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Stock Assessment of Bluefin Tuna in the Pacific Ocean in 2014

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Report of the Pacific Bluefin Tuna Working Group[1]

[1] International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean

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

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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 historical Pacific bluefin tuna (PBF) catch records are scant, there are PBF landings records dating back to 1804 from coastal Japan and to the early 1900s for U.S. fisheries operating in the EPO. Estimated catches of PBF were 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 and more reliable estimates indicate that annual catches of PBF fluctuated widely from 1952-2012 (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). Historical catches (1952-2012) are predominately composed of juvenile PBF, but since the early 1990s, the catch of age-0 PBF has increased significantly (Figure 3).

3. Data and Assessment

Population dynamics were estimated using a fully integrated age-structured model (Stock Synthesis (SS) v3.23b) fitted to catch, size-composition and catch-per-unit of effort (CPUE) data from 1952 to 2013, 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). 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 14 fisheries were defined for use in the stock assessment model based on country/gear type 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 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 fit 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.

The PBFWG identified uncertainties in the standardized CPUE series, the procedures used to weight the data inputs (including catch, CPUE, and size composition) relative to each other in the model, and the methods used to estimate selectivity patterns. The influence of these uncertainties on the stock dynamics was assessed by constructing four different model runs, each with different updated CPUE and length composition data (Table 1). While no single model run provided a good fit to all sources of data that were deemed reliable, the PBFWG agreed on the depleted state of the stock among all scenarios, although estimates of current SSB varied. Long-term fluctuations in spawning stock biomass (SSB) occurred throughout the assessment period (1952-2012) and in the most recent period SSB was found to have been declining for over a decade. The recruitment level in 2012 was estimated to be relatively low (the 8^{th} lowest in 61 years), and the average recruitment level for the last five years may have been below the historical average level (Figures 4 and 5).

While the updated stock assessment model was unable to adequately represent much of the updated data, certain results are clear. Poor fit to the two adult indices of abundance and their associated size composition in the last two years indicate results are highly uncertain. Improvements to the model are advisable before re-assessing, and the current results with regard to the recent trends in SSB should be interpreted with caution.

4. Stock Status and Conservation Advice

Stock Status

Using the updated stock assessment, the 2012 SSB was 26,324 t and slightly higher than that estimated for 2010 (25,476 t).

Across sensitivity runs in the update stock assessment, estimates of recruitment were considered robust. The recruitment level in 2012 was estimated to be relatively low (the 8^{th} lowest in 61 years), and the average recruitment level for the last five years may have been below the historical average level (Figure 6). Estimated age-specific fishing mortalities on the stock in the period 2009-2011 relative to 2002-2004 (the base period for WCPFC Conservation and Management Measure 2010-04) increased by 19%, 4%, 12%, 31%, 60%, 51% and 21% for ages 0-6, respectively, and decreased by 35% for age 7+ (Figure 7).

Although no target or limit reference points have been established for the PBF stock under the auspices of the WCPFC and IATTC, the current F average over 2009-2011 exceeds all target and limit biological reference points (BRPs) commonly used by fisheries managers except for F_{loss}, and the ratio of SSB in 2012 relative to unfished SSB (depletion ratio) is less than 6%. In summary, based on reference point ratios, overfishing is occurring and the stock is overfished (Table 2).

For illustrative purposes, two examples of Kobe plots (plot A based on SSB_{MED} and F_{MED}, plot B based on $SSB_{20\%}$ and $SPR_{20\%}$, Figure 8) are presented. Because no reference points for PBF have yet been agreed to, these versions of the Kobe plot represent alternative interpretations of stock status in an effort to prompt further discussion.

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 fleet has increased its impact, and the effect of this fleet is currently greater than any of the other fishery groups. The impact of the EPO fishery was large before the mid-1980s, thereafter decreasing significantly. The WPO longline fleet has had a limited effect on the stock throughout the analysis period. 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 (Figures 9 and 10).

Conservation Advice

The current (2012) PBF biomass level is near historically low levels and experiencing high exploitation rates above all biological reference points except for F_{loss}. Based on projection results, the recently adopted WCPFC CMM (2013-09) and IATTC resolution for 2014 (C-13-02) if continued in to the future, are not expected to increase SSB if recent low recruitment continues.

In relation to the projections requested by NC9, only Scenario 6[1], the strictest one, results in an increase in SSB even if the current low recruitment continues (Figure 11). Given the result of Scenario 6, further substantial reductions in fishing mortality and juvenile catch over the whole range of juvenile ages should be considered to reduce the risk of SSB falling below its historically lowest level.

If the low recruitment of recent years continues, the risk of SSB falling below its historically lowest level observed would increase. This risk can be reduced with implementation of more conservative management measures.

Based on the results of future projections requested at NC9, unless the historical average level (1952-2011) of recruitment is realized, an increase of SSB cannot be expected under the current WCPFC and IATTC conservation and management measures[2], even

[1] For the WCPO, a 50% reduction of juvenile catches from the 2002-2004 average level and F no greater than $F_{2002-2004}$. For the EPO, a 50% reduction of catches from 5,500 t. From the scientific point of view, juvenile catches were not completely represented in the reductions modeled under Scenario 6 for some fisheries although these reductions comply with the definition applied by the NC9.

[2] WCPFC: Reduce all catches of juveniles (age 0 to 3-(less than 30 kg)) by at least 15% below the 2002-2004 annual average levels, and maintain the total fishing effort below the 2002-2004 annual average levels. IATTC: Catch limit of 5000 t with an additional 500 t for commercial fisheries for countries with catch history. (1. In the IATTC Convention Area, the commercial catches of bluefin tuna by all the CPCs during 2014 shall not exceed 5,000 metric tons. 2. Notwithstanding paragraph 1, any CPC with a historical record of eastern Pacific bluefin catches may take a commercial catch of up to 500 metric tons of eastern Pacific bluefin tuna annually. (C-13-02), see https://www.iattc.org/PDFFiles2/Resolutions/C-13-02-Pacific-bluefin-tuna.pdf)

under full implementation (Scenario 1)[3].

If the specifications of the harvest control rules used in the projections were modified to include a definition of juveniles that is more consistent with the maturity ogive[4] used in the stock assessment, projection results could be different; for example, rebuilding may be faster. While no projection with a consistent definition of juvenile in any harvest scenario was conducted, any proposed reductions in juvenile catch should consider all non-mature individuals.

Given the low level of SSB, uncertainty in future recruitment, and importance of recruitment in influencing stock biomass, monitoring of recruitment should be strengthened to allow the trend of recruitment to be understood in a timely manner.

[3] Although these measures assume F be kept below $F_{2002\text{-}2004}$, $F_{2009\text{-}2011}$ was higher than $F_{2002\text{-}2004}$.

[4] 20% at age 3; 50% at age 4; 100% at age 5 and older

Table 1. Model configurations for four runs evaluating the effect of updates of Pacific bluefin tuna (*Thunnus orientalis*) CPUE and size composition data for Japanese longline (JLL) and Taiwanese longline (TWLL). Run 1 is the base case assessment model.

Run number	**CPUE**		**Size composition data**	
	JLL (F15, S1)	**TWLL (F23, S9)**	**JLL (F1)**	**TWLL (F11)**
Run 1 (Base case)	Extending to 2012	Extending to 2012	Extending to 2011*	Extending to 2012
Run 2	Removing 2011 and 2012	Extending to 2012	Removing 2010 and 2011	Extending to 2012
Run 3	Extending to 2012	Removing 2011 and 2012	Extending to 2012	Removing 2011 and 2012
Run 4	Removing 2011 and 2012	Removing 2011 and 2012	Removing 2010 and 2011	Removing 2011 and 2012

*Size composition data in terminal year (2012) cannot be calculated by the estimation procedure proposed by Mizuno et al. (2012).

Table 2. Ratio of the estimated fishing mortalities $F_{2002\text{-}2004}$, $F_{2007\text{-}2009}$ and $F_{2009\text{-}2011}$ relative to computed F-based biological reference points for Pacific bluefin tuna (*Thunnus orientalis*) (PBF), depletion ratio (ratio of SSB in 2012 relative to unfished SSB), and estimated SSB (t) in year 2012 for four model configurations (runs). Run 1 is the base case assessment model for the PBF updated stock assessment. Values in the first eight columns above 1.0 indicate overfishing. See the full text for biological reference point definitions.

	F_{max}	$F_{0.1}$	F_{med}	F_{loss}	$F_{10\%}$	$F_{20\%}$	$F_{30\%}$	$F_{40\%}$	Depletion Ratio	Estimated SSB(t) (yr=2012)
$F_{2002\text{-}2004}$										
Run1	**1.70**	**2.44**	**1.09**	**0.84**	**1.16**	**1.68**	**2.26**	**2.98**	**0.042**	**26,324**
Run2	1.73	2.47	1.09	0.85	1.16	1.68	2.26	2.99	0.054	33,736
Run3	1.78	2.55	1.16	1.03	1.24	1.79	2.40	3.17	0.031	19,369
Run4	1.77	2.52	1.13	0.89	1.21	1.75	2.36	3.11	0.043	26,952
$F_{2007\text{-}2009}$										
Run1	**2.09**	**2.96**	**1.40**	**1.08**	**1.48**	**2.14**	**2.87**	**3.79**	**0.042**	**26,324**
Run2	1.93	2.74	1.25	0.99	1.34	1.94	2.60	3.43	0.054	33,736
Run3	2.34	3.31	1.54	1.38	1.65	2.38	3.20	4.23	0.031	19,369
Run4	2.11	2.98	1.36	1.07	1.46	2.11	2.84	3.74	0.043	26,952
$F_{2009\text{-}2011}$										
Run1	**1.79**	**2.54**	**1.25**	**0.97**	**1.32**	**1.90**	**2.55**	**3.36**	**0.042**	**26,324**
Run2	1.61	2.30	1.11	0.88	1.19	1.71	2.29	3.02	0.054	33,736
Run3	2.02	2.86	1.37	1.23	1.46	2.11	2.83	3.73	0.031	19,369
Run4	1.77	2.52	1.20	0.95	1.29	1.85	2.49	3.27	0.043	26,952

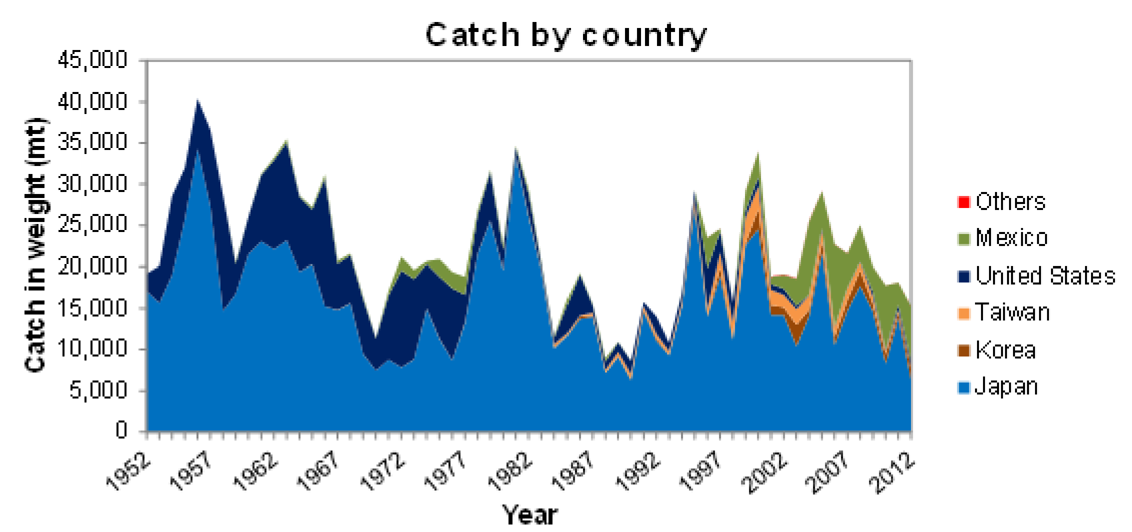

Figure 1. Historical annual catch of Pacific bluefin tuna (*Thunnus orientalis*) by country from 1952 through 2012 (calendar year).

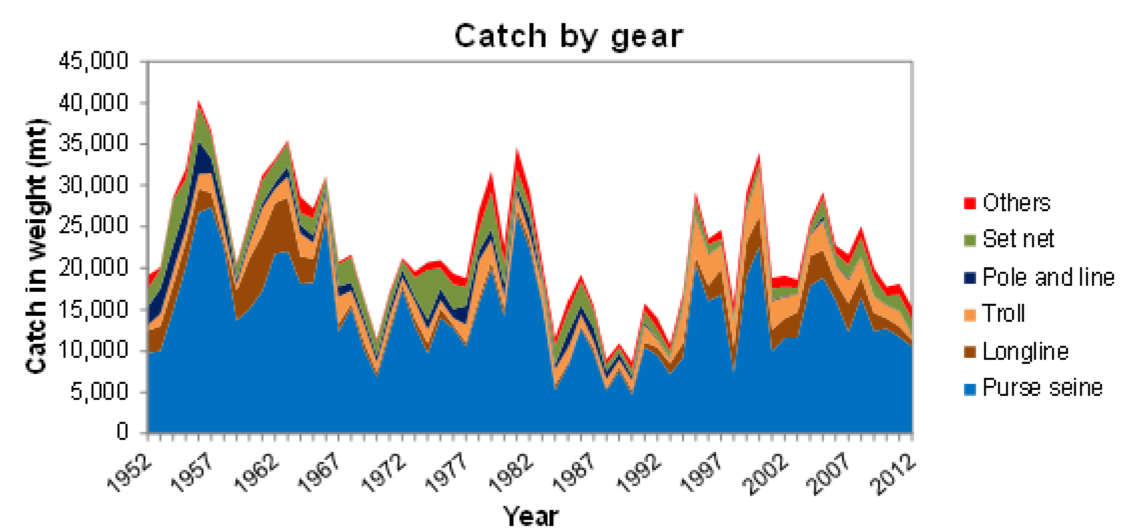

Figure 2. Historical annual catch of Pacific bluefin tuna (*Thunnus orientalis*) by gear type from 1952 through 2012 (calendar year).

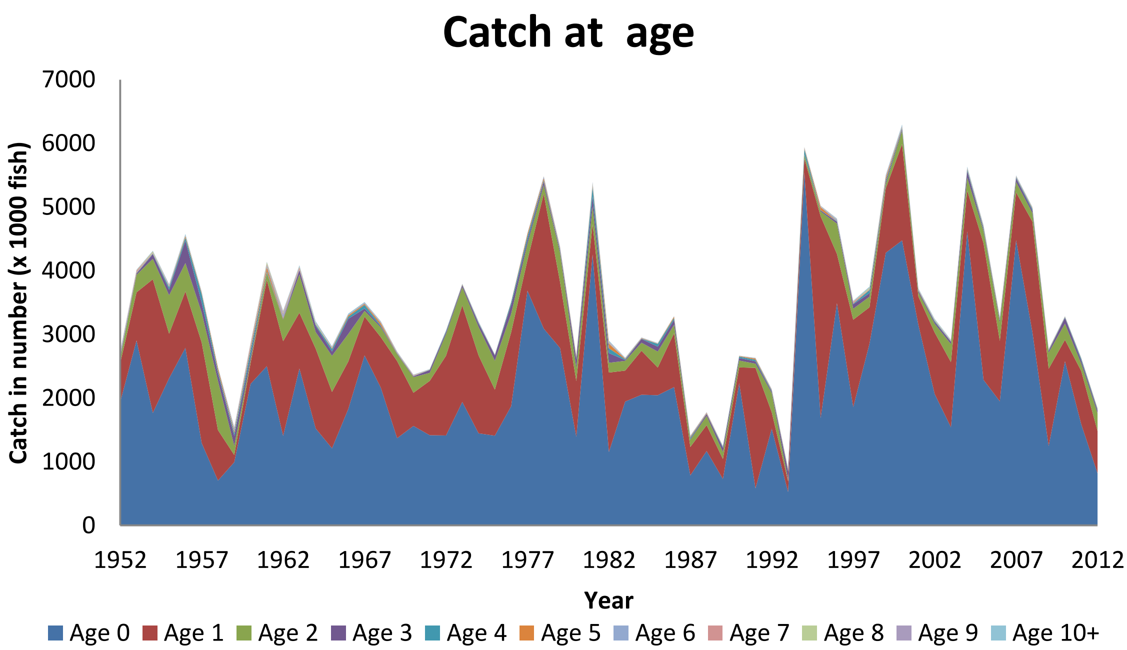

Figure 3. Historical annual catch-at-age of Pacific bluefin tuna (*Thunnus orientalis*) by fishing year (1952-2012; data for 1952 are incomplete).

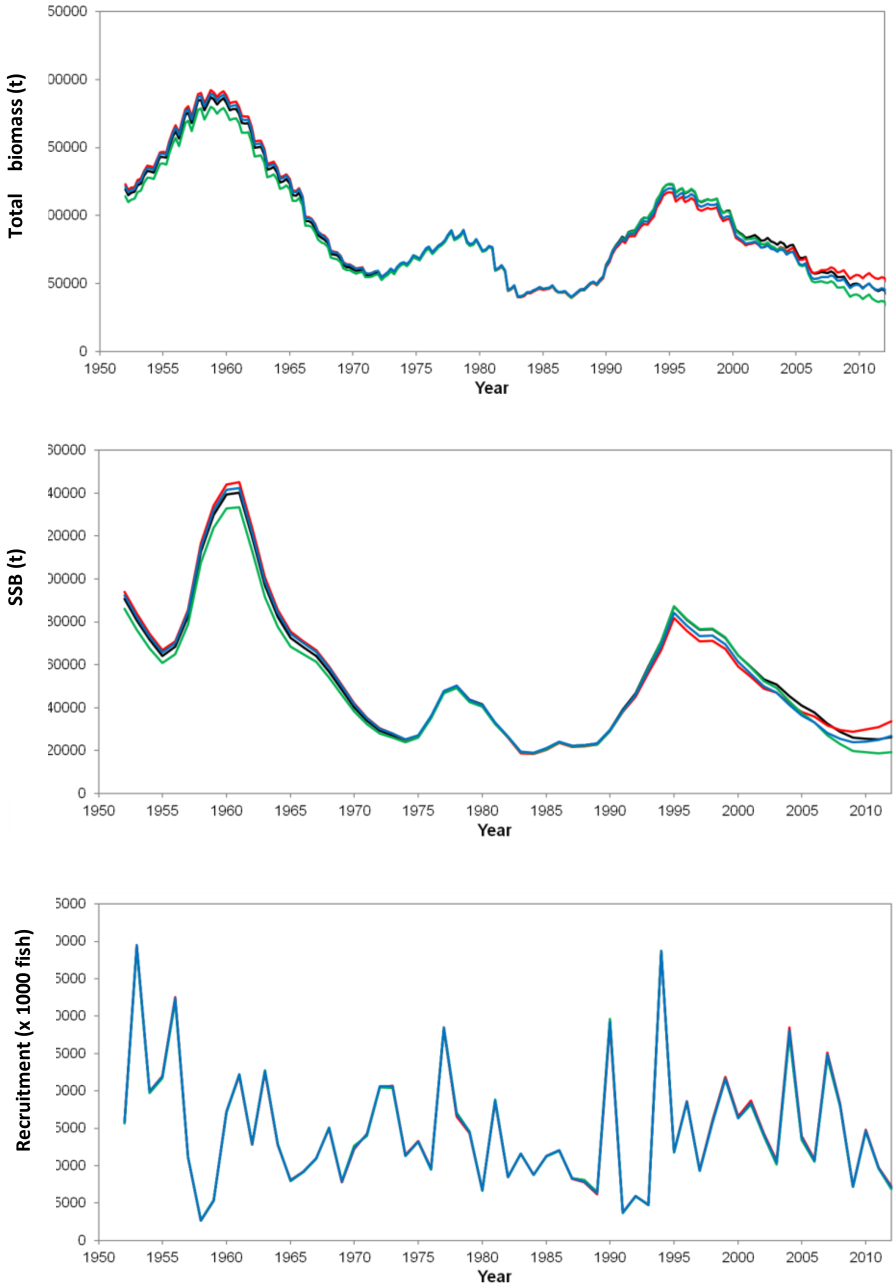

Figure 4. Pacific bluefin tuna (*Thunnus orientalis*) total stock biomass (TSB, upper panel), spawning stock biomass (SSB, middle panel) and recruitment (lower panel) estimated from four runs. Black, red, green and blue lines indicate Runs 1 through 4, respectively.

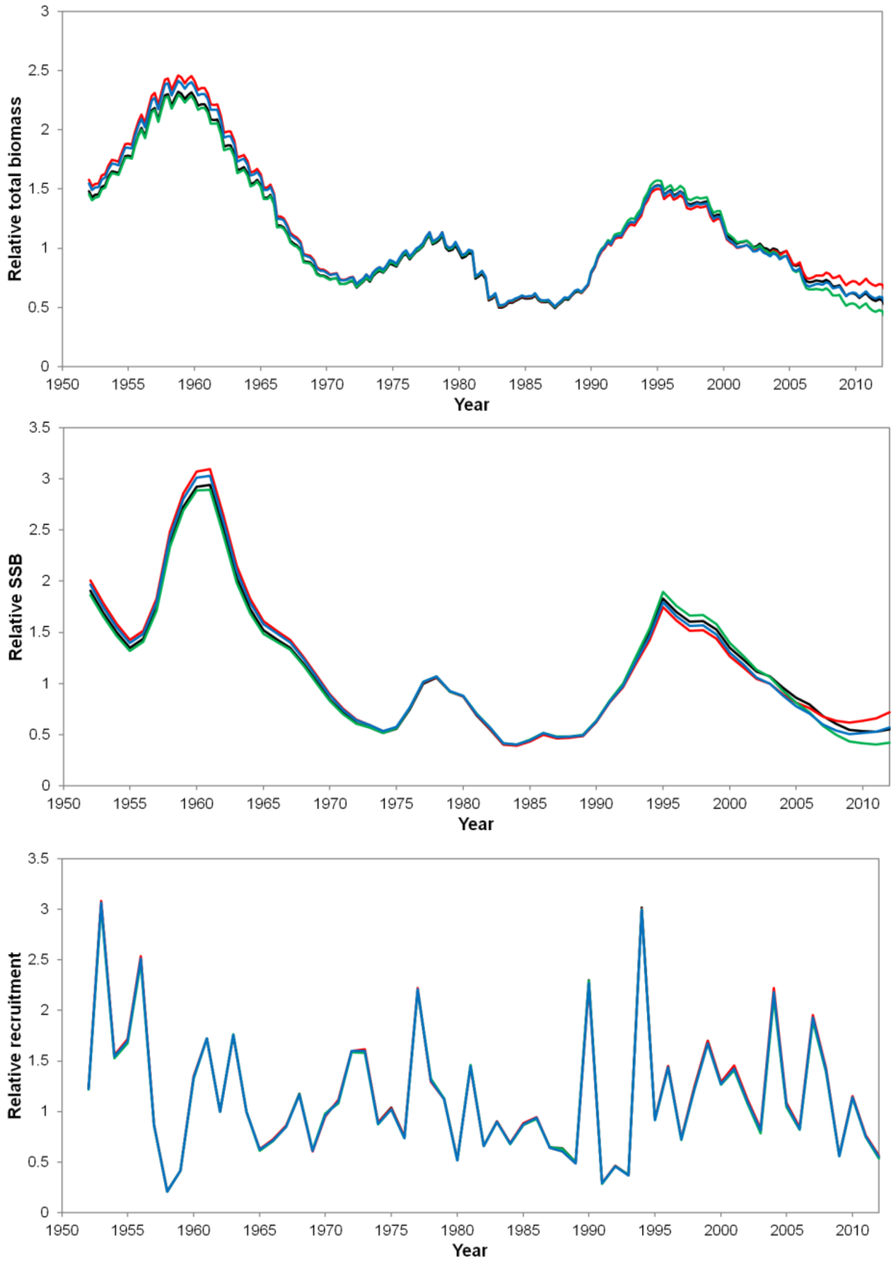

Figure 5. Relative values (to long-term average) of total Pacific bluefin tuna (*Thunnus orientalis*) stock biomass (TSB, upper panel), spawning stock biomass (SSB, middle panel) and recruitment (lower panel) estimated from four runs. Black, red, green and blue lines indicate Runs 1 through 4, respectively.

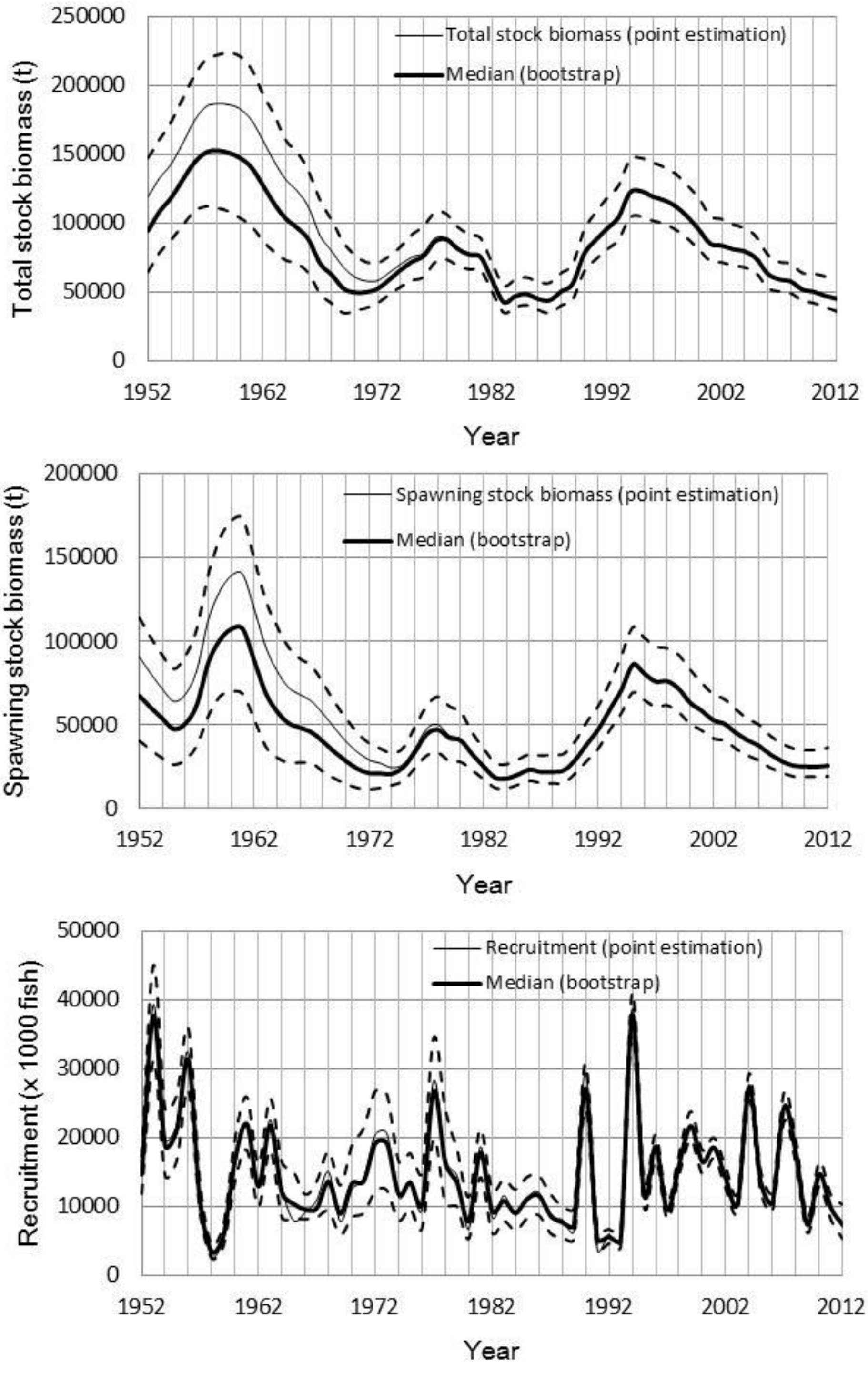

Figure 6. Pacific bluefin tuna (*Thunnus orientalis*) total stock biomass (upper panel), spawning stock biomass (middle panel) and recruitment (lower panel) of PBF from the base case run (Run1). Thick line indicates median, thin line indicates point estimate, and dashed lines indicate the 90% confidence interval

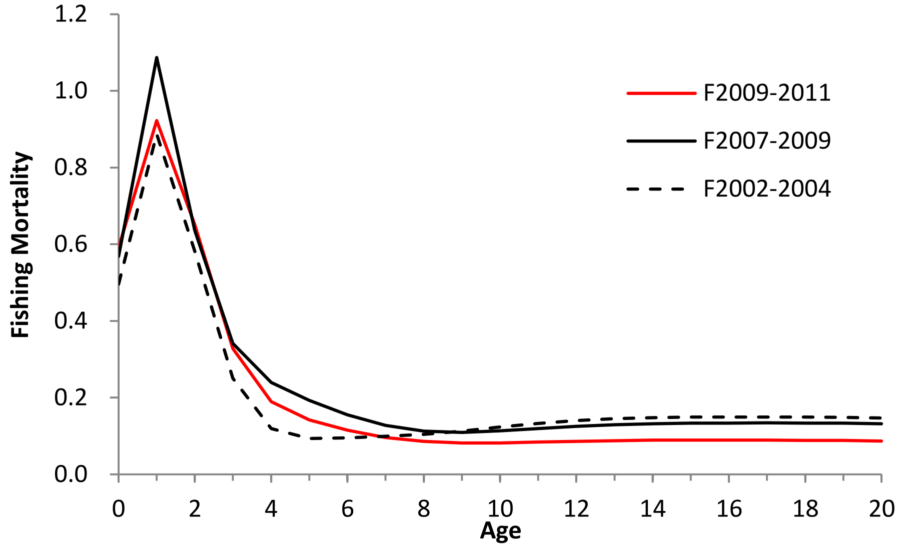

Figure 7. Geometric mean annual age-specific Pacific bluefin tuna *(Thunnus orientalis*) fishing mortalities for 2002-2004 (dashed line), 2007-2009 (solid line) and 2009-2011 (red line).

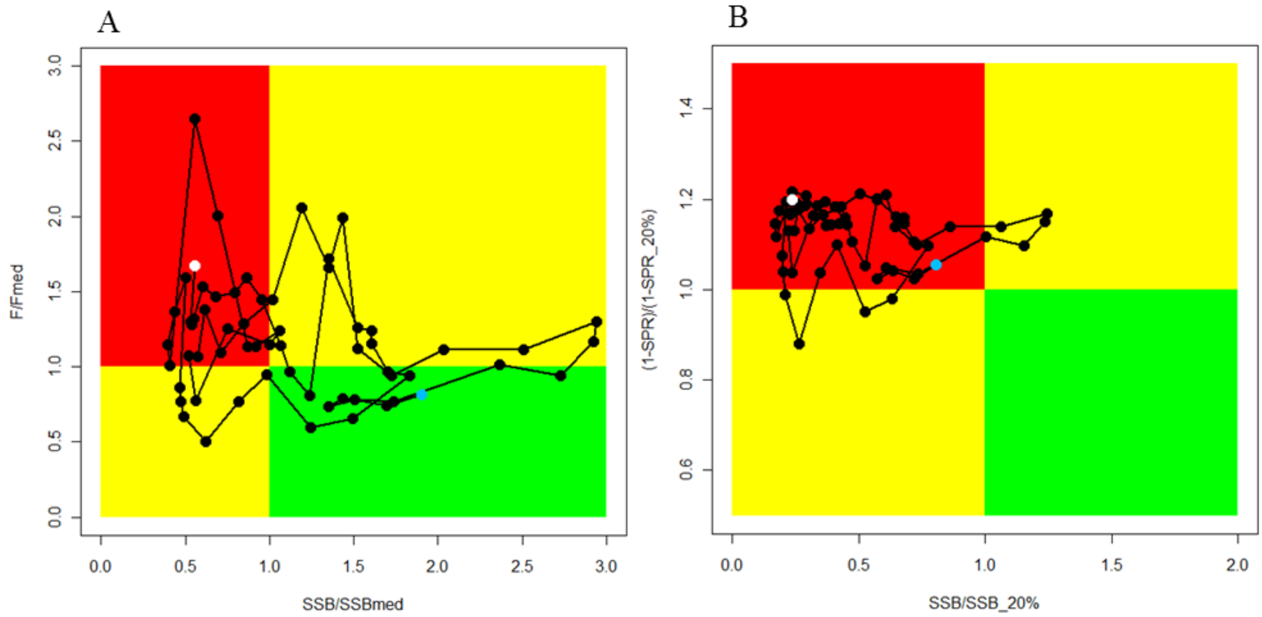

Figure 8. Alternative Kobe plots for Pacific bluefin tuna (*Thunnus orientalis*). A. SSB_{MED} and F_{MED}; B. $SSB_{20\%}$ and $SPR_{20\%}$. Citation of these Kobe plots should include clarifying comments in the text. The blue and white points on the plot show the start (1952) and end (2012) year of the period modeled in the stock assessment, respectively.

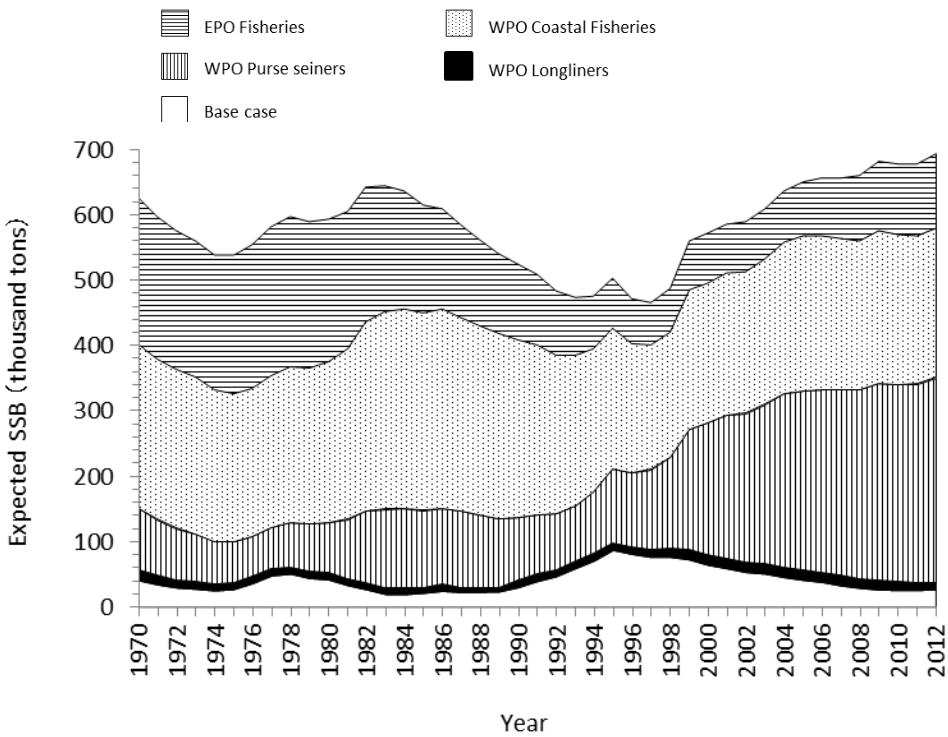

Figure 9. Trajectory of the spawning stock biomass of a simulated population of Pacific bluefin tuna (*Thunnus orientalis*) that was unexploited (topmost line) and that predicted by the base case (white area). The shaded areas between the two lines show the proportions of impact of each fishery.

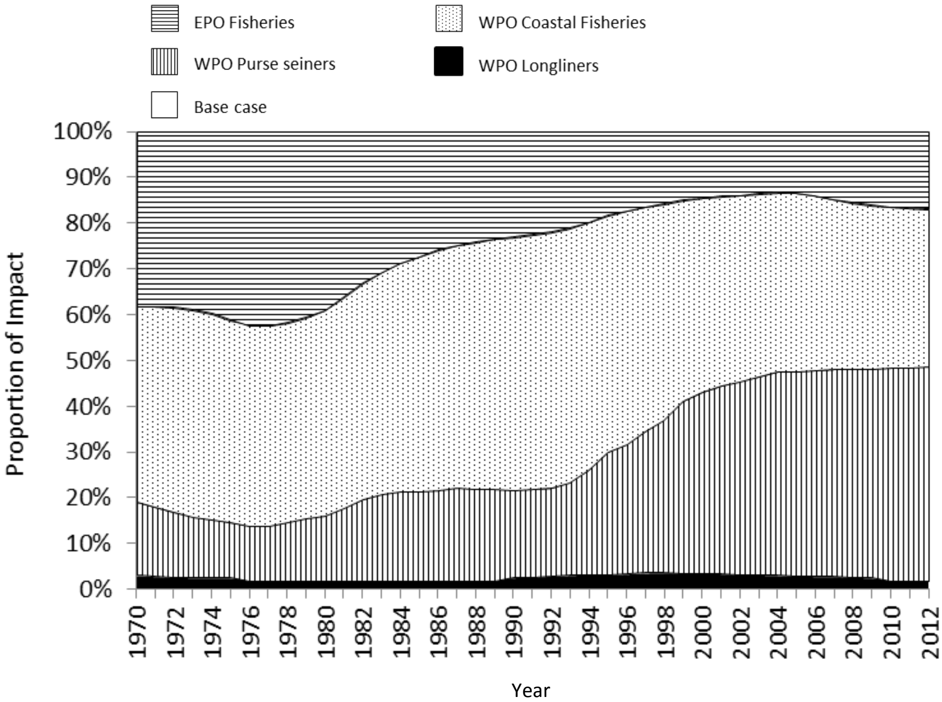

Figure 10. The proportion of the impact on the Pacific bluefin tuna (*Thunnus orientalis*) spawning stock biomass by each group of fisheries.

