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Stock Assessment of Pacific Bluefin Tuna in 2012

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ISC 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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PACIFIC BLUEFIN TUNA WORKING GROUP

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*) is a single Pacific-wide stock that is 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 their juvenile stage in the EPO before returning to the WPO.

2. Catch History

While historical Pacific bluefin tuna (PBF) catch records are scant, PBF landing records from coastal Japan date back to as early as 1804 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 59,000 mt (47,000 mt in the WPO and 12.000 mt in the EPO) in 1935; thereafter estimated catches of PBF dropped precipitously due to WWII. Estimated 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 annual catches of PBF fluctuated widely from 1952-2011 (Figure 1). During this period reported catch peaked at 40,383 mt in 1956 and reached a low of 8,653 mt in 1990. While a suite of fishing gears catch PBF, the majority are caught in purse seine fisheries (Figure 2). Historical catches (1952-2011) are predominately comprised of juvenile PBF, and 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 v3.23b; SS) fitted to catch, size composition and catch-per-unit of effort (CPUE) data from 1952 to 2011 provided by ISC Pacific Bluefin Tuna Working Group (PBFWG) members. Life history parameters included a length-at-age relationship from otolith-derived ages and natural mortality estimates from a tag-recapture study.

A total of 14 fisheries were defined for use in the stock assessment model based on country/gear stratification. Quarterly observations of catch and (when available) size composition were inputs into the model to describe the removal processes. Annual estimates of standardized CPUE from the Japanese distant water and coastal longline, Taiwanese longline and Japanese troll fleets were used as measures of population relative abundance. 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 recognized uncertainties in standardized CPUE series, the procedures used to weight data inputs (catch, CPUE, 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 20 different models, each with alternative data weightings and structural assumptions (Table 1). While no single model scenario provided a good fit to all sources of data deemed reliable, there was general agreement among all scenarios in terms of the key model results; long-term fluctuations in spawning stock biomass (SSB) occurred throughout the assessment period (1952-2011) and SSB in recent years has been declining for over a decade, however, there is no evidence of reduced recruitment (Figures 4 & 5). Age-specific fishing mortality has increased 8-41% in the recent period (2007-2009) relative to the baseline period (2002-2004) used in recent CMMS by the WCPFC and the IATTC.

4. Status of Stock

The model configuration associated with Run 2 was chosen as the base-case assessment model to determine stock status and provide management advice, acknowledging that while it represents the general conclusions above, the model was unable to reconcile all key data sources (Figure 6). Based on the trajectory of the base-case model stock biomass (age 0+) and SSB are estimated to be 53,216 mt and 22,606 mt, respectively, in 2010. The recent 5-year average level of recruitment (2006-2010, calendar year) was 15.6 million fish. Estimated age-specific fishing mortalities on the stock in the recent period (2007-2009) relative to 2002-2004 (the base period for the current WCPFC conservation and management measure 2010-04) show 4,17, 8, 41 and 10% increases for ages 0,1,2,3 and 4+, respectively (Figure 7). Although no target or limit reference points have been established for the Pacific bluefin tuna stock under the auspices of the WCPFC and IATTC, the current F (average 2007-2009) is above all target and limit biological reference points (BRPs) commonly used by fisheries managers (Table 2), and the ratio of SSB in 2010 relative to unfished SSB is low (Table 3).

Stock projections of spawning biomass and catches of Pacific bluefin tuna from 2011 to 2030 were conducted assuming four alternative harvest scenarios. A quarterly based age-structured simulation model was used for the projections, and included uncertainty in the population size-at-age at the starting year of stock projection (2011), fishing mortality at age, and future recruitment levels. Future recruitments used in the projections were randomly resampled from the dynamic period (1952-2009). Six thousand future projection simulations (300 SS bootstrap runs with 20 stochastic simulations each) were conducted for each of the harvest scenarios.

The four harvest scenarios analyzed were: (1) constant fishing mortality at current *F* ($F_{2007\text{-}2009}$); (2) constant fishing mortality at $F_{2002\text{-}2004}$; (3) constant fishing mortality at $F_{2007\text{-}2009}$ and setting catch limitations on purse seine fleets in the EPO and WPO; and (4) constant fishing mortality at $F_{2002\text{-}2004}$ and setting catch limitations on purse seine fleets in the EPO and WPO. Projection results are shown in Figure 8.

The future projections indicate that:

(1) The median SSB is not expected to increase recover substantially from the present median SSB in Scenario (1);

(2) The median SSB is expected to increase to approximately 41,000 mt by 2030 in Scenario (2);

(3) The median SSB is expected to increase to approximately 50,000 mt by 2030 in Scenario (3); and

(4) The median SSB is expected to increase substantially to approximately 83,000 mt by 2030 in Scenario (4).

In summary, based on the reference point ratios, overfishing is occurring (Table 2) and the stock is overfished. Model estimates of 2010 spawning stock biomass (SSB) are at or near their lowest level and SSB has been declining for over a decade; however, there is no evidence of reduced recruitment.

5. Conservation Advice

The current (2010) PBF biomass level is near historically low levels and experiencing high exploitation rates above all biological reference points (BRPs) commonly used by fisheries managers. Based on projection results, extending the status quo (2007-2009) fishing levels is unlikely to improve stock status.

Recently WCPFC[1] (entered into force in 2011) and IATTC[2] (entered into force in 2012) conservation and management measures combined with additional Japanese voluntary domestic regulations aimed at reducing mortality[3], if properly implemented and enforced, are expected to contribute to improvements in PBF stock status. Based on those findings, it should be noted that implementation of catch limits is particularly effective in increasing future SSB when strong recruitment occurs. It is also important to note that if recruitment is less favorable, a reduction of F could be more effective than catch limits to reduce the risk of the stock declining.

The ISC requires advice from the WCPFC regarding which reference point managers prefer so that it can provide the most useful scientific advice. Until which time a decision is rendered, the ISC will continue to provide a suite of potential biological reference points for managers to consider.

[1]WCPFC CMM 2010-04 specifies that "… total fishing effort by their vessels fishing for Pacific bluefin tuna in the area north of the 20 degrees north shall stay below the 2002-2004 levels for 2011 and 2012, except for artisanal fisheries. Such measures shall include those to reduce catches of juveniles (age 0-3) below the 2002-2004 levels, except for Korea. Korea shall take necessary measures to regulate the catches of juveniles (age 0-3) by managing Korean fisheries in accordance with this CMM. CCMs shall cooperate for this purpose." For full text see: http://www.wcpfc.int/node/3407

[2]IATTC Resolution C-12-09 specifies that "… 1. In the IATTC Convention Area, the commercial catches of bluefin tuna by all the CPCs during the two-year period of 2012-2013 shall not exceed 10,000 metric tons; 2. The commercial catch of bluefin tuna in the commercial fishery in the Convention Area shall not exceed 5,600 metric tons during the year 2012; 3. Notwithstanding paragraphs 1 and 2, 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." For full text see: iattc.org/PDFFiles2/Resolutions/C-12-09-Conservation-of-bluefin-tuna.pdf

[3] This is described in WCPFC-NC8-2012/DP-01. For full text see; http://www.wcpfc.int/system/files/documents/meetings/northern-committee/8th-regular-session/delegation-proposals-and-papers/NC8-DP-01-%5BEXPLANATION-AND-IMPLEMENTATION-CMM-2010-04%5D.pdf

