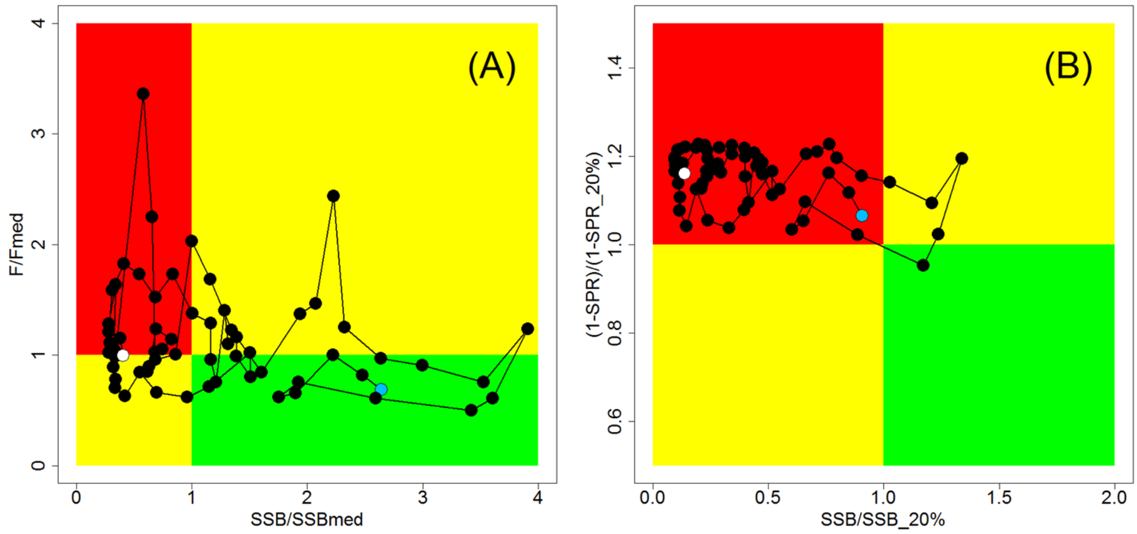

Figure 7-1. Kobe plots for Pacific bluefin tuna (*Thunnus orientalis*). (A) SSB_{MED} and F_{MED}; (B) $SSB_{20\%}$ and $SPR_{20\%}$. Note that SSB_{MED} is estimated as the median of estimated SSB over whole assessment period (40,944 tons) and F_{MED} is calculated as an F to provide SSB_{MED} in long-term, while the plots are points of estimates. The blue and white points on the plot show the start (1952) and end (2014) year of the period modeled in the stock assessment, respectively.

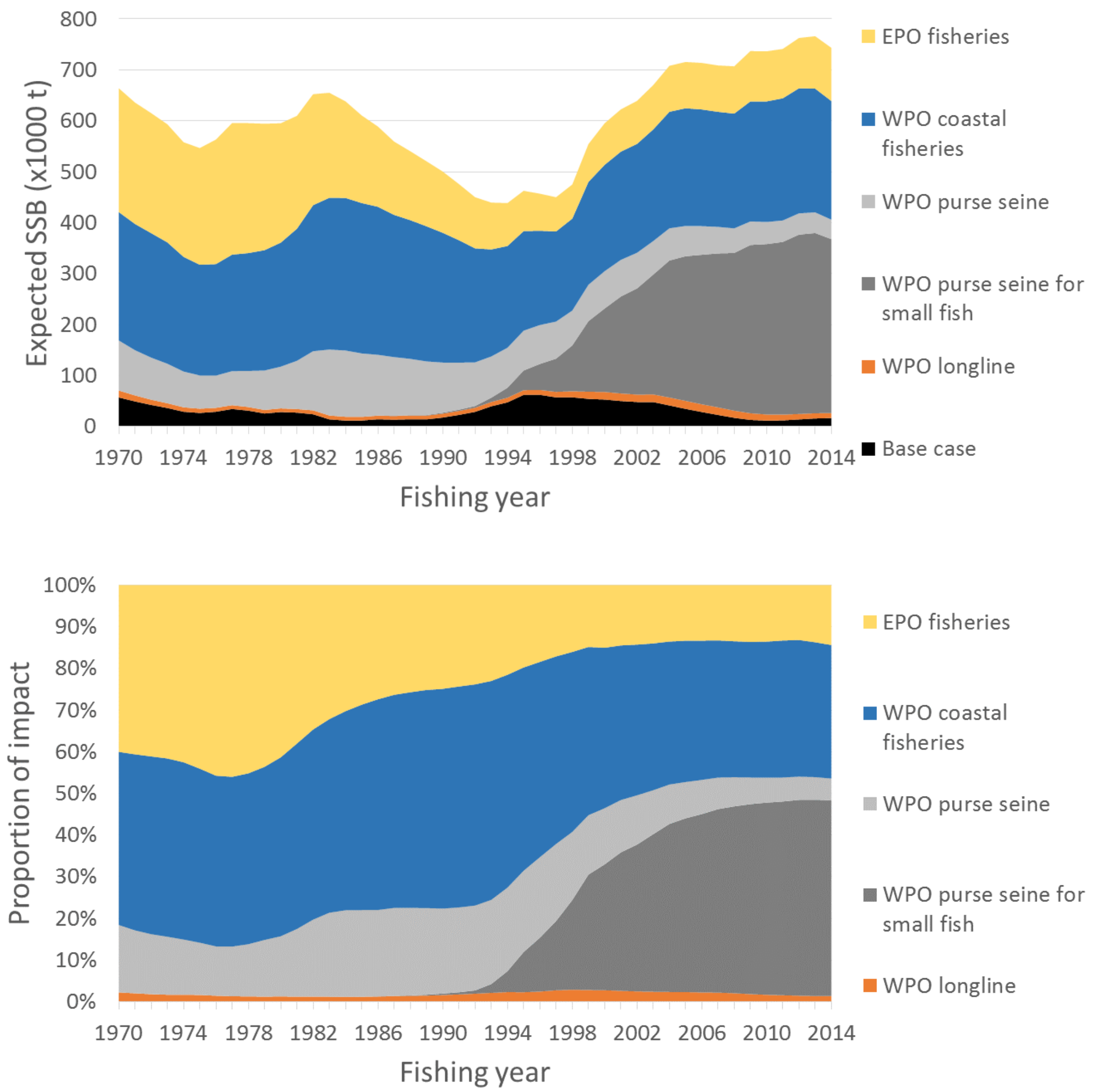

Figure 7-2. Trajectory of the spawning stock biomass of a simulated population of Pacific bluefin tuna (*Thunnus orientalis*) when zero fishing mortality is assumed, estimated by the base-case model. (top: absolute impact, bottom: relative impact). Fleet definition; WPO longline: F1, F12, F17. WPO purse seine for small fish: F2, F3, F18. WPO purse seine: F4, F5. WPO coastal fisheries: F6-11, F16, F19. EPO fisheries: F13, F14, F15.