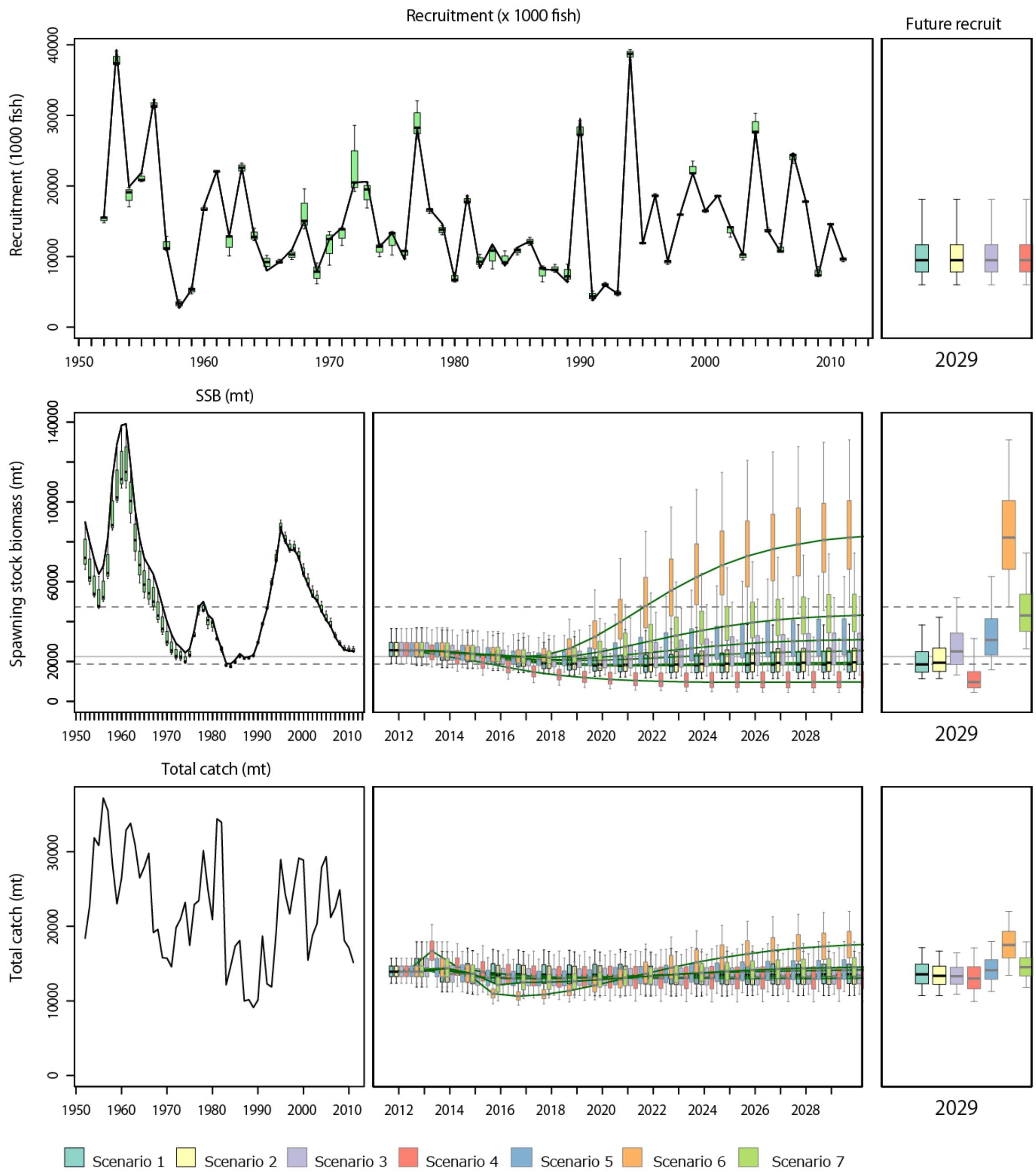

Figure 11-1. Comparison of future Pacific bluefin tuna (*Thunnus orientalis*) SSB trajectories in seven harvest scenarios (see full text for scenario definitions) under low recruitment conditions. Error bars represent 90% confidence limits.

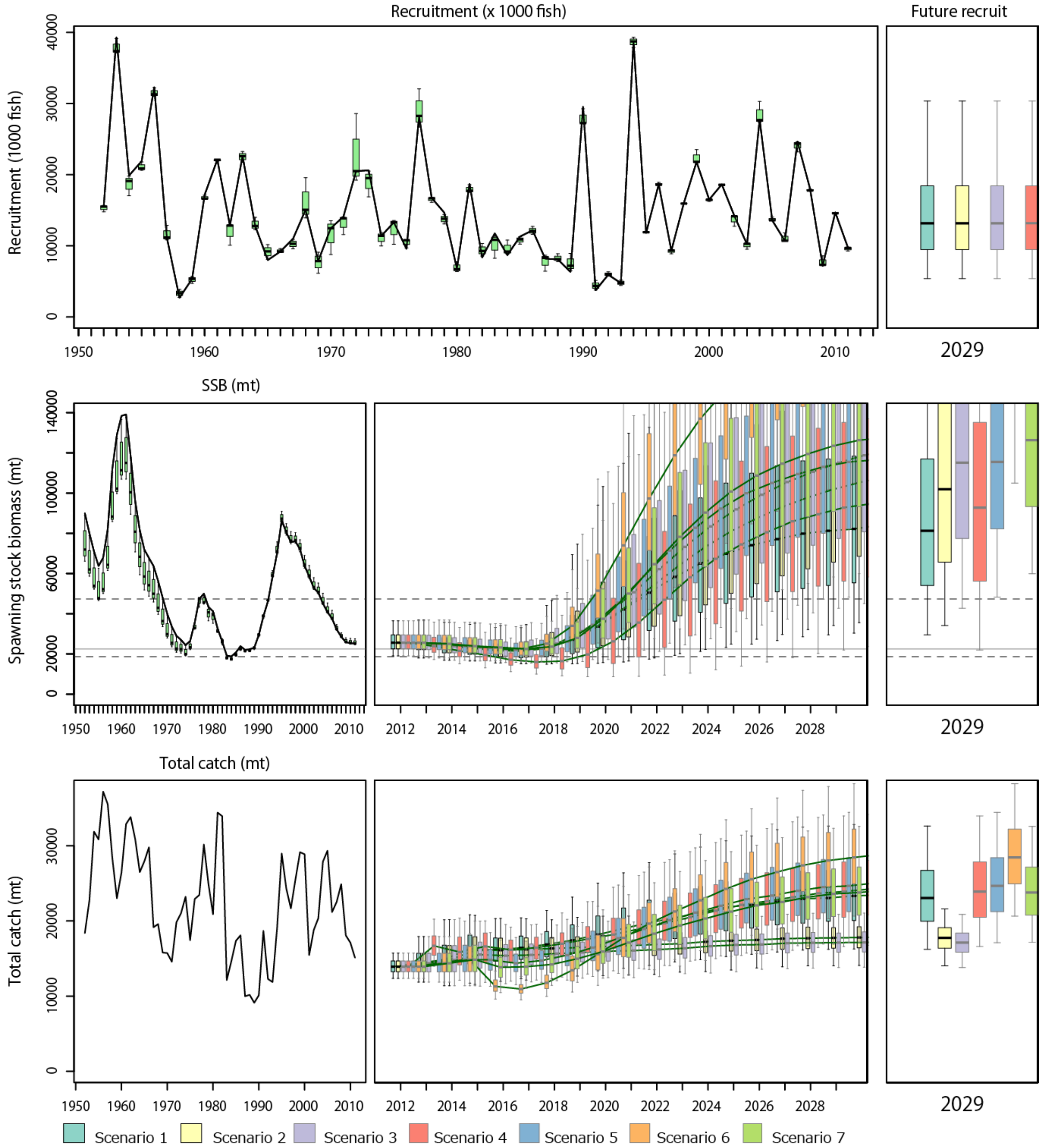

Figure 11-2. Comparison of future Pacific bluefin tuna (*Thunnus orientalis*) SSB trajectories in seven harvest scenarios (see full text for scenario definitions) under average recruitment conditions (resampling from recruitment in 1952-2011). Error bars represent 90% confidence limits.

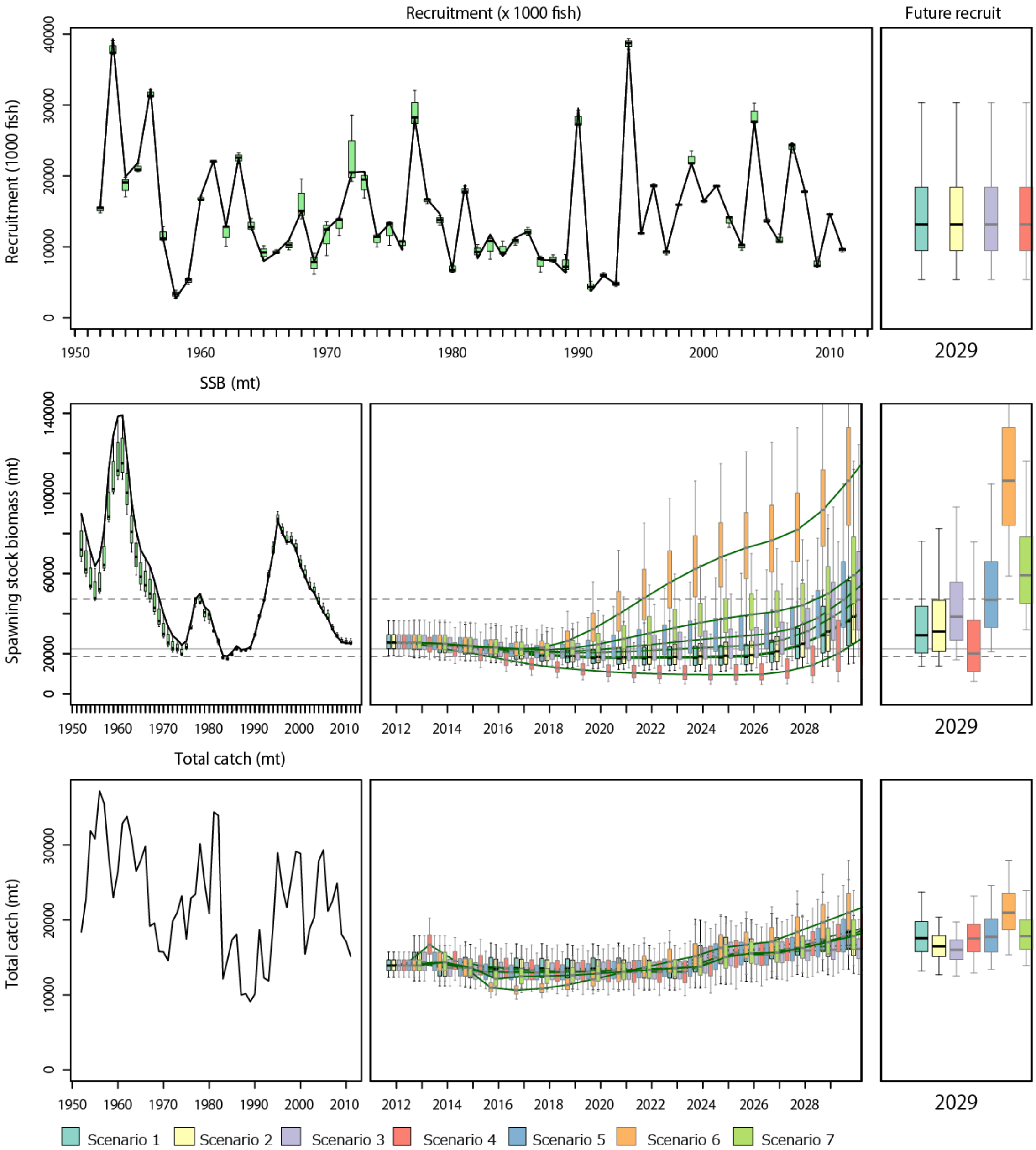

Figure 11-3. Comparison of future Pacific bluefin tuna (*Thunnus orientalis*) SSB trajectories in seven harvest scenarios (see full text for scenario definitions) assuming 10 years (2014-2023) of low recruitment followed by average recruitment after 2024 (resampling from recruitment in 1952-2011). Error bars represent 90% confidence limits.

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 International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) is responsible for assessing the status of this stock.

The ISC established the PBF Working Group (PBFWG) in 1996, intending to assemble fishing statistics and operational data, conduct biological studies, estimate abundance trends, and conduct regular stock assessments of PBF. Stock status determination and conservation advice resulting from the assessments have since been provided to Pacific tuna regional fisheries management organizations (RFMOs), namely the Northern Committee of the Western Central Pacific Fisheries Commission (WCPFC-NC) and the Inter-American Tropical Tuna Commission (IATTC), for consideration when establishing possible Conservation and Management Measures (CMMs).

The PBFWG completed the last stock assessment in 2012 (PBFWG 2012). Based on the results, the WCPFC amended the CMM of Pacific bluefin tuna for the Western Central Pacific Ocean (WCPO) in 2013, effective 2014 (WCPFC CMM 2013-09). The IATTC also amended its resolution for the Eastern Pacific Ocean (EPO) in 2013, and this resolution came into effect in 2014 (IATTC Resolution C-13-02).

The latest full stock assessment was conducted by the ISC PBFWG in 2012 at Honolulu using fishery data from 1952 through 2010 (PBFWG. 2012b). Model estimates of current biomass are at or near the lowest level in the time series. In addition to those stock assessment results, newly available fishery data (catch per unit effort (CPUE) and catch through 2011) suggested the potential risk of further declines in spawning stock biomass (SSB) in the coming years. Under these circumstances, the PBFWG proposed to conduct an updated stock assessment with two additional years of fishery data (2011 and 2012) to monitor stock status carefully with the most recent data, with particular emphasis on recruitment trends (PBFWG. 2013). This proposal was approved at the 13th ISC plenary (ISC. 2013).

This updated stock assessment was developed after PBFWG members provided the requisite 2011-2012 catch, CPUE, and size composition data (Oshima et al., 2014). The stock assessment was conducted according to the work plan of Fukuda et al. (2014), summarized as follows:

1. Conduct a model run with additional data from the 2011 and 2012 fishing years using the same Stock Synthesis (SS) model version (Version 3.23b) for the stock assessment platform, and with the same model structure and parameters as were used in the base case run from the 2012 stock assessment.
2. The stock assessment duration will be from July 1952 to June 2013 (calendar year).
3. The WG will not change the fishery data (quarterly catch, size composition) used in the 2012 stock assessment.
4. In the case of CPUE time series, due to the nature of the CPUE standardization method, the whole time series will need to be re-standardized with the

additional 2 years data. The statistical method used to standardize CPUE (error structure, etc.) will be the same as that used in the 2012 stock assessment.

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 2011 fishing year corresponds to 1 July 2011 to 30 June 2012. Relationships between calendar year, fishing year, and year class are shown in Table 1-1.

For this assessment, four model runs were conducted to evaluate effect of updates of CPUE and size composition data for Japanese longline and Taiwanese longline.

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 Regional Fishery Management Organizations (RFMOs), the Food and Agriculture Organization of the United Nations (FAO), and ISC.

Major spawning areas of PBF are known located in the western North Pacific Ocean (WPO) in waters near the Ryukyu Islands in Japan to 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 & Smith 2012) suggest that PBF comprise a single stock. This is the operative premise accepted by the relevant RFMOs (WCPFC and IATTC) and regional fisheries organizations (RFOs) (ISC and FAO), and it underlies this stock assessment and the associated conservation advice.

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 area around the Ryukyu Islands and off eastern Chinese Taipei, and in July to August in the Sea of Japan (Yonemori 1989) (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 July to August were mature (Tanaka 2006). Almost all of the fish caught off the Ryukyu Islands and east of Chinese Taipei were above 60 kg (> 150 cm fork length (FL)). These fish are at least 5 years old, and all are mature.

2.1.3 Distribution and Movements

PBF are mainly distributed between 20° N and 40°N, but are also occasionally found in tropical waters and even in the southern hemisphere (Figure 2-2).

Although there are large interannual variations (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). Under certain ocean conditions, a variable portion of immature ages 1-3 fish in the WPO make a seasonal clockwise migration eastward across the North Pacific Ocean, spending up to several years as juveniles in the EPO before returning to the WPO (Inagake et al. 2001). However, the oceanographic factors responsible for the observed migration are unknown. While in the EPO, the juvenile PBF make seasonal north-south migrations along the west coast of North America (Kitagawa et al. 2007; Boustany et al. 2010).

Adults found in the WPO generally migrate north to feeding grounds after spawning, but there are a limited number of fish that move south or eastwards (Itoh 2006).

2.1.4 Growth

Recent studies examining the annuli from otolith samples have advanced our knowledge of PBF age-and-growth (Shimose et al. 2008; 2009; Shimose and Takeuchi 2012). These studies indicate that young fish grow rapidly until age 5 (approximately 150 cm fork length (FL)), after which growth slows down (Figure 2-3). At age 13, the fish reach 225 cm FL, corresponding to 90% of the maximum FL of this species. Large fish (above 250cm 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 are rarely found in commercial catches.

This stock assessment is based on the growth curve proposed by Shimose et al. (2009). However, this growth curve underestimates the size of the age 0 fish from the commercial catch taken during summer. Therefore, the PBFWG adjusted the expected length-at-age of fish at age 0.125 to a higher value (21.54 cm FL from 15.47 cm FL) (PBFWG 2012a). The difference between the growth curve and the size of fish observed in the summer catch may be attributed to spatial and temporal variation in spawning, and sex-specific growth (Shimose and Takeuchi 2012). Length and weight 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

The instantaneous natural mortality coefficient (natural mortality or M) is assumed to be high at a young age and decrease thereafter as the fish grow. The natural mortality estimate for age 0 fish was based on results obtained from conventional tagging studies (Takeuchi and Takahashi 2006; Iwata et al. 2012a; Iwata et al. 2014). For age 1 fish, natural mortality was based on length-adjusted M estimates from conventional tagging studies on southern bluefin tuna (*T. maccoyii*) (Polacheck et al. 1997, PBFWG 2009). Bayliff (1994) estimated natural mortality of PBF in the 16-256 cm size range using

Pauly's equation (Pauly 1980); the estimate was 0.275 per year. Based on this estimate and life history parameter comparisons among temperate tuna species (Aires-da-Silva et al. 2008, PBFWG 2009), *M* was assumed to be 0.25 per year for age 2 and older PBF (Figure 2-5). While a analysis estimated a lower *M* for age 2 and older PBF based on tagging data (Whitlock et al., 2012), this updated stock assessment used the same *M* value as the 2012 stock assessment.

2.2 Review of Fishery

In this section, year corresponds to calendar year. Annual PBF catches from 1952 to 2012 are shown in Figure 2-6 by country and fishing gear. Five countries 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 relatively low and sporadic.

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 (fleet/fishery definition), 3.4 (catches), 3.5 (abundance indices), 3.6 (size compositions) 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 also 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 relatively small numbers of PBF.

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, and Section 3.6.9.

In the USA, two main types of fisheries, purse seine and recreational fisheries, catch PBF off the west coast of North America. A 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). 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. The development and changes in this fishery are further detailed in Sections 3.5.8 and 3.6.9.

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). For assessment purposes, and because of the similar sizes of fish taken, the Korean OLPS fleet has been combined with Fleet 2 (small pelagic purse seine fisheries) in the East China Sea. However, for future assessments the PBFWG agreed to separate the Korean OLPS from these fisheries. More details are provided in Sections 3.3 and 3.6.3.

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. In 1979, the landings started to increase sharply, 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. In 2010, landings of PBF by this fishery fell to their lowest levels of about 300 t.

2.3 Previous Stock Assessment

The ISC completed the previous PBF assessment in 2012 using Stock Synthesis version 3.23 (SS). The 2014 assessment was conducted with the same structural assumptions and parameters as used in the Representative Run (base case) in the 2012 assessment, and as documented by the work plan agreed by the ISC13 Plenary (see Section 1). Consequently, the model structure, the biological assumptions, and the handling of fishery data, as described in the following sections, were generally the same as the 2012 stock assessment report (PBFWG. 2012b). Small changes to the 2012 base case included the following:

a. The stock assessment period was extended by 2 years, to cover 1952 to 2012; three CPUE time series, which were used to represent the recent abundance trends, were updated for the entire time series with two additional years of data (2011 and 2012);
b. The catch for farming by the Japanese troll fishery (ISC13 Plenary Report, Annex 14, Appendix 2, Appendix A) was included in the first quarter catch of that fishery for 1998-2012;
c. The catch unit of the U.S. recreational fishery fleet was converted from weight to number of fish;
d. Two parameters, which represented the size selectivity of fleet, were fixed to relevant values; and
e. The input sample size of the eastern Pacific Ocean (EPO) commercial fleet was changed to maintain consistency with the past stock assessment.

Four sensitivity runs were also conducted to investigate results from the 2012 and the current assessment, especially in light of the above (a-e) modifications. The sensitivity of adding the catch for farming by the Japanese troll fleet, the correction of the catch unit for the U.S. recreational fishery fleet, the fixing of the two size selectivity parameters, and the change of the input sample size for the EPO commercial fleet were tested and the WG confirmed the limited effect of these changes (ISC-PBFWG/14-01/11).

3.0 STOCK ASSESSMENT INPUT DATA

3.1 Spatial Stratification

As discussed in Section 2.1.1, PBF are distributed across the North Pacific Ocean and considered a single stock. Juvenile PBF move between the WPO and the EPO, but the movement rate is unknown and probably varies interannually. Given the lack of information on the movement rate, this assessment did not use a spatially explicit model, but assumed a single area for the model without spatial stratification.

3.2 Temporal Stratification

The time period modeled in this assessment was 1952-2012 (fishing years), with catch and size composition data compiled quarterly (July–September, October–December, January–March, April–June). Although fisheries catching PBF have operated since at least the beginning of the 20th century in the EPO and for several centuries in the western Pacific Ocean (WPO), the data prior to 1952, especially from the WPO, were of relatively poor quality. The PBFWG set the starting year to 1952 because catch-and-effort data from Japanese longline fleets and size composition 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 14 fisheries were defined as “fleets” for the stock assessment according to gear type, the consistency of the size composition of the catch within a fleet, and the availability of CPUE series (Table 3-1). The 14 fleets are thus: Japanese longline (Fleet 1); purse seine fisheries operating in the East China Sea (Fleet 2), the Sea of Japan (Fleet 3), and off the Pacific coast of Japan (Fleet 4); Japanese troll (Fleet 5); Japanese pole and line (Fleet 6); Japanese set net classified by location and size composition (Fleet 7 to 10); Chinese Taipei longline (Fleet 11); EPO commercial fisheries (Fleet 12); the US recreational fishery (Fleet 13); and Japanese other fisheries (Fleet 14).

Fleet 2 is an aggregate of Japanese and Korean small pelagic fish purse seine fisheries. The length composition of the Japanese small pelagic fish purse seine fishery was used to represent this fleet.

Fleet 3 and Fleet 4 are Japanese tuna purse seine fisheries in the Sea of Japan and the

Pacific, respectively. They were defined as separate fisheries because of differences in the length composition of the catch (Abe et al. 2012b).

Fleets 7, 8, 9 and 10 are Japanese set net fisheries. The fleets were separated based on the availability of length-weight measurements and the locations of set nets that had differences in observed length compositions. Three definitions were proposed at the ISC PBFWG WS held in January-February 2012. However, because seasonal changes in length compositions caused significant differences between expected and observed length compositions, the original Fleet 9 was separated into two fleets based on season. Fleet 9 in this assessment includes the 1st, 2nd and 3rd quarters, and Fleet 10 includes the 4th quarter.

3.4 Catch

Catch data for the SS3 model were expressed in tonnes for all fleets except for Fleet 13, whose catch was expressed in thousands of fish. PBF catches from all fleets fluctuated substantially over time.

The historical maximum and minimum annual PBF catches were 39,824 t in 1956 and 8,588 t in 1990, respectively (Figure 3-2). The total catch has averaged 21,250 t during the last 10 years (2003−2012).

Purse seine fisheries caught a large portion of the PBF throughout the assessment period (1952-2012). The Japanese tuna purse seine fishery operating in the Pacific Ocean (Fleet 4) accounted for a large portion of the catch until the 1990s. However, catches of the Japanese small-scale purse seine fishery operating in the East China Sea (Fleet 2) and the Japanese tuna purse seine fishery operating in the Sea of Japan (Fleet 3) have become relatively larger since the mid-2000s. The catch for Japanese troll fishing for farming was included in the Japanese troll fleet (Fleet 5; Oshima et al. 2014). The largest catches in the EPO come from the US and Mexican commercial purse seine fisheries (Fleet 12).

The PBFWG developed time series of quarterly catch data from 1952 through 2012 (fishing year). For some of these fisheries, proportions of quarterly catches in recent years were extrapolated using past quarterly catch proportions applied to annual catches. For other fisheries (e.g. Japanese troll before 1994, and Japanese purse seine before 1971), quarterly catches were directly derived from logbook or landing statistics.

3.5 Abundance Indices

3.5.1 Overview

Abundance indices (CPUE) available for this assessment are shown in Figure 3-3 and Table 3-2. These series were derived from fishery-specific catch-and-effort data standardized with appropriate statistical methods, except for Series S4 which was not standardized. Indices S1 to S3 were derived from the Japanese longline fishery (Fleet 1), S4 was derived from the Japanese tuna purse seine fishery in the Sea of Japan (Fleet 3), S5 to S8 were derived from the Japanese troll fishery (Fleet 5), S9 was derived from the

Taiwanese longline fishery (Fleet 11), and S10 and S11 were derived from EPO commercial purse seine fishery (Fleet 12). Some abundance indices (S4, S6-S8, S10 and S11) were not used for this stock assessment (see details below). Consequently, this stock assessment used five indices: four longline indices for adults (S2 and S3 for the past periods (1952-1973 and 1974-1992), and S1 and S9 for the recent periods (1993-2012 and 1998-2012, respectively) and one troll index for recruitment (S5 for the recent period 1980-2012).

3.5.2 Input CV for the CPUE Series

Input coefficients of variation (CVs) for the abundance indices are shown in Table 3-3. The input CVs were first estimated by the statistical model used to standardize the index and set to 0.2 if the estimated CV was less than 0.2. For the Japanese coastal longline CPUE (S1), the PBFWG recognized that some vessels may have shifted fishing effort toward the Ishigaki region, while other vessels may have switched from targeting PBF to other species, such as yellowfin and albacore tuna, due to poor PBF catches. These shifts may have changed the observation and process errors in the abundance index, therefore CPUE error was modeled using a linear ramp of increasing CV in the index from 2005 (0.24) to 2010 (0.43) and constant (0.43) thereafter.

3.5.3 Japanese Longline CPUE (S1, S2 & S3)

Until the mid-1960s, PBF longline catches in Japanese coastal waters were made by offshore or 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.

Two Japanese longline CPUE time series (1952-1973 [S2] and 1974-1992 [S3]) were developed to span the period from 1952 through 1993 (Fujioka et al. 2012; Yokawa 2008). The time series was split because operational patterns changed in the mid-1970s (e.g., the superfreezer 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). Another CPUE series from 1993 to 2012 was developed for the coastal longline fishery as logbook data from this fishery became available from 1993 (Kai et al. 2012; Ichinokawa and Takeuchi 2012; Hiraoka et al. 2014). All three time series were used in the stock assessment: the coastal longline fishery index from 1993-2012 (S1), and the distant-water longline fishery indices from 1952-1973 (S2) and 1974-1992 (S3).

The standardized CPUE for S1 showed a continuous decline from 2006 to 2011 and then a slight recovery in 2012. The length and weight frequencies indicated that the 2007, 2008, or both were relatively strong year classes (Hiraoka et al. 2014).

3.5.4 Japanese Purse Seine in the Sea of Japan CPUE (S4)

Kanaiwa et al. (2012b, 2014) described the Japanese purse seine fishery in the Sea of Japan. There were two concerns with this time series: 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 unresolved issues this index was not used in the base case model.

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

Catch-and-effort data for coastal troll fisheries from 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 units of effort in the catch-and-effort data are the cumulative daily number of troll vessels that unload PBF, which is nearly equivalent to the total number of troll vessel trips because most trollers make one-day trips. Because effort data in Kochi and Wakayama Prefectures include landings without PBF catch (zero-catch data), a zero-inflated negative binomial model was used to standardize CPUE for these prefectures. A log-normal model was applied for Nagasaki Prefecture because effort data in Nagasaki Prefecture did not include landings without PBF catch.

While four indices are available (S5 from Nagasaki Prefecture, S6 from weighted average CPUE from Kochi and Nagasaki Prefectures, S7 from Kochi Prefecture, and S8 from Wakayama Prefecture) in this fishery, only S5 was fitted in the assessment model due to representativeness (Table 3-1). The updated standardized CPUE for S5 showed a similar trend with the previous CPUE index through 2011, and then greatly decreased in 2012. The CPUE in 2012 is the historically second lowest (Fujioka et al. 2014).

3.5.6 Taiwanese Longline CPUE (S9)

The Taiwanese PBF catch and effort data were derived from landings by individual fishing boats targeting PBF, the number of fishing days, and the number of hooks deployed per day for these boats. The fishing effort of these boats was estimated as the number of hooks per day multiplied by the number of fishing days minus 2 days (assumed to be transit days) (Hsu and Wang 2012). Numbers of days-at-sea data were obtained from the security check stations of the harbors. Catch data were estimated from auction records.

A generalized linear model (GLM) (with three factors: year, month, and vessel type) was used to standardize the annual PBF CPUE for 1999-2013. The annual abundance index time series shows a sharp decline from a high in 1999 to a low in 2002, a steady level in 2003 and 2004, a decline to a low level in 2005 and 2006, a slight increase in 2008, a further two-year decline in 2009 and 2010, and an increase over the 2009 level from 2011 onward. The standardized CPUE was also influenced by a lower abundance of PBF in May and an increase in vessel size in June. The general agreement between the abundance index and the total catch trend provides evidence that the catch and effort data collected and compiled in this study can be used to develop a representative abundance index of spawning bluefin tuna targeted by the Taiwanese small-scale longline fishery (Wang et al. 2014).

The PBFWG agreed that Taiwanese longline fleet landings by port should be appropriately accounted for in the CPUE standardization models for this fleet. The results of a sensitivity analysis comparing the Taiwanese longline fleet's CPUE from the previous assessment and the new CPUE index presented in Wang et al. (2014) was used to determine which CPUE index should be used in the update stock assessment. The PBFWG agreed that the full Taiwanese longline CPUE series should be used and a sensitivity analysis conducted to examine the effect of excluding data from the most recent two years.

3.5.7 US Purse Seine CPUE (S10)

Standardized catch rates are available for two periods of this fishery: (1) the developed phase of the US fishery targeting PBF (1960-1982); and (2) the extinction phase of the US fishery (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 at an unknown but likely variable rate. Due to unresolved issues concerning the representativeness of these data to reflect abundance, this index was not used in the assessment.

3.5.8 Mexican Purse Seine CPUE (S11)

Mexican standardized catch rates 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) and Section 3.6.9). 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.

3.6 Size Composition Data

3.6.1 Overview and Input Sample Size

Quarterly size composition (both length and weight) data from 1952 to 2012 were used for this assessment. The size composition data for Fleets 4, 6 and 13 were not updated after 2010 (Oshima et al 2014). Length composition data were available for Fleets 1-6 and 8-13, while weight composition data were available for Fleets 7 and 14. Length composition bins of 2, 4, and 6 cm width were used for 16-58, 58-110, and 110-290 cm fork length (FL) fish, respectively. All lengths in the model were FL measured to the nearest cm. Weight composition bins were of variable width, ranging from 1 kg for fish 0-2 kg, to 30 kg for fish >243 kg. The width of the weight bins were set to minimize the misinterpretation of the data. The lower boundary of each bin was used to define the bin.

Figure 3-4 shows the aggregated size compositions of Fleets 1-14, and Figure 3-5 shows the quarterly size compositions of Fleets 1-14. For the update stock assessment, estimated catch-at-size was used for all fleets. Catch-at-size estimation methods were detailed by Mizuno et al. (2012), Oshima et al. (2012a), Kanaiwa et al. (2012a), Fukuda and Oshima (2012), Abe et al. (2012a; 2012b) and Kai and Takeuchi (2012). Table 3-4 summarizes the relative reliability of each fleet's catch-at-size data.

The input sample sizes for the size composition data are shown in Table 3-5. Most fleets had a maximum input sample size of approximately 12. The exceptions were Fleets 3 (Japanese tuna purse seines in the Sea of Japan) and 12 (EPO commercial purse seines) because these fleets were considered by the PBFWG to have good sampling programs for the size composition data.

3.6.2 Japanese Longline (Fleet 1)

Length-composition data from the Japanese longline fishery (Fleet 1) are available for the periods of 1952-1968 and 1994-2011. These data were collected mainly from Tsukiji market until the 1960s. Since the 1990s, sampling 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, and were not included in this assessment.

Monthly length compositions were raised by the landings from corresponding months (Mizuno et al. 2012). The raised length compositions from the appropriate months were then combined to obtain the seasonal length compositions.

3.6.3 Purse Seines in the East China Sea (Fleet 2)

Length composition data from the Japanese purse seine fishery in the East China Sea were developed from length measurements taken at Fukuoka and Matsuura, which were the major landing ports for this fishery. These length measurements were stratified by market size category because the fish were sorted into market categories prior to measurement. The number of boxes in each market size category (number of fish per box) that were landed at the port was also collected and used to estimate the raised length compositions (Oshima et al. 2012a). Length composition data for this fleet were thus available after 2001.

Length composition data from the Korean purse seiners in the East China Sea were collected at Busan (Yoo et al. 2012; Yoon et al. 2012, Yoon et al. 2014). A preliminary examination of the data indicated that the size of fish caught was similar to the Japanese fleet fishing in neighboring waters. The stock assessment did not directly use the length composition data from the Korean fleet but instead assumed that it was similar to the Japanese fleet.

3.6.4 Japanese Purse Seine in the Sea of Japan (Fleet 3)

Length composition data for the Japanese purse seine fleet in the Sea of Japan (Fleet 3) were collected by port samplers in Sakaiminato and were available from 1987-2012, except for 1990, when there was no catch. Port samplers obtained length measurements from approximately 50% of the catch on an average. This fleet catches mainly PBF older than age 3 (Fukuda et al. 2012).

3.6.5 Japanese Purse Seine off the Pacific Coast of Japan (Fleet 4)

Size composition data from Japanese purse seiners operating off the Pacific coast of Japan were collected at 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. 2012a).

In the 2010 stock assessment, the Japanese tuna purse seine fisheries in the Sea of Japan and the Pacific coast (Fleets 3 and 4) were treated as a single fleet. However, for the current assessment the tuna purse seine fishery was separated into two fleets because of differences in the size composition of the catch in the two fisheries (Abe et al. 2012a; Kanaiwa et al. 2012a). Although length measurements for Fleet 4 have been made since the 1980s, an appropriate method to create catch-at-size data has not yet been established for the entire period. The PBFWG tentatively decided to use the catch-at-size data from this fishery for 1995-2006. The PBFWG recognized that the size composition data for this fishery is highly variable and further research is needed for this dataset.

3.6.6 Japanese Troll and Pole-and-Line (Fleet 5 and Fleet 6)

Comprehensive length composition data have been collected from Japanese troll and pole and line vessels at their main unloading ports since 1994. These were assigned to Fleets 5 and 6, respectively. Length measurements were very limited in the number of sampling ports and number of fish measured before 1994 (Oshima et al. 2007; Fukuda and Oshima 2012). Length composition data from the Japanese troll fishery (Fleet 5) were raised using the catch from each region and month strata. The sampling of pole and line vessels was considered to be relatively poor compared to the more numerous troll vessels. Both fisheries operate in the same area and catch similar-sized fish (primarily age 0 individuals).

3.6.7 Japanese Set Net (Fleets 7-10)

Size composition data from Japanese set net fleets (Fleets 7-10) were available from 1993 to 2012. Fleet 7 size composition data were based on weights, whereas the others (i.e. Fleets 8, 9 and 10) were based on lengths (Kai and Takeuchi 2012; Teo and Piner 2012). All fleets' size data were estimated by raising the size measurement data using the catch in the corresponding strata.

3.6.8 Taiwanese Longline (Fleet 11)

Length composition data for the Taiwanese longline fishery (Fleet 11) collected by port samplers are available for 1992-2012. The size sampling coverage is very high for this fleet, with > 90% of landed fish being measured. The Taiwanese longline fishery catches the largest PBF of all the fisheries.

3.6.9 EPO Commercial Purse Seine (Fleet 12)

Aires-da-Silva and Dreyfus (2012) and Dreyfus and Aires-da-Silva (2014) reviewed the PBF size composition data for the EPO purse seine fishery. PBF size composition data were collected by port samplers from IATTC and national sampling programs. For the most recent Mexican fishery targeting PBF for pen rearing operations, size composition samples were also collected at sea by IATTC observers during pen transfer operations.

There is strong evidence that the average size of the purse seine catch has changed over time. While the average length of the catch fluctuated around about 75 cm (age 1 fish) before the mid 1980s when the USA's PBF-targeting fishery was operating, there has been a shift towards larger fish (mean size of about 85 cm; age 2) in the late 1990s and 2000s, as the Mexican purse seine fishery has targeted PBF for farming operations. In 2001, several vessels targeting PBF changed their purse seine nets to deeper nets. Since 2002, all vessels targeting PBF have adopted this fishing method, as this species is usually found in deeper waters. Under the new method, the depth of the purse seine nets ranged from 240 m to about 315 m, deeper than the nets targeting yellowfin tuna (about 210 m). Mexican PBF farms have recently introduced stereoscopic cameras to obtain size-composition data. Data collected by this method for 2010 and 2011 corroborate the size composition data collected by IATTC observer and port sampler data (Aires-da-Silva and Dreyfus 2012). Mexico provided additional data for 2012-2013 to the PBFWG in Dreyfus and Aires-da-Silva (2014).

3.6.10 EPO Recreational Fishery (Fleet 13)

Size composition data for the US recreational fishery have been collected by IATTC staff since 2002. Due to low sample sizes, these data were not used in the assessment but indicated that the sizes of fish caught were similar to the EPO commercial purse seine fishery. The size composition data for this fleet in the last two years were not provided for the update stock assessment (Oshima et al. 2014).

3.6.11 Other Fisheries (Fleet 14)

This fishery contains a variety of Japanese gear types and fisheries, mainly from Tsugaru Strait (between Honshu and Hokkaido). The size composition data, based on weights, shows a large peak at around 10 kg with a long tail extending to 250 kg (Abe et al. 2012b). Given the model structure, preliminary analysis indicated that poorly fitted size composition estimates from this fleet strongly influenced the estimated population dynamics (see Section 5). The relative contribution of each gear type included in this mixed fleet is unknown but likely varies over time. In the update stock assessment, the size composition data for Fleet 14 were used in a preliminary run to estimate the selectivity for this fleet, but were not used in the final model (see Section 4.3.2).

4. MODEL DESCRIPTION

4.1 Stock Synthesis

A seasonal, length-based, age-structured, forward-simulation population model was used to assess the status of PBF. The model was implemented using Stock Synthesis (SS) Version 3.23b (Methot and Taylor 2011; 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 has historically been used primarily for ground fishes, it has recently gained popularity for stock assessments of tunas and other highly migratory species in the Pacific Ocean. The structure of the model allows for Bayesian estimation processes and full integration across parameter space using a Monte Carlo Markov Chain (MCMC) algorithm.

SS is comprised of three subcomponents: 1) a population subcomponent that recreates an estimate of the numbers/biomass at age using estimates of natural mortality, growth, fecundity etc., 2) an observational sub-component that consists of observed (measured) quantities such as CPUE or proportion at length/age, and 3) a statistical sub-component 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 otolith samples from 1690 fish, ranging from 46.5 to 260.5 cm, and aging them to the nearest fractional year based on an assumed biological birth date of 15 May (Shimose and Takeuchi 2012). 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 0.1574743 y^{-1} and L_1 and L_2 at 21.5 cm and 109.194 cm for age 0 and age 3, respectively. The CV of the length-at-age for age 0 fish was estimated in the model (approximately 0.26, depending on the run); the CV for age 3 and older fish was fixed at 0.05.

The von Bertalanffy equation growth based on the above parameters is as follows:

$L_t = 254.413\,\{1\text{-}e^{-0.1574743(t+0.560689)}\}$

where

L_t = length at age t;

L_∞ = 254.413 cm = theoretical maximum length;

K = 0.1574743 y^{-1} = growth coefficient or the rate at which L_∞ is asymptotically reached; and

t_0 = -0.560689 (assumed July 1 as birth day, the first day in fishing year) = theoretical age where length is equal to zero.

In 2008, when the SS model was used for the first time to assess PBF, age of A_2 was manually tuned to optimize the model fit (A_2 = 3). In the 2008 stock assessment, CV_2 was also manually tuned to optimize the model fit in a preliminary run and fixed to 0.08 in the base case (Ichinokawa et al. 2008). In the current stock assessment, the choice of age 3 for A_2 was re-examined in preliminary runs and found to be optimal again. The value of CV_2 was also re-estimated and 0.05 was found to be optimal for the model fit using the current stock assessment's data.

4.2.2 Maximum Age

The maximum age modeled was age 20, which 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-at-Length

A sex-combined weight-at-length relationship was used to convert fork length (L) in cm to weight (W_L) in kg (Kai 2007). 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-at-length relationship was applied as a fixed parameter in the model (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 (Figure 2-5).