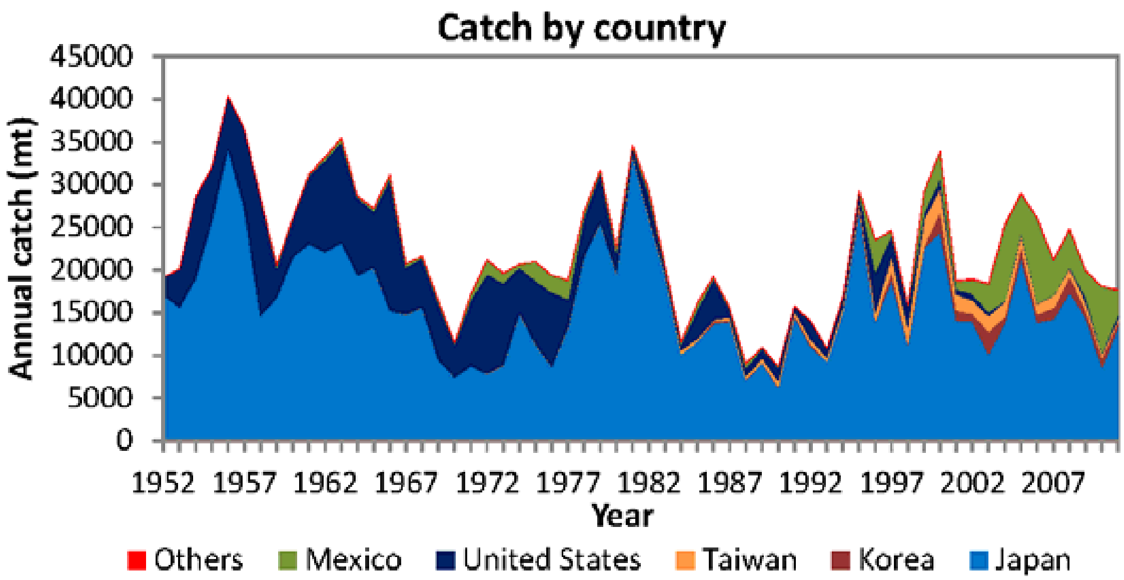

Figure 1. Historical annual catch of Pacific bluefin tuna by country, 1952-2011 (data in calendar year 1952 and 2010 are incomplete).

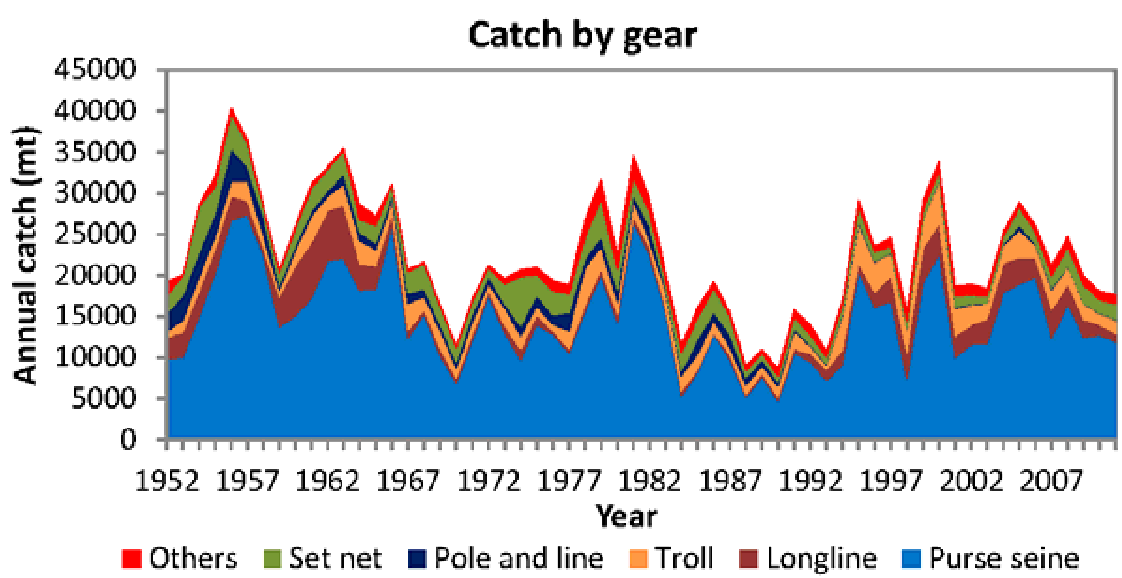

Figure 2. Historical annual catch of Pacific bluefin tuna by gear, 1952-2011 (data in calendar year 1952 and 2010 are incomplete).

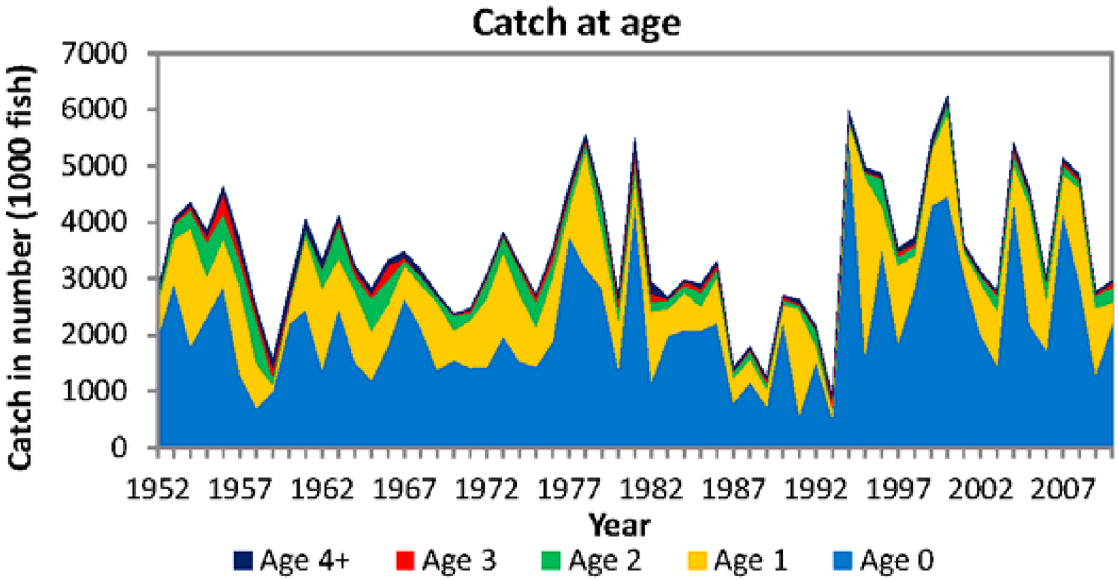

Figure 3. Historical annual catch-at-age of Pacific bluefin tuna in 1952-2011.

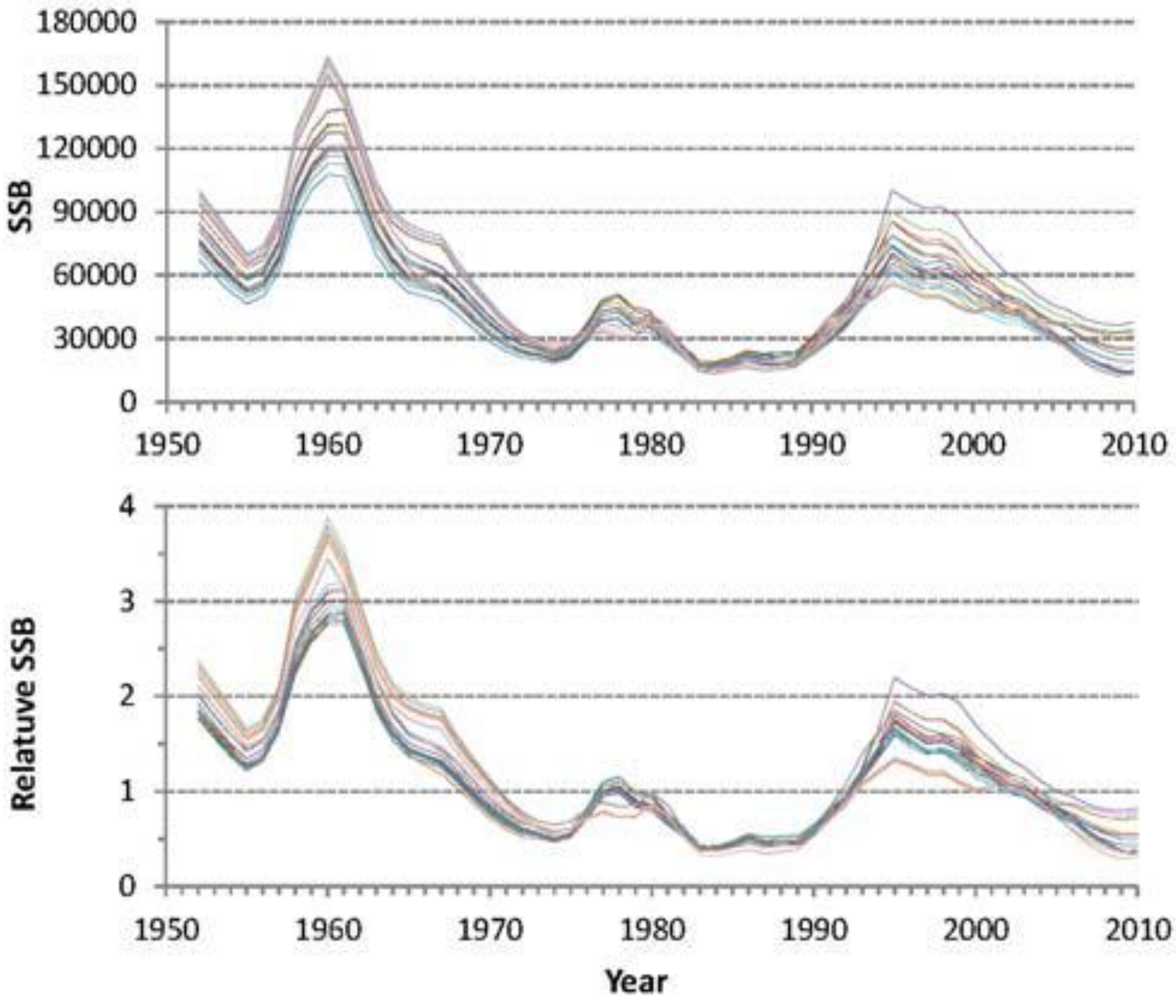

Figure 4. Absolute and relative spawning stock biomass (SSB) (mt) estimated for 20 trial runs with different combination of parameters (see Table 1). Relative time series are calculated by dividing absolute SSB by the respective median values of each run.

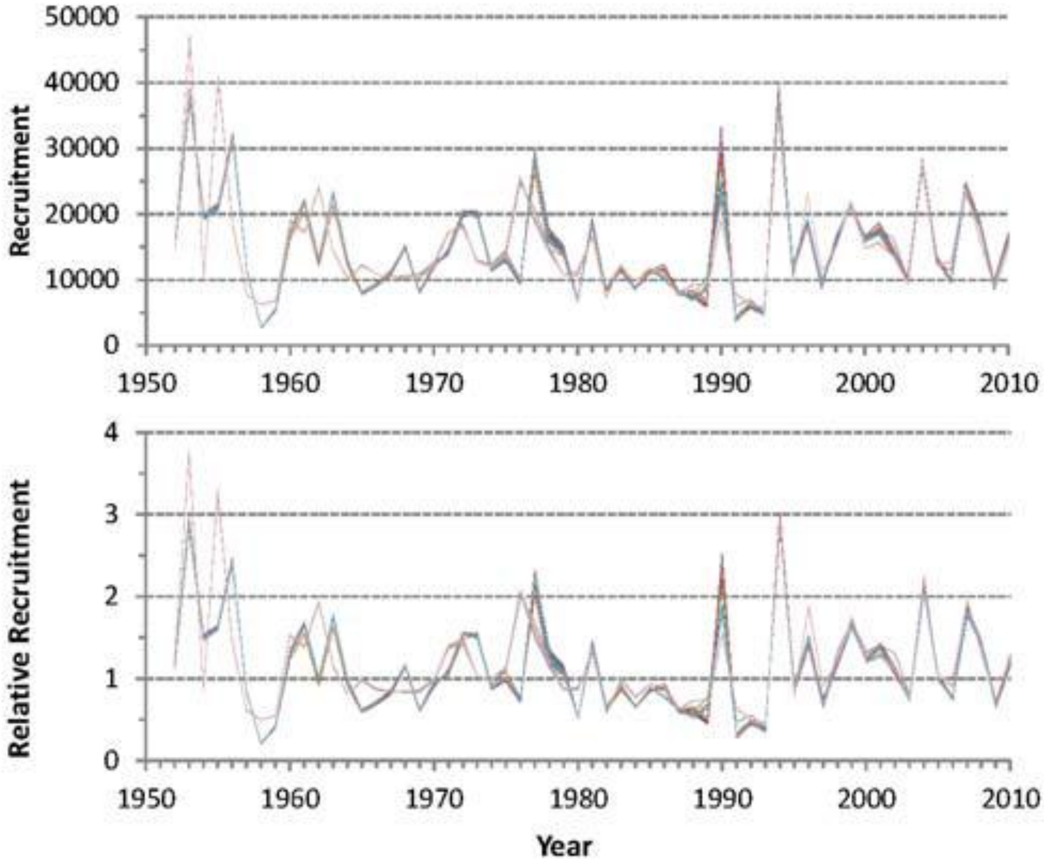

Figure 5. Absolute and relative recruitment (thousands of fish) estimated for 20 trial runs with different combination of parameters (see Table 1). Relative time series are calculated by dividing absolute recruitment by the respective median values of each run.