4.2.6 Recruitment and Reproduction

PBF spawn throughout spring and summer (April-August) in different areas 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, which is the beginning of the spawning cycle. 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 (Section 2.1.2). Recruitment was assumed to occur in July-September.

A standard Beverton and Holt stock recruitment model was used in this assessment. The expected annual recruitment was a function of spawning biomass with steepness (h), virgin recruitment (R_0), and unfished equilibrium spawning biomass (SSB_0) corresponding to R_0, and was assumed to follow a lognormal distribution with standard deviation σ (Methot and Taylor 2011, Methot and Wetzel 2013). Annual recruitment deviations were estimated based on the information available in the data. 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.

Recruitment variability (σ: the standard deviation of log-recruitment, see Section 4.6.2 for more detail) was fixed at 0.6. The log of R_0 (virgin recruitment) and annual recruitment deviates were estimated by the model. The offset for the initial recruitment relative to R_0 was estimated in the model and found to be small (approximately 0.075, depending on the run). Annual recruitment deviates were estimated from 1949 to 2011 (recruitment deviations in 1942-1951 represent deviations from a stable age structure corresponded ages 1-10 in 1952, i.e. the first year included in the stock assessment) and expectations of recruitment deviates for the terminal year derived from the stock-recruitment (S-R) relationship. A full bias adjustment of recruitment estimates is applied from 1953-2011, while no bias adjustments are applied to the recruitment estimates prior to 1952. This was determined from preliminary runs using the method described in Methot and Taylor 2011.

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.

4.2.7 Stock Structure

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

4.2.8 Movement

PBF is a highly migratory species 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 be well-mixed and distributed throughout the Pacific Ocean, and 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 and time-varying selectivities to approximate changes in the movement patterns of the stock.

4.3 Model Structure

4.3.1 Initial Conditions

Stock assessment models must make assumptions about what occurred prior to the start of the dynamic period. Two approaches describe the extreme alternatives for reducing the influence of equilibrium assumptions on the estimated dynamics. The first approach is to start the model as far back in time as is necessary in order to assume that there was no fishing prior to the dynamic period. Usually this entails creating a series of catches but these can be unreliable. The other approach is to estimate (where possible) initial conditions. 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 initial fishing mortality rates (*Fs*) in the assessment model. Not fitting to the equilibrium catch is equivalent to estimating the catch and therefore the *Fs* that best correspond to the data during the dynamic period. For this assessment, equilibrium catches (and *Fs*) for the Japanese longline (Fleet 1) and Japanese troll (Fleet 5) fleets were estimated and corresponding Fs were allowed to match other data during the dynamic period. These two fleets were chosen to estimate initial *Fs* because they represented fleets that take large and small fish, thereby allowing for model flexibility. In addition, ten recruitment deviations were estimated prior to the dynamic period to allow the initial population to better match size composition information available at the start of the dynamic period.

4.3.2 Selectivity

Selectivity patterns were fishery-specific and assumed to be length-based. Selectivity patterns were used to model not only gear function but availability of the stock (spatial patterns and movement) by spatially and temporally stratifying fisheries. In this assessment, selectivity patterns were estimated using length composition data for all fisheries except for Fleet 14, which was a composite of several different gear types, and Fleet 6, which was poorly sampled relative to a similar fishery (Fleet 5).

4.3.3 Selectivity Functional Forms

Selectivity assumptions can have large influences on the expected length frequency distribution given the relative importance of length frequency data in the total log-likelihood function. Functional forms of logistic or double normal curves were used in this assessment to approximate selection patterns. A logistic curve implies that fish below a certain size range are not vulnerable to the fishery, but then gradually increase in vulnerability to the fishery with increasing size until all fish are fully vulnerable (asymptotic selectivity curve). A double normal curve consists of the outer sides of two adjacent normal curves with separate variance parameters for the left and right hand sides and peaks joined by a horizontal line. This implies that the fishery selects a certain size range of fish (dome-shaped selectivity curve). Although dome-shaped selectivity curves are flexible, studies have indicated that their descending limbs are confounded with natural mortality, catchability, and other model parameters if all fisheries are dome-shaped.

This assessment assumed that one fleet has an asymptotic selectivity curve to eliminate the estimation of “cryptic biomass” and to stabilize parameter estimation (Table 4-1). This assumption meant that at least one of the fisheries sampled from the entire population above a specific size. This is a strong assumption that was evaluated in a separate analysis, whose results indicated that the Taiwanese longline fleet (Fleet 11) consistently produced the best fitting model when specified as asymptotically selective (Piner 2012). This assumption along with the observed sizes and life history parameters, sets an upper bound to population size. Two parameters, both of which were estimated in this assessment describe asymptotic selectivity: the length at 50% selectivity, and the difference between the length at 95% selectivity and the length at 50% selectivity.

All other fleets with length-composition data were allowed to be dome-shaped (Table 4-1) with six parameters describing the shape of the pattern. For most fisheries, the initial and final parameters of the selectivity patterns were assigned values of -999 or were fixed to a small value (-15). The setting to 0.999 causes SS to ignore the first and last size bins and allows it to decay the selectivity of small and large fish according to parameters of ascending width and descending width, respectively. For some fisheries, the parameter specifying the width of the constant selectivity plateau was often estimated to be very small (-9) and often reached assigned bounds. For these fisheries, the width of the plateau was set to -9. Other parameters describing dome-shaped selectivity were estimated by the model, i.e. the length at which full selectivity is reached, the ascending and the descending width of the length selectivity plateau. Given the data and the model structure, the estimation of ascending and descending width of selectivities for Fleet 8 and Fleet 10 reached the upper limit of the estimation bounds.

These parameters were fixed at the values of their upper limits.

4.3.4 Special Selectivities including Fixed, Time Varying and Mirrored

The selectivities of the Japanese pole-and-line fishery (Fleet 6) and the US recreational fishery (Fleet 13) were assumed to be the same as those of the Japanese troll fishery (Fleet 5) and the EPO commercial purse seine fishery (Fleet 12), respectively. This is because both Fleets 6 and 13 had relatively small sample sizes due to the substantially smaller sampling effort relative to Fleets 5 and 12. In addition, Fleets 6 and 13 and Fleets 5 and 12 were similar in terms of fishing areas and sizes of fish caught. The size composition data of Fleets 6 and 13 were not fitted by the model.

Selectivity of the Japanese “other” fishery (Fleet 14), which was a mixed gear fishery, likely varied over time due to the changes in the relative contribution of different gear types. Given the relatively small catches from this fleet and the difficulties in modeling it’s selectivity, the selectivity of Fleet 14 was fixed with parameters estimated by a preliminary run with relative weight (lambda) = 0.1. Due to the fixed parameters, the Fleet 14 size composition data were not fitted by the final model. Lambda is the multiplicative weighting factor on the negative log likelihood for that data component.

Time varying selectivity patterns in the form of periods of constant selection were employed for the Japanese longline, Japanese tuna purse seine, and EPO purse seine fisheries (Fleets 1, 3 and 12). Two periods of selection patterns were estimated for the Japanese longline fishery (Fleet 1: 1952-1992 and 1993-2012). These two periods corresponded to a potential change in fishing operations, divergence in the CPUE series, and a seasonal shift in the timing of fishing, however the PBFWG was unable to determine the cause. Two periods of selection patterns (1952-2006 and 2007-2012) were also estimated for the Japanese tuna purse seine fishery (Fleet 3), which corresponded to a change in fishery operations described in Fukuda et al. (2012). Two periods were also assumed for the EPO purse seine fleet (Fleet 12: 1952-2001 and 2002-2012). The second period corresponded to a time when the EPO fleet changed gear types to target larger fish (Aires-da-Silva and Dreyfus 2012). Therefore, for 2002-2012, it was assumed that the selectivity of Fleet 12 was the same as the earlier period, except that the point on the plateau at which fish become fully selected was assumed to be 10 cm larger than the earlier period. This resulted in a 10cm rightward shift of the selectivity curve in the latter period (Section 3.6.9).

The Japanese set net fishery (other areas of Japan) (Fleet 9) was divided into two seasonal fleets (Quarters 1-3 and Quarter 4 of the fishing year) and separate selectivities were estimated for each. The division of Fleet 9 into seasonal fleets was based on examining the data and characteristics of the fleets, which indicated that fish taken in Quarter 4 were larger than could be explained by a single selection pattern (see Section 3.3)

4.3.5 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 depended on the fleet-specific selection pattern and underlying population numbers-at-age. Potential changes in q were approximated by assuming larger observation errors in the abundance indices (Ichinokawa and Takeuchi 2012; Oshima et al. 2012b).

4.4 Likelihood Components

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. Model fits to the data and likelihood components were systematically checked.

4.4.1 Observation Error Model

The observed total catch data are assumed to be unbiased and relatively precise. They were fitted with a lognormal error distribution with standard error (SE) equal to 0.10. An unacceptably poor fit to catch was defined as models that did not remove >99% of the total observed catch from any fishery.

4.4.2 Recruitment Penalty Function

According to the Methot and Taylor (2011), the true variability of recruitment in the

$$\mathrm{SE}(\hat{r}_y)^2+\mathrm{SD}(\hat{r})^2=\left(\left(\frac{1}{\sigma_d{}^2}+\frac{1}{\sigma_R{}^2}\right)^{-1/2}\right)^2+\left(\frac{\sigma_R{}^2}{\left(\sigma_R{}^2+\sigma_d{}^2\right)^{1/2}}\right)^2=\sigma_R{}^2.$$

population, σ, constrains the estimates of recruitment deviations and is not affected by data. When data that are informative about recruitment deviations are available, σ is partitioned into i) variability among the recruitment estimates in the time series (signal) and ii) residual variability of each recruitment estimate:

When there are no data, no signal can be estimated, the individual recruitment deviations approach 0.0, and the variance of each recruitment deviation approaches σ. Conversely, when there are highly informative data on the recruitment deviations, then the variability among the estimated recruitment deviations will approach σ and the variance of each recruitment deviation will approach zero. The value of σ was fixed at 0.6 for the update assessment.

4.4.3 Weighting of the Data

Two types of weighting were used in the model: i) relative weighting among length compositions (effective sample size), and ii) weighting of the different data types (sources of information, e.g. length compositions, abundance indices, and conditional age-at-length) relative to each other.

Except for Fleets 3 and 12, effective sample sizes were determined by two steps: (1) maximum input sample sizes were set to 200 (i.e. the sample size was 200 if the actual sample size was larger than 200); and (2) the effective sample size of each fleet length or weight composition data were scaled by the average sample size of the tuna purse seine fleet in the Sea of Japan (Fleet 3) and the EPO commercial purse seine fleet (Fleet 12) from 1952-2010.

All size composition data, except for Fleets 6, 13 and 14 were fitted by the model with full weight (Section 4.3.4). The CPUE indices for Japanese coastal longline (S1, S2, S3), Japanese coastal troll (S5) and Taiwanese longline (S9) fleets were fitted by the model with full weight (Section 3.5).

4.5 Convergence Criteria

Convergence to a global minimum was examined by randomly perturbing the starting values of all parameters by 10% and refitting the model. This analysis was conducted as a quality control procedure to ensure that the model was not converging on a local minimum.

4.6 Model Analysis

4.6.1 Retrospective Analysis

Retrospective analysis was conducted to assess the consistency of stock assessment results by sequentially eliminating data from the terminal year while using the same model configuration. In this analysis, up to five years of data were removed and the PBFWG examined changes in the estimates of SSB and recruitment. The results of this analysis were used to assess potential biases and uncertainty in terminal year estimates.

4.6.2 Sensitivity to Alternative Assumptions

Sensitivity analyses were used to examine the effects of plausible alternative model configurations relative to the results for the base case.

It was agreed to conduct the following base case and sensitivity runs (Table 4-2):

1. A base case run with both the Taiwanese and Japanese longline CPUE series through 2012; the size composition for the Japanese longline fleet extending through 2011 (fishing year) and the size composition for the Taiwanese longline fleet extending through 2012 (fishing year);

2. A sensitivity run removing CPUE data for the Japanese longline fleet for 2011-2012 (fishing year), and removing size composition data for the Japanese longline fleet for 2010 and 2011[4];

[4] Size composition data in the terminal year (2012) cannot be calculated using the estimation procedure proposed by Mizuno et al. (2012).

3. A sensitivity run removing CPUE data for the Taiwanese longline fleet for 2011-2012 (fishing year), and removing size composition data for the Taiwanese longline fleet for 2011 and 2012;

4. A sensitivity run with both the Japanese and Taiwanese longline CPUE series for 2011 and 2012 (fishing year) removed, and also removing the Japanese longline size composition data for 2010 and 2011, and the Taiwanese longline size composition data for 2011 and 2012.

For each trial run, trends in estimated SSB and recruitment were compared. In addition, estimates of $F_{2009\text{-}2011}$ (current F) or $F_{2002\text{-}2004}$ (reference year by current WCPFC CMMs) relative to a subset of F-based BRPs (F_{max}, $F_{0.1}$, F_{med}, F_{loss}, $F_{10\%}$, $F_{20\%}$, $F_{30\%}$, $F_{40\%}$), the estimated depletion ratio (SSB_{2012} relative to SSB_0), and SSB_{2012} were calculated.

4.6.3 Future Projections

Stochastic future projections were performed using a quarterly age-structured population dynamics model that was identical in model structure to that used in the assessment. The software used for the future projections is distributed as an R-package named ‘ssfuture’, and is described in Ichinokawa (2012). This software has been validated as being capable of generating highly similar results on numbers-at-age and catch weight by fleets with deterministic future projections generated by SS (Ichinokawa 2012).

The projections were based on the results of the base case. Each projection was conducted from 300 bootstrap replicates followed by 20 stochastic simulations. The bootstrap replicates were derived by estimating parameters using SS and fishery data generated with parametric resampling of residuals from the expected values. Error structure was assumed to be lognormal for CPUE and multinomial for size-composition data. The CVs of abundance indices and input sample sizes of size compositions for the bootstrap replicates were the CVs and 100*input sample sizes from the input data of the base case. The effective sample sizes for the bootstrap replicates were increased by 100-fold in order to provide adequate resampling of the size compositions. These projections included the parameter uncertainties of the stock assessment model because the stochastic simulations were conducted from the bootstrap run, which included estimation of model parameters. Specifically, estimation uncertainty in the population size in the starting year of the stock projection and fishing mortalities-at-age were included.

Future recruitment is randomly resampled from the whole stock assessment period (1952-2011) for the average recruitment scenario, and re-sampled from the low recruitment period (1980-1989) for the low recruitment scenario, without any spawner-recruitment relationship. This was an appropriate assumption because the steepness of the base case was very high (h = 0.999). For the recruitment in 2012-2013 which has already occurred, re-sampling was conducted from recruitment in 1986-1988, which represents the lowest three years of recruitment between 1980-1989. Ishida et al (2014) analyzed the patterns of estimated recruitments of the “preliminarily updated” base case of Fukuda et al (2014). They found that the recruitment in

1980-1993 is significantly lower (P=0.0275) than the historically average recruitments in 1952-2012 (Table 5 in Ishida et al 2014). As was demonstrated, the period in 1980-1993 can be an alternative candidate for representing the low recruitment period. Nevertheless, this stock assessment continues to identify the period 1980-1989 as representing the low recruitment period. This is because the 1990 year class was estimated as the second strongest year class since 1960.

As for the duration of the low recruitment period, Ishida et al (2014) also found that recruitment in 1980-1993 was significantly lower (p=0.040), than the level of recruitment for the later period in 1994-2008. They also found that the recruitment in 2009-2012 was significantly lower (p=0.0278) than the recruitment in 1994-2008 (Table 5 in Ishida et al 2014). They applied a sequential t-test (Rodionov and Overland 2005) to the same time series of estimated recruitments and found two break points: between the 1993 and 1994 year classes, and between the 2008 and 2009 year classes with significance level of p<0.2. Their finding suggests that the duration of different productivity phases (regimes) may be on the order of 14 or 15 years. Based on these observations, two scenarios of low recruitment were chosen: i) a low recruitment level similar to the period 1980-1989 continues, or ii) 10 years of low recruitment from 2014 assuming low recruitment period actually started from 2009 followed by a period of historically average level of recruitment.

The terminal year of the 2014 stock assessment is 2012 (fishing year or 1 July 2012 to 30 June 2013 in calendar year). The latest recruitment estimate available from the SS model is the 2012 year class. Similar to the last stock assessment, since the latest recruitment estimate is likely imprecise, it was proposed to use estimated recruitment through 2011 but replace it with randomly resampled recruitment over an appropriate period to represent future recruitment. However, year classes 2012 and 2013 were already born. In particular, the ISC13 Plenary paid particular attention to the possible very weak 2012 year class. As for the 2013 year class, currently available information from fisheries targeting age 0 PBF suggest a possible weak 2013 year class, even though its strength might be relatively stronger than the 2012 year class. Based on these considerations, it was proposed to assume the 2012 and 2013 year classes' recruitment may be very weak. This was implemented by generating recruitments in 2012 and 2013 from resampling estimated recruitments in 1986-1988 which are the three lowest year classes in 1980-1989.

$SSB_{recent,F=0}$ can roughly be defined as the theoretical spawning stock biomass size without fishing assuming recent levels of recruitment. Recent levels of recruitments were chosen based on the fixed size moving window approach which uses a fixed number of years of recent recruitment. In this particular calculation, in order to ensure the projected population has a steady state, a forward projection of 60 years from 2012 was conducted. This resulted in a mean $SSB_{recent,F=0}$ of 620,116 t (median of 616,625 t, standard deviation of 70,586 t) in 2072.

NC9 defined seven candidate harvest scenarios from 2015. Scenario 1 is continuation of management measures for 2014 until 2028 by both WCPFC and IATTC, while the other scenarios considered alternative measures (Table 4-3). In principle, the harvest scenarios represent combinations of constant effort strategies and catch capping for juvenile and/or adult catches for WPO fisheries; and a constant catch strategy for EPO commercial fisheries with no catch cap for the EPO recreational fishery.

The following assumptions were applied:

i. Fishing effort is interpreted as fishing mortality, i.e. fishing effort at the 2002-2004 level was translated into an average F in 2002-2004;

ii. Fourteen fisheries in the stock assessment model were reorganized into six fleets, with each fishery approximating one country's fishery;

iii. If reduction of juvenile catch is required to a certain level, the *F* for ages 0-2 is assumed to be reduced to meet the necessary juvenile catch reduction requirement; and

iv. If, in addition, reduction of adult catch is required, *F* of ages 3 and older is assumed to be reduced.

For the EPO commercial fishery (Fleet 12 of the base case), NC9 requested application of a type of constant catch strategy with maximum *F* level twice as much as that in 2002-2004. There is no distinction between juvenile and adult catch, despite the fact that the results of the 2012 stock assessment and 2014 base case of Fukuda et al (2014) suggests that the majority of fishing mortality occurs in age classes 1-3. For the EPO recreational fishery (Fleet 13), we simply applied the average partial *F* in 2002-2004, since IATTC's Resolution C-13-02 as well as NC9's requests do not cover the EPO recreational fishery.

NC9 requested information on "the probability of achieving each of five particular SSB levels (10%, 15%, 20%, and 25% $SSB_{recent,F=0}$, and historical median SSB) within 10 and 15 years" as well as the "expected average yield over the final three years of the projection". To accomplish this, the PBFWG calculated the probability of future SSB exceeding the specified reference levels of SSB in at least one year from 2014 to 2023 (10 years) or from 2014 to 2028 (15 years). The average expected yield in 2026-2028 was also calculated. In addition, the probability of SSB falling below the historical lowest observed level of SSB (about 18,300 t) at least once within 15 years was also calculated.

4.6.4 Biological Reference Points

The ratio of $F_{2009\text{-}2011}$ (current *F*) or $F_{2002\text{-}2004}$ (reference year under the current WCPFC management measure) as compared to a suite of candidate *F*-based biological reference points (F_{BRP}), i.e. F_{max}, $F_{0.1}$, F_{med}, F_{loss} and $F_{10\%\text{-}40\%}$, were contrasted in this assessment. The estimates were expressed as the ratio of $F_{2009\text{-}2011}$ /F_{BRP}, which means that when the ratio was more than 1.0, $F_{2009\text{-}2011}$ was above the reference point. The F_{max}, F_{med} and $F_{0.1}$ reference points are based on yield-per-recruit analysis while the $F_{10\text{-}40\%}$ reference points are spawning biomass-based proxies of F_{MSY}.

5.0 MODEL RESULTS

5.1 Base Case Results

The dynamics of SSB and recruitment during stock assessment period (1952-2012) are shown in Figure 5-1. Point estimates of the base case indicate that the current levels (2012) of stock biomass and SSB are 44,849 t and 26,324 t, respectively. The recent five-year average of recruitment (2007-2011) was 14.8 million fish (Figure 5-1, Table 5-1).

Fishing mortality dynamics during the stock assessment period (1952-2012) are shown in Figure 5-2. Age-specific fishing mortalities for 2009-2011 were estimated to be 19%, 4%, 12%, 31% and 60% higher than 2002-2004 (reference year of the current WCPFC conservation and management measure) for ages 0-4 fish, respectively (Figure 5-2, Table 5-2).

5.1.1 Model Convergence Diagnostics

The update stock assessment converges with maximum gradient of 2.0×10^{-4} and total negative log likelihood of 2412. One hundred runs with randomly generated initial values showed that the model likely converged to a global minimum, with no evidence of further improvements to the total likelihood (Figure 5-3).

5.1.2 Fit to Abundance Indices

The model fit to the abundance indices are shown in Figure 5-4. The abundance trends in most of the abundance indices were well-represented by the model. The Japanese troll index (S5) and both Japanese longline indices before 1993 (S2 and S3) were fit very well (root mean square error (rmse) = 0.22 for S5 and 0.21 for the rest of three). However, the fit for the Japanese longline index for 1993-2010 (S1) and the Taiwanese longline index for 1998-2010 (S9), were relatively poor (rmse = 0.52 and 0.41 respectively).

5.1.3 Fit to Size Composition Data

Pearson residuals of the model fit to the quarterly size composition data are shown in Figure 5-5.

5.1.4 Model Parameter Estimates

5.1.4.1 Recruitment Deviations

A Beverton-Holt relationship based on a steepness value of h=0.999 was used for the base case, and stock and recruitment plots are presented in Figure 5-6. The estimated recruitment deviations were relatively precise for both 1996-2011 and 1960-1988, which indicated that these periods were well informed by data (upper panel in Figure 5-6). The variability of the estimated recruitment deviates appeared to be slightly lower than input recruitment variability (σ = 0.6). However, the estimated and input recruitment variabilities were close enough that the estimated population dynamics would not be substantially affected.

5.1.4.2 Selectivity

The estimated selectivity curves for the base case are shown in Figure 5-7. Given the model structure, most of the selectivity parameters were relatively well-estimated. In particular, the selectivity parameters for the Taiwanese longline fishery (Fleet 11), which was assumed to have an asymptotic selectivity, were well-estimated. Both the estimated length at 50% selectivity and width of 95% selectivity had small CVs (1 and 11%, respectively). The selectivity for the Japanese "others" fishery (Fleet 14) was also estimated to be asymptotic (in an initial run), although the selectivity was assumed to be dome-shaped (using five parameters). However, it should be noted that the selectivity for Fleet 14 was fixed after the initial run and that the size compositions from Fleet 14 were not fitted in the final model due to the large differences for this data component.

All other selectivities were estimated to be dome-shaped. However, the selectivity for the Japanese longline fishery (F1) showed a low level of selectivity even at the largest sizes of fish, especially for the late period. This is expected because this fishery operated on the spawning grounds targeting a wide size range of large adult fish . The parameters for the width of the descending limb and the selectivity at the last bins for the late period had large standard deviations compared to the range of parameter estimation, which indicated they were not well-estimated (SD = 13.0 and 19.0, respectively). This was likely due to the small number of observations for this fishery at the largest sizes.

The most precise selectivity parameters were generally the parameters for the length at peak selectivity, with CVs ranging from 1% to 10%.

5.2 Stock Assessment Results

Results from the base case were used to determine trends in population biomass, spawning biomass, recruitment and fishing intensity for the PBF stock during the stock assessment period 1952-2012 (i.e. July 1952 to June 2013).

5.2.1 Total and Spawning Stock Biomass

Point estimates of total stock biomass from the base case showed long-term fluctuations (Table 5-1 and Figure 5-1). In 1952, the starting year of the current stock assessment, total stock biomass was 119,400 t. During the stock assessment period, the total stock biomass reached the historical maximum of 185,559 t in 1959, and a historical minimum of 40,263 t in 1983. Total stock biomass started to increase again in the mid-1980s and reached its second highest peak of 123,286 t in 1995. Total stock biomass decreased throughout 2008-2012, averaging 50,243 t per year, but reached 44,848 t in 2012.

Spawning stock biomass (SSB) estimates also exhibited long term fluctuations (Table

5-1 and Figure 5-1). SSB relative to unfished SSB has ranged from 0.03 to 0.22 during the assessment period (1952-2012). Estimates of SSB at the beginning of quarter 4 (April-June) in the first five years (1952-1956) of the assessment period averaged approximately 75,000 t. The maximum (140,148 t) and minimum (18,807 t) SSB levels occurred in 1961 and 1984, respectively. The SSB reached its second highest level (87,258 t) in 1995. The 2008-2012 average was 26,369 t. The 2012 value (26,324 t) was approximately 4% of the stock's estimated unfished SSB level. The quadratic approximation to the likelihood function at the global minimum, using the Hessian matrix, indicated that the CV of SSB estimates was about 19% on average for 2008-2012, and 21% for 2012.

5.2.2 Recruitment

Recruitment (age 0 fish on July 1st) estimates fluctuated widely with no apparent trend. Recent strong cohorts occurred in 1990 (29 million fish), 1994 (39 million fish), 2004 (28 million fish) and 2007 (25 million fish) (Table 5-1 and Figure 5-1). The average estimated recruitment was approximately 15 million fish for the entire stock assessment period (1952-2012), and 15 million fish for 2002-2011. Estimates were relatively precise for the initial 12 years of the stock assessment, i.e. 1952-1963 (average CV = 14%), but were less precise for 1964-1980 (average CV = 30%, maximum CV = 42%). Recruitment estimates became more precise (average CV = 12%, maximum CV = 28%) after 1981, when recruitment indices from the Japanese troll fishery became available. In the most recent years (1994-2010), recruitment estimates have further improved in their precision (average CV = 6% or maximum CV = 11%) due to the comprehensive size data collection for Japanese fisheries that began in 1994.

5.2.3 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 predicted annual catch-at-age matrix from the base case (Figure 5-2 and Table 5-2). Throughout the stock assessment period (1952-2012), average fishing mortality for ages 0-3 juveniles (0.49) was higher than that for age 4+ fish (0.10). The *F* at age 1 started to increase in 1995. The average *F* of age 1 fish during 1995-2011 was 0.99, while average *Fs* of ages 0, 2 and 3 fish were 0.56, 0.54, and 0.24, respectively. The average *F* of age 4+ fish during the same period was 0.13. In the recent period (2009-2011), average *Fs* of ages 0-4+ fish were 0.59, 0.92, 0.65, 0.33 and 0.10, respectively. During 2002-2004 (the base period for the current WCPFC CMM), average *Fs* of ages 0-4+ fish were 0.50, 0.89, 0.58, 0.25 and 0.13, respectively. Therefore, the *Fs* at ages 0-6 during 2009-2011 were 19%, 4%, 12% 31%, 60%, 51% and 21% higher than 2002-2004, respectively. The *Fs* at ages 7+ during 2009-2011 were 35% lower than 2002-2004.

5.2.4 Fishing Mortality by Gear

Age-specific fishing mortalities by fishing gear are summarized in Figure 5-8. For all age classes, there is no clear trend in the age-specific fishing mortality from 2000-2011.

For ages 2 and 3, rapidly increasing *F* is confirmed through 2012, however there is some uncertainty associated with the estimate in the terminal year (2012).

5.2.5 Number-at-Age

The population size in numbers-at-age at the beginning of the fishing year (July 1st) is shown in Table 5-3 and Figure 5-9. Several strong cohorts were apparent (**e.g. 1990 and 1994 year classes in recent years**). In general, the estimated numbers-at-age reflect the age structure of PBF with fewer old-age fish as expected.

5.3 Retrospective Analyses

The retrospective analysis showed no particular tendency of estimation in the SSB during 2008-2012. The SSB was usually underestimated between 1993-2002, except when the one-year-dropped model was used (Figure 5-10). Recruitment in the terminal year was over-estimated in 2009-2011 and under-estimated in 2007-2008. The recruitments of the 2000-2004 year classes were also overestimated (Figure 5-10).

5.3.1 Total Biomass, SSB and Recruitment

All four runs showed similar trends in total biomass and SSB, except after 2005 there was some slight divergence. In the terminal year, the SSB estimates from Runs 2 and 3 were the highest and lowest, respectively. There were few apparent differences in the recruitment time series among the four runs. In all trial runs, the estimated SSB showed long-term fluctuations with three biomass peaks (Figures 5-11 and 5-12). All four runs showed declining SSB over the most recent decade with an estimated SSB in 2012 ranging from 19,369 t to 33,376 t (-26% to +24% of the base case). The depletion ratio estimated for each run varied from 0.031 to 0.054. All trial runs indicated that the current $F_{2009\text{-}2011}$ was above F_{max}, $F_{0.1}$, F_{med}, $F_{10\%}$, $F_{20\%}$, $F_{30\%}$ and $F_{40\%}$ (Table 5-4).

5.3.2 Fit to CPUE and size composition

Results indicated that removing CPUE and size composition data from the most recent two years affected the fit to the S1 and S9 indices (Figure 5-13). The fit to CPUE for Japanese longline (S1) and/or Taiwanese longline (S9) were improved in Runs 3 and Run 4, respectively, after 2006, and in parallel the improvements in fit increased (or decreased) the estimates of recent SSB in those runs.

In general, removing CPUE and length composition data did not substantially improve the fit to the observed length compositions (Figure 5-14).

5.4 Future Projections

The historical recruitment and SSB estimated by 300 bootstrapped simulations are shown in Figures 5-15, 5-16, and 5-17. Point estimates of SSB, especially during 1950s-1970s, and some SSB indicators, such as the historical minimum and median, were generally above the median estimators from the bootstrap. These discrepancies between point estimates and the bootstrap median were also observed in past stock assessments for this and other species and are not understood.

Table 5-5 summarizes the results for the benchmarks for $SSB_{\text{recent,F=0}}$ as listed in Section 4.6.3. Figures 5-15, 5-16, and 5-17 compare expected outcomes using combinations of seven harvest scenarios and three future recruitment scenarios. During the 10-year simulation period, all low recruitment scenarios except Scenario 6 have a low probability of reaching the SSB benchmarks specified by NC9. Under Scenario 6, there is a very high probability (over 80%) that SSB will exceed the benchmark of 10% of $SSB_{\text{recent,F=0}}$ and the historical median within 15 years. Scenario 7 did not perform as well as Scenario 6 when future recruitment was assumed to be at the average level, and the expected increase of SSB was lower than under Scenario 6. In addition, if future recruitment is assumed to be low, Scenario 7 performed poorly, in the sense that there was only a 10% probability of SSB reaching the benchmark of 10% of $SSB_{\text{recent,F=0}}$ within 10 years.

Scenario 1 can be considered as the "status quo", in the sense that WCPFC's and IATTC's regulations and additional measures adopted by Japan for national waters in 2014 were assumed to have been fully implemented and effectuated in Japan, the WPO, and the EPO. The overall result for Scenario 1 is that if future recruitment remains within historically average levels, SSB can be expected to increase steadily and is likely to exceed 15% of $SSB_{\text{recent,F=0}}$ within 10 years. If, however, future recruitment is at low recruitment levels such as those as experienced in the 1980s, the SSB is likely to remain at its current very low level. Furthermore, it is very likely (79% in low recruitment scenario) that SSB will decline below the historically lowest observed level (Figure 5-15) at some point in the next ten years. For the other six remaining harvest scenarios, Scenarios 2-4 exhibited very poor performance under low recruitment conditions. The other three harvest scenarios (Scenarios 5-7) are expected to show an increase in SSB to some extent, but the degree of increase varies under each harvest scenario. In summary, Scenario 6 performed best across the three recruitment scenarios; Scenario 7 was second but its performance did not suffice to increase SSB and avoid risking further declines in SSB (24% of scenario 6 against 31% of scenario 7) if future recruitment remains low.

As discussed, average recruitment in 2009-2012, and possibly in 2013, may be lower than that observed before 2009. Given the future projection results, the importance of considering the risk of low recruitment in the coming decade has increased.

6.0 STOCK STATUS AND CONSERVATION ADVICE

6.1 Stock Status

Using the updated stock assessment, the 2012 SSB was 26,324 t and slightly higher than that estimated for 2010 (25,476 t).

Across sensitivity runs in the update stock assessment, estimates of recruitment were considered robust. The recruitment level in 2012 was estimated to be relatively low (the 8th lowest in 61 years), and the average recruitment level for the last five years may have been below the historical average level (Figure 5-1). Estimated age-specific fishing mortalities on the stock in the period 2009-2011 relative to 2002-2004 (the base period for WCPFC Conservation and Management Measure 2010-04) increased by 19%, 4%, 12%, 31%, 60%, 51% and 21% for ages 0-6, respectively, and decreased by 35% for age 7+ (Figure 6-1).

Although no target or limit reference points have been established for the PBF stock under the auspices of the WCPFC and IATTC, the current F average over 2009-2011 exceeds all target and limit biological reference points (BRPs) commonly used by fisheries managers except for F_{loss}, and the ratio of SSB in 2012 relative to unfished SSB (depletion ratio) is less than 6%. In summary, based on reference point ratios, overfishing is occurring and the stock is overfished (Table 5-4).

For illustrative purposes, two examples of Kobe plots (plot A based on SSB_{MED} and F_{MED}, plot B based on $SSB_{20\%}$ and $SPR_{20\%}$, Figure 6-2) are presented. Because no reference points for PBF have yet been agreed to, these versions of the Kobe plot represent alternative interpretations of stock status in an effort to prompt further discussion.

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 fleet has increased its impact, and the effect of this fleet is currently greater than any of the other fishery groups. The impact of the EPO fishery was large before the mid-1980s, thereafter decreasing significantly. The WPO longline fleet has had a limited effect on the stock throughout the analysis period. 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 (Figures 6-3 and 6-4).

6.2 Conservation Advice

The current (2012) PBF biomass level is near historically low levels and experiencing high exploitation rates above all biological reference points except for F_{lOSS}. Based on projection results, the recently adopted WCPFC CMM (2013-09) and IATTC resolution for 2014 (C-13-02) if continued in to the future, are not expected to increase SSB if recent low recruitment continues.

In relation to the projections requested by NC9, only Scenario 6[5], the strictest one, results in an increase in SSB even if the current low recruitment continues. Given the result of Scenario 6, further substantial reductions in fishing mortality and juvenile catch over the whole range of juvenile ages should be considered to reduce the risk of SSB falling below its historically lowest level.

If the low recruitment of recent years continues the risk of SSB falling below its historically lowest level observed would increase. This risk can be reduced with

[5] For the WCPO, a 50% reduction of juvenile catches from the 2002-2004 average level and F no greater than $F_{2002\text{-}2004}$. For the EPO, a 50% reduction of catches from 5,500 t. From the scientific point of view, juvenile catches were not completely represented in the reductions modeled under Scenario 6 for some fisheries although these reductions comply with the definition applied by the NC9.

implementation of more conservative management measures.

Based on the results of future projections requested at NC9, unless the historical average level (1952-2011) of recruitment is realized, an increase of SSB cannot be expected under the current WCPFC and IATTC conservation and management measures[6], even under full implementation (Scenario 1)[7].

If the specifications of the harvest control rules used in the projections were modified to include a definition of juveniles that is more consistent with the maturity ogive[4] used in the stock assessment, projection results could be different; for example, rebuilding may be faster. While no projection with a consistent definition of juvenile in any harvest scenario was conducted, any proposed reductions in juvenile catch should consider all non-mature individuals.

Given the low level of SSB, uncertainty in future recruitment, and importance of recruitment in influencing stock biomass, monitoring of recruitment should be strengthened to allow the trend of recruitment to be understood in a timely manner.

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[6] WCPFC: Reduce all catches of juveniles (age 0 to 3-(less than 30 kg)) by at least 15% below the 2002-2004 annual average levels, and maintain the total fishing effort below the 2002-2004 annual average levels. IATTC: Catch limit of 5000 t with an additional 500 t for commercial fisheries for countries with catch history. (1. In the IATTC Convention Area, the commercial catches of bluefin tuna by all the CPCs during 2014 shall not exceed 5,000 metric tons. 2. Notwithstanding paragraph 1, any CPC with a historical record of eastern Pacific bluefin catches may take a commercial catch of up to 500 metric tons of eastern Pacific bluefin tuna annually. (C-13-02), see https://www.iattc.org/PDFFiles2/Resolutions/C-13-02-Pacific-bluefin-tuna.pdf)

[7] Although these measures assume F be kept below $F_{2002\text{-}2004}$, $F_{2009\text{-}2011}$ was higher than $F_{2002\text{-}2004}$.

[4] 20% at age 3; 50% at age 4; 100% at age 5 and older

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8.0 Tables and Figures

Table 1-1. Relationships between calendar year, fishing year and year class.

Fishing year	2010				2011				2012				2013	
Quarter	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
SSB				SSB in 2010				SSB in 2011				SSB in 2012		
Day of Birth in SS	Birthday of 2010 year class				Birthday of 2011 year class				Birthday of 2012 year class				Birthday of 2013 year clas	
Recruitment	Recruitment in 2010				Recruitment in 2011				Recruitment in 2012				Recruitment in 2013	
Year class	2010 year class				2011 year class				2012 year class				2013 year class	
Calendar year	2010		2011				2012				2013			
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. Length and weight of PBT based on the von Bertalanffy growth curve use in this stock assessment.

Age	Length (cm)	Lt + SD	Lt - SD	Weight (kg)
0	21.5	27.1	15.9	0.19
1	55.4	66.0	44.9	3.40
2	84.4	94.6	74.3	12.20
3	109.2	114.7	103.7	26.66
4	130.4	136.9	123.8	45.67
5	148.4	155.8	141.0	67.75
6	163.9	172.1	155.7	91.52
7	177.1	185.9	168.2	115.79
8	188.3	197.7	178.9	139.67
9	198.0	207.9	188.1	162.52
10	206.2	216.5	195.9	183.91
11	213.2	223.9	202.6	203.62
12	219.2	230.2	208.3	221.55
13	224.3	235.6	213.1	237.67
14	228.7	240.2	217.3	252.05
15	232.5	244.1	220.8	264.80
16	235.7	247.4	223.9	276.02
17	238.4	250.3	226.5	285.85
18	240.7	252.8	228.7	294.44
19	242.7	254.9	230.6	301.91
20	244.4	256.6	232.2	308.39

Table 3-1. Definition of fleets considered for size composition (rows 1-14) and abundance indices (row 15-25) in the PBF stock assessment.