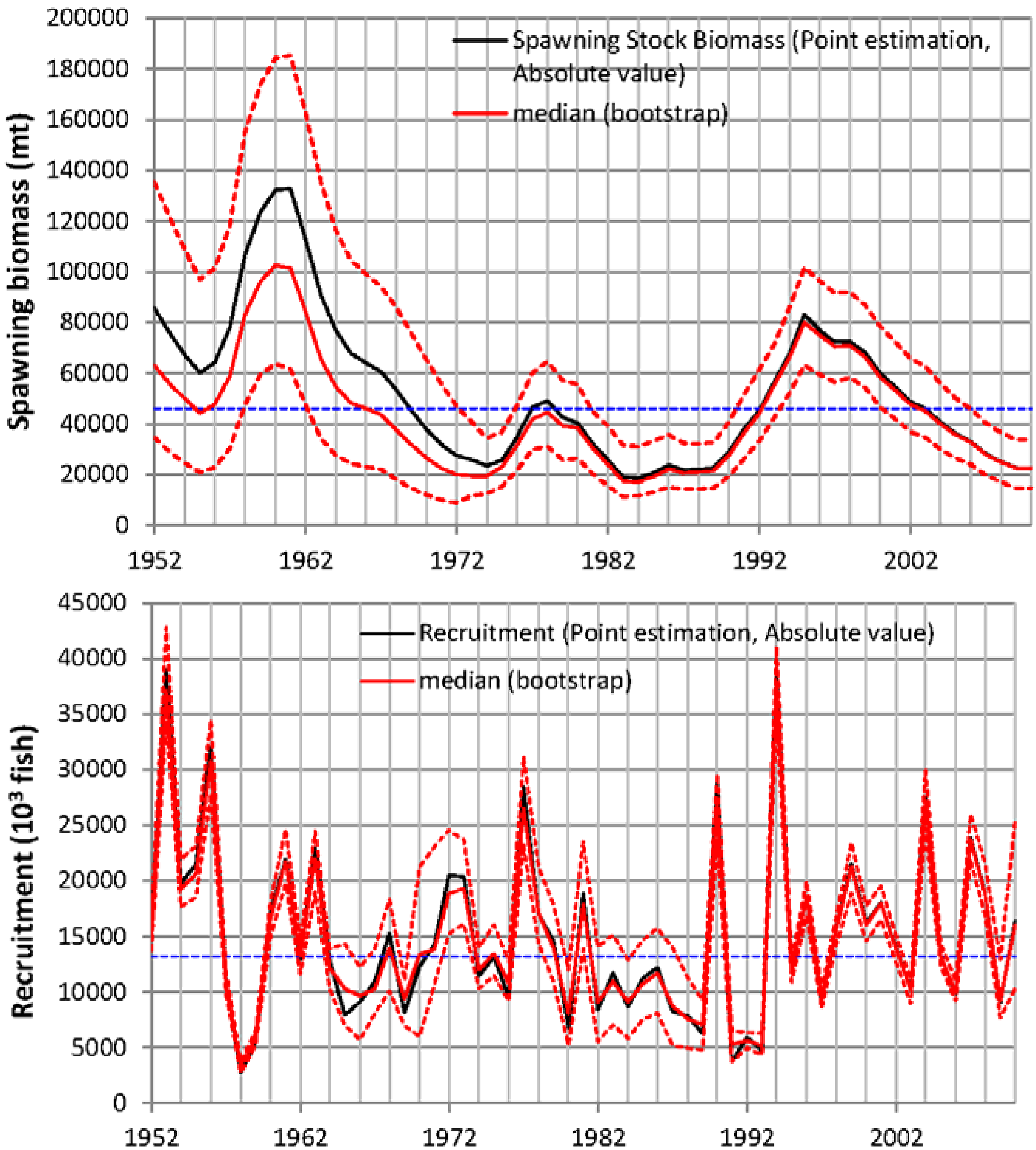

Figure 6. Spawning biomass (SSB) and recruitment estimated for the base case model run (black lines). Dashed red line and solid red lines indicate 80% confidence intervals and median time series estimated from bootstrapping the base case model. Dashed blue lines indicate the overall median SSB and recruitment associated with the base case model.

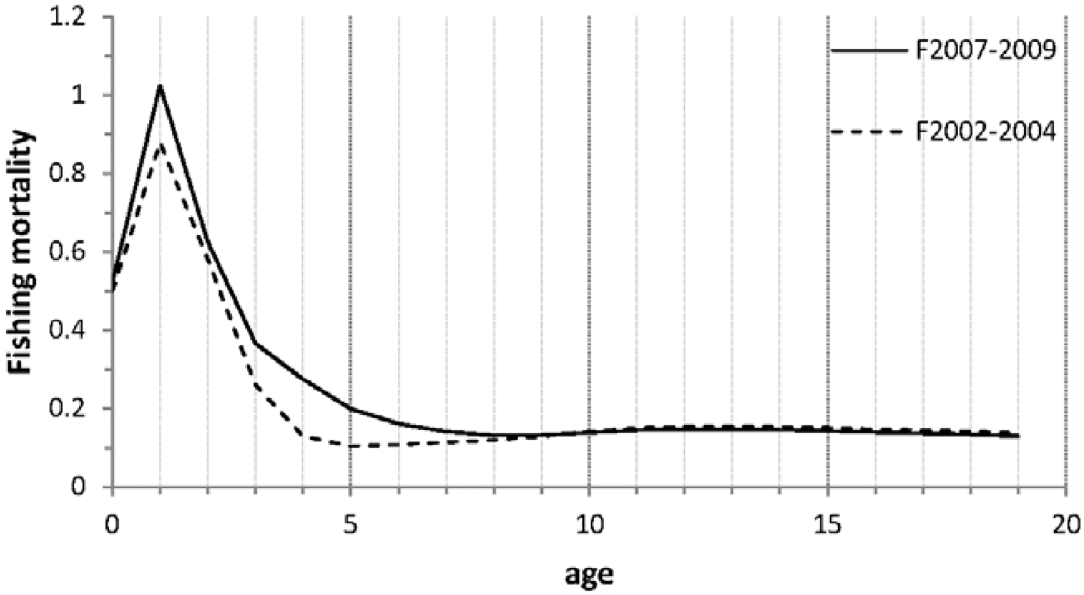

Figure 7. Average age-specific fishing mortality during 2002-2004 and 2007-2009.