Serial No.	Fleet No.	Short name	Data type	Available Period	Corresponding Fisheries	Other Fisheries	Lambda (*1)	Size data type	Average input sample size or C.V.	Data quality	Document for reference
1	F1	JLL	Fishery	1952-1968, 1994-2011	Japanese longline		1	Length	12.3	Catch at length	ISC/12/PBFWG-1/01
2	F2	SPelPS	Fishery	2001-2012	Purse seinein the East China Sea	Korean small pelagic fish purse seine	1	Length	12.1	Catch at length	ISC/12/PBFWG-1/02
3	F3	TunaPSJS	Fishery	1986-1989, 1991-2012	Japanese tuna purse seine fisheries in the Sea of Japan		1	Length	20.8	Catch at length	ISC/12/PBFWG-1/07
4	F4	TunaPSPO	Fishery	1994-2006	Japanese purse seine off the Pacific coast of Japan		1	Length	5.8	Catch at length	ISC/12/PBFWG-1/03
5	F5	JpnTroll	Fishery	1993-2012	Japanese troll		1	Length	12.1	Catch at length	ISC/12/PBFWG-1/04
6	F6	JpnPL	Fishery	1994-1996, 1998-2004, 2005-2010	Japanese pole- and-line	Japanese driftnet Taiwanese driftnet Taiwanese others	0	Length	12.1	Raw mearsurement	ISC/07/PBFWG-1/05
7	F7	JpnSetNet NOJWeight	Fishery	1993-2012	Japanese set net (northern part of Japan)		1	Weight	12.0	Catch at weight	ISC/12/PBFWG-1/05
8	F8	JpnSetNet NOJLength	Fishery	1994-2008, 2012	Japanese set net (Q1-Q2, Hokuriku)		1	Length	12.2	Catch at length	ISC/12/PBFWG-1/05
9	F9	JpnSetNet OAJLength Q1-3	Fishery	1993-2012	Japanese set net (other area, Q1-Q3)		1	Length	12.0	Catch at length	ISC/12/PBFWG-1/05
10	F10	JpnSetNet OAJLength Q4	Fishery	1993-2012	Japanese set net (other area, Q4)		1	Length	12.1	Catch at length	ISC/12/PBFWG-1/05
11	F11	TWLL	Fishery	1992-2012	Taiwanese longline	New Zealand Other country	1	Length	12.1	raw measurement (high coverage)	No document
12	F12	EPOPS	Fishery	1952-1965, 1969-1982, 2005-2012	Eastern Pacific Ocean commercial purse seine		1	Length	9.3	Catch at length	ISC/12/PBFWG-3/02 ISC/14/PBFWG-1/04
13	F13	EPOSP	Fishery	1993-2003, 2005-2006, 2008-2011	Eastern Pacific Ocean sports fishery		0	Length	12.1	Raw measurement	No document
14	F14	Others	Fishery	1994-2012	Others	Japanese trawl Japanese other longline	0.1	Weight	12.1	Catch at weight	ISC/12/PBFWG-1/06

Table 3-1. (continued).

Serial No.	Fleet No.	Corresponding Fisheries	Short name	Data type	Available Period	Lambda (*1)	Fleet No. for size data	Average input sample size or C.V.	Data quality	Document for reference
15	S1	Japanese coastal longline conducted in spawning area and season.	JpCLL	CPUE	1993-2012	1	F1	0.26 or 0.20	Standerdized	ISC/12/PBFWG-1/08 ISC/14/PBFWG-1/02
16	S2	Japanese offshore and distant water longliners until 1974	JpnDWLLFujioka Revto74	CPUE	1952-1973	1	F1	0.2	Standerdized	ISC/12/PBFWG-1/10
17	S3	Japanese offshore and distant water longliners from 1975	JpnDWLLYokawa Revfrom75	CPUE	1974-1992	1	F1	0.2	Standerdized	ISC/12/PBFWG-1/10
18	S4	Japanese tuna purse seine in Sea of Japan	TPSJO	CPUE	1987-1989, 1991-2010	0	F3	0.2	Standerdized	ISC/12/PBFWG-1/09
19	S5	Japanese troll in Nagasaki (Sea of Japan and East China sea)	JpnTrollChinaSea	CPUE	1980-2012	1	F5	0.2	Standerdized	ISC/12/PBFWG-1/11 ISC/14/PBFWG-1/07
20	S6	Japanese troll combined with Kochi and Wakayama by catch-weighted average	JpnTrollPacific	CPUE	1994-2010	0	F5	0.2	Standerdized and combined by ad-hoc way	ISC/12/PBFWG-1/11
21	S7	Japanese troll in Kochi (Pacific)	JpnTRKochi	CPUE	1981-2010	0	F5	0.3	Standerdized	ISC/12/PBFWG-1/11
22	S8	Japanese troll in Wakayama(Pacific)	JpnTRWakayama	CPUE	1994-2010	0	F5	0.2	Standerdized	ISC/12/PBFWG-1/11
23	S9	Taiwanese longline	TWLL	CPUE	1998-2012	1	F11	0.2	Standerdized	ISC/12/PBFWG-2/14 ISC/14/PBFWG-1/01
24	S10	EPO purse seine during US target fisheries	USPSto82	CPUE	1960-1982	0	F12	0.93	Standerdized	ISC/12/PBFWG-1/18
25	S11	EPO purse seine during Mexico operating	MexPSto06	CPUE	1999-2010	0	F12	0.77	Standerdized	ISC/12/PBFWG-1/18

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

Table 3-2. PBF abundance indices (CPUE) available for this stock assessment (only S1, S2, S3, S5, and S9 were used in the assessment model).

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
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			0.0016							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					0.62	
1981			0.0035		1.14		0.82			0.34	
1982			0.0020		0.58		0.25			0.38	
1983			0.0012		0.89		0.21				
1984			0.0013		0.89		1.14				
1985			0.0012		0.83		0.77				
1986			0.0014		0.95		0.28				
1987			0.0014	709.5	0.68		0.16				
1988			0.0016	353.9	0.77		0.58				
1989			0.0024	598.8	0.62		0.32				
1990			0.0024		1.23		0.64				
1991			0.0038	289.1	1.32		0.58				
1992			0.0041	485.5	0.57		0.30				
1993	1.91		0.0051	600.3	0.47		0.51				
1994	1.39		0.0037	2402.0	1.97	2.36	3.20	1.3959			
1995	1.72		0.0059	1169.3	1.07	0.84	1.05	0.7816			
1996	1.80		0.0066	706.3	1.60	0.85	0.90	1.2641			
1997	1.57		0.0053	459.5	0.90	0.46	0.48	0.7082			
1998	1.13		0.0045	550.6	0.82	1.11	1.54	0.5542	0.43		
1999	0.87		0.0039	766.1	1.49	0.25	0.33	0.1826	0.35		20.47
2000	0.68		0.0032	754.8	1.15	0.32	0.32	0.5259	0.21		0.56
2001	0.79		0.0030	438.6	1.16	1.56	2.11	0.9419	0.13		0.55
2002	1.31			459.7	0.73	0.67	0.83	0.6222	0.19		0.24
2003	1.39			474.9	0.65	0.32	0.40	0.2986	0.18		2.38
2004	1.64			752.8	1.29	3.17	3.47	4.3717	0.09		1.64
2005	0.82			856.7	1.36	0.87	0.99	1.0757	0.11		0.51
2006	1.15			388.4	0.71	0.82	0.93	1.0406	0.10		0.29
2007	0.63			865.7	1.38	1.27	1.47	1.5108	0.12		0.27
2008	0.40			751.6	1.44	0.68	0.66	1.2016	0.09		0.41
2009	0.21			585.1	1.11	0.08	0.08	0.127	0.06		1.64
2010	0.21			603.5	1.09	1.35	1.97	0.3975	0.11		3.01
2011	0.14				0.94				0.15		
2012	0.23				0.52				0.16		

Table 3-3. Coefficient of variation (CV) of PBF abundance indices (CPUE) available for the stock assessment (only S1, S2, S3, S5, and S9 were used in the assessment model).

Year	S1(*1)		S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
1952			0.20									
1953			0.20									
1954			0.20									
1955			0.20									
1956			0.20									
1957			0.20									
1958			0.20									
1959			0.20									
1960			0.20								1.07	
1961			0.20								0.79	
1962			0.20								0.80	
1963			0.20								0.79	
1964			0.20								0.72	
1965			0.20								0.73	
1966			0.20								0.55	
1967			0.20								0.83	
1968			0.20								0.97	
1969			0.20								0.95	
1970			0.20								0.89	
1971			0.20								0.86	
1972			0.20								0.81	
1973			0.20								1.01	
1974				0.20							1.06	
1975				0.20							0.87	
1976				0.20							0.88	
1977				0.20							1.10	
1978				0.20							0.94	
1979				0.20							1.10	
1980				0.20		0.20					1.02	
1981				0.20		0.20		0.51			1.32	
1982				0.20		0.20		0.51			1.25	
1983				0.20		0.20		0.58				
1984				0.20		0.20		0.51				
1985				0.20		0.20		0.49				
1986				0.20		0.20		0.49				
1987				0.20	0.20	0.20		0.46				
1988				0.20	0.20	0.20		0.33				
1989				0.20	0.20	0.20		0.32				
1990				0.20		0.20		0.28				
1991				0.20	0.20	0.20		0.31				
1992				0.20	0.20	0.20		0.31				
1993	0.20	0.23			0.20	0.20		0.24				
1994	0.20	0.21			0.20	0.20	0.20	0.20	0.20			
1995	0.20	0.22			0.20	0.20	0.20	0.21	0.20			
1996	0.20	0.20			0.20	0.20	0.20	0.20	0.20			
1997	0.20	0.20			0.20	0.20	0.20	0.23	0.20			
1998	0.20	0.19			0.20	0.20	0.20	0.22	0.20	0.20		
1999	0.20	0.19			0.20	0.20	0.20	0.21	0.20	0.20		1.90
2000	0.20	0.19			0.20	0.20	0.20	0.21	0.20	0.20		0.77
2001	0.20	0.20			0.20	0.20	0.20	0.20	0.20	0.20		0.93
2002	0.20	0.19			0.20	0.20	0.20	0.21	0.20	0.20		0.75
2003	0.20	0.18			0.20	0.20	0.20	0.23	0.20	0.20		0.63
2004	0.20	0.18			0.20	0.20	0.20	0.23	0.20	0.20		0.60
2005	0.24	0.19			0.20	0.20	0.20	0.20	0.20	0.20		0.64
2006	0.28	0.19			0.20	0.20	0.20	0.21	0.20	0.20		0.58
2007	0.31	0.19			0.20	0.20	0.20	0.20	0.20	0.20		0.59
2008	0.35	0.20			0.20	0.20	0.20	0.23	0.20	0.20		0.61
2009	0.39	0.22			0.20	0.20	0.22	0.25	0.20	0.20		0.68
2010	0.43	0.23			0.20	0.20	0.20	0.22	0.20	0.20		0.60
2011	0.43					0.20				0.20		
2012	0.43					0.20				0.20		

(*1) Two scenarios are proposed to quantify uncertainty of Japanese CPUE in S1. Details were described in 3.5.2.

Table 3-4. Notes on the quality of input PBF size composition data for each fleet.

Fleet No.	Notation on data quality
F1	Good.The quality has changed historically. The quality in the early and recent periods is high (10-20%), but in the mid-period is low, (i.e. only weight data) and not used for assessment.
F2	Good. Catch-at-size is estimated from stratified sampling data in the main fishing ports, with catch weight by size category. Length composition of Korean PS is not included. As the fishing grounds of Korean and Japanese PS is close to each other, the size composition from Korean PS is assumed to be the same as that from Japanese PS.
F3	Very good, coverage is high.
F4	Fair. Catch-at-size since 1980 were estimated in data the preparatory meeting, but highly time-varying length compositions are observed in the last meeting and more investigation is needed. The data before 1993 were reviewed again and catch-at-size were re-constructed. Based on these results, the length composition for the 1980s are generally similar to those after 1990.
F5	Good, but there are many landing ports. The size data are raised by catch in spatial stratification using appropriate methods.
F6	Fair. Raw length measurements, not measurements raised by catch.
F7	Very good. Coverage is high because this is based on sales slip data.
F8	Western Japan. Good. Size measurements raised by spatial strata.
F9 and F10	Fair. Miscellaneous set net data from various regions. Raised by spatial strata.
F11	Very good. For 1993-2005 about 95%, coverage for 2006- about 100% coverage for length measurements.
F12	Sampling is fair to good, varying over time, better to use estimate average size composition. (In recent period, observer and port samples are mixed.)
F13	Fair. Catch is very small and opportunistic, but the coverage was high in San Diego port from early 2000. Data and share selectivity for early period of EPS PS not fit. In future, take care of this size data.
F14	Fair. Include variety of fisheries mainly from Tsugaru Strait.

Table 3-5. Input sample size for PBF size composition data.

year	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14
1952	12.8											5.0		
1953	11.0											3.0		
1954	11.6											4.9		
1955	12.0											5.8		
1956	11.6											9.0		
1957	8.7											20.5		
1958	12.5											17.5		
1959	12.8											15.5		
1960	12.8											14.5		
1961	12.8											14.6		
1962	12.4											14.7		
1963	12.0											19.5		
1964	11.8											11.5		
1965	12.8											25.3		
1966	12.8													
1967	12.8													
1968	12.2													
1969												3.5		
1970												7.0		
1971												3.0		
1972												1.0		
1973												5.5		
1974												3.3		
1975												3.5		
1976												11.5		
1977												4.2		
1978												9.0		
1979												5.0		
1980												6.8		
1981												6.0		
1982												9.8		
1983												2.8		
1984												5.2		
1985												6.6		
1986												8.0		
1987			12.2									2.8		
1988			8.6											
1989			12.5											
1990												5.5		
1991			3.0									2.0		
1992			2.5								12.4	0.5		
1993			1.2		10.0		12.4		12.1	12.1	12.4	1.5	13.0	
1994	12.8		51.2		12.2	12.8	11.7	12.9	12.1	12.1	12.4	1.0	13.0	12.6
1995	12.8		7.3	12.2	12.2	12.8	12.4	12.0	12.1	12.1	12.4	3.0	10.6	12.6
1996	12.8		51.2	1.0	12.2	12.8	11.9	12.9	12.1	12.1	12.4		7.4	12.6
1997	12.8		23.2	1.0	12.2		12.4	12.9	12.1	12.1	12.4		13.0	12.6
1998	12.8		2.6	6.6	12.2	10.7	12.4	11.3	12.1	12.1	12.4		13.0	12.6
1999	12.8		7.9	6.6	12.2	12.8	12.4	12.9	12.1	12.1	12.4		13.0	12.6
2000	12.8		15.7	4.7	12.2	11.4	12.4	11.2	12.1	12.1	12.4		13.0	12.6
2001	12.8	12.1	51.2	6.6	12.2	12.8	12.4	12.9	12.1	12.1	12.4		13.0	12.6
2002	12.8	12.1	11.4	6.6	12.2	11.5	12.4	12.9	12.1	12.1	12.4		13.0	12.6
2003	12.8	12.1	9.8	6.6	12.2	12.8	12.4	12.9	12.1	12.1	12.4		12.1	10.6
2004	12.8	12.1	13.6	6.6	12.2	11.8	12.4	9.7	12.1	12.1	12.4			12.6
2005	12.8	12.1	51.2	6.6	10.8		10.8	10.9	12.1	12.1	12.4	2.2	13.0	12.6
2006	12.8	12.1	41.1	1.0	12.2	12.8	12.4	12.9	12.1	12.1	12.4	2.5	8.3	12.6
2007	12.8	12.1	22.9		12.2	10.0	12.4	12.9	12.1	12.1	12.4			10.7
2008	12.8	12.1	35.7		12.2	9.8	12.4	12.9	12.1	12.1	12.4	13.5	13.0	10.5
2009	12.8	12.1	8.9		12.2	12.8	12.4		12.1	12.1	9.6	3.5	13.0	12.6
2010	12.8	12.1	22.6		12.2	12.5	10.7	12.9	12.1	12.1	12.4	11.3	13.0	12.6
2011	12.8	12.1	23.8		12.2		9.4	12.9	10.1	12.1	12.4	4.5	10.2	12.6
2012		12.1	27.6		12.2		12.4	12.9	12.1	12.1	12.4	10.0		12.6

Table 4-1.Description of size composition data and the type of the selectivity pattern for PBF fisheries.

Fleet	Selectivity Pattern	Data treatment and time block
F1	Double normal	Eliminate data in q1 of 1956 as outlier, lambda=1. Only q4 after 1993. Time block=1952-1992 and 1993-2012
F2	Double normal	lambda=1
F3	Double normal	Time block=1952-2006 and 2007-2012
F4	Double normal	Eliminate data before1993 and after 2007 Combine q4 in year t and q1 in year t+1.
F5	Double normal	lambda=1
F6	Mirror F5 selectivity	lambda=0
F7	Double normal	lambda=1
F8	Double normal	lambda=1
F9	Double normal	lambda=1, q1-q3
F10	Double normal	lambda=1, q1, q4
F11	Flat top	lambda=1
F12	Double normal	lambda=1,Eliminate data during 1983-2004, 2007. Time block=1952-2001 and 2002-2012
F13	Mirror F12 selectivity	lambda=0
F14	Double normal	lambda=0

Table 4-2. Model configurations for four runs for examination to evaluate effect of updates of CPUE and size composition data for Japanese longline (JLL) and Taiwanese longline (TWLL). Run 1 is the base-case assessment model.

Run number	**CPUE**		**Size composition data**	
	JLL (F15, S1)	**TWLL (F23, S9)**	**JLL (F1)**	**TWLL (F11)**
Run 1 (Base case)	Extending to 2012	Extending to 2012	Extending to 2011*	Extending to 2012
Run 2	Removing 2011 and 2012	Extending to 2012	Removing 2010 and 2011	Extending to 2012
Run 3	Extending to 2012	Removing 2011 and 2012	Extending to 2012	Removing 2011 and 2012
Run 4	Removing 2011 and 2012	Removing 2011 and 2012	Removing 2010 and 2011	Removing 2011 and 2012

*Size composition data in terminal year (2012) cannot be calculated using the estimation procedure proposed by Mizuno et al. (2012).

Table 4-3. Amount of catch reduction and catch limit by country by scenario.

			WPO : Catch limit (left) and amount of catch reduction(right) of juvenile by country						**EPO : Quota by scenario**			
	juvenile catch	adult catch	Japan		Korea		Taiwan		EPO Comm		EPO SPORT	
no1	85% of 2002-2004 average		6549	1156	1220	215	-	-	5500	-	-	-
no2	85% of 2002-2004 average	85% of 2002-2004 average	6549	1156	1220	215	-	-	5500	-	-	-
no3	85% of 2002-2004 average	85% of 2002-2004 average	6549	1156	1220	215	-	-	4675	-	-	-
no4	85% of 2002-2004 average		6549	1156	1220	215	-	-	4675	-	-	-
no5	75% of 2002-2004 average		5778	2004	1077	359	-	-	4125	-	-	-
no6	50% of 2002-2004 average		3852	3852	718	718	-	-	2750	-	-	-
no7	75% of 2002-2004 average		5778	2004	1077	359	-	-	4125	-	-	-

Table 5-1. Trends in spawning stock biomass and recruitment of PBF estimated by the base case.

Year	Total biomass (B in t)	Spawning stock biomass (SSB in t)	StdDev for SSB	CV for SSB	Recruitment (R in 1000 fish)	StdDev for R	CV for R
1952	119400	90734.3	37992.7	0.42	15696.7		
1953	122244	80705.8	34486.8	0.43	39319.8	4549.8	0.12
1954	132440	71629.4	31122	0.43	19866.5	3450.8	0.17
1955	143229	64236	28448.3	0.44	21898.7	3072.6	0.14
1956	162172	68369.3	28951.1	0.42	32311.1	2871.3	0.09
1957	175910	82727	32492.5	0.39	11160.2	1205.2	0.11
1958	185266	112730	40066.1	0.36	2697.64	622.93	0.23
1959	185559	129867	44233.4	0.34	5356.34	1099.7	0.21
1960	183126	139344	47445.7	0.34	17181.9	2151.7	0.13
1961	174985	140148	49070.9	0.35	22100.9	2416.1	0.11
1962	160224	119425	45496.7	0.38	12833.6	1869.8	0.15
1963	144651	96885.8	40398.3	0.42	22600.4	2361.3	0.10
1964	131575	82242.6	35676.5	0.43	12801.4	2324.9	0.18
1965	123342	72456.9	31752.9	0.44	7985.21	3342.3	0.42
1966	111120	68251.9	29024.8	0.43	9195.24	3752.2	0.41
1967	90680.4	64221.4	26777.5	0.42	10968.9	4344.4	0.40
1968	79569.5	56806.6	25099.1	0.44	15063.4	3990.2	0.26
1969	68134.8	48365.2	22388.5	0.46	7866.19	2702.8	0.34
1970	60849.3	40318.9	19436.1	0.48	12475.1	4713.9	0.38
1971	56411.4	33884.4	16307.3	0.48	14115.1	5098.6	0.36
1972	58250.1	29242.5	13169.5	0.45	20496.2	5255.3	0.26
1973	60146.5	27225.7	10326.6	0.38	20621	4808.8	0.23
1974	65225.3	24620.6	7969.61	0.32	11399.6	2965.9	0.26
1975	69384.3	26621.5	6908.08	0.26	13303.2	2958.1	0.22
1976	76792.7	35776.5	7640.02	0.21	9597.89	3123.8	0.33
1977	79319.2	47624.9	9568.31	0.20	28252.4	5662.9	0.20
1978	83248.4	50332.3	10310.5	0.20	16685.4	5161	0.31
1979	80880.1	43752.2	9658.33	0.22	14485.6	3303.7	0.23
1980	77896.7	41514.4	8660.12	0.21	6714.76	1996.2	0.30
1981	76403.4	32923.6	6218.58	0.19	18681.4	2235.5	0.12
1982	59246.3	26407.6	5009.07	0.19	8473.32	2219.6	0.26
1983	40263.1	19249.4	4275.5	0.22	11590.7	2270.1	0.20
1984	43554.9	18807	4088.92	0.22	8791.11	2225.9	0.25
1985	46125.4	20862.2	4035.65	0.19	11306.2	2158.4	0.19
1986	44947.5	23967.5	4383.08	0.18	12061.9	2175.8	0.18
1987	41622.9	22210.1	4493.27	0.20	8316.65	2169.3	0.26
1988	45840.8	22507.2	4740.74	0.21	8124.86	1881.7	0.23
1989	51315	23219.2	4844.62	0.21	6413.28	1530.6	0.24
1990	63529	29682	5503.75	0.19	29494.2	1898.6	0.06
1991	80447.5	38980.1	6353.17	0.16	3717.61	1057	0.28
1992	88571.5	46745.1	6926.19	0.15	5954.64	708.32	0.12
1993	98246.3	59086.5	7984.97	0.14	4797.52	647.68	0.14
1994	111447	70958.8	9485.28	0.13	38731.5	1356.7	0.04
1995	123286	87257.7	11743.6	0.13	11822.2	1260	0.11
1996	119997	81054.9	11410.6	0.14	18584.3	993.64	0.05
1997	117246	76349.8	11063.6	0.14	9361.61	842.35	0.09
1998	112026	76563.6	10756.7	0.14	16021.6	971.87	0.06
1999	105269	72642.5	10641.9	0.15	21816.1	1080.9	0.05
2000	96018.9	64322.7	9881.94	0.15	16558.4	873.12	0.05
2001	83626	58964.9	9020.16	0.15	18579	800.81	0.04
2002	83692.6	53232.2	8081.59	0.15	14189.7	850.34	0.06
2003	80838.6	50823.3	7275.18	0.14	10292.1	840.49	0.08
2004	79352.5	45447.1	6590.1	0.15	27678.3	947.98	0.03
2005	74369.9	41132.7	6104.5	0.15	13597.5	851.05	0.06
2006	63212.1	37850.1	5743.07	0.15	10699.9	859.28	0.08
2007	58503.5	32452.3	5303.31	0.16	24641.6	1089.3	0.04
2008	57821.5	28789.2	4977.51	0.17	18000.8	994.6	0.06
2009	51849.1	26027.6	4802.98	0.18	7199.54	687.36	0.10
2010	49299.4	25476.4	4725.83	0.19	14679.1	903.02	0.06
2011	47398.5	25227.1	4911.12	0.19	9701.24	1065	0.11
2012	44848.7	26324	5565.52	0.21	7014.6	1405.4	0.20

Table 5-2. Age-specific fishing mortality estimates of PBF from the base case.

Year	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Age 9	Age 10+
1951	0.04	0.08	0.00	0.00	0.01	0.03	0.08	0.15	0.21	0.24	0.96
1952	0.33	0.45	0.42	0.22	0.14	0.12	0.11	0.12	0.12	0.11	0.52
1953	0.18	0.48	0.46	0.21	0.12	0.10	0.10	0.10	0.10	0.09	0.44
1954	0.23	0.46	0.45	0.22	0.14	0.12	0.11	0.11	0.11	0.10	0.51
1955	0.28	0.29	0.26	0.23	0.19	0.17	0.16	0.16	0.15	0.14	0.69
1956	0.19	0.35	0.35	0.25	0.19	0.18	0.17	0.17	0.17	0.16	0.76
1957	0.32	0.41	0.37	0.21	0.14	0.12	0.11	0.11	0.10	0.10	0.48
1958	0.74	0.78	0.41	0.16	0.08	0.07	0.08	0.08	0.09	0.08	0.36
1959	0.52	0.73	0.37	0.14	0.09	0.09	0.11	0.13	0.14	0.14	0.59
1960	0.33	0.87	0.80	0.28	0.13	0.11	0.11	0.13	0.13	0.12	0.55
1961	0.27	0.92	0.99	0.35	0.15	0.12	0.13	0.14	0.14	0.13	0.61
1962	0.29	0.68	0.74	0.32	0.17	0.14	0.14	0.15	0.15	0.14	0.63
1963	0.26	0.70	0.77	0.33	0.17	0.14	0.13	0.13	0.12	0.11	0.54
1964	0.29	0.51	0.55	0.28	0.18	0.15	0.14	0.14	0.13	0.12	0.61
1965	0.41	0.78	0.55	0.28	0.19	0.16	0.14	0.13	0.12	0.11	0.56
1966	0.64	1.55	1.40	0.50	0.22	0.17	0.15	0.13	0.12	0.11	0.57
1967	0.67	1.22	0.96	0.43	0.24	0.18	0.15	0.13	0.12	0.11	0.58
1968	0.37	1.46	1.63	0.62	0.28	0.21	0.18	0.16	0.14	0.13	0.67
1969	0.46	1.03	1.04	0.41	0.18	0.13	0.12	0.11	0.10	0.09	0.45
1970	0.36	0.98	0.74	0.34	0.21	0.17	0.15	0.14	0.13	0.11	0.59
1971	0.25	0.83	0.75	0.30	0.15	0.12	0.11	0.10	0.09	0.08	0.45
1972	0.17	0.98	1.14	0.40	0.17	0.13	0.13	0.13	0.13	0.12	0.57
1973	0.23	0.66	0.75	0.30	0.15	0.13	0.14	0.15	0.15	0.14	0.66
1974	0.32	0.56	0.50	0.31	0.23	0.21	0.21	0.21	0.21	0.19	0.96
1975	0.23	0.67	0.48	0.17	0.07	0.06	0.07	0.07	0.08	0.08	0.36
1976	0.63	0.94	0.76	0.28	0.12	0.09	0.09	0.08	0.08	0.08	0.51
1977	0.29	0.75	0.68	0.36	0.23	0.19	0.16	0.14	0.13	0.11	0.69
1978	0.44	0.84	0.62	0.34	0.23	0.19	0.17	0.16	0.15	0.14	0.80
1979	0.44	0.78	0.51	0.30	0.21	0.17	0.15	0.14	0.13	0.12	0.84
1980	0.46	0.73	0.41	0.31	0.24	0.21	0.18	0.16	0.14	0.13	0.93
1981	0.50	0.91	0.65	0.67	0.61	0.55	0.48	0.42	0.36	0.32	1.98
1982	0.27	0.95	1.21	1.07	0.94	0.82	0.71	0.60	0.51	0.44	2.67
1983	0.36	0.56	0.33	0.27	0.25	0.23	0.20	0.18	0.16	0.15	1.51
1984	0.76	0.68	0.34	0.22	0.21	0.19	0.17	0.15	0.14	0.12	0.98
1985	0.44	0.92	0.67	0.39	0.28	0.24	0.20	0.18	0.15	0.14	0.90
1986	0.46	1.02	1.03	0.47	0.27	0.21	0.18	0.16	0.15	0.15	1.47
1987	0.23	0.39	0.40	0.30	0.22	0.19	0.16	0.14	0.13	0.11	0.84
1988	0.34	0.42	0.25	0.19	0.17	0.16	0.15	0.13	0.12	0.12	1.00
1989	0.27	0.35	0.22	0.17	0.15	0.14	0.13	0.12	0.11	0.11	0.89
1990	0.16	0.33	0.23	0.13	0.09	0.08	0.07	0.07	0.07	0.08	1.00
1991	0.49	0.57	0.16	0.12	0.11	0.10	0.10	0.10	0.10	0.10	1.30
1992	0.70	0.94	0.18	0.09	0.07	0.07	0.07	0.07	0.08	0.09	1.12
1993	0.30	0.40	0.20	0.12	0.09	0.09	0.09	0.09	0.10	0.11	1.60
1994	0.36	0.42	0.25	0.14	0.10	0.09	0.08	0.08	0.07	0.08	0.92
1995	0.34	1.06	0.30	0.13	0.10	0.08	0.08	0.08	0.08	0.09	1.52
1996	0.56	0.70	0.49	0.17	0.08	0.06	0.06	0.06	0.08	0.10	2.06
1997	0.61	1.19	0.38	0.13	0.09	0.08	0.07	0.08	0.08	0.10	1.90
1998	0.56	1.06	0.53	0.22	0.14	0.12	0.11	0.11	0.12	0.14	2.52
1999	0.75	0.96	0.37	0.21	0.18	0.16	0.14	0.13	0.13	0.14	2.26
2000	1.07	1.61	0.62	0.23	0.14	0.12	0.11	0.10	0.10	0.11	1.58
2001	0.55	0.58	0.29	0.13	0.08	0.07	0.07	0.07	0.07	0.08	1.32
2002	0.50	0.70	0.40	0.20	0.12	0.09	0.09	0.09	0.09	0.10	1.49
2003	0.46	1.16	0.56	0.19	0.07	0.06	0.06	0.07	0.08	0.09	1.49
2004	0.53	0.86	0.87	0.40	0.20	0.16	0.15	0.16	0.15	0.15	1.78
2005	0.55	1.39	0.79	0.28	0.18	0.17	0.17	0.16	0.15	0.15	1.57
2006	0.51	1.15	0.80	0.34	0.17	0.14	0.15	0.16	0.16	0.17	2.13
2007	0.53	1.10	0.73	0.38	0.24	0.18	0.15	0.12	0.11	0.11	1.57
2008	0.54	1.10	0.66	0.39	0.31	0.25	0.20	0.16	0.13	0.13	1.65
2009	0.64	1.06	0.53	0.27	0.19	0.16	0.13	0.11	0.10	0.09	1.10
2010	0.66	0.73	0.77	0.39	0.18	0.12	0.10	0.08	0.08	0.07	0.91
2011	0.49	1.00	0.67	0.34	0.20	0.15	0.12	0.10	0.08	0.08	0.89
2012	0.40	1.00	1.43	0.63	0.21	0.11	0.09	0.08	0.08	0.08	1.15

Table 5-3. Estimated numbers-at-age of PBF from the base case.

Year	Age0	Age1	Age2	Age3	Age4	Age5	Age6	Age7	Age8	Age9	Age10+
1952	15697	1859	233	112	121	139	425	102	51	37	101
1953	39320	2268	802	119	70	82	97	295	70	36	100
1954	19867	6609	951	396	75	48	58	68	208	50	99
1955	21899	3173	2850	473	246	51	33	40	47	145	107
1956	32311	3335	1607	1704	293	159	33	22	27	32	174
1957	11160	5400	1592	880	1034	188	104	22	15	18	142
1958	2698	1641	2443	854	556	697	129	72	15	10	117
1959	5356	259	511	1268	566	398	505	93	52	11	94
1960	17182	640	85	275	855	404	284	352	64	35	76
1961	22101	2505	183	30	161	586	283	197	242	44	80
1962	12834	3406	677	53	16	108	405	195	134	164	88
1963	22600	1939	1175	251	30	11	73	273	131	90	175
1964	12801	3523	654	423	141	20	7	50	187	90	189
1965	7985	1940	1442	295	248	91	13	5	34	128	198
1966	9195	1071	602	645	173	160	61	9	3	23	233
1967	10969	977	154	116	306	108	106	41	6	2	185
1968	15063	1138	196	46	59	188	70	71	28	4	136
1969	7866	2104	179	30	19	35	119	46	47	19	102
1970	12475	1007	512	50	16	12	24	83	32	33	90
1971	14115	1758	256	189	27	10	8	16	56	22	89
1972	20496	2215	520	94	109	18	7	6	11	40	82
1973	20621	3493	566	129	49	72	12	5	4	8	88
1974	11400	3313	1225	208	74	33	49	8	3	3	68
1975	13303	1671	1282	578	118	46	21	31	5	2	50
1976	9598	2130	580	620	380	86	34	15	22	4	39
1977	28252	1027	564	212	364	261	61	24	11	16	32
1978	16685	4271	330	223	115	225	169	40	16	7	35
1979	14486	2161	1253	138	123	71	144	110	27	11	30
1980	6715	1879	673	584	80	78	47	96	74	18	29
1981	18681	855	616	347	333	49	50	30	64	50	33
1982	8473	2281	233	250	138	140	22	24	16	35	49
1983	11591	1304	598	54	67	42	48	8	10	7	45
1984	8791	1637	505	333	32	41	26	31	5	7	35
1985	11306	831	562	281	207	20	26	17	20	4	29
1986	12062	1472	225	224	148	122	13	17	11	14	23
1987	8317	1532	361	62	108	89	77	8	11	7	25
1988	8125	1333	706	188	36	68	57	51	6	8	23
1989	6413	1167	594	429	122	24	45	38	35	4	22
1990	29494	984	559	371	283	82	16	31	27	24	18
1991	3718	5099	480	347	255	202	59	12	22	19	30
1992	5955	459	1954	318	238	178	142	42	8	16	35
1993	4798	594	122	1271	227	173	129	103	30	6	36
1994	38732	719	272	78	878	161	124	92	73	21	28
1995	11822	5428	322	164	53	619	115	89	67	53	36
1996	18584	1704	1276	187	113	37	443	83	64	48	62
1997	9362	2149	575	607	122	81	27	325	60	46	76
1998	16022	1023	444	307	416	87	59	20	235	43	84
1999	21816	1854	242	204	191	281	60	41	14	163	83
2000	16558	2083	484	130	128	125	187	41	28	9	164
2001	18579	1148	284	203	81	87	86	130	29	20	119
2002	14190	2159	435	166	139	58	63	63	95	21	97
2003	10292	1735	727	226	106	96	41	45	45	67	81
2004	27678	1317	369	324	145	77	71	30	32	32	103
2005	13598	3276	381	120	168	93	51	47	20	22	90
2006	10700	1579	555	134	71	109	61	34	31	13	75
2007	24642	1301	340	193	74	46	74	41	22	21	57
2008	18001	2923	295	128	103	46	30	50	28	16	53
2009	7200	2118	661	119	67	59	28	19	33	19	47
2010	14679	767	497	302	71	43	39	19	13	23	47
2011	9701	1528	250	180	160	46	30	28	14	10	50
2012	7015	1203	381	99	100	102	31	21	20	10	43

Table 5-4. Ratio of the estimated fishing mortalities $F_{2002\text{-}2004}$, $F_{2007\text{-}2009}$ and $F_{2009\text{-}2011}$ relative to computed F-based biological reference points for Pacific bluefin tuna (PBF), depletion ratio (ratio of SSB in 2012 relative to unfished SSB), and estimated SSB (t) in year 2012 for four model configurations (runs). Run 1 is the base case assessment model for the PBF update stock assessment. Values in the first eight columns above 1.0 indicate overfishing.

	F_{max}	$F_{0.1}$	F_{med}	F_{loss}	$F_{10\%}$	$F_{20\%}$	$F_{30\%}$	$F_{40\%}$	Depletion Ratio	Estimated SSB(t) (yr=2012)
$F_{2002\text{-}2004}$										
Run1	**1.70**	**2.44**	**1.09**	**0.84**	**1.16**	**1.68**	**2.26**	**2.98**	**0.042**	**26,324**
Run2	1.73	2.47	1.09	0.85	1.16	1.68	2.26	2.99	0.054	33,736
Run3	1.78	2.55	1.16	1.03	1.24	1.79	2.40	3.17	0.031	19,369
Run4	1.77	2.52	1.13	0.89	1.21	1.75	2.36	3.11	0.043	26,952
$F_{2007\text{-}2009}$										
Run1	**2.09**	**2.96**	**1.40**	**1.08**	**1.48**	**2.14**	**2.87**	**3.79**	**0.042**	**26,324**
Run2	1.93	2.74	1.25	0.99	1.34	1.94	2.60	3.43	0.054	33,736
Run3	2.34	3.31	1.54	1.38	1.65	2.38	3.20	4.23	0.031	19,369
Run4	2.11	2.98	1.36	1.07	1.46	2.11	2.84	3.74	0.043	26,952
$F_{2009\text{-}2011}$										
Run1	**1.79**	**2.54**	**1.25**	**0.97**	**1.32**	**1.90**	**2.55**	**3.36**	**0.042**	**26,324**
Run2	1.61	2.30	1.11	0.88	1.19	1.71	2.29	3.02	0.054	33,736
Run3	2.02	2.86	1.37	1.23	1.46	2.11	2.83	3.73	0.031	19,369
Run4	1.77	2.52	1.20	0.95	1.29	1.85	2.49	3.27	0.043	26,952

Table 5-5. Results for the future projections requested by NC9 under seven harvest scenarios and assuming three future recruitment conditions where $SSB_{recent,F=0}$ is calculated using the most recent ten year's recruitment (2002-2011).

NC9`s scenarios	Future recruit level		Within 10 years from 2014					Within 15 years from 2014					Mean yield in 2026 - 2028
			Probability achieving reference level at least one year					Probability achieving reference level at least one year					
	2014 - 2023 (10years)	From 2024	62KT (10%SSB0)	93KT (15%SSB0)	124KT (20%SSB0)	155KT (25%SSB0)	Historical Median(43KT)	62KT (10%SSB0)	93KT (15%SSB0)	124KT (20%SSB0)	155KT (25%SSB0)	Historical Median(43KT)	
No.1	Low	Low	0%	0%	0%	0%	4%	1%	0%	0%	0%	7%	13664.7
	Low	Middle	0%	0%	0%	0%	4%	3%	0%	0%	0%	14%	16320.9
	Middle	Middle	48%	24%	10%	4%	69%	76%	50%	29%	15%	90%	22932.5
No.2	Low	Low	1%	0%	0%	0%	5%	2%	0%	0%	0%	9%	13455.7
	Low	Middle	1%	0%	0%	0%	5%	4%	0%	0%	0%	17%	15817.9
	Middle	Middle	53%	30%	16%	8%	72%	80%	59%	40%	26%	92%	17572.0
No.3	Low	Low	1%	0%	0%	0%	9%	4%	0%	0%	0%	18%	13380.1
	Low	Middle	1%	0%	0%	0%	9%	8%	1%	0%	0%	29%	15447.2
	Middle	Middle	60%	36%	20%	10%	79%	87%	67%	48%	31%	96%	17019.4
No.4	Low	Low	1%	0%	0%	0%	2%	1%	0%	0%	0%	5%	13186.2
	Low	Middle	1%	0%	0%	0%	2%	2%	0%	0%	0%	9%	15834.0
	Middle	Middle	48%	27%	13%	5%	64%	77%	57%	37%	20%	87%	23565.0
No.5	Low	Low	3%	0%	0%	0%	16%	8%	1%	0%	0%	32%	14195.6
	Low	Middle	3%	0%	0%	0%	16%	16%	2%	0%	0%	46%	16225.3
	Middle	Middle	70%	43%	22%	10%	87%	92%	75%	52%	32%	98%	24219.0
No.6	Low	Low	51%	12%	2%	0%	85%	84%	39%	9%	2%	98%	17055.8
	Low	Middle	51%	12%	2%	0%	85%	90%	51%	17%	4%	99%	18767.5
	Middle	Middle	96%	83%	61%	38%	99%	100%	98%	91%	77%	100%	27453.9
No.7	Low	Low	6%	1%	0%	0%	31%	18%	2%	0%	0%	59%	14453.7
	Low	Middle	6%	1%	0%	0%	31%	30%	4%	0%	0%	73%	16502.3
	Middle	Middle	77%	49%	26%	13%	92%	96%	81%	59%	38%	99%	23316.9

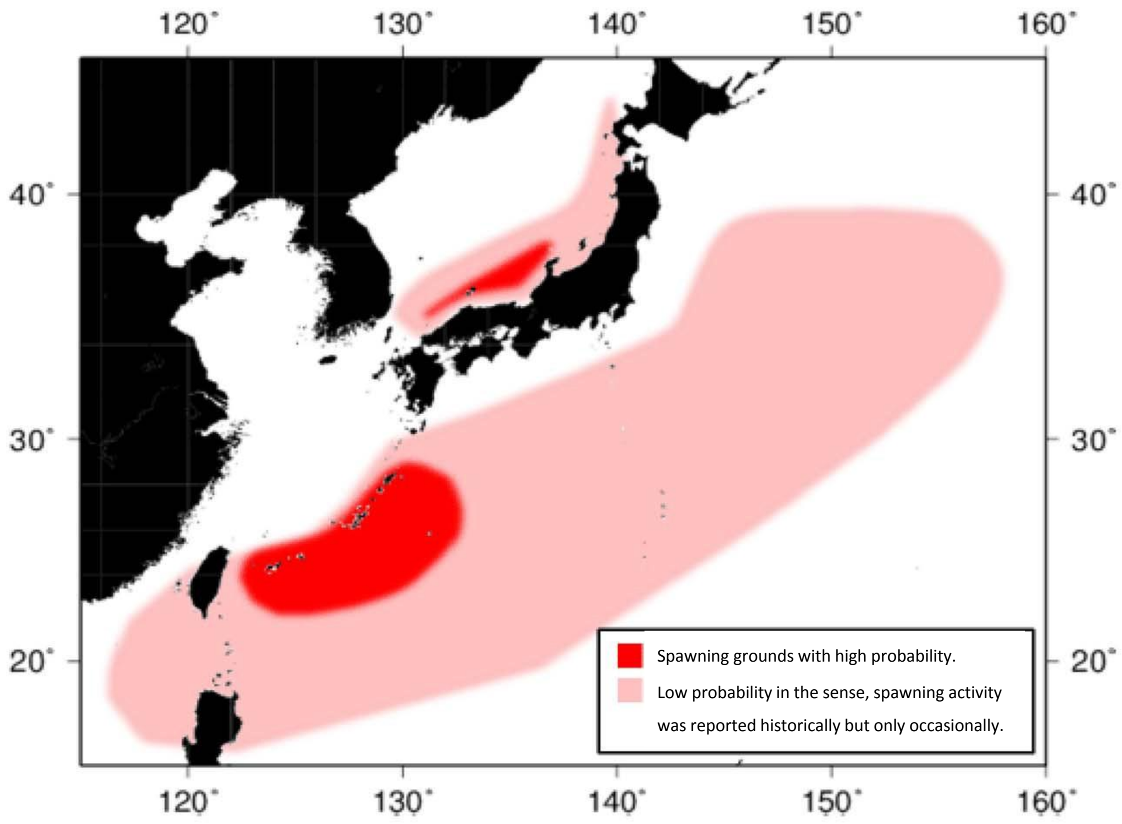


Figure 2-1.Generalized spawning grounds for PBF. Red areas represent higher probability of spawning.

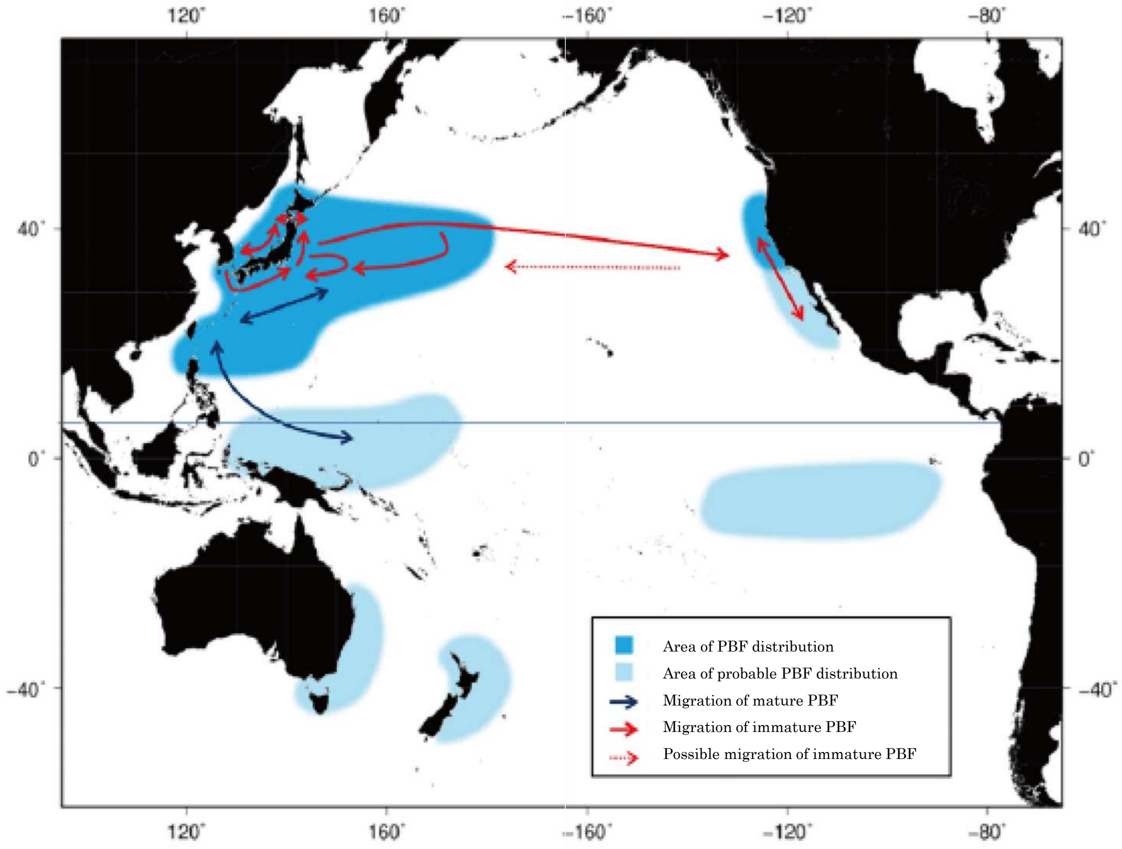


Figure 2-2. Generalized distribution of PBF. Darker areas indicate the core habitat.

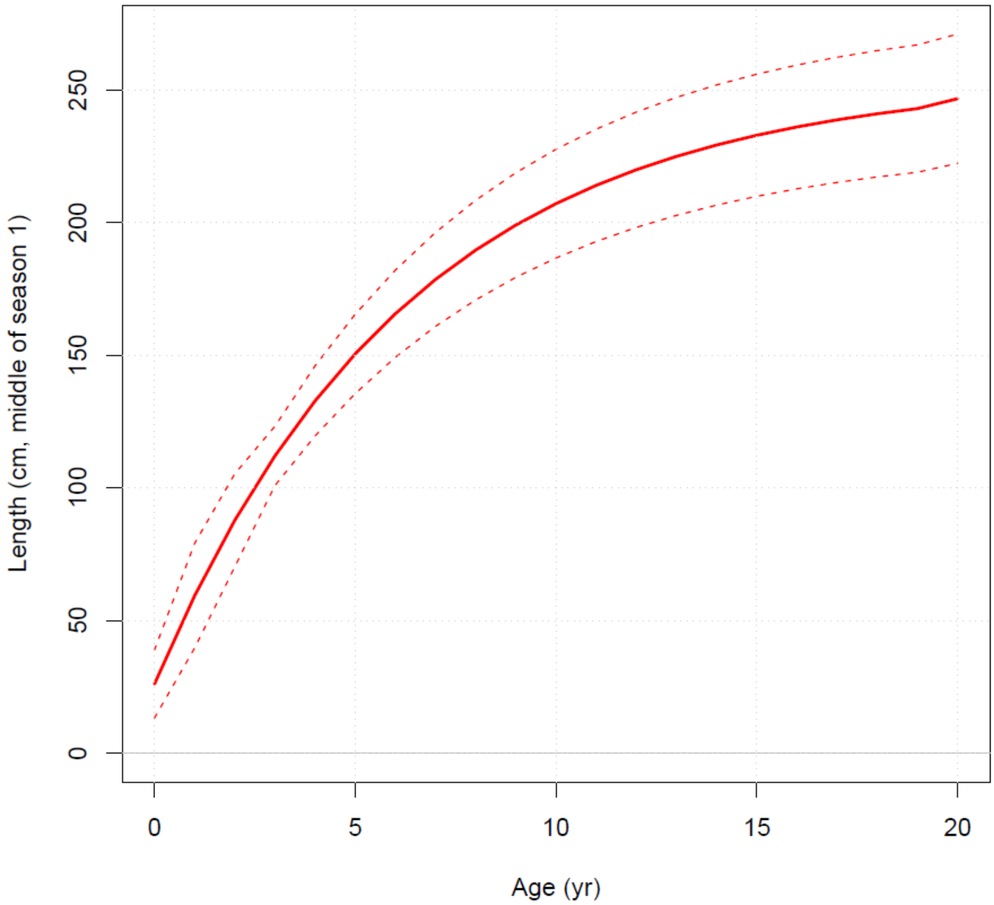


Figure 2-3. The von Bertalanffy growth curve for PBF used in this stock assessment. Integer age (0,1,2,3,…) is corresponds to the middle of first quarter 1 of each fishing year (i.e., August 15 in the calendar year).

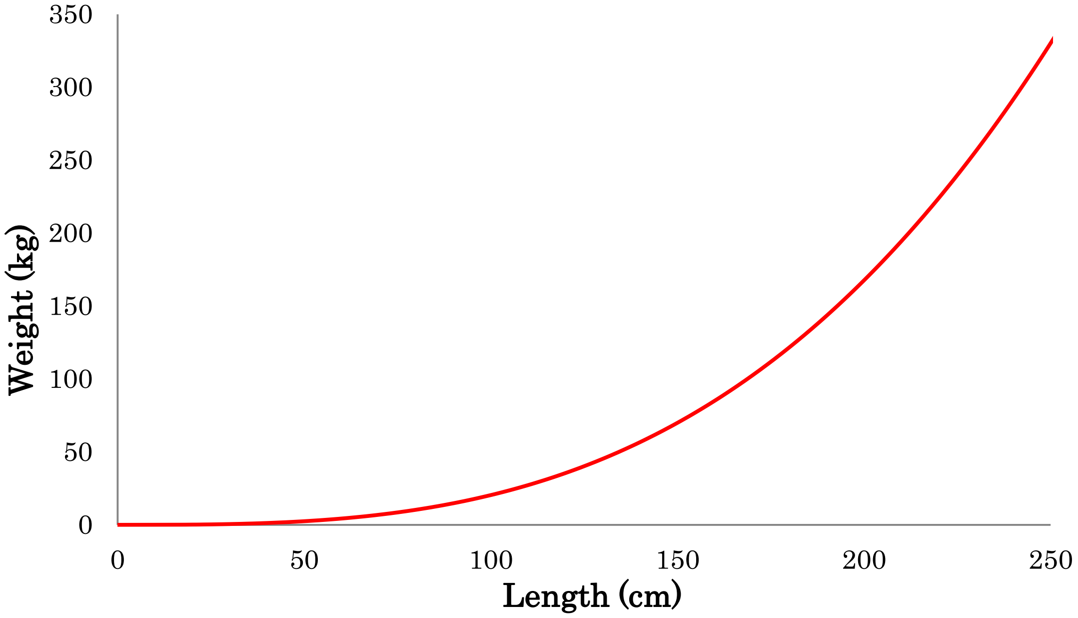


Figure 2-4. Length-weight relationship for PBF used in this stock assessment.

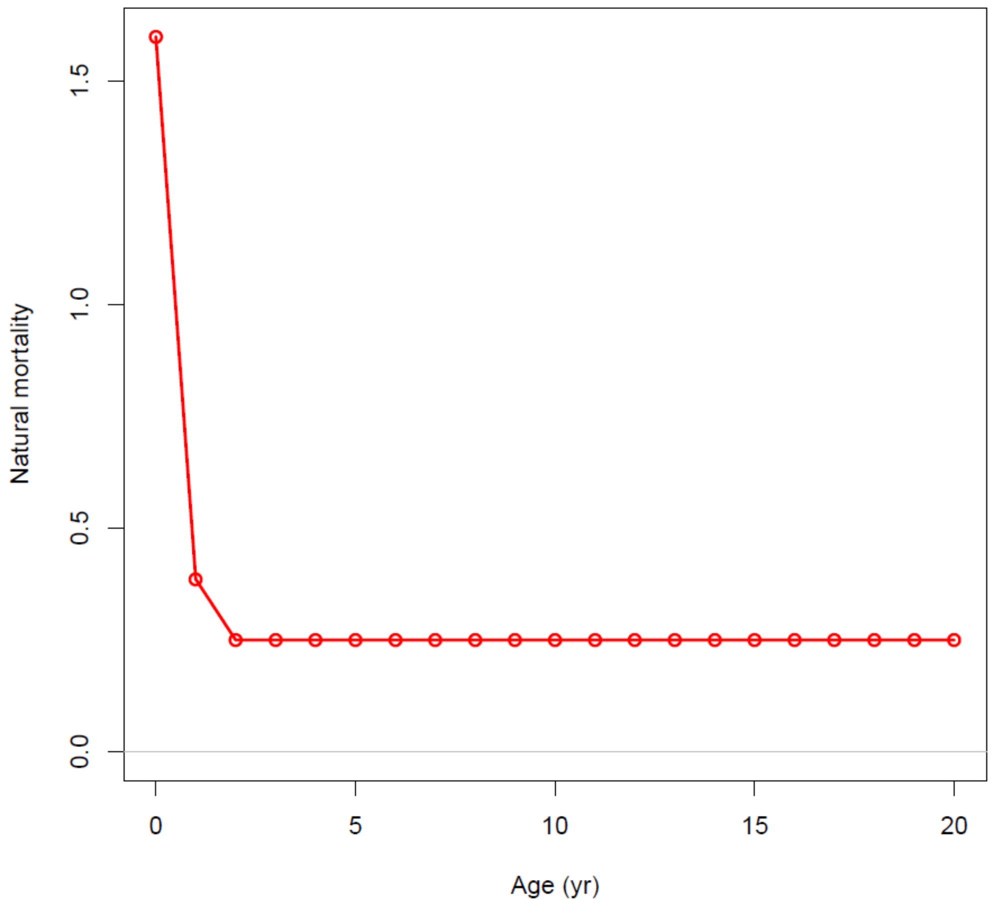


Figure 2-5. Assumed scenario of natural mortality (*M*) of PBF used in this stock assessment.

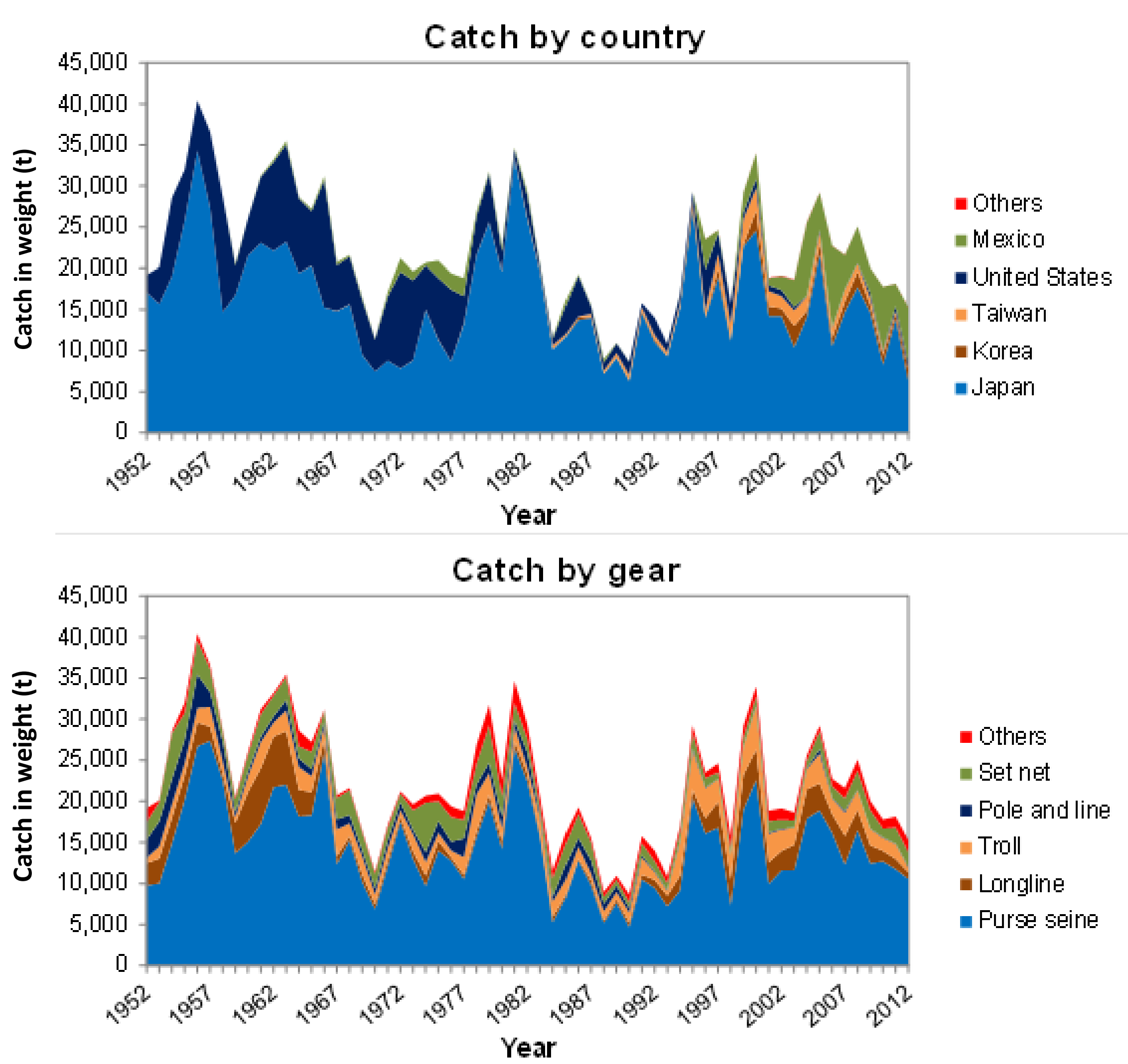


Figure 2-6. Historical annual catch of Pacific bluefin tuna by country (upper panel) and by gear (lower panel), from 1952 through 2012 (calendar year).

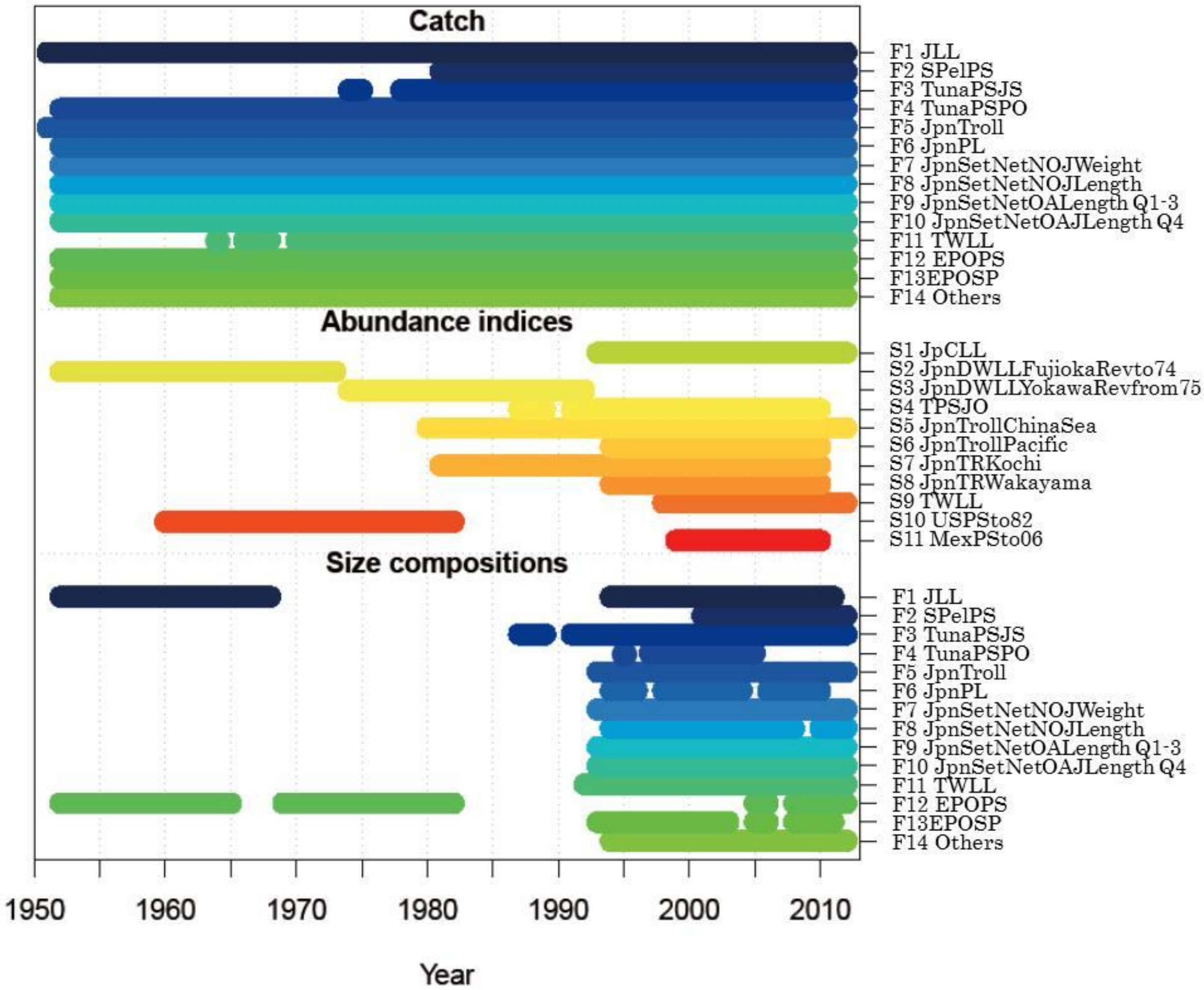


Figure 3-1. Temporal coverage and sources of catch, abundance indices, size composition data used in the 2013 assessment of PBF (for a key to abbreviation see Table 3-1).

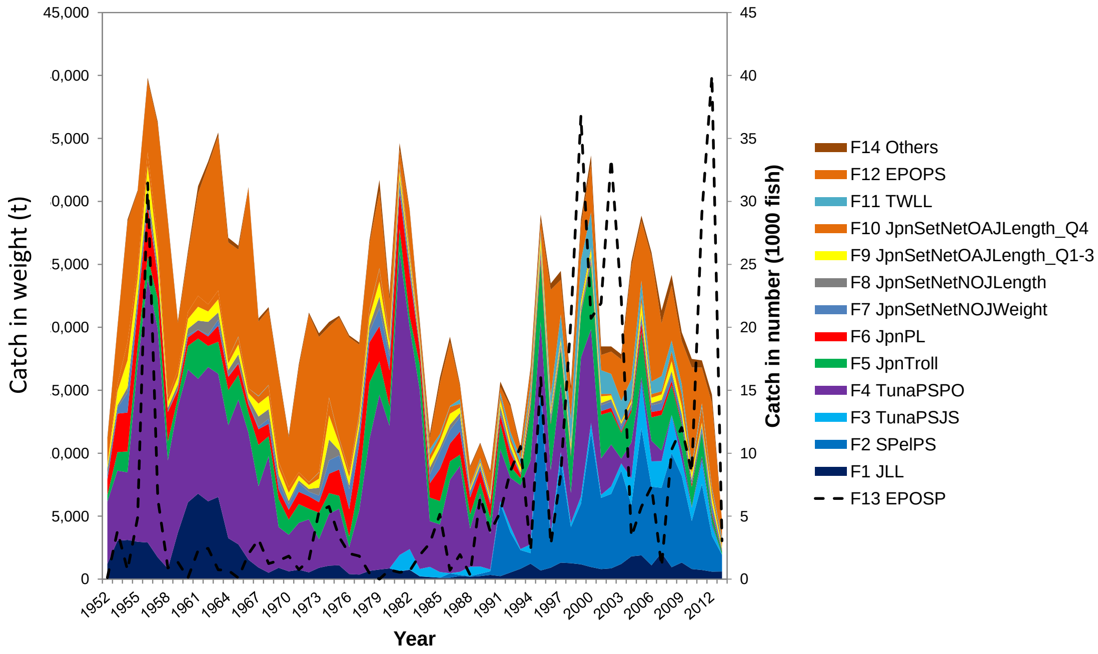
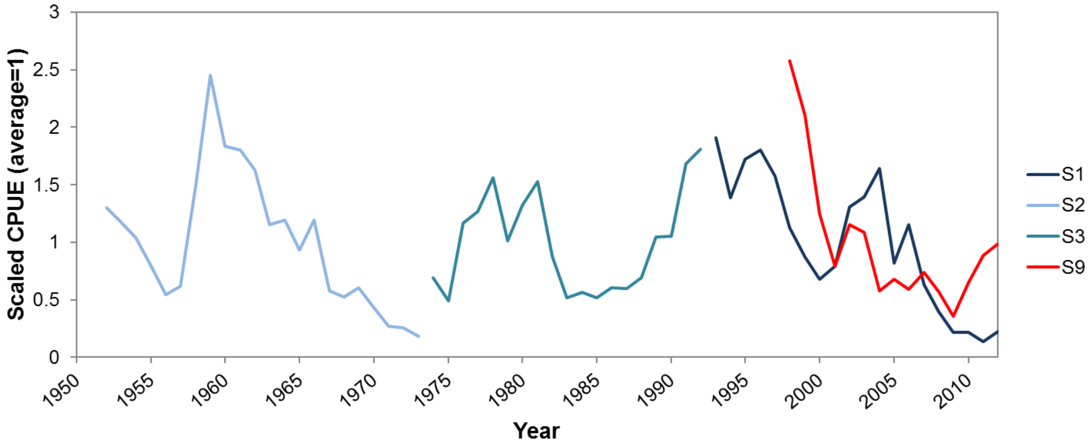
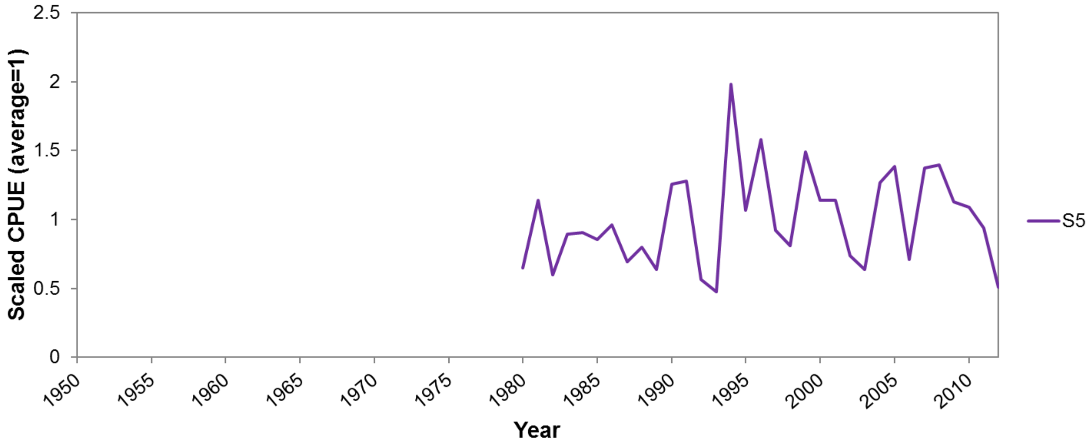


Figure 3-2. Annual nominal catch of Pacific bluefin tuna from 1952 through 2013 in calendar year. Catch in first and second quarters of 1952 and third and fourth quarters of 2013 were not included, because these data were derived from input data for the SS3 model. Catch data from all fleets with exception of Fleet 13 were based on weight, whereas a unit of number of fish was applied for Fleet 13. The black dashed line indicates the annual catch in number (1000 fish) from Fleet 13.

(a) CPUE indices from longline fisheries



(b) CPUE indices from troll fishery



(c) CPUE indices not for use of this stock assessment

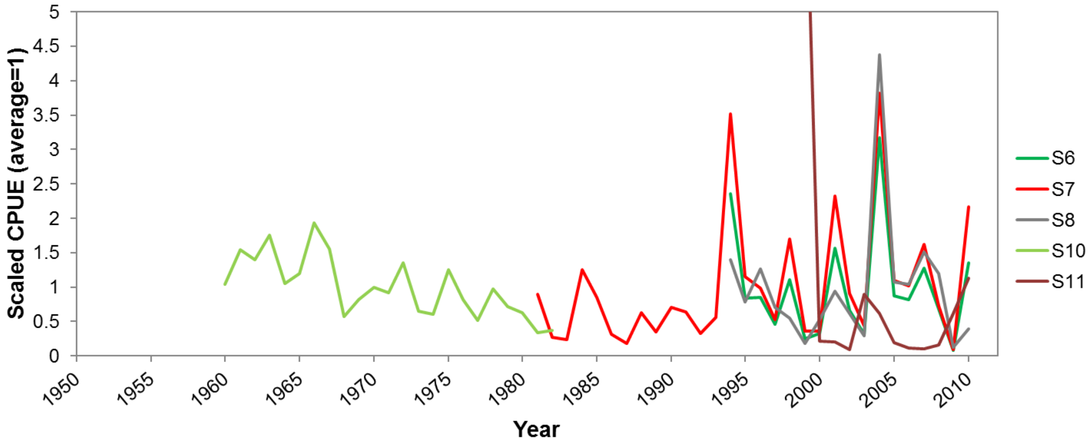


Figure 3-3. Abundance indices presented at the PBFWG. The indices of Japanese and Taiwanese longliners were used to represent adult abundance (a), and indices of the Japanese troll fishery were used to index recruitments (b). Other indices presented were not used (c).

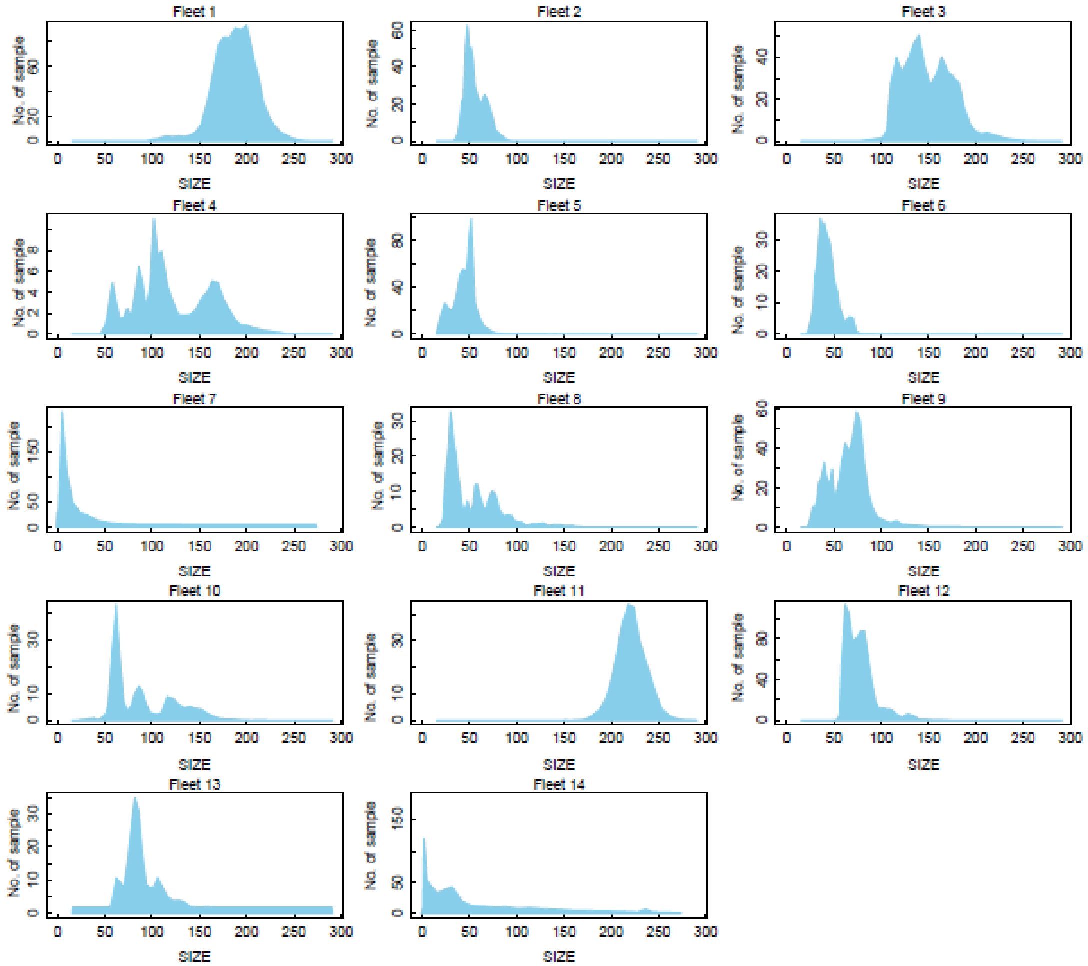


Figure 3-4. Aggregated size compositions of PBF for each fleet used in the stock assessment. The data are pooled over seasons and years after being scaled by fleet size (see Section 4.4.3 for explanations). The x-axis is in fork length (cm) for all fleets except for Fleets 7 and 14, which are in weight (kg).

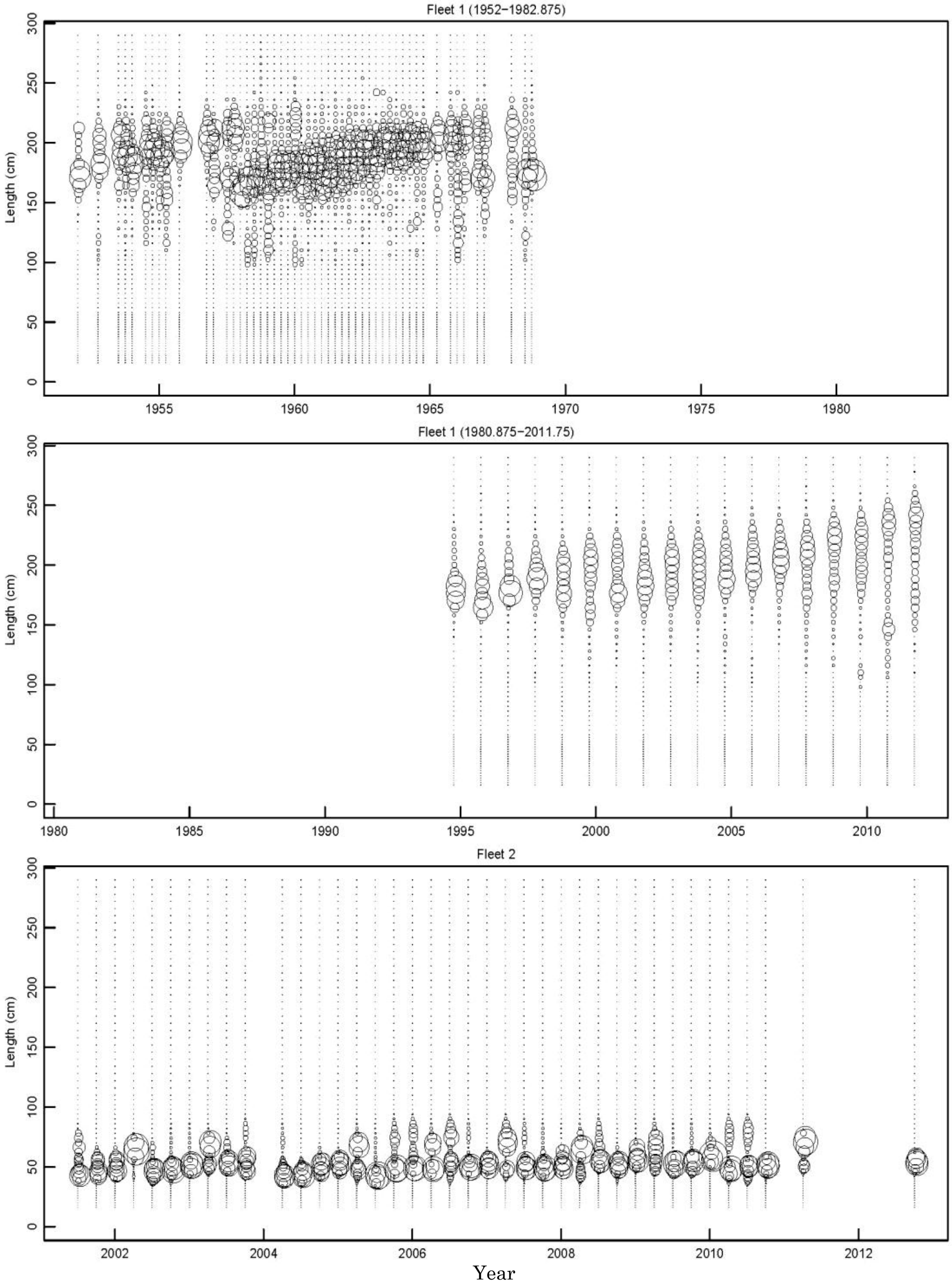


Figure 3-5. Size composition data of PBF in this stock assessment, by fleet and quarter. Larger circles indicate higher proportions at that time.