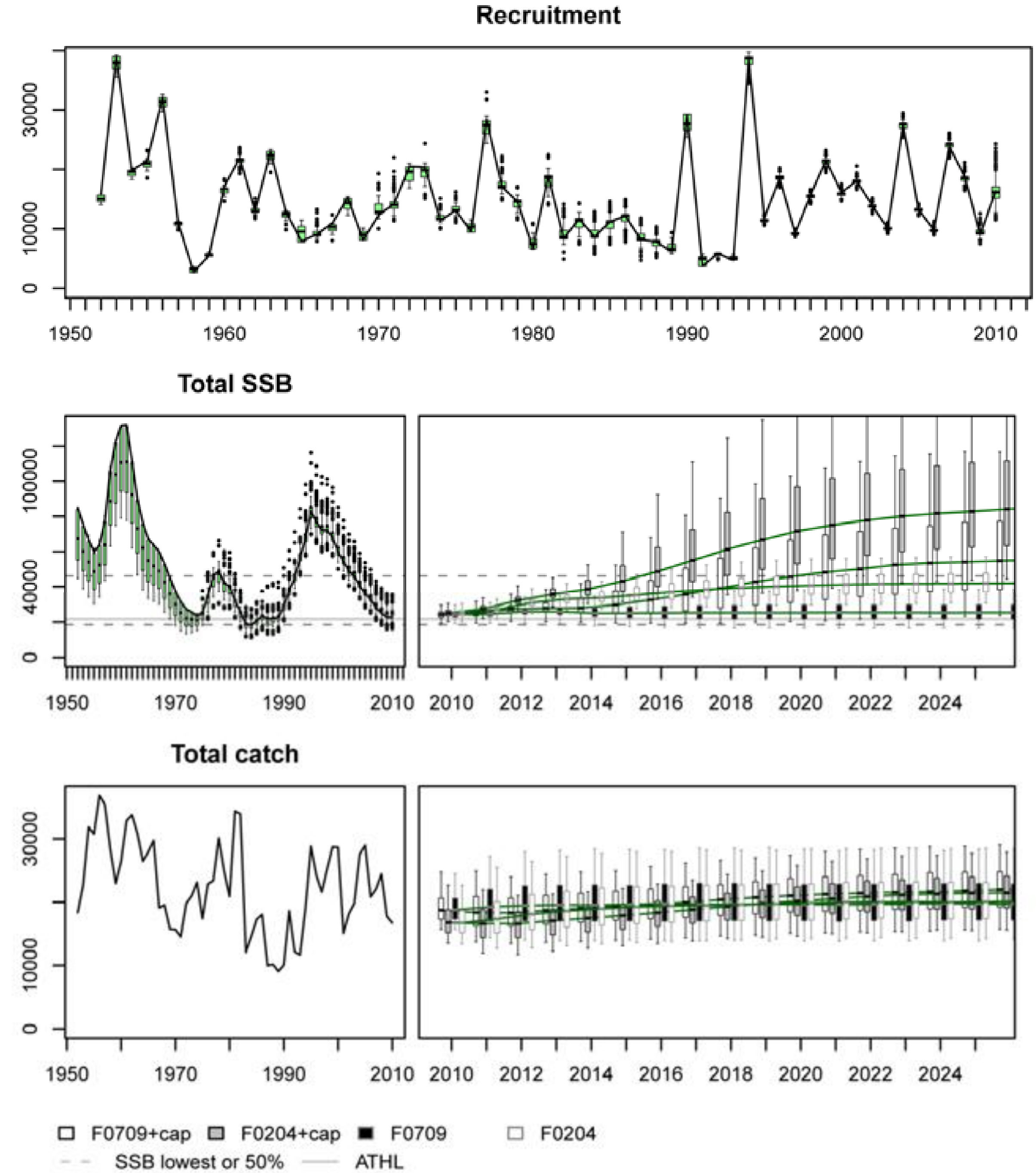

Figure 8. Expected recruitment, spawning biomass, and total catch from 2011 to 2030, based on future projections. Four scenarios were used in the projections: (1) $F_{2007\text{-}2009}$; (2) $F_{2002\text{-}2004}$; (3) $F_{2007\text{-}2009}$ with catch limits (cap) on purse seine fleets in EPO and WPO; and (4) $F_{2002\text{-}2004}$ with catch limits (cap) on purse seine fleets in EPO and WPO. Bars indicate 80% confidence intervals.

Table 1. Model configurations for the 20 model runs. Run 2 is the base case model (see the stock assessment report or the different CV and Effective Sample Size (EFFN) values.

Run#	CPUE for recent LL	CV for CPUE S1	EffN for F3	Size selectivity estimated	Size composition fitted
1	S1 and S9	CPUE CV #1	EffN #1	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
2	S1 and S9	CPUE CV #1	EffN #2	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
3	S1 and S9	CPUE CV #2	EffN #1	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
4	S1 and S9	CPUE CV #2	EffN #2	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
5	S1	CPUE CV #1	EffN #1	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
6	S1	CPUE CV #1	EffN #2	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
7	S1	CPUE CV #2	EffN #1	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
8	S1	CPUE CV #2	EffN #2	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
9	S9	-	EffN #1	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
10	S9	-	EffN #2	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
11	S1	CPUE CV #2	EffN #1	Mirror to other fleet: F6, 13. Estimated: The rest of Fleets.	All fleets except F6, F13
12	S1	CPUE CV #2	EffN #1	Mirror to other fleet: F6, 13. Fixed: F3, 4, 7, 12, 14. Estimated: The rest of Fleets.	All fleets except F3, F4, F6, F7,F12,F13,F14
13	S1	CPUE CV #2	EffN #2	Mirror to other fleet: F6, 13. Fixed: F3, 4, 7, 12, 14. Estimated: The rest of Fleets.	All fleets except F3, F4, F6, F7,F12,F13,F14
14	S9	-	EffN #1	Mirror to other fleet: F6, 13. Fixed: F3, 4, 12, 14. Estimated: The rest of Fleets.	All fleets except F3, F4, F6,F12,F13,F14
15	S9	-	EffN #2	Mirror to other fleet: F6, 13. Fixed: F3, 4, 12, 14. Estimated: The rest of Fleets.	All fleets except F3, F4, F6,F12,F13,F14
16	S9	-	EffN #1	Mirror to other fleet: F6, 13. Estimated: The rest of Fleets.	All fleets except F6, F13
17	S1 and S9	CPUE CV #2	EffN #1	Mirror to other fleet: F6, 13. Estimated: The rest of Fleets.	All fleets except F6, F13
18	S1 and S9	CPUE CV #2	EffN #1	Mirror to other fleet: F6, 13. Fixed: F3, 4, 7, 12, 14. Estimated: The rest of Fleets.	All fleets except F3, F4, F6, F7,F12,F13,F14
19	S1 and S9	CPUE CV #1	EffN #1	Mirror to other fleet: F6, 13. Fixed: F3, 4, 7, 12, 14. Estimated: The rest of Fleets.	All fleets except F3, F4, F6, F7,F12,F13,F14
20	S1 and S9	CPUE CV #1	EffN #2	Mirror to other fleet: F6, 13. Fixed: F3, 4, 7, 12, 14. Estimated: The rest of Fleets.	All fleets except F3, F4, F6, F7,F12,F13,F14

Table 2. Ratio of several common biological reference points to the estimated fishing mortality from 2002-2004 (F_{0204}) and 2007-2009 (F_{0709}). Values less than 1.0 indicate that estimated fishing mortality is higher than the reference point.

	F_{max}	$F_{0.1}$	F_{med}	F_{loss}	$F_{10\%}$	$F_{20\%}$	$F_{30\%}$	$F_{40\%}$
F_{0204}	0.57	0.40	0.91	1.19	0.85	0.58	0.43	0.33
F_{0709}	0.48	0.34	0.73	0.95	0.68	0.47	0.35	0.26

Table 3. Computed F-based biological reference points (BRPs; F_{max}, F_{med}, and $F_{20\%}$) for Pacific bluefin tuna relative to $F_{2002-2004}$ and $F_{2007-2009}$, estimated depletion rate (ratio of SSB in 2010 relative to unfished SSB), and estimated SSB (mt) in year 2010 for 20 model configurations (Runs). Run 2 is highlighted as it represents the base case model for the PBF stock assessment. F-ratio based BRP values less than 1 indicate overfishing.

	F_{max} ($F_{2002-2004}$)	F_{max} ($F_{2007-2009}$)	F_{med} ($F_{2002-2004}$)	F_{med} ($F_{2007-2009}$)	$F_{20\%}$ ($F_{2002-2004}$)	$F_{20\%}$ ($F_{2007-2009}$)	Depletion Ratio	Estimated SSB (mt) (yr = 2010)
Run 1	0.54	0.45	0.90	0.71	0.56	0.45	0.032	20,030
Run 2	0.57	0.48	0.91	0.73	0.58	0.47	0.036	22,606
Run 3	0.51	0.39	0.88	0.63	0.53	0.38	0.022	13,678
Run 4	0.54	0.41	0.89	0.64	0.55	0.40	0.025	15,794
Run 5	0.58	0.49	0.93	0.75	0.59	0.48	0.037	23,794
Run 6	0.60	0.50	0.97	0.78	0.60	0.49	0.041	25,595
Run 7	0.52	0.39	0.90	0.65	0.53	0.39	0.022	13,996
Run 8	0.54	0.40	0.90	0.65	0.55	0.40	0.024	15,388
Run 9	0.61	0.54	0.94	0.82	0.61	0.53	0.047	30,085
Run 10	0.63	0.57	0.96	0.84	0.63	0.55	0.051	32,519
Run 11	0.51	0.38	0.92	0.64	0.54	0.38	0.022	13,141
Run 12	0.46	0.39	0.82	0.66	0.48	0.39	0.021	13,060
Run 13	0.46	0.39	0.82	0.66	0.48	0.38	0.021	12,944
Run 14	0.62	0.55	0.98	0.82	0.64	0.54	0.051	31,196
Run 15	0.60	0.55	1.04	0.87	0.64	0.54	0.053	32,741
Run 16	0.61	0.55	1.04	0.87	0.65	0.55	0.054	33,383
Run 17	0.49	0.38	0.91	0.63	0.54	0.37	0.021	12,838
Run 18	0.46	0.39	0.81	0.65	0.48	0.39	0.022	13,389
Run 19	0.50	0.45	0.83	0.74	0.50	0.45	0.030	18,419
Run 20	0.49	0.45	0.82	0.74	0.50	0.45	0.030	18,206