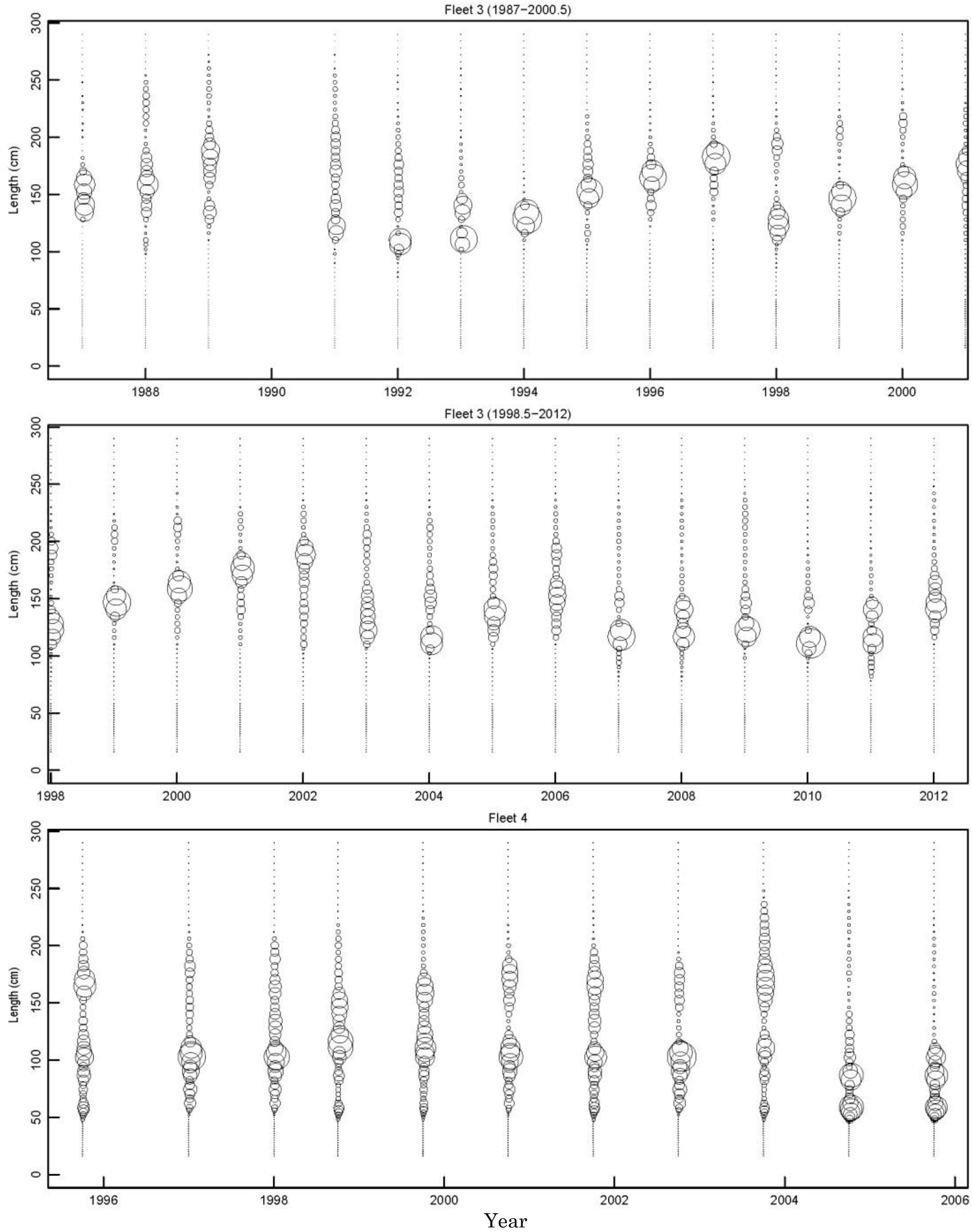


Figure 3-5. (continued).

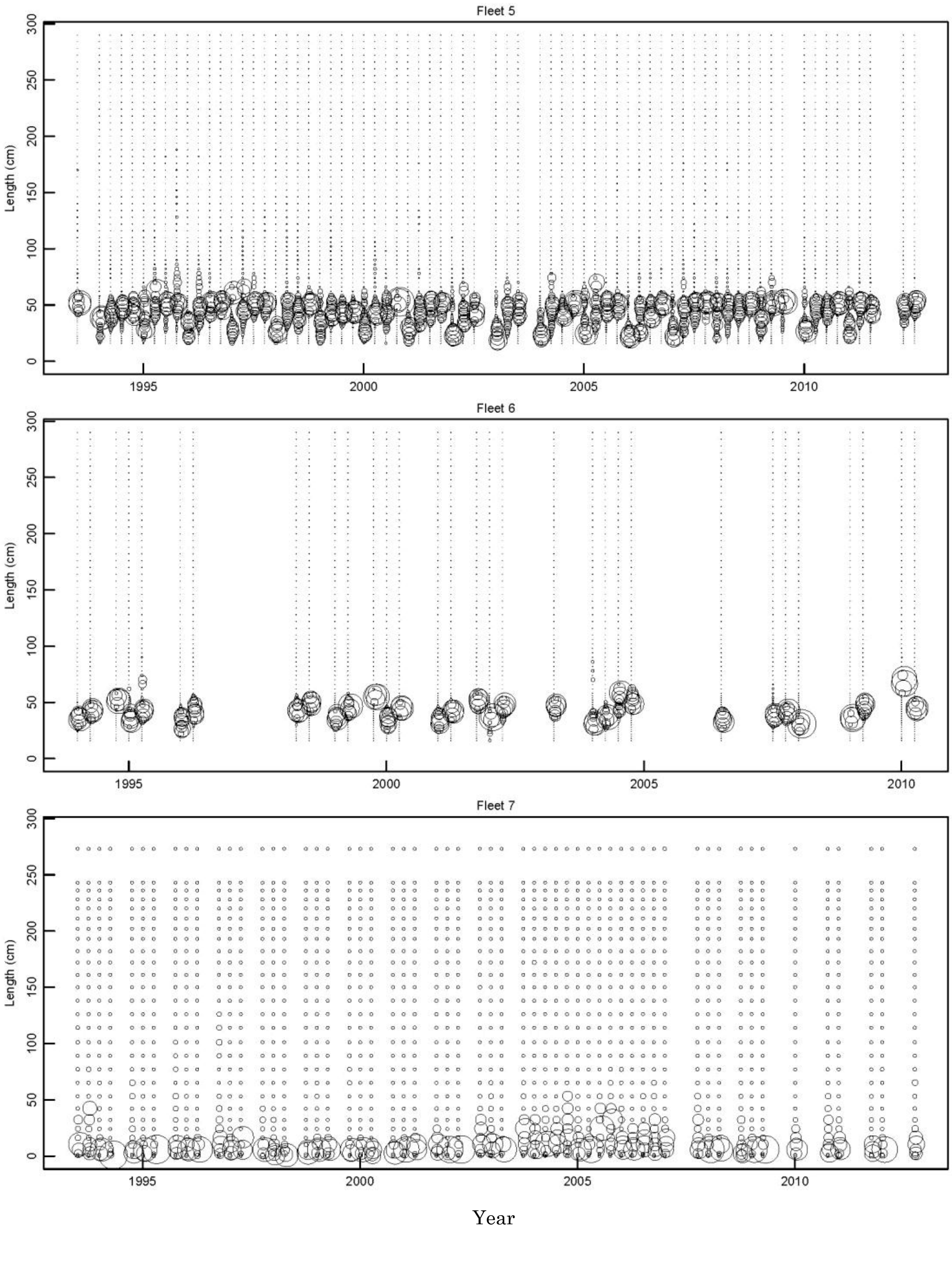


Figure 3-5. (continued).

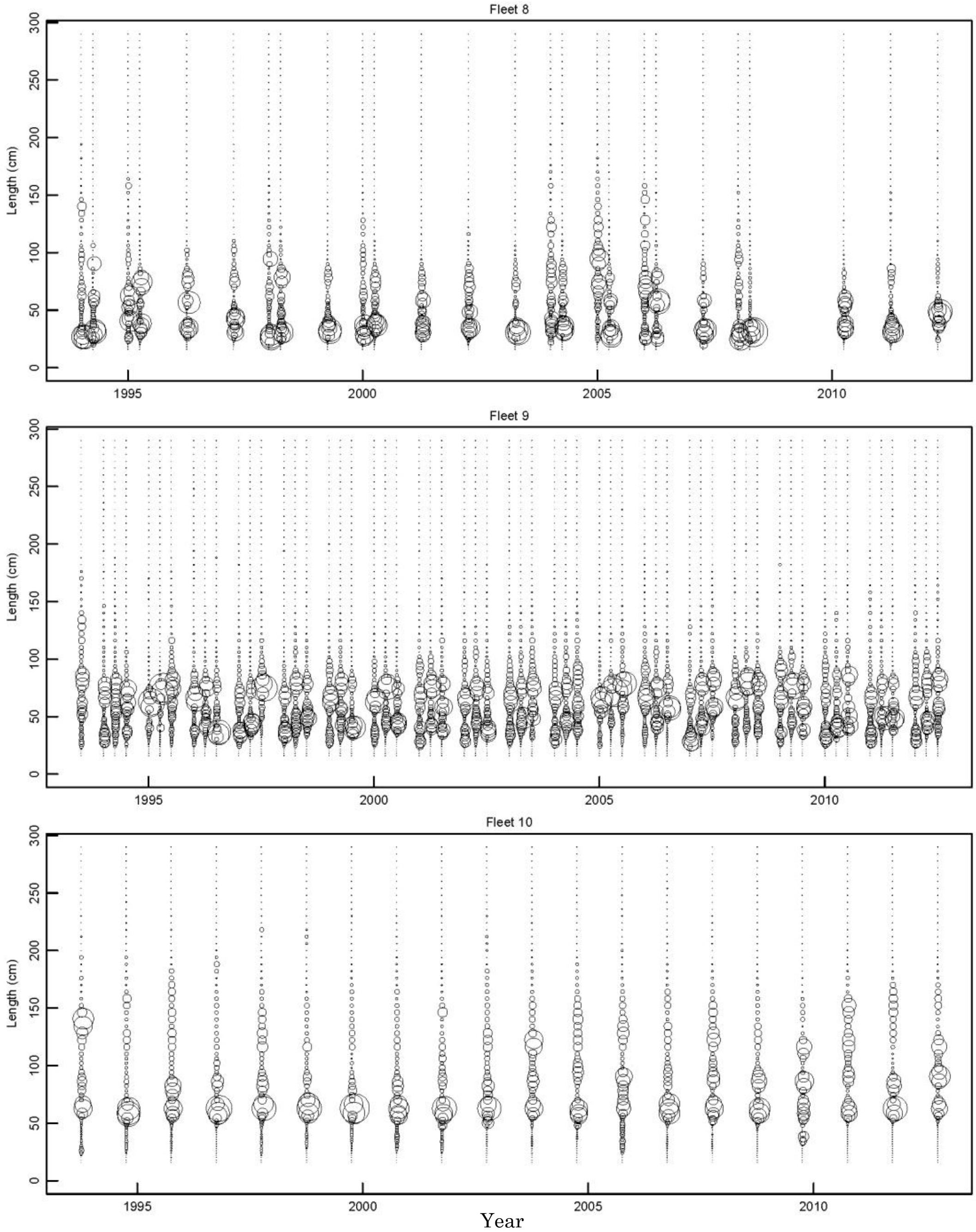


Figure 3-5. (continued).

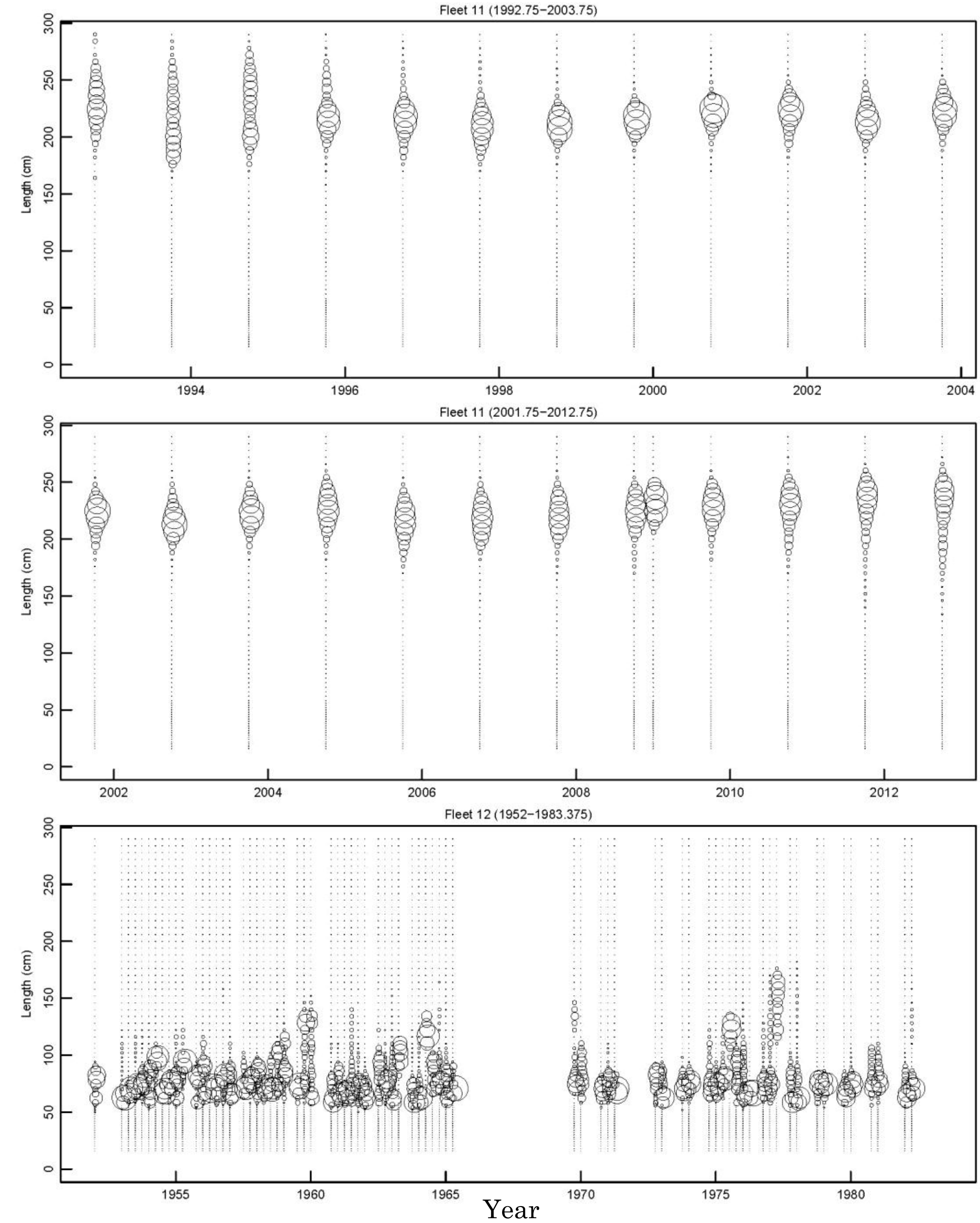


Figure 3-5. (continued).

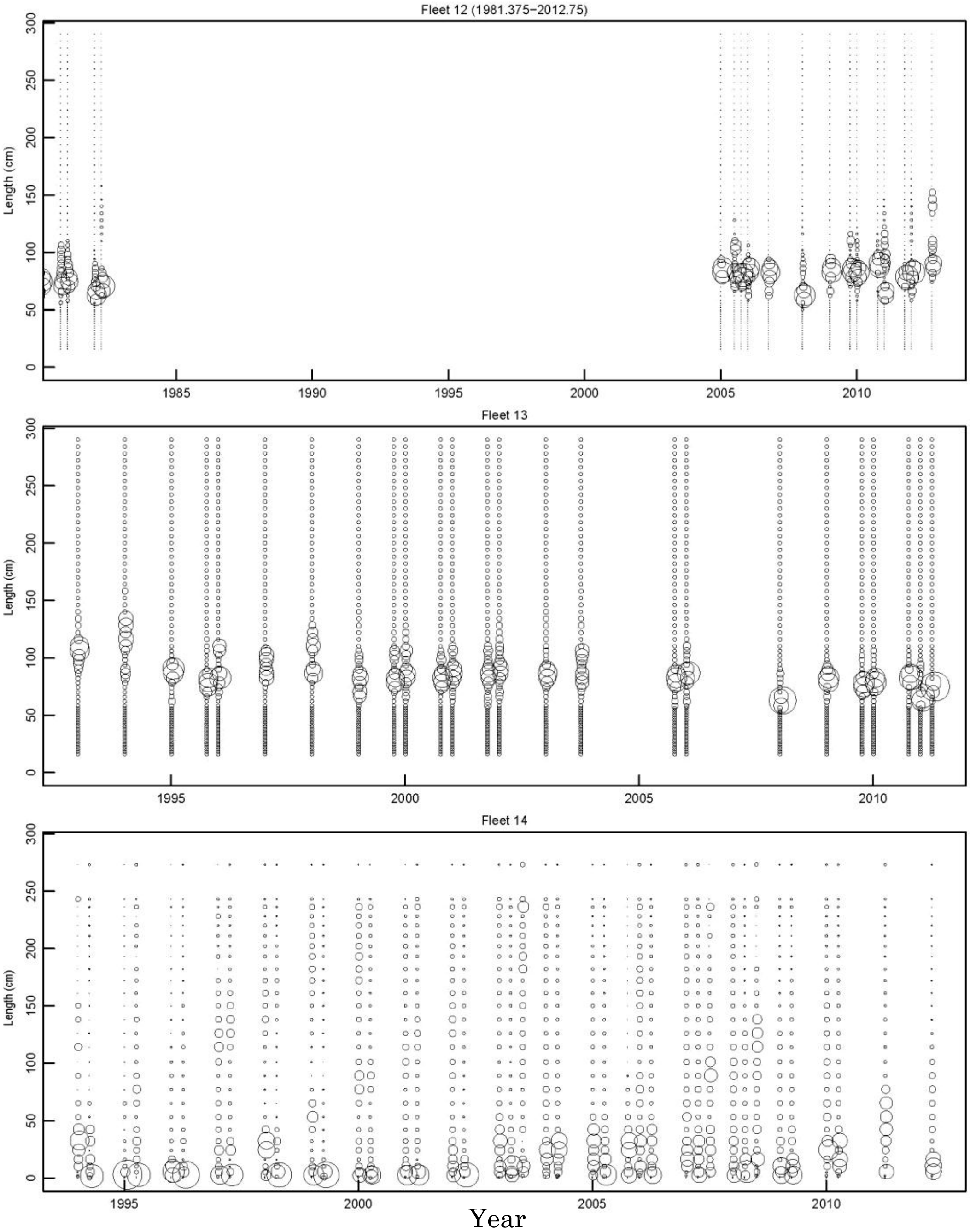


Figure 3-5. (continued).

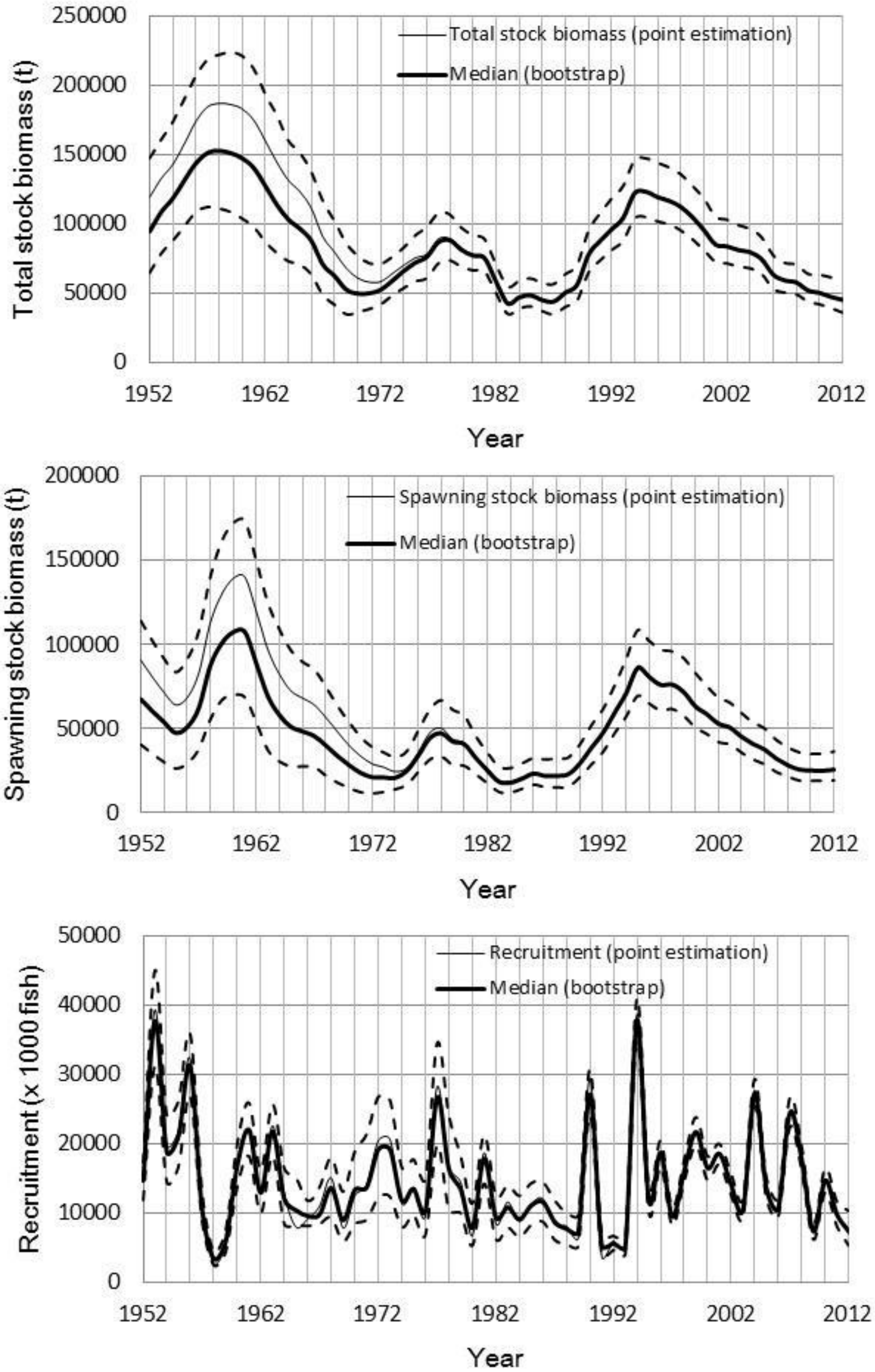


Figure 5-1. Total stock biomass (upper panel), spawning stock biomass (middle panel) and recruitment (lower panel) of PBF from the base case run (Run1). Thick line indicates median, thin line indicates point estimate, and dashed lines indicate the 90% confidence interval.

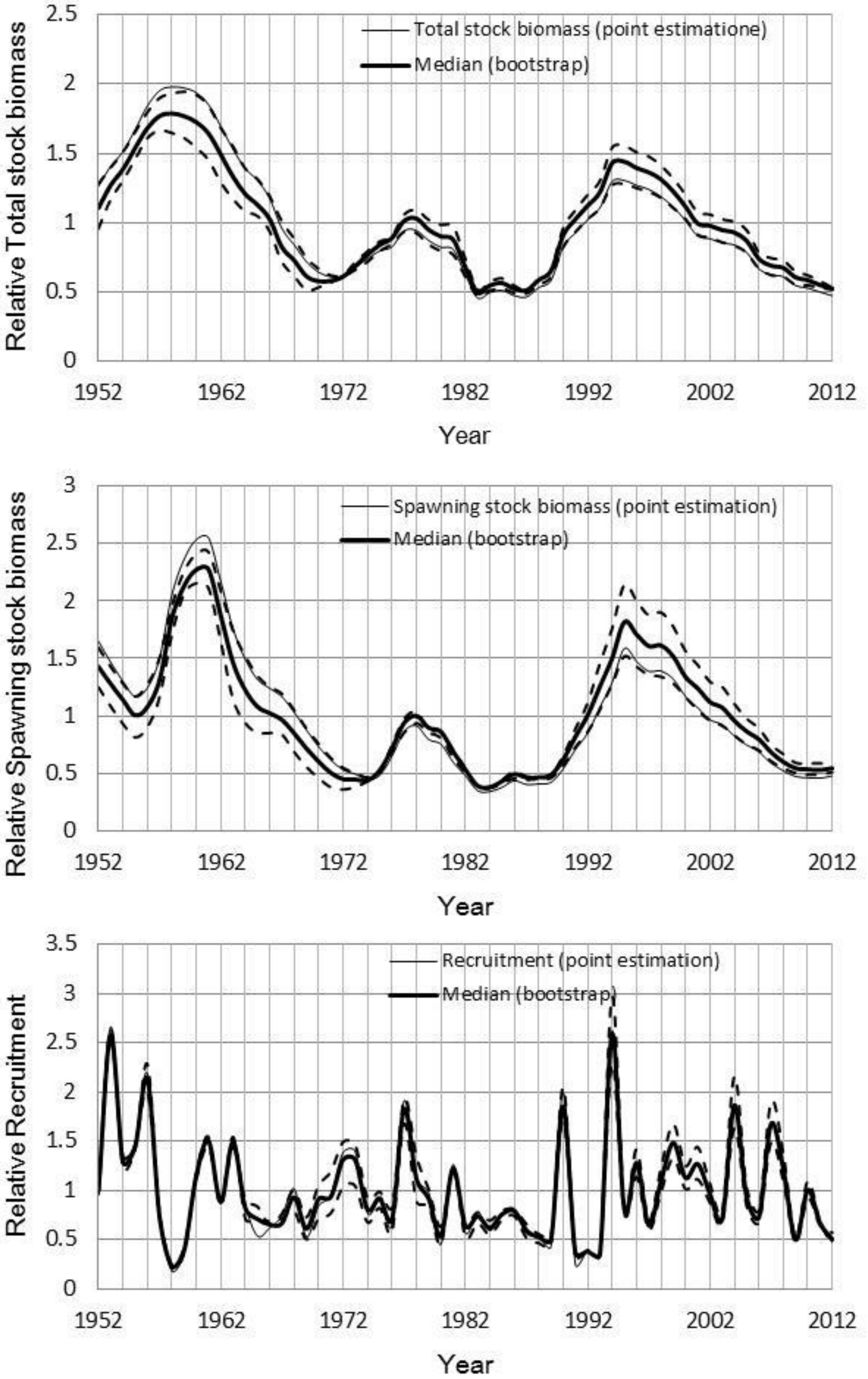


Figure 5-1. (continued).

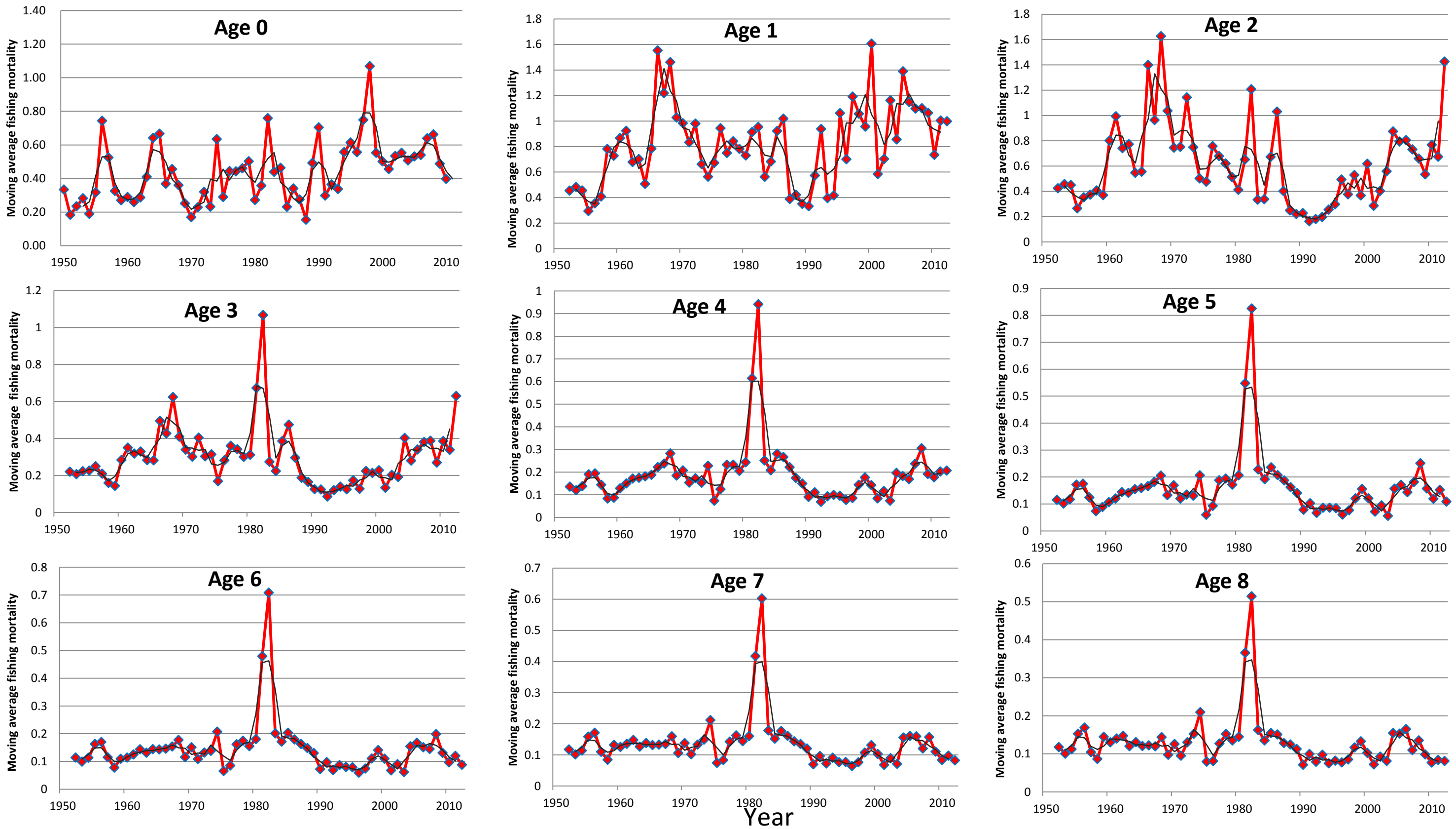


Figure 5-2. Estimated age specific fishing mortality of PBF for 1952-2012. Red lines represent annual fishing mortality. Gray lines represent the three year moving average fishing mortality.

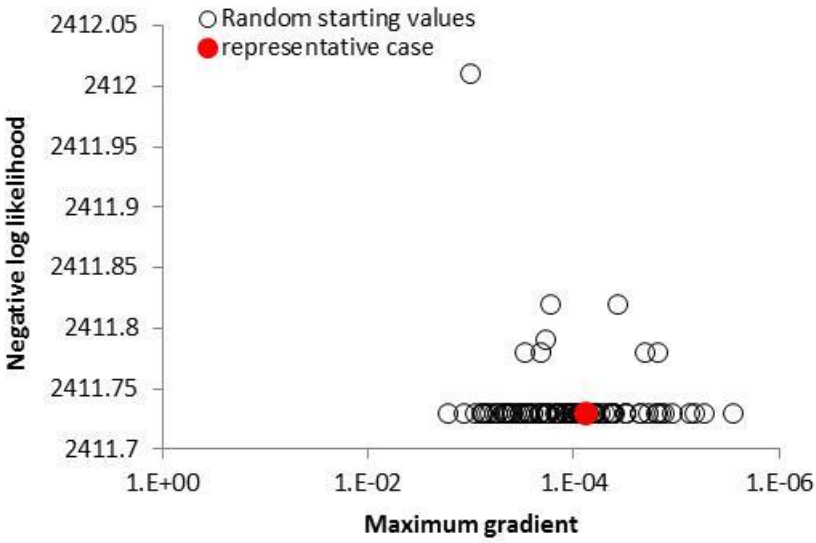


Figure 5-3. Plot of negative log likelihood and the maximum gradient.

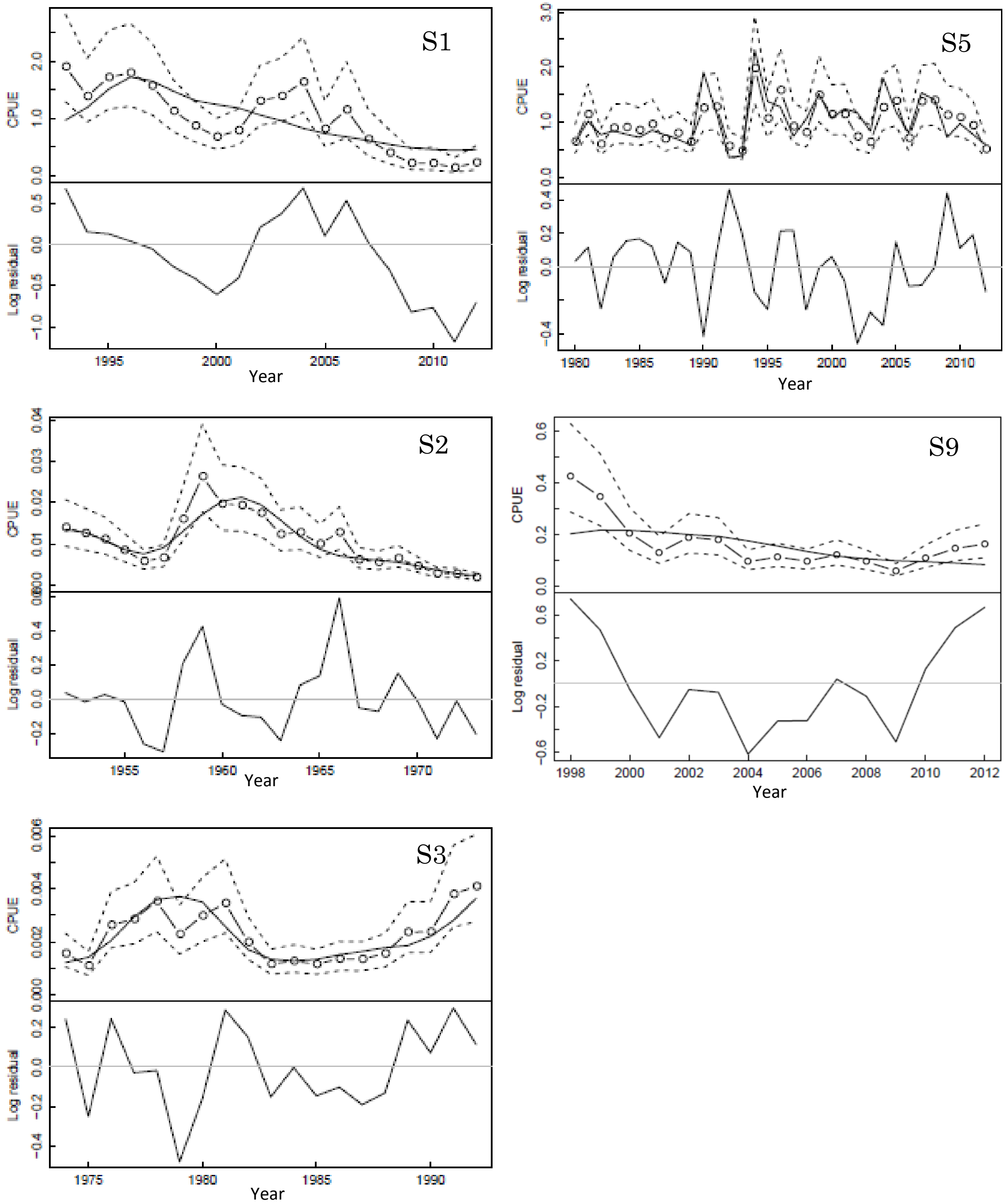


Figure 5-4. Observed (line + circles) and expected (line) CPUE, and its residuals (observed minus expected) for Pacific bluefin tuna fleets S1, S2, S3, S5 and S9.

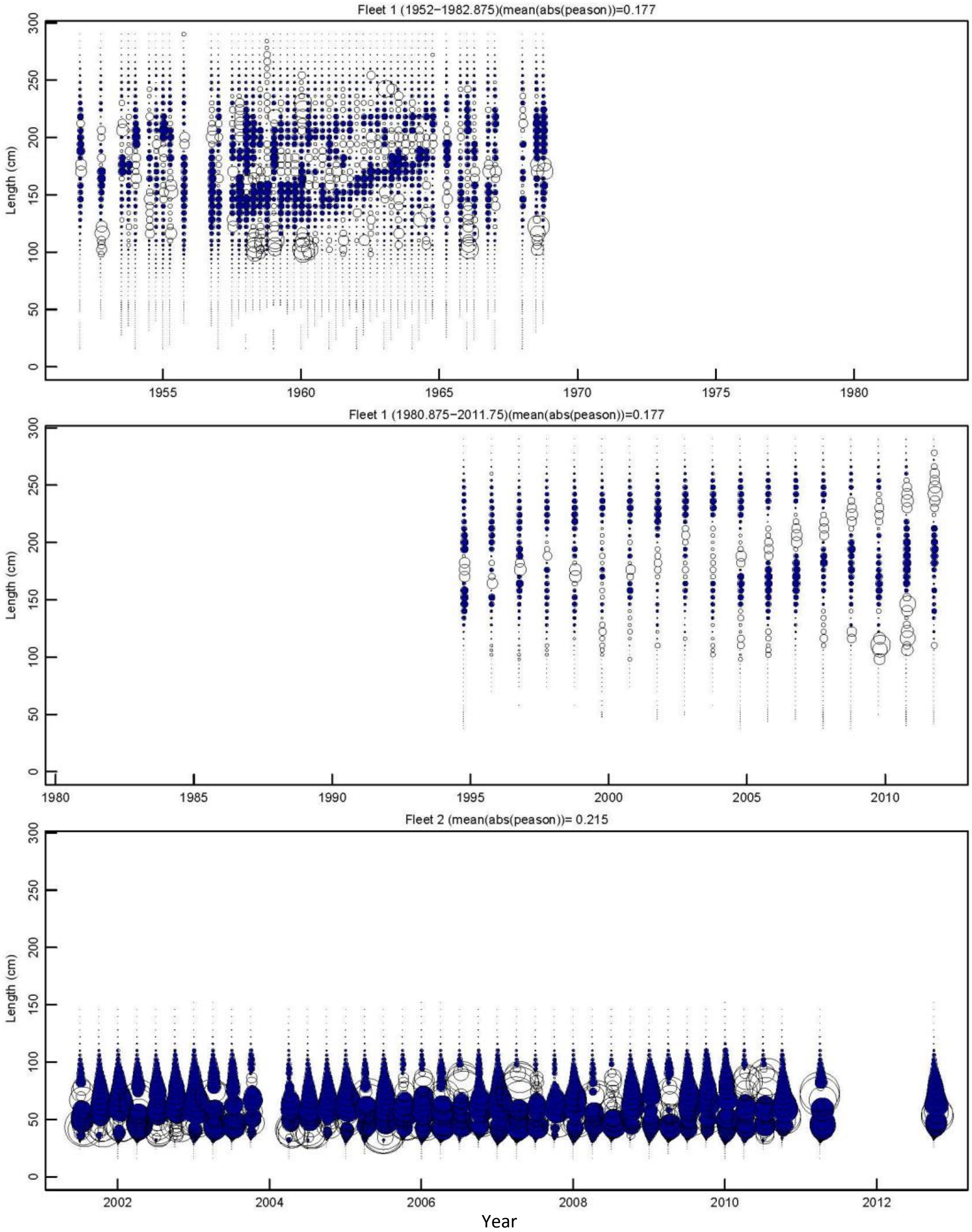


Figure 5-5. The model fits of the length composition data for PBF by fleets. Blue circle indicate observation value < expected value; white circle indicate observation value > expected value.

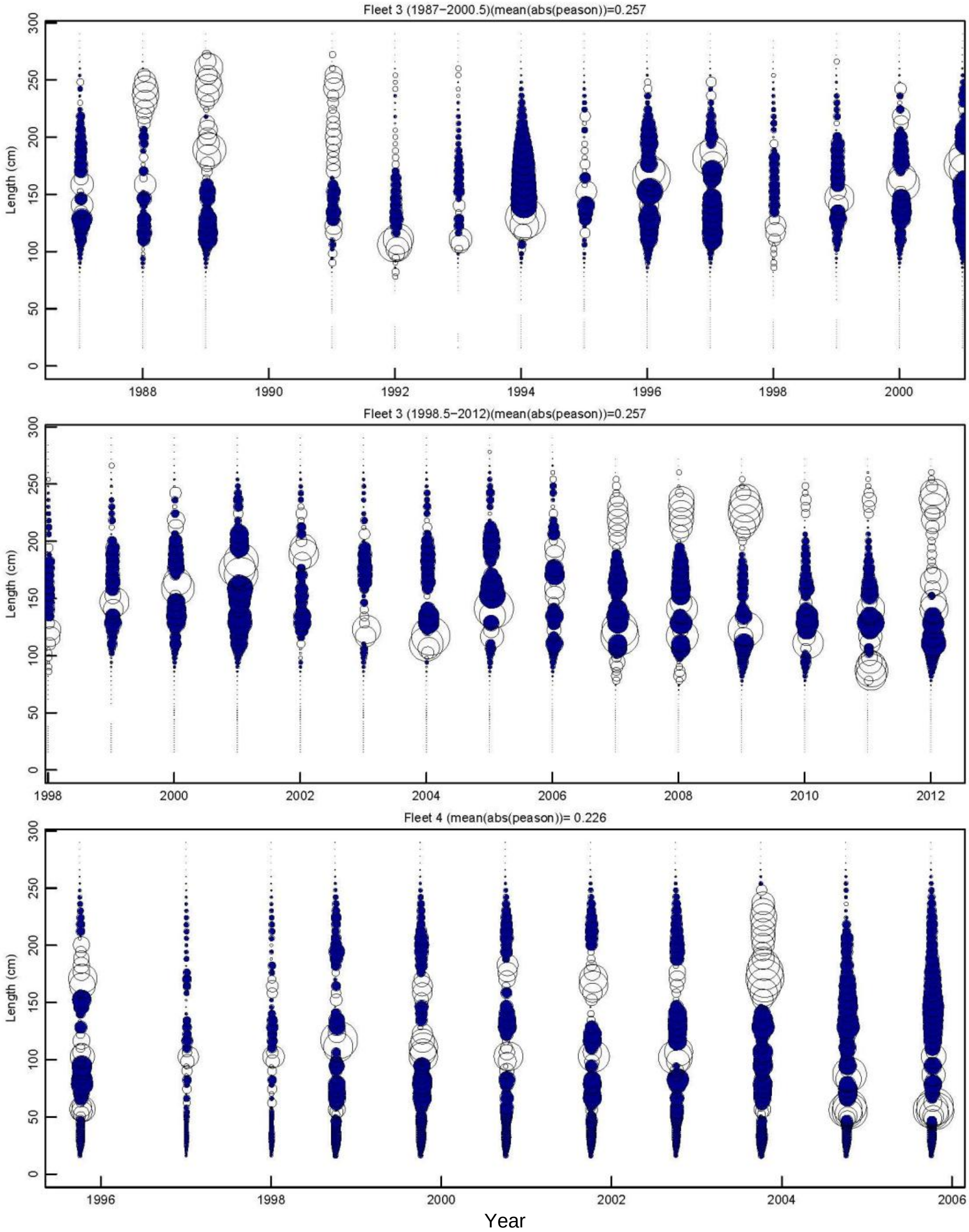


Figure 5-5. (continued).

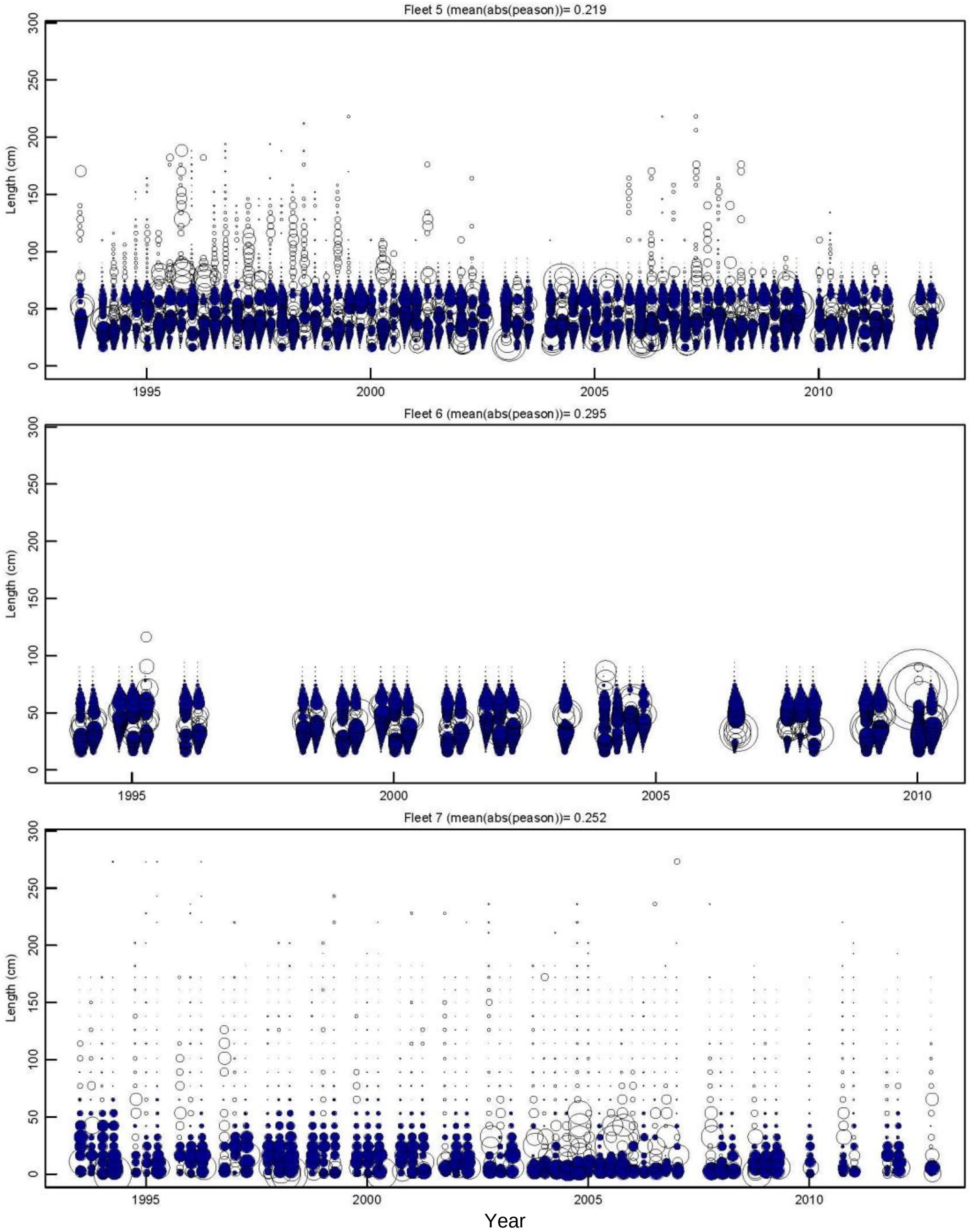


Figure 5-5. (continued).

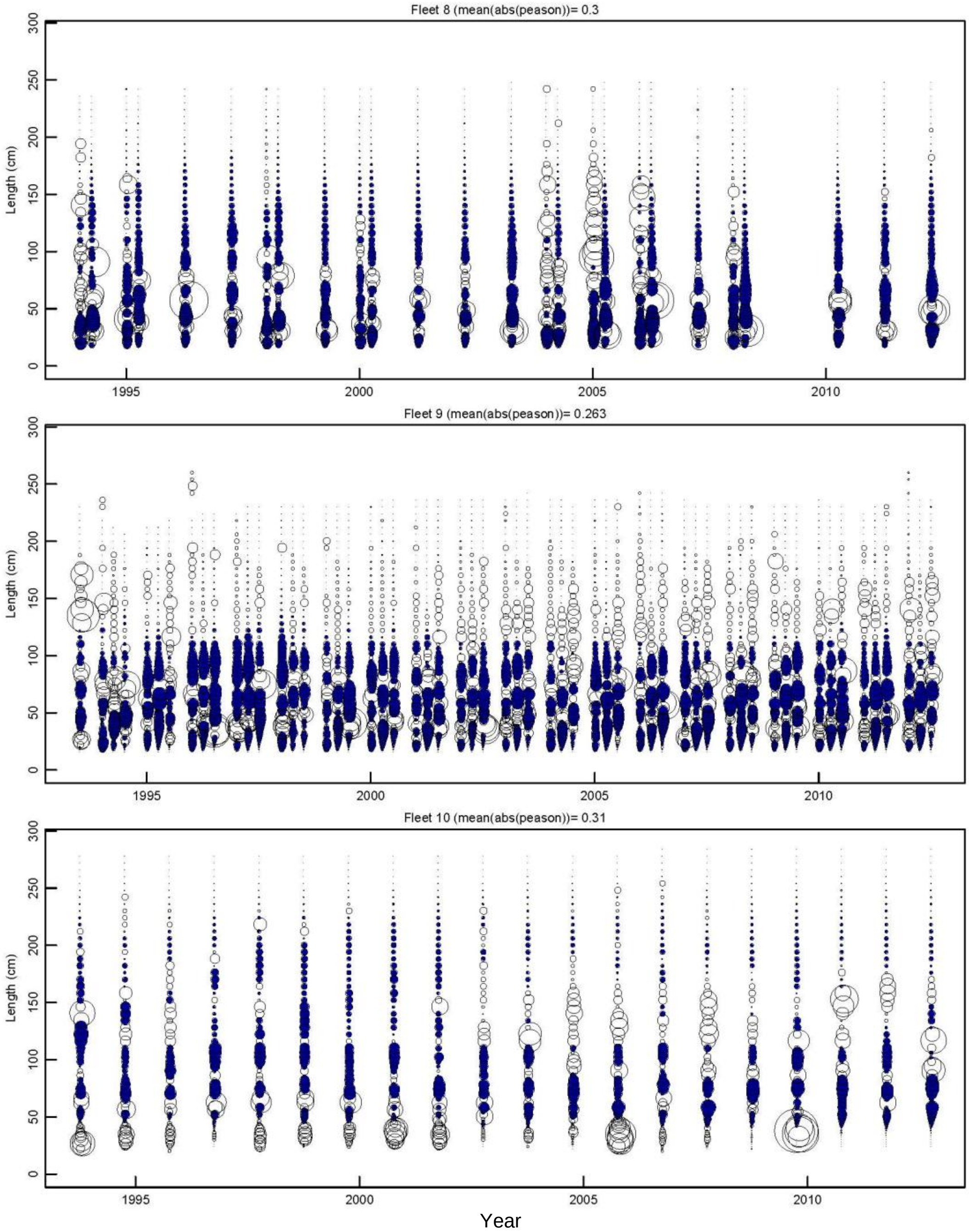


Figure 5-5. (continued).

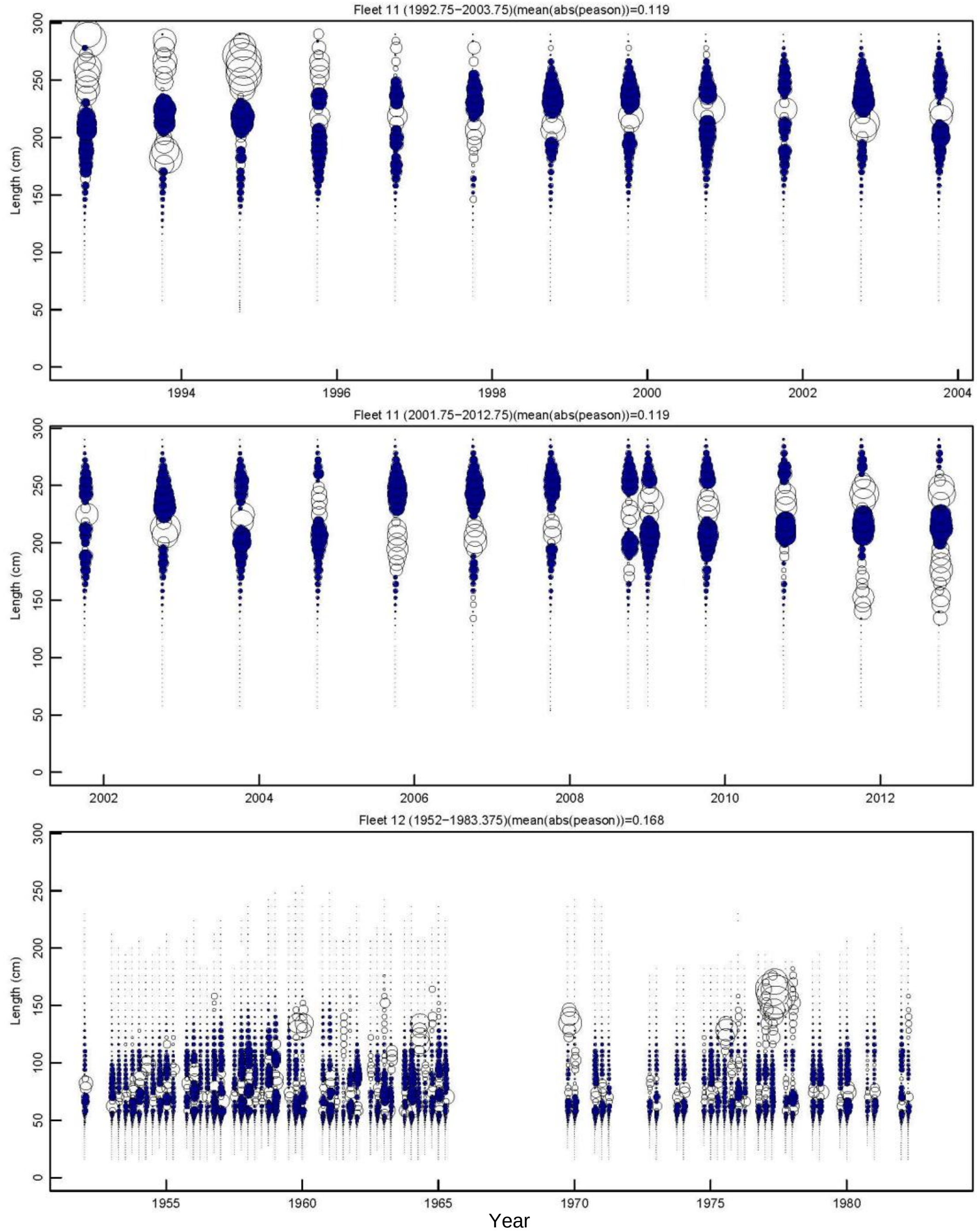


Figure 5-5. (continued).

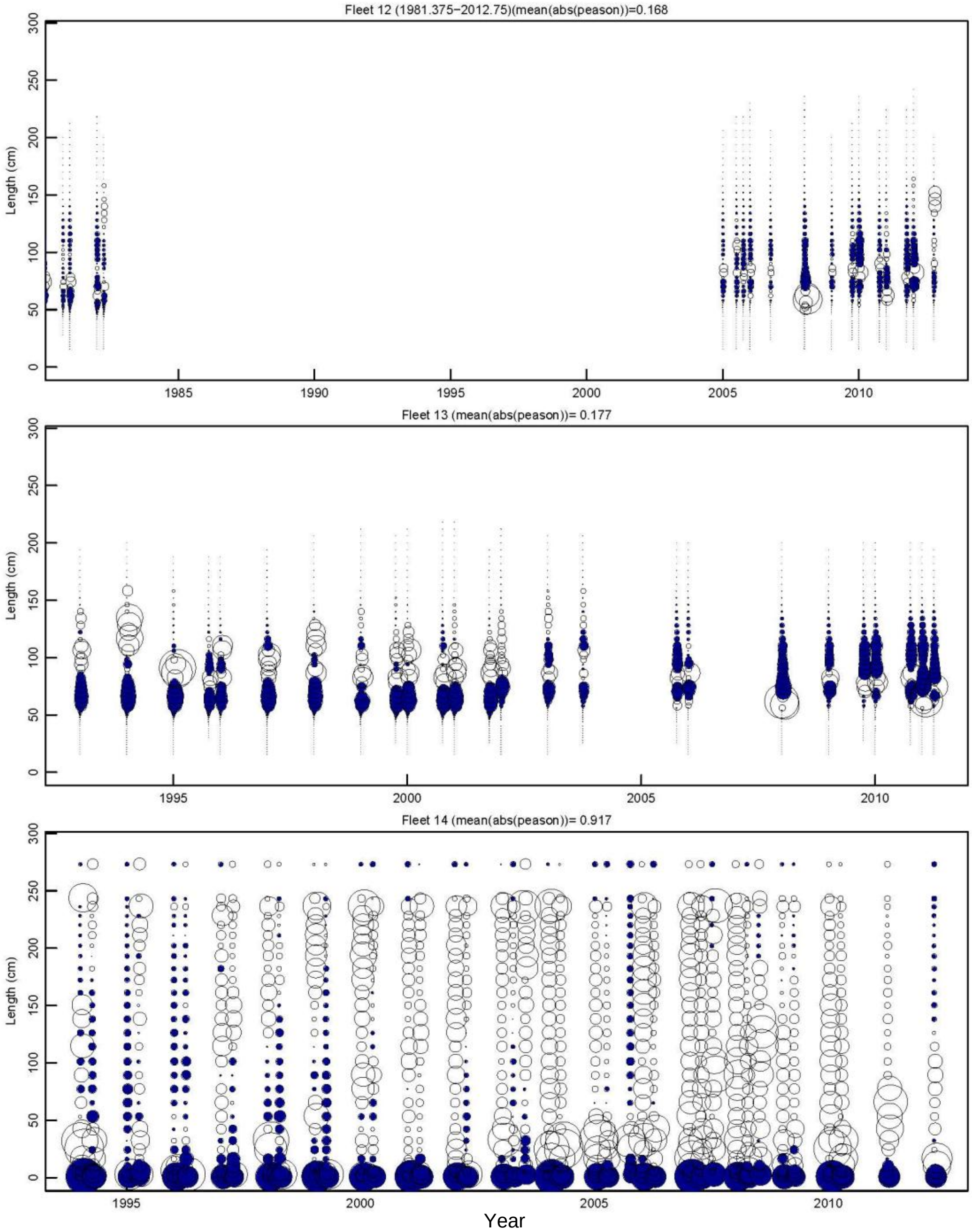


Figure 5-5. (continued).

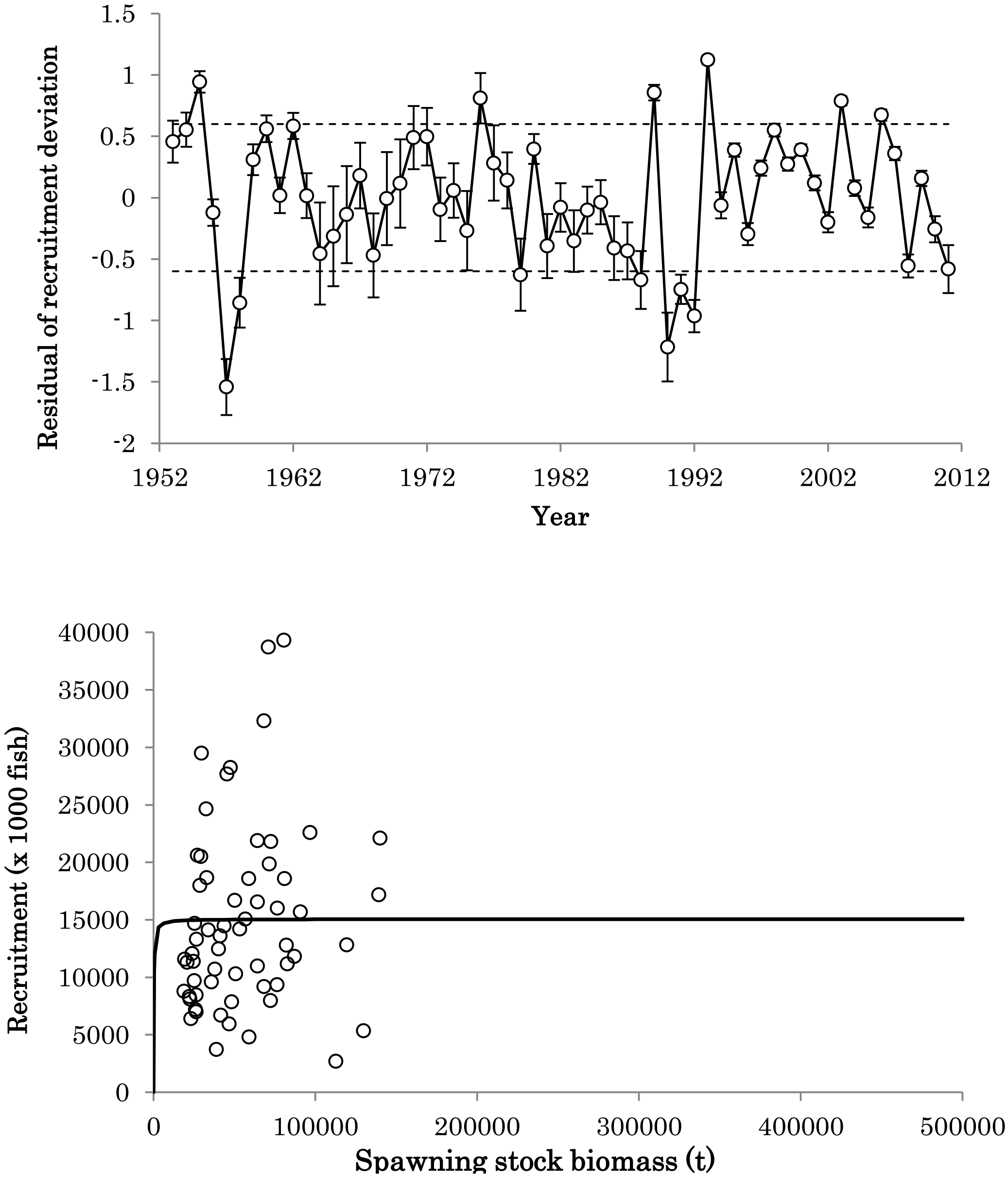


Figure 5-6. Residuals of recruitment deviation. Top: temporal dynamics of observed value (R deviation). The dashed line indicates mean. Dotted lines indicate σ and $-\sigma$. Small dotted lines indicate 2σ and -2σ. Bottom: Stock and recruitment plots. The line indicates the Beverton-Holt relationship based on steepness h=0.999 used for the base case.

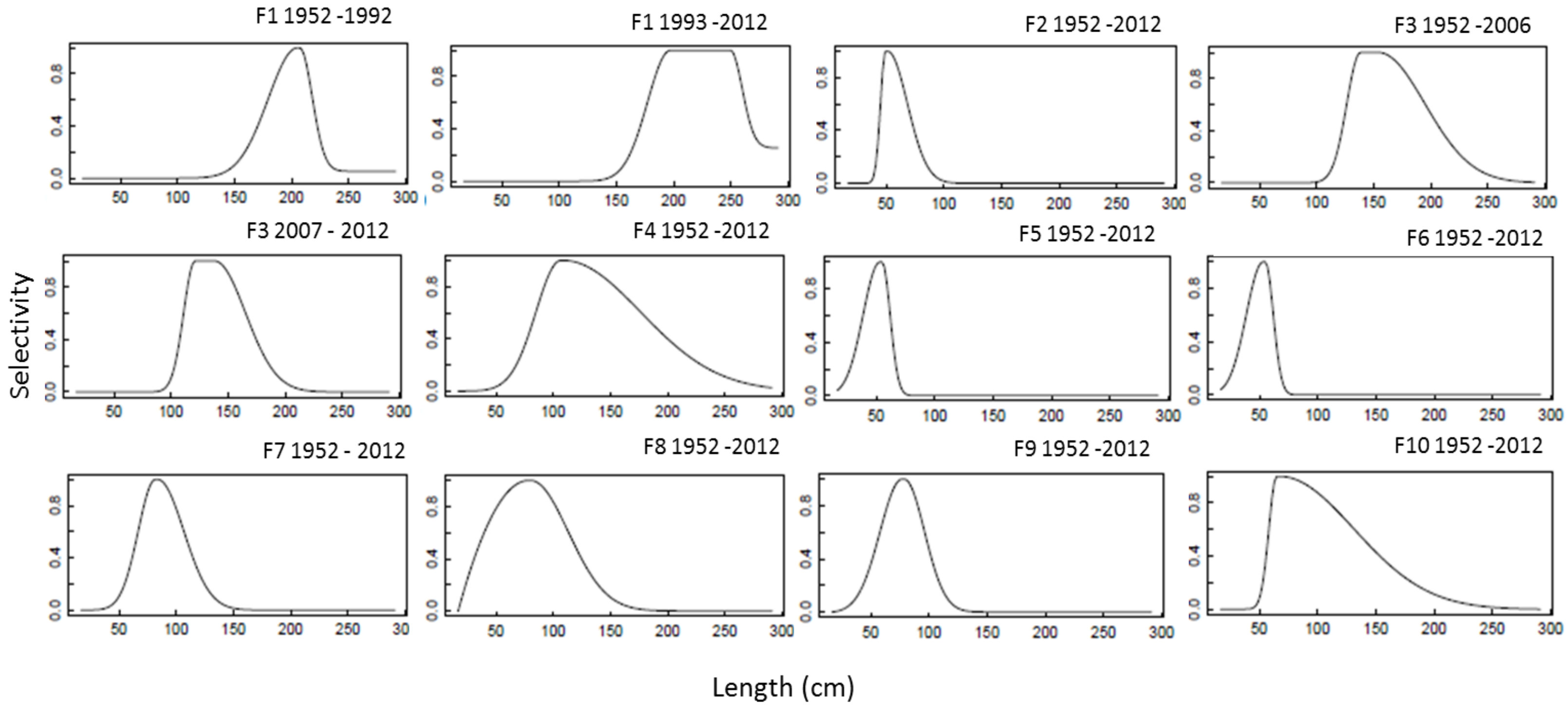


Figure 5-7. Estimated length-based selectivity curves of PBF by fleet from the base case.

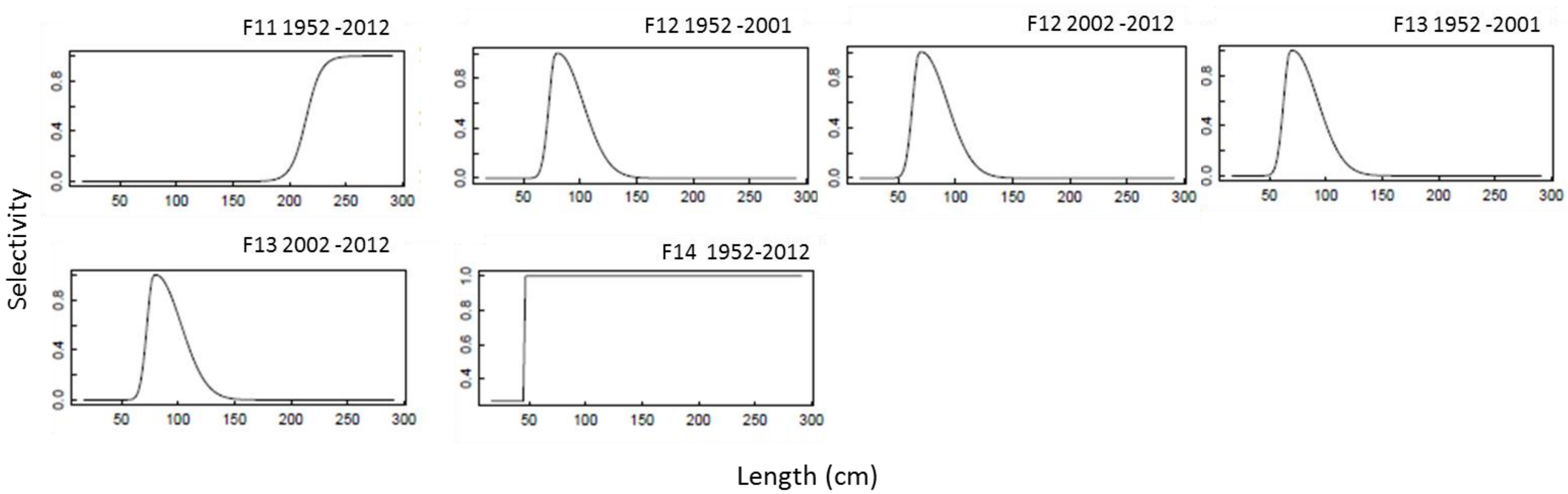


Figure 5-7. (continued)

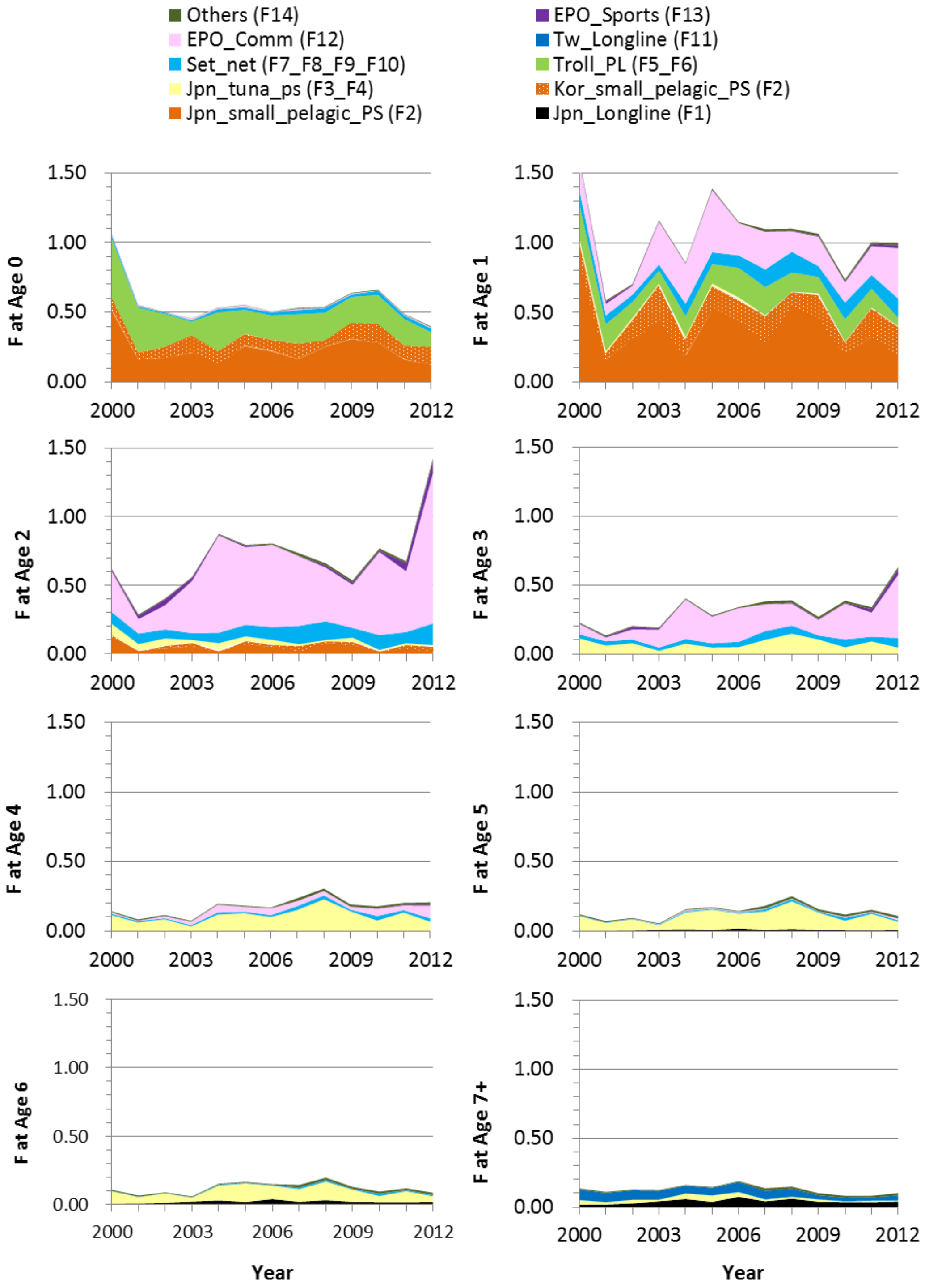


Figure 5-8. Estimated annual fishing mortality by gear in each age from 2000 to 2012. The fishing mortality of Fleet 2 (small pelagic purse seine) is divided into two gears (JP PS and KOR PS) in accordance with the contributions of catch in each country.

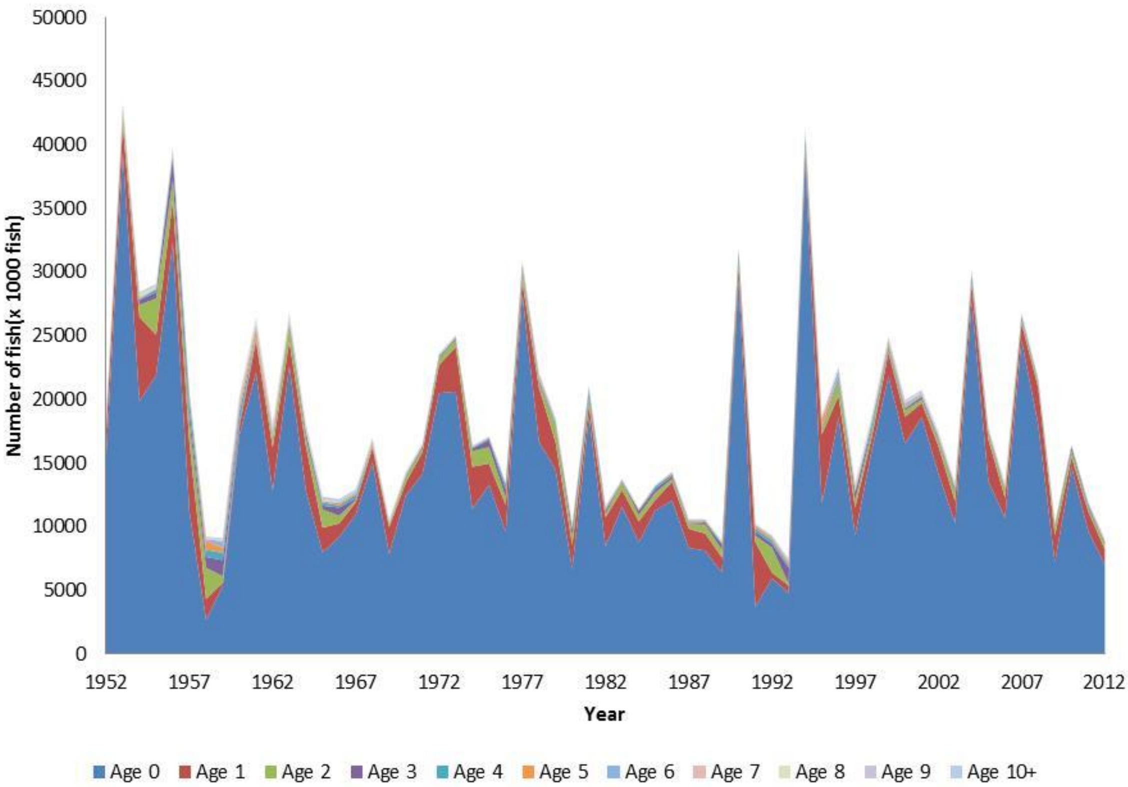
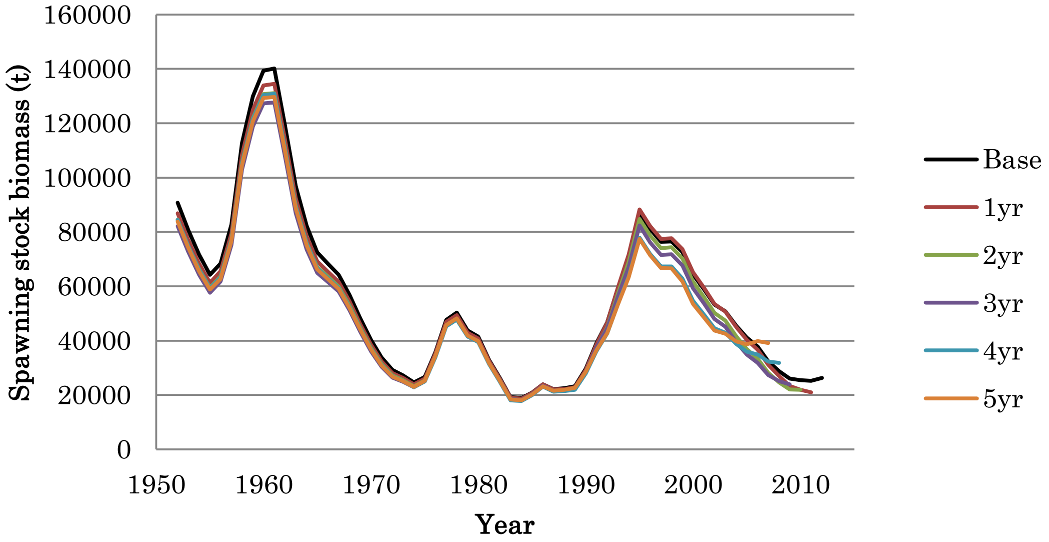


Figure 5-9. Annual numbers-at-age of PBF estimated by the base case.



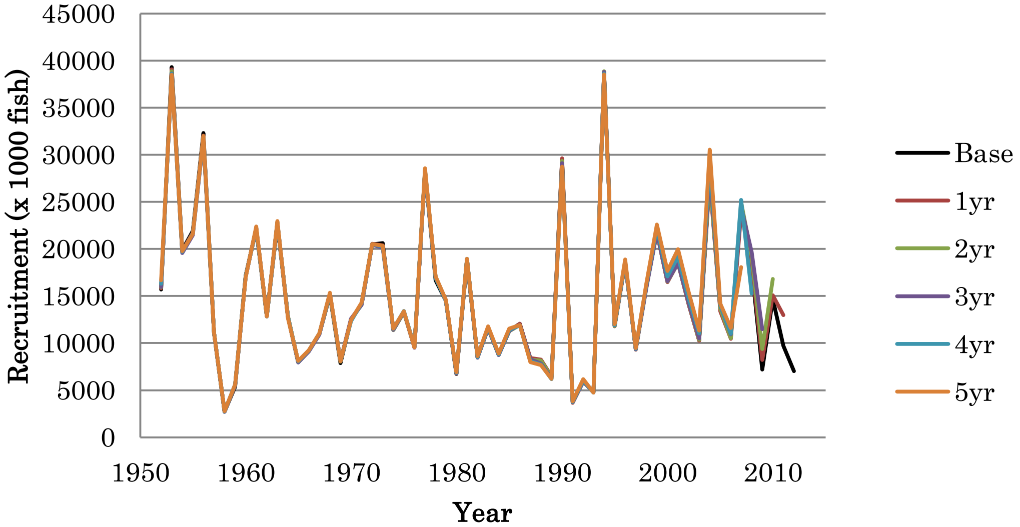


Figure 5-10. Plots of retrospective (five year) analysis for SSB and recruitment for the update stock assessment model.