1.0 INTRODUCTION

Pacific bluefin tuna (*Thunnus orientalis*) is found primarily in the North Pacific Ocean and the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) is responsible for assessing this stock and determining its status. To facilitate the requisite research, the ISC established a Pacific bluefin tuna Working Group (PBFWG) in 1996, and tasked it to assemble fishing statistics and operational data, conduct biological studies, estimate abundance trends, and conduct regular stock assessments of Pacific bluefin tuna. Stock status determination and conservation advice resulting from the assessments are provided to Pacific tuna regional fisheries management organizations (RFMOs), namely the Northern Committee (NC) 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 previous stock assessment in 2010 (PBFWG 2010) and based on the results, the WCPFC-NC adopted a CMM for the Western Central Pacific Ocean (WCPO) that entered into effect in 2011 (WCPFC 2010 – CMM2010-04) and IATTC adopted a CMM for the Eastern Pacific Ocean (EPO) which came into effect in 2012 (IATTC 2012; Resolution C-12-09).

To facilitate an updated stock assessment scheduled for completion in 2012, a series of PBFWG workshops were convened in 2011 and 2012 to prepare data sets, develop biological parameters and abundance time series, investigate modeling approaches, and conduct the stock assessment. This report summarizes the efforts directed towards completing the 2012 stock assessment and reports results on the stock status and future outlook of Pacific bluefin tuna.

In this report, years refer to fishing years unless otherwise specified; July 1 is assumed to be the day of birth for Pacific bluefin tuna in the models. A fishing year starts on July 1 and ends on June 30th of the following year. For example, the year 2011 refers to the period July 1, 2011 to June 30, 2012. All the input data in this report, unless mentioned specifically, are by fishing year.

For this assessment, extensive model runs were conducted using alternative data weightings and structural assumptions, which are described in this report. After examining these model runs and substantial discussion, the PBFWG agreed to use a Representative Run to determine stock status and provide management advice, acknowledging that while it represents the general conclusions of the assessment, the Representative Run may not be able to reconcile all key data sources.

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*) composed of two sub-species (*Thunnus thynnus orientalis* and *Thunnus thynnus thynnus*, respectively). However, these two groups of bluefin tuna are now considered to be separate species (*Thunnus orientalis* and *Thunnus thynnus*, respectively) based on genetics and morphometric studies (Collette 1999). This taxonomy is accepted by relevant RFMOs, FAO and ISC.

The known spawning grounds for Pacific bluefin tuna (PBF) are restricted to the western North Pacific Ocean (WPO), in waters adjacent to the Ryukyu Islands in Japan to the east of Taiwan, and in the southern portion of the Sea of Japan (Schaefer 2001). Based on the available genetics and tagging information (e.g., Bayliff 1994, Tseng & Smith 2011), the PBFWG considered that Pacific bluefin tuna consisted of a single stock. In addition, the relevant RFMOs (WCPFC and IATTC) and regional fisheries organizations (RFOs) (ISC and FAO) also consider Pacific bluefin tuna to be a single stock . Therefore, this stock assessment and the conservation advice contained hereinafter are based on a single stock hypothesis. The PBFWG will continue to investigate the potential for sub-stocks throughout the range.

2.1.2 Reproduction

Pacific bluefin tuna are iteroparous spawners. Spawning in the area between the around Ryukyu Islands and off eastern Taiwan generally occurs from April to July, and from July to August in the Sea of Japan (Yonemori, 1989) (Figure 2-1). A recent histological study showed that 80% of the fish of about 30 kg (corresponding to age-3) caught in the Sea of Japan from July to August were mature (Tanaka 2006). Almost all the fish caught off the Ryukyu Islands and east of Taiwan were above 60 kg (over 150 cm fork length [FL], corresponding to age 5+) and mature. While there is evidence that fish in the Sea of Japan mature at an earlier age, additional research is required.

2.1.3 Distribution and movement

Pacific bluefin tuna are mainly distributed between 20˚ to 40° N, but are occasionally found in tropical waters and the southern hemisphere (Figure 2-2).

Although there is large interannual variation, age-0 and -1 fish tend to migrate north along the Japanese coast in the summer and south in the winter (Inagake et al. 2001; Itoh et al. 2003). Under certain ocean conditions, a variable portion of immature age-1 to 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). While in the EPO, the juvenile Pacific bluefin tuna 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, with the exception of 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 Pacific bluefin tuna 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 FL), after which growth slows down (Figure2-3). At age 13, fish reach 225 cm FL, corresponding to 90% of the maximum fork length (FL) of this species. Large fish (above 250 cm FL) are primarily older than age 20, indicating that this species likely lives longer than 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 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 2012). 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). The PBFWG recommended continuing research to further improve the growth curve before the next stock assessment.

2.1.5 Natural mortality

The instantaneous natural mortality coefficient (natural mortality or M) is assumed to be high at a young age, decreasing thereafter as the fish grow. The natural mortality estimate for age-0 fish was based on results obtained from a conventional tagging study (Takeuchi and Takahashi 2006; Iwata et al. 2012a). For age-1 fish, natural mortality was based on length-adjusted M estimates from southern bluefin tuna (*Thunnus maccoyii*) conventional tagging studies (Polacheck et al. 1997, PBFWG 2009). Natural mortality of older fish (age 2+) was estimated as 0.25 per year using the Pauly's equation (Figure 2-4).

2.2 Review of fishery

Annual Pacific bluefin tuna catches from 1952 to 2011 are shown in Figure 2-5 by country and fishing gear. Many countries harvest these fish but Japan catches the majority, followed by Mexico, U.S.A., Korea and Chinese Taipei. Catches in tropical waters and the southern hemisphere are relative low and sporadic.

The fisheries of the main Pacific bluefin tuna 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 definition), 3.4 (catches), 3.5 (abundance indices), 3.6 (size compositions), and 4.3 (selectivity and time blocks).

Currently, the most important Pacific bluefin tuna fisheries in Japan are longline, purse seine, and pole-and- line, but other gears such as troll, set-net, hand-line and other miscellaneous gears can take substantial catches as well. The fishing grounds are generally coastal or near-shore waters, extending from Hokkaido to the Ryukyu Islands. The distant-water longline fishery also catches relatively small numbers of Pacific bluefin tuna. Total annual catches by Japanese fisheries have fluctuated between a maximum of 34,000 mt in 1956 and a minimum of 6,000 mt in 1990 (calendar year). Yamada (2007) provides a general review of the Japanese fisheries that catch Pacific bluefin tuna. Changes in the longline fishery are described in Section 3.5.2, and changes in the purse seine fishery are covered in Section 3.5.5, 3.5.6, and particularly 3.6.10.

In the U.S.A., two main types of gear are used to catch Pacific bluefin tuna off the west coast of North America. A US purse seine fishery targeting Pacific bluefin tuna mainly for canning was fully developed in traditional Pacific bluefin tuna fishing grounds off Baja California until the early 1980s. In 1976, Mexico established its 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 Pacific bluefin tuna basically ceased operations with only opportunistic catches thereafter (Aires-da-Silva et al. 2007). A US recreational fleet also catches relatively small amounts of Pacific bluefin tuna, typically while fishing in Mexican waters.

The Mexican purse seine fishery is the most important large pelagic fishery of Mexico. This fishery developed strongly 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 VMS. Most of the purse seine sets target yellowfin tuna (the dominant species in the catch) in tropical waters, while Pacific bluefin tuna are caught near Baja California. The Mexican Pacific bluefin tuna catch recorded three large caches (above 7,000 mt) in the years 2004, 2006 and 2010. The development and changes in this fishery are further detailed in Sections 3.5.5, and 3.6.10.

Pacific bluefin tuna are caught by the Korean offshore large purse seine fleet (OLPS), which targets a variety of pelagic fish species, such as common mackerel (60% of the total catch), spotted mackerel, horse mackerel, Pacific sardine and common squid. Pacific bluefin tuna account for less than 1% of the total catch by this fleet. The fleet size has declined from 48 vessels in 1994 to 25 in 2011, and total catch of all species combined has also declined from 459,000 mt in 1986 to approximately 200,000 mt in recent years. Pacific bluefin tuna catch by the OLPS was below 500 mt until the mid-1990s, increased thereafter, and peaked at 2,601 mt in 2003. The catch has fluctuated in recent years, with the 2011 catch being 670 mt. Pacific bluefin tuna fishing grounds have been located around Jeju Island over March and April for the past 5 years. For assessment purposes, this fishery was combined into a single fleet with the Japanese purse seine fishery in the East China Sea because of the similar sizes of fish taken. However, the PBFWG agreed to separate these two fisheries into two fleets in future assessments. More details are provided in Sections 3.3 and 3.6.4.

Since 1993, the majority of catch from Chinese Taipei has come from a small-scale longline fleet (<100 GRT) that targets Pacific bluefin tuna. Landing records indicate that small amounts (<300 mt) of Pacific bluefin tuna 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 on the spawning grounds east of Taiwan from April to June. The highest observed catch of 3,000 mt was in 1999 but has declined rapidly to less than 1,000 mt. In 2010, landings of Pacific bluefin tuna by this fishery fell to the lowest level of about 300 mt.

2.3 Previous stock assessment

The ISC completed the previous Pacific bluefin tuna assessment in 2010 using Stock Synthesis. There were several major differences in the input data and structural assumptions used in the current assessment, compared to the base case in the 2010 assessment. In the 2010 assessment,

a. The stock assessment period covered 1952 to 2008;
b. The steepness parameter (h) was assumed to be 1.0 in the 2010 base case;
c. The growth curve of Shimose et al. (2008) was used;
d. Japanese purse seine fleets operating in the Sea of Japan (Fleet 3) and Pacific Ocean

(Fleet 4) were aggregated into a single fleet;
e. Japanese set net fisheries were aggregated into a single fishery;
f. Selectivity for the Japanese longline fleet (Fleet 1) was assumed to be asymptotic; and
g. Models were fit to equilibrium catch.

The PBFWG conducted two sensitivity runs to compare the influence of different model assumptions made in the current and 2010 assessment. One run tested the sensitivity of the model to a steepness parameter of 1. Another run used the growth curve of Shimose et al. (2008) (See Sections 4.6.2 and 5.4.5 for more detail).

3.0 STOCK ASSESSMENT INPUT DATA

3.1 Spatial stratification

As discussed in the Section 2.1.1, Pacific bluefin tuna are distributed across the North Pacific Ocean and considered a single stock.

Juvenile Pacific bluefin tuna 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 is 1952-2010 (fishing years). Within this period, catch and size-composition data were compiled into quarters (July-September, October-December, January-March, and April-June). Although fisheries catching Pacific bluefin tuna have operated since at least the beginning of the 20th century in the EPO and for several centuries in the WPO, the data prior to 1952, in particular from the WPO, were of relatively poor quality. Thus, the PBFWG set the starting year of the models was set to 1952, because catch-and-effort data from Japanese longline and size-composition data from Japanese longline and EPO commercial purse seine fleets were available from 1952.

3.3 Fishery definitions

A total of 14 fisheries (called “Fleets” hereafter) were defined for the stock assessment according to gear, consistency of size compositions of catch within a fleet, and the availability of CPUE series (Table 3-1). The 14 Fleets are: 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 (Fleet 7 to 10), Taiwanese longline (Fleet 11), EPO commercial fisheries (Fleet 12), US sport (Fleet 13) and other miscellaneous fisheries (Fleet 14).

Fleet 2 is an aggregation of both Japanese and Korean small pelagic purse seine fisheries. Length compositions from the Japanese small pelagic purse seine fishery are used to represent this fleet.

Fleets 3 and 4 are Japanese tuna purse seine fisheries in the Sea of Japan and Pacific, respectively. They are 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 are separated based on availability of length‐weight measurements and locations of set‐nets that had differences in observed length compositions. Three definitions were proposed at the data preparatory workshop. However, because seasonal changes in length compositions caused significant misfits between expected and observed length compositions, the original Fleet 9 was separated into two Fleets based on season; Fleet 9 in the assessment includes the 1st, 2nd and 3rd quarters, and Fleet 10 includes the 4th quarter.

3.4 Catch

The Pacific bluefin tuna catch fluctuated substantially over time and by gear. The total reported annual catch of Pacific bluefin tuna peaked at 40,383 mt in 1956 and the historical lowest catch of 8,653 mt occurred in 1990 (Figure 3-1). The total catch averaged 21,914 mt during the last 10 years (2002−2011).

Purse seine fisheries caught a large portion of the Pacific bluefin tuna throughout the assessment period (1952-2010). The Japanese tuna purse seine fishery operating in the Pacific Ocean (Fleet 4) accounted for a large portion of total catch until the 1990s. However, catches of the Japanese small-scale purse seine fishery (Fleet 2) and Japanese tuna purse seine fishery operating in the Sea of Japan (Fleet 3) have become relatively large since the mid-2000s. 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 2010 (fishing years). For some of these fisheries, proportions of quarterly catches in recent years were extrapolated from past catches to estimate the quarterly catch from annual catch. For other fisheries (e.g. Japanese troll before 1994, 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 available for this assessment are shown in Figure 3-2, Table 3-1, and Table 3-2. Those series were derived from fishery-specific catch and effort data and 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 the 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 uses five indices: four longline indices for adults (S2 and S3 for the past periods and S1 and S9 for recent periods) and one troll index for recruitment (S5).

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. The PBFWG recognized that some vessels may have shifted fishing effort towards the Ishigaki region, while other vessels may have switched from targeting Pacific bluefin tuna to other tuna species, such as yellowfin and albacore tuna, due to poor bluefin catches. These shifts may have, in turn, changed observation and process errors in the abundance index associated with this fishery.

The PBFWG agreed that the assessment model should account for the changes in the observation and process errors. Two methods were proposed: 1) a linear ramp of increasing CV in the index from 2005 (0.24) to 2010 (0.43); and 2) a fixed additive scalar to the estimated observation error so that the average CV of the index equals 0.2 (Table 4-3-Appendix). Although the Representative Run (base case), from which stock status and management advice was developed, was based on a linear ramp of increasing CV (method #1), other plausible model configurations used a fixed additive CV (method #2) (see section 4.6.2 and Tables 4-3 and 4-3-Appendix).