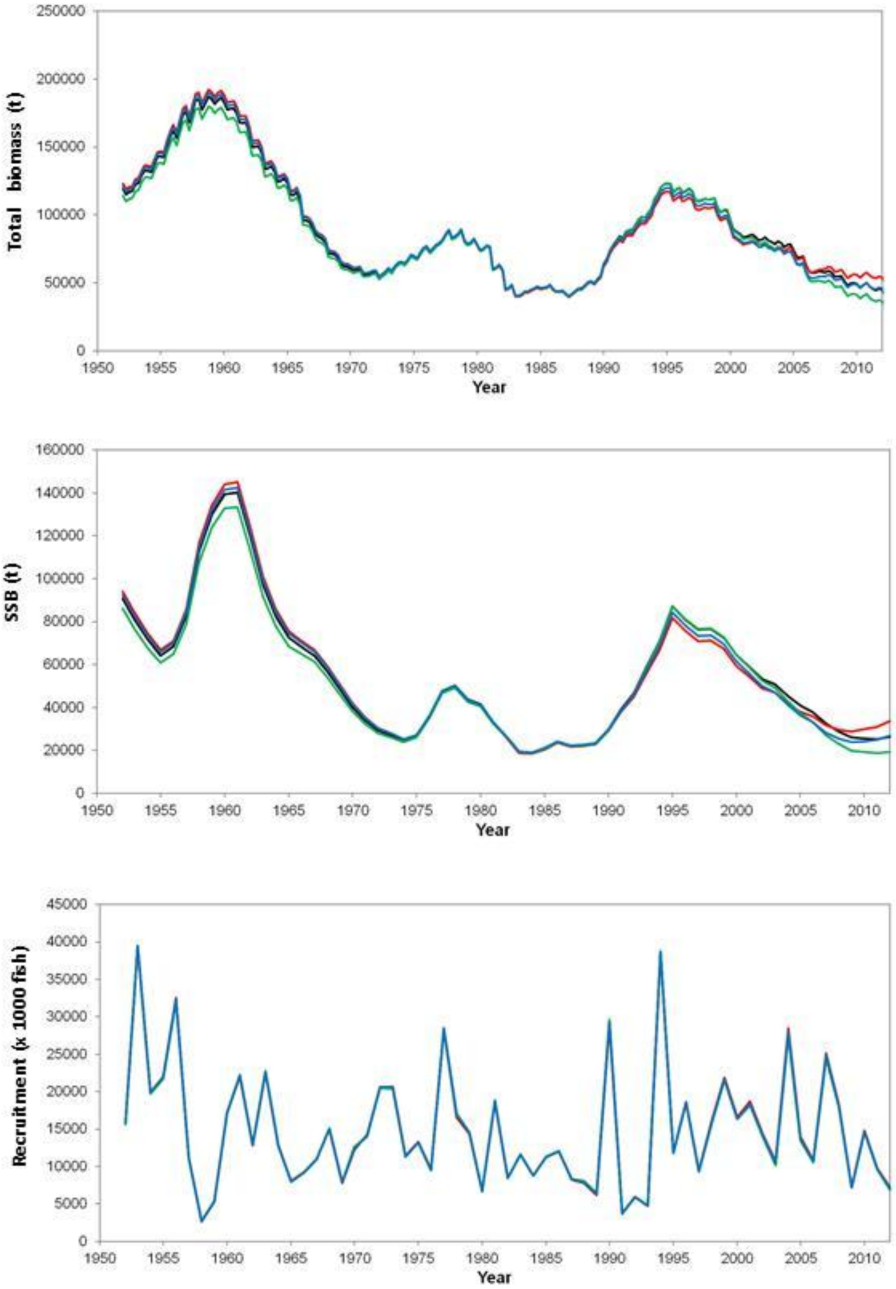


Figure 5-11. Total stock biomass (TSB, upper panel), spawning stock biomass (SSB, middle panel) and recruitment (lower panel) estimated from four runs. Black, red, green and blue lines indicate Runs 1through 4, respectively.

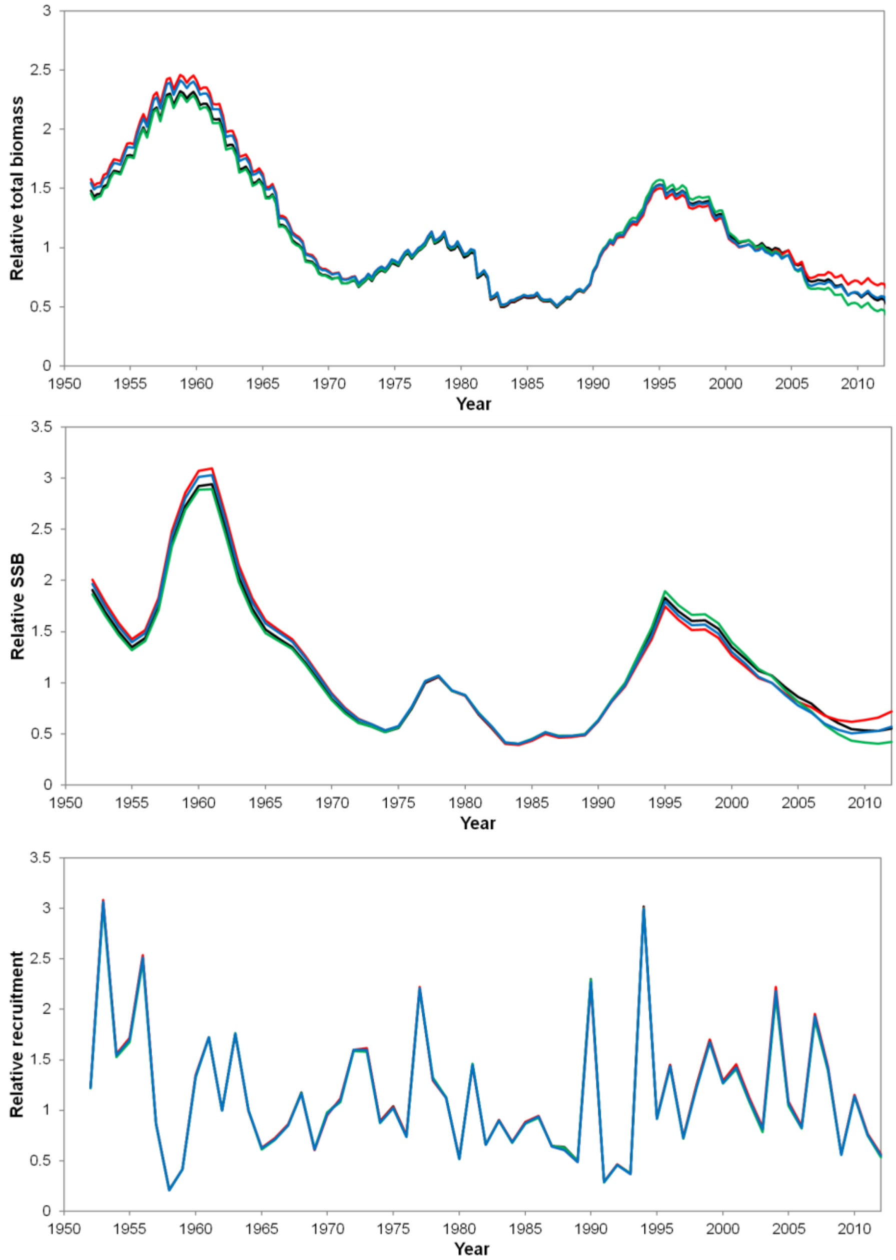


Figure 5-12. Relative values of total stock biomass (TSB, upper panel), spawning stock biomass (SSB, middle panel) and recruitment (lower panel) estimated from four runs. Black, red, green and blue lines indicate Runs 1through 4, respectively.

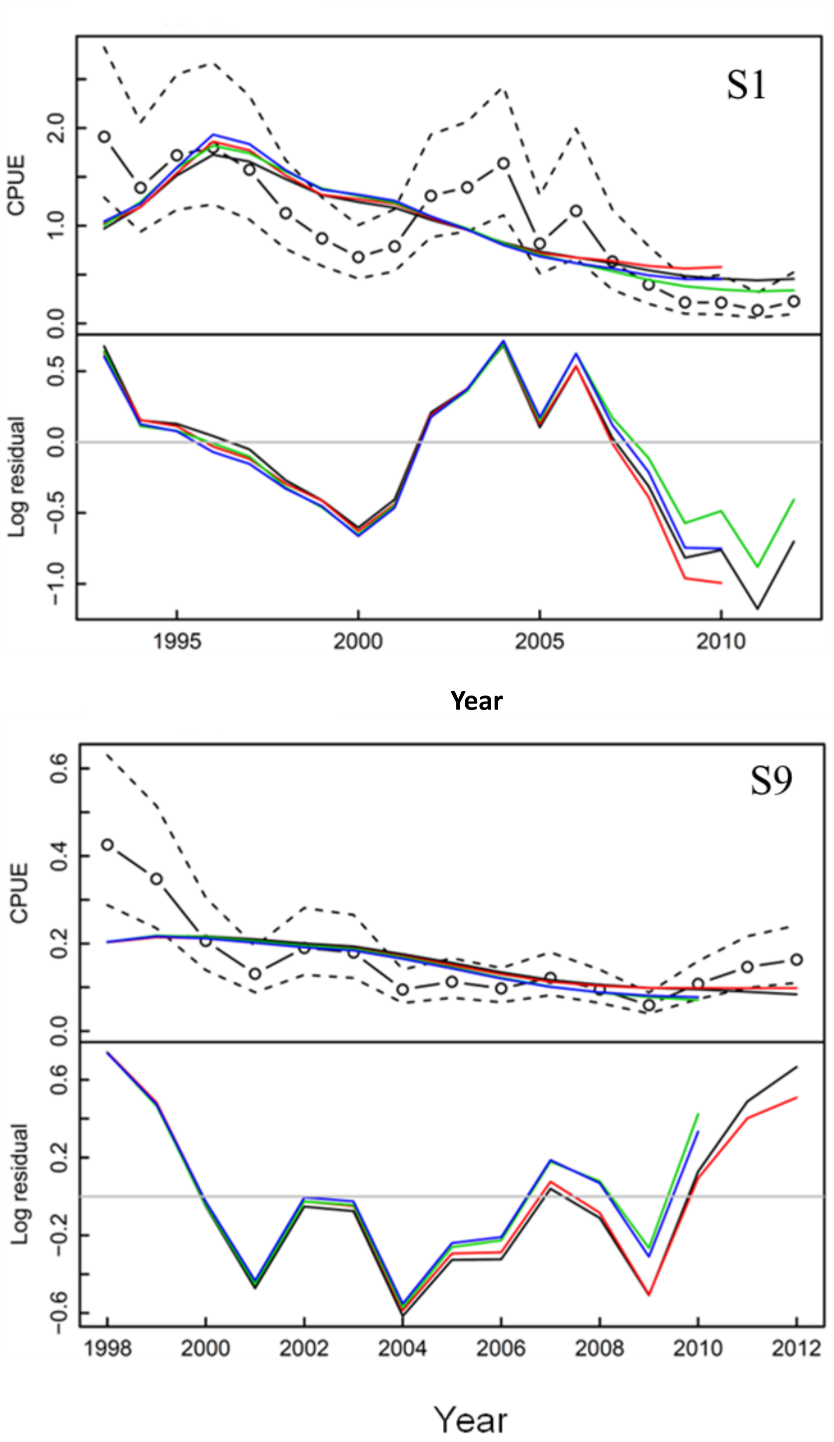


Figure 5-13. Observed CPUE time series and predicted CPUE time series from each sensitivity run and logarithm of residual for each year. Black, red, green and blue lines indicate Runs 1through 4, respectively. Upper panel, S1; Lower panel, S9.

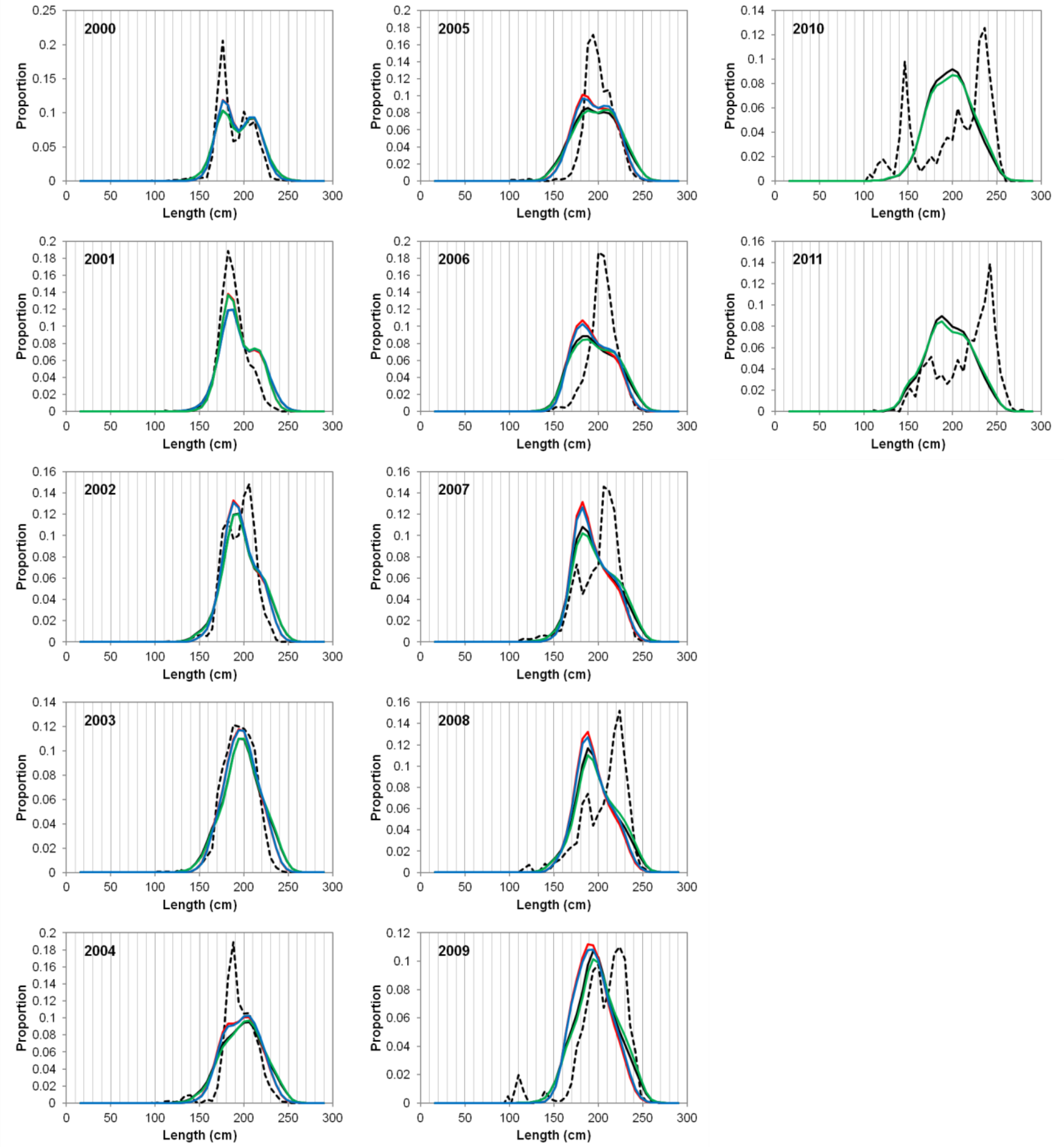


Figure5-14. Fits of predicted quarterly length composition of fourth quarter of 2000 through 2011 and 2000 through 2012 (continuation page) for F1 and F11, respectively, from each sensitivity runs to the observed length composition. Dashed line indicates observed length composition. Black, red, green and blue lines indicate length compositions from Runs 1through 4, respectively.

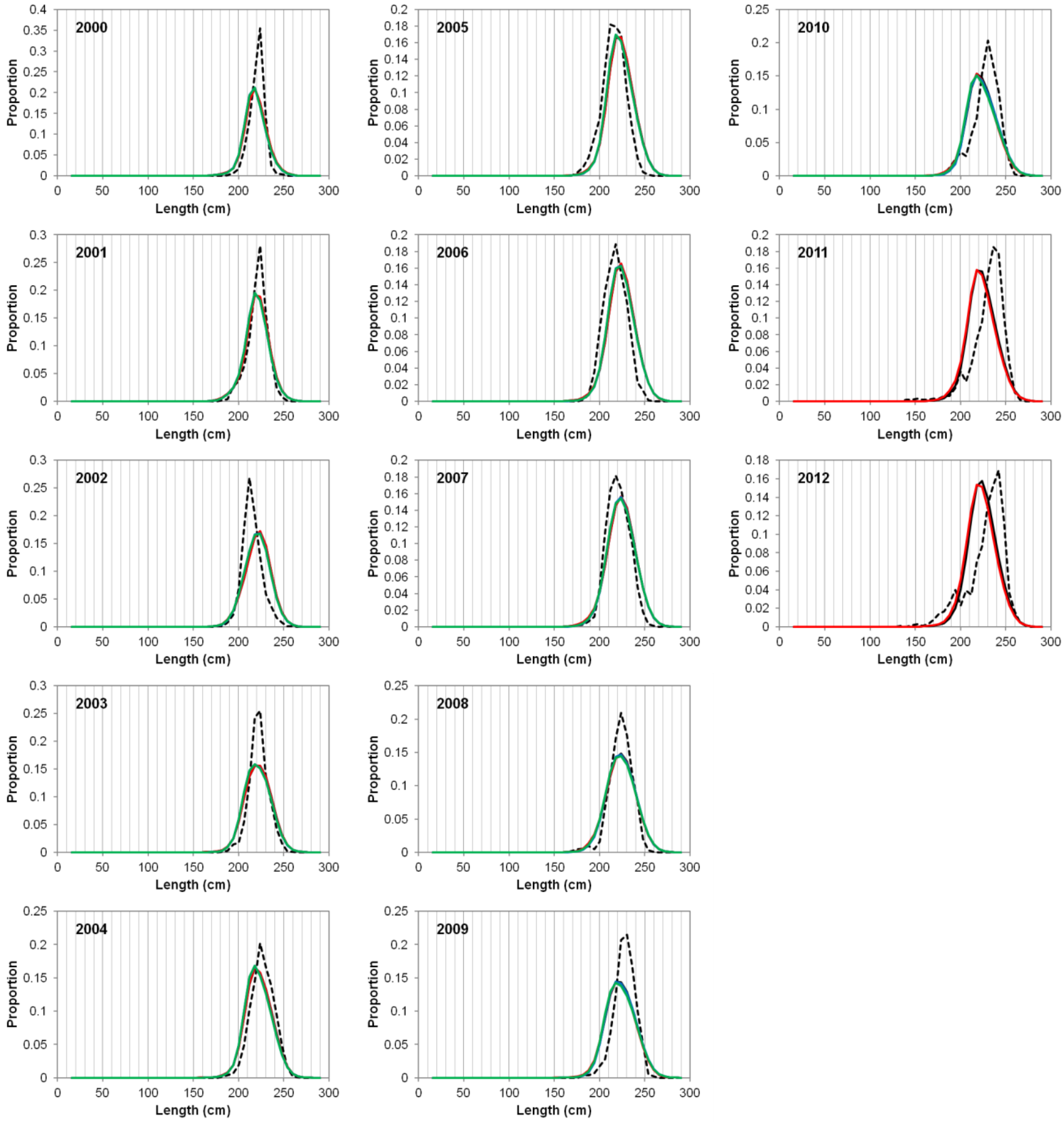


Figure 5-14. (continued).

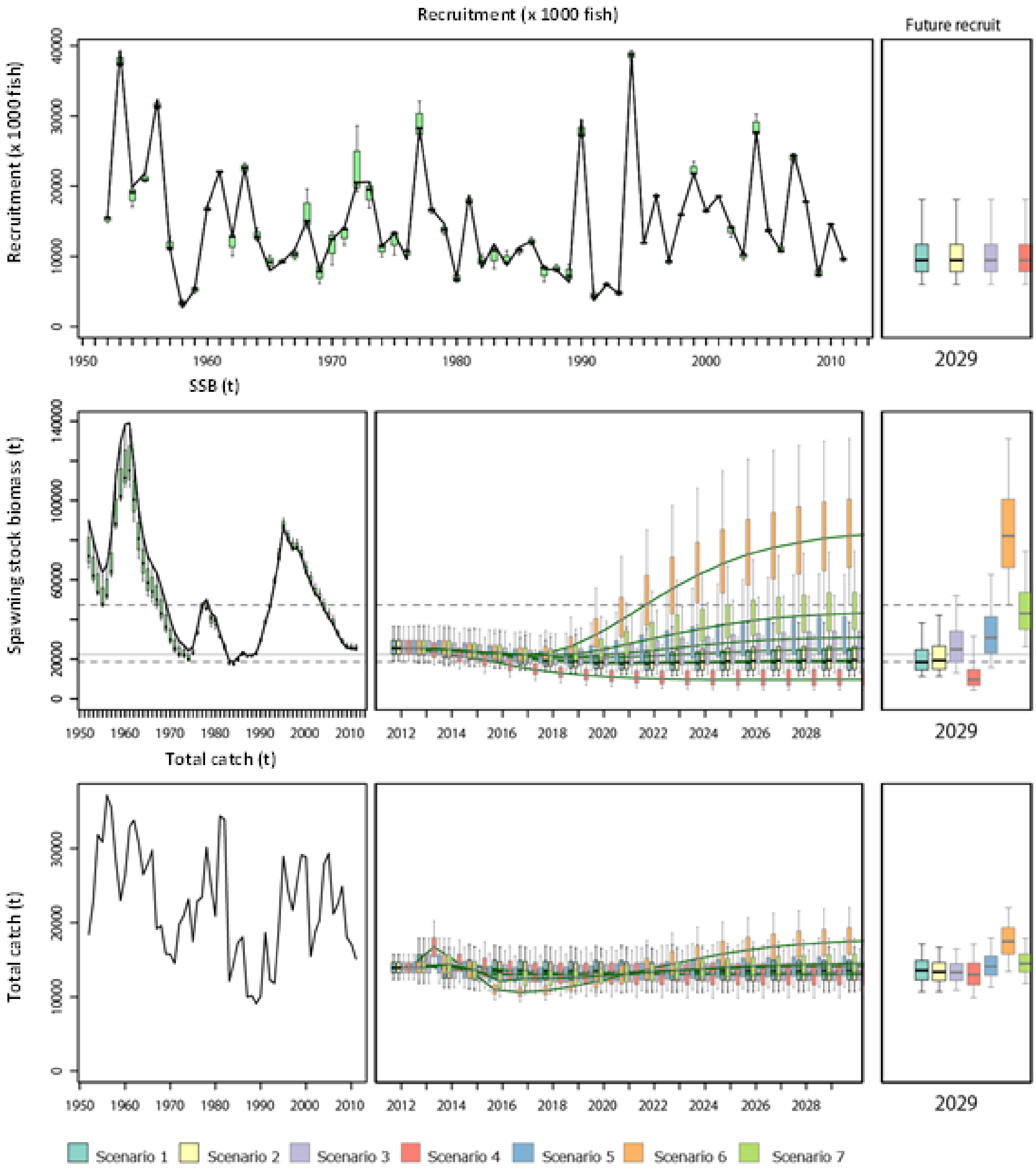


Figure 5-15. Comparison of future SSB trajectories in seven harvest scenarios under low recruitment conditions. Error bars represent 90% confidence limits.

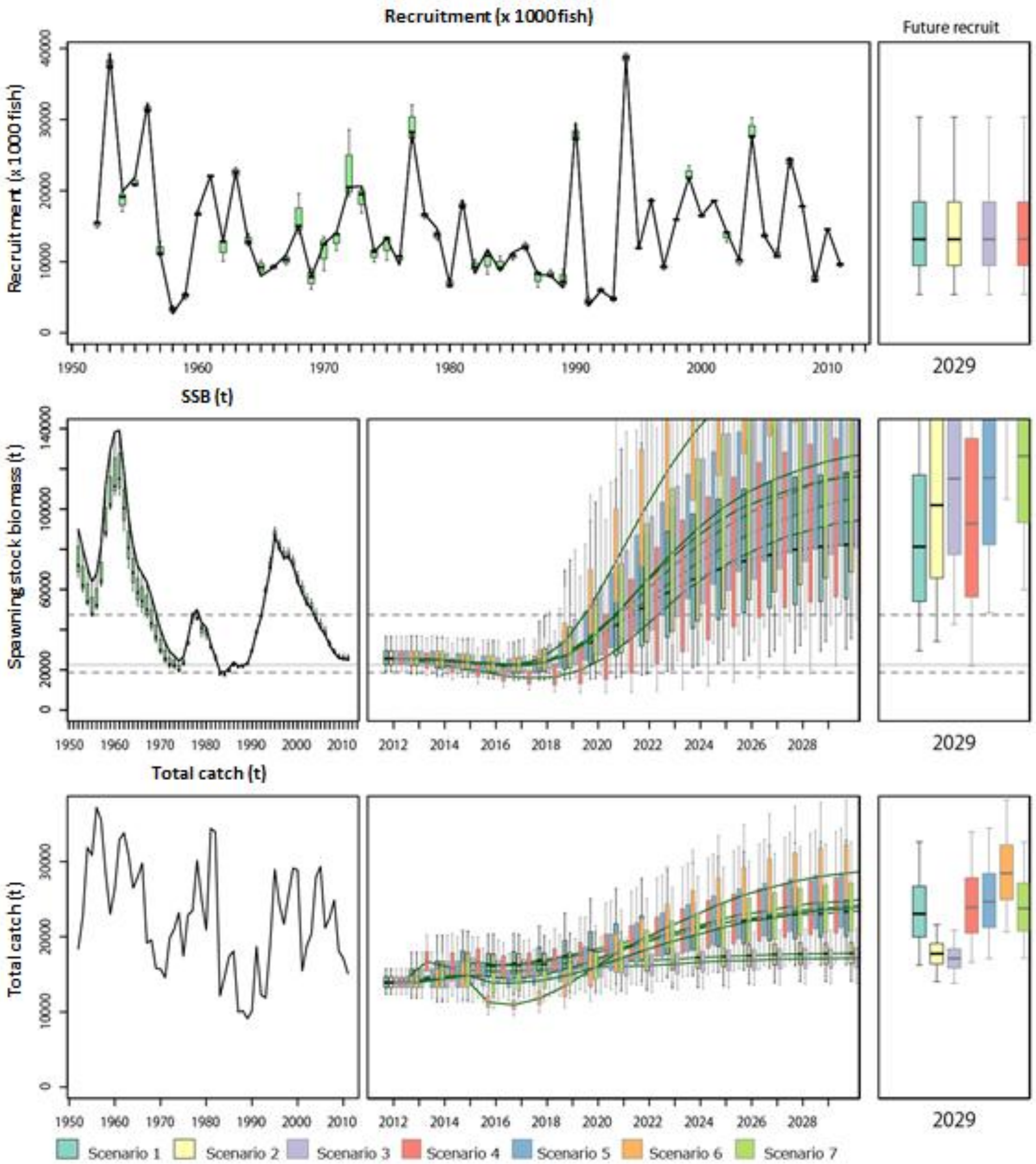


Figure 5-16. Comparison of future SSB trajectories in seven harvest scenarios under average recruitment conditions (resampling from recruitment in 1952-2011). Error bars represent 90% confidence limits.

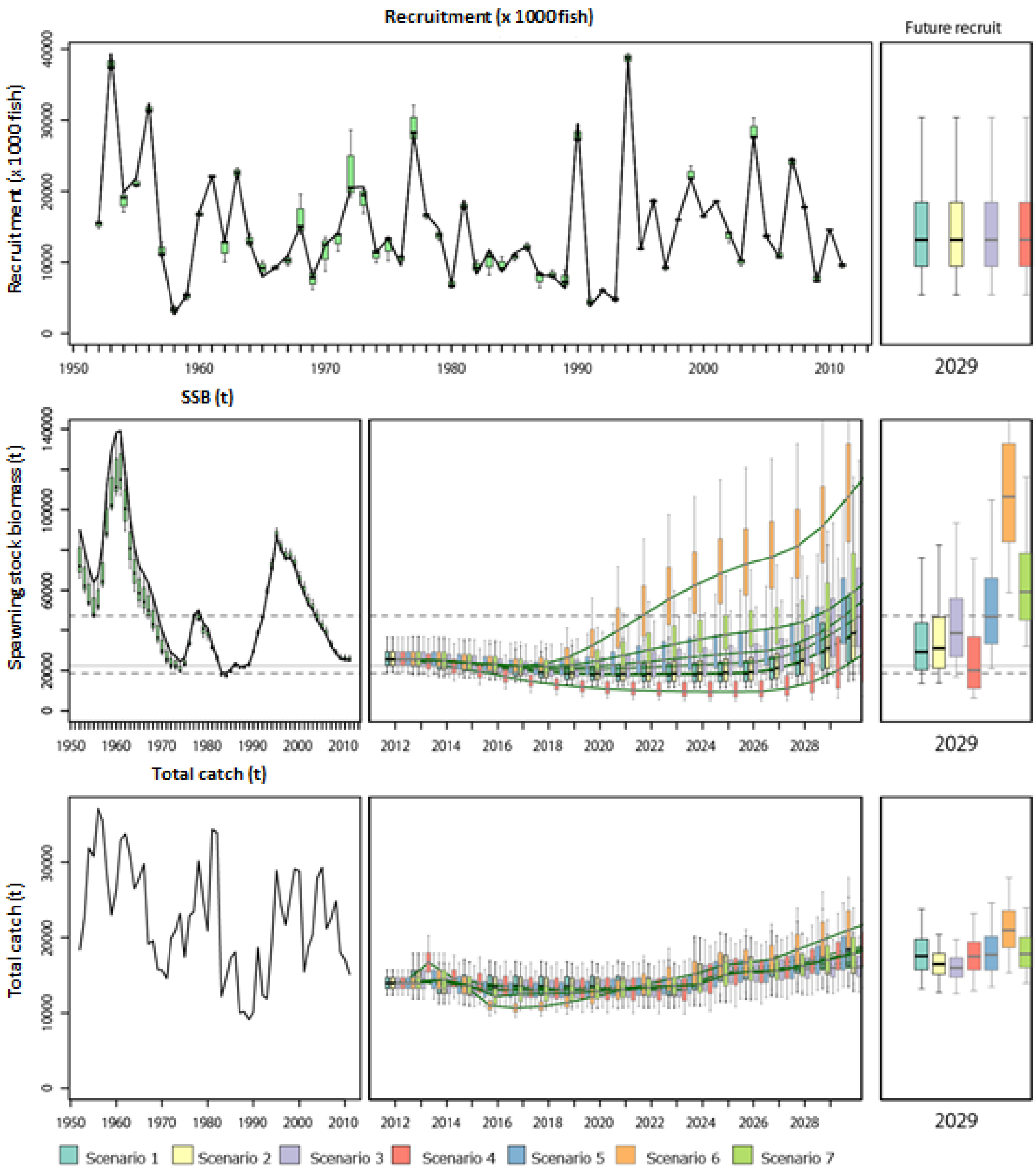


Figure 5-17. Comparison of future SSB trajectories in seven harvest scenarios under 10 years (2014-2023) of low recruitment conditions followed by average recruitment conditions after 2024 (resampling from recruitment in 1952-2011). Error bars represent 90% confidence limits.

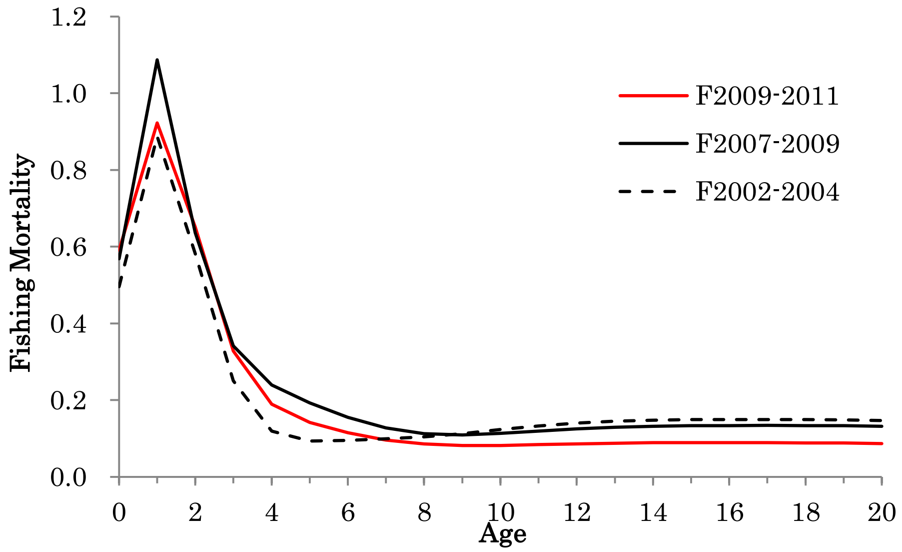


Figure 6-1. Geometric mean annual age-specific fishing mortalities for 2002-2004 (dashed line), 2007-2009 (solid line) and 2009-2011 (red line).

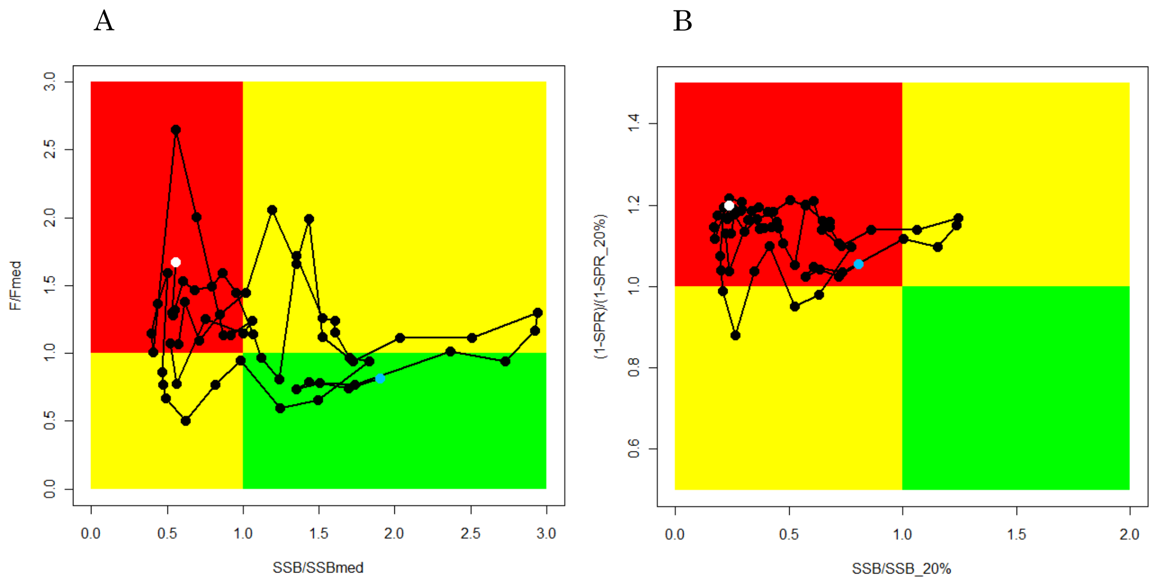


Figure 6-2. Alternative Kobe plots for Pacific bluefin tuna (*Thunnus orientalis*). A. SSB_{med} and F_{med}; B. $SSB_{20\%}$ and $SPR_{20\%}$. Citation of these Kobe plots should include clarifying comments in the text. The blue and white points on the plots show the start (1952) and end (2012) year of the period modeled in the stock assessment respectively.

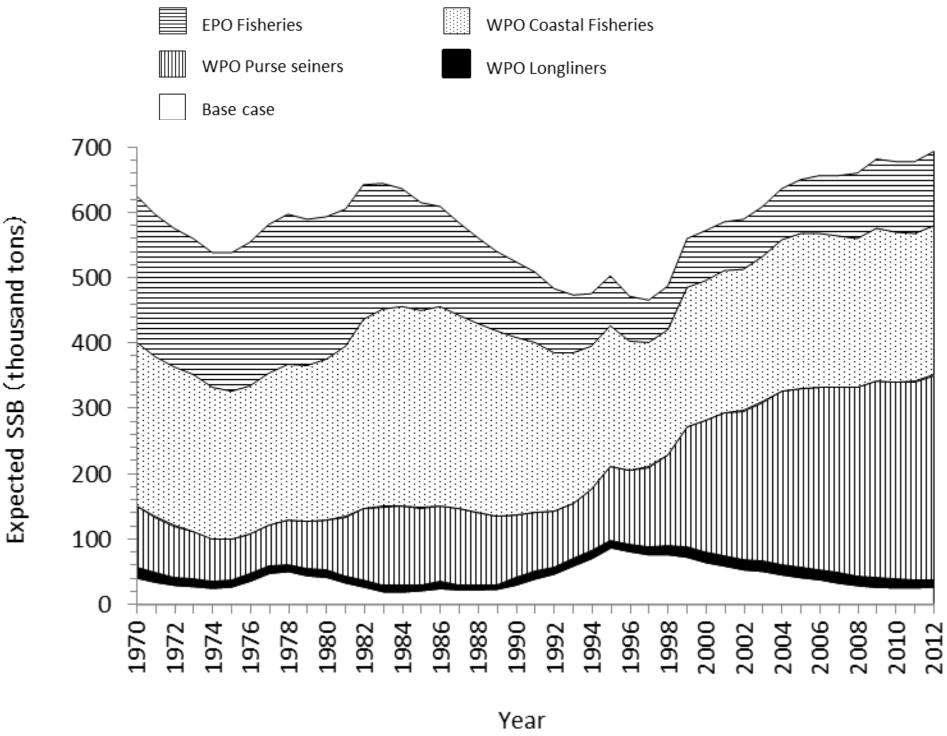


Figure 6-3. Trajectory of the spawning stock biomass of a simulated population of Pacific bluefin tuna (*Thunnus orientalis*) that was unexploited (topmost line) and that predicted by the base case (white area). The shaded areas between the two lines show the proportions of impact of each fishery.

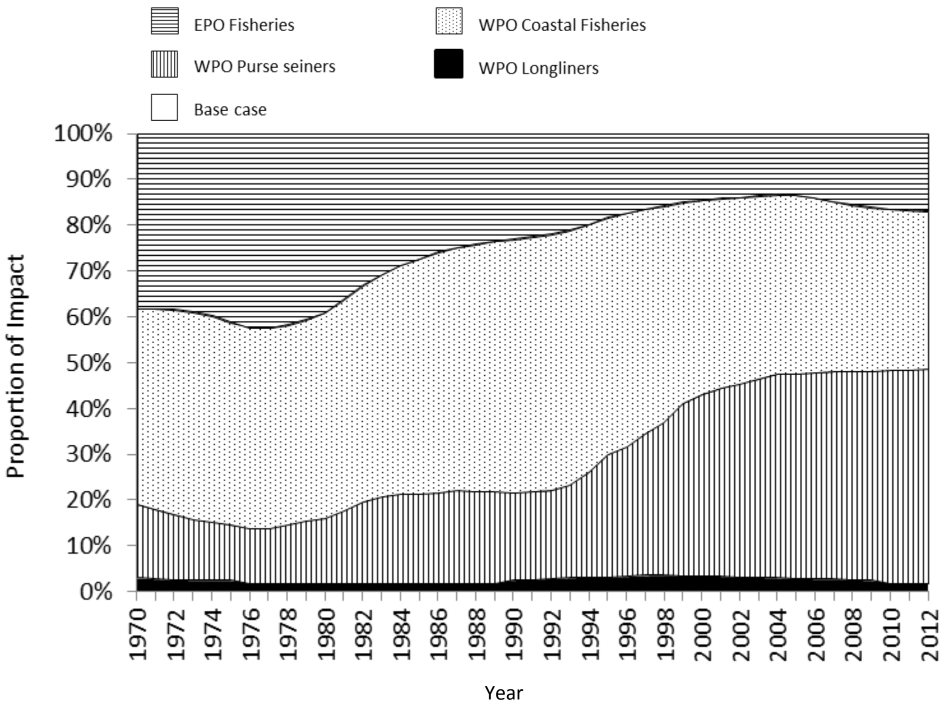


Figure 6-4. The proportion of the impact on the Pacific Bluefin tuna (*Thunnus orientalis*) spawning stock biomass by each group of fisheries.