3.5.3 Japanese longline CPUE (S1, S2 & S3)

Until the mid-1960s, Pacific bluefin tuna longline catches in Japanese coastal waters were made by offshore or distant-water longline vessels. Since the mid-1960s, the coastal longline fleet has consisted of smaller longline vessels. A logbook system was not established until 1993 for the coastal longline fleet, while aggregated logbook data from 1952 onward are available for the offshore and distant-water longline Fleets.

Two Japanese longline CPUE time series (1952-1974 [S2] and 1975-1993 [S3]) were developed to span the period from 1952 through 1993 (Fujioka et al. 2012). The time series is split because of major changes in operational patterns that took place in the mid-1970s (e.g. the development of the super freezer and a shift from targeting yellowfin tuna and albacore tuna to targeting bigeye tuna). In addition, hooks-per-basket information, which is used to standardize for these targeting changes, has only been collected since the mid-1970s (Ichinokawa et al. 2012). Another CPUE series from 1993 to 2010 was developed for the coastal longline fishery because logbook data from this fishery became available from 1993 (Kai et al. 2012; Ichinokawa and Takeuchi 2012; Oshima et al. 2012b). All three time series were used in the stock assessment: the coastal longline fishery index from 1993-2010 (S1), and the distant-water longline fishery indices from 1952-1974 (S2) and 1975-1993 (S3).

3.5.4 Japanese purse seine (in the Sea of Japan) CPUE (S4)

Kanaiwa et al. (2012b) 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 of 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. Because of 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 6, 4 and 5 fishing ports in these Prefectures, respectively. The units of effort in the catch-and-effort data are the cumulative daily number of troll vessels that unload Pacific bluefin tuna, 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 Pacific bluefin tuna 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 Pacific bluefin tuna catch. The CPUE time series from Kochi and Wakayama Prefectures were combined into a single time series (S6) while the Nagasaki time series remained separate (S5) (Ichinokawa et al. 2012). The S7 and S8 indices are the indices derived from Kochi and Wakayama Prefectures, respectively (Table 3-1). The S7 and S8 indices were not used because the PBFWG agreed that combining the data from both Prefectures into a single index was more appropriate.

After several preliminary runs it was decided not to use the S6 index for three reasons: 1) the S6 series represents only a part of the recruitment; 2) preliminary model runs showed that the S6 index is inconsistent with other data in the model; and 3) excluding the S6 index would maintain continuity with the previous stock assessment. Therefore, only the S5 index was used an indicator of recruitment strength from 1980 to 2010.

3.5.6 Taiwanese longline CPUE

The Taiwanese Pacific bluefin tuna catch and effort data were derived from landings by individual fishing boats targeting Pacific bluefin tuna, the number of fishing days, and the number of hooks deployed per day for these boats. Fishing effort of these boats was estimated as number of hooks per day * 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.

Two statistical models were used to standardize the annual PBF CPUE for 1999-2011: a GLM (with three factors: Year, Month, and vessel types) and a GLMM (with interaction terms Year*Month and Year*vessel type as random effects). Both model fits showed that CPUE sharply declined from 1999 to 2002, slightly increased in 2003 and 2004, dropped to a low level in 2005, and then decreased again in 2009-2010. There was a small increase in CPUE in 2011. Given the similar fits but different levels of complexity between the two models, the GLM-standardized CPUE index was used as input data for the stock assessment (Hsu and Wang 2012; PBFWG 2012).

3.5.7 US Purse Seine CPUE (1960-1982)

Standardized catch rates are available for two periods of this fishery: (1) the developed phase of the US fishery targeting Pacific bluefin tuna (1960-1982); and (2) the extinction phase of the US fishery (post-1982). Jackknifing was used to estimate the CV (Aires-da-Silva and Teo 2012). The availability of Pacific bluefin tuna in the EPO depends on the migration of Pacific bluefin tuna from the WPO at an unknown but likely variable rate. Because of 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 (1999-2011)

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 Pacific bluefin tuna since 1999. This fishery has also supplied Pacific bluefin tuna for pen rearing operations since 2002. Jackknifing was used to estimate the CV (Aires-da-Silva and Teo 2012 and Section 3.6.9). As mentioned above, the availability of the Pacific bluefin tuna in the EPO depends on the migration of Pacific Bluefin tuna from the WPO at an unknown but likely variable rate. Therefore, this index was not use in this 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 2010 were used for this assessment. 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 FL fish, respectively. All lengths in the model were fork lengths 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 widths of the weight bins were set to minimize aliasing of the data. The lower boundary of each bin was used to define the bin.

Figure 3-3 shows the aggregated size compositions of Fleets 1 through 14 and Figure 3-4 shows the quarterly size compositions of Fleets 1 through 14. For the current 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. (2012), 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. All of the fleets had a maximum input sample size of approximately 12, except for Fleet 3 (Japan tuna purse seine in Sea of Japan) and Fleet 12 (EPO commercial purse seine). This was because both Fleets 3 and 12 were considered by the PBFWG to have good sampling programs for the size composition data. However, the WG differed in their opinions on the appropriate input sample size for Fleet 3 (see Section 4.4.3).

3.6.2 Japanese longline (Fleet 1)

Length-composition data from the Japanese longline fishery (Fleet 1) were available for the periods of 1952-1968 and 1994-2009. These data were collected mainly from the Tsukiji market until the 1960s. Since the 1990s, sampling and market record data have been collected at the major Pacific bluefin tuna unloading ports, e.g. Okinawa, Miyazaki and Wakayama. 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 seine in the East China Sea (Fleet 2)

Length composition data from Japanese purse seiners in the East China Sea were developed from length measurements taken at the Fukuoka port, which is the main unloading port of this fleet. 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 available for 2002-2010.

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

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 the Sakai-minato port and were available for 1987-2010 except for 1990, when there was no catch. Port samplers obtained length measurements from an average of 47.5% of the catch. This fleet catches mainly Pacific bluefin tuna 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 the Japanese purse seiners off the Pacific coast of Japan had been collected primarily in weight from the 1950s until 1993 at the Tsukiji market and several unloading ports in Tohoku region. Since 1994, length and weight composition data have been collected at the 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, the tuna purse seine fishery was separated into two fleets because of differences in the size compositions of the catch in the fisheries (Abe et al. 2012a; Kanaiwa et al. 2012). 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 since 1994 at the main unloading ports. 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 by the catch from each region and month strata. The sampling of pole-and-line vessels were 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 fish).

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 2010. Fleet 7 size composition data were based on weight composition, whereas the others (i.e. Fleet 8, 9 and 10) were based on the length compositions (Kai and Takeuchi 2012; Teo and Piner 2012). All of them were estimated by raising the size measurement data with the catch in the respective strata. The coverage of size measurement data was about 5.8%.

3.6.8 Taiwanese longline (Fleet 11)

Length composition data for the Taiwanese longline fishery (Fleet 11) were collected by port samplers, and were available for 1992-2010. The size sampling coverage is very high for this fleet, with >90% of landed fish being measured. The Taiwanese longline fishery catches the largest Pacific bluefin tuna among all the fisheries.

3.6.9 EPO commercial purse seine (Fleet 12)

Aires-da-Silva and Dreyfus (2012) reviewed the Pacific bluefin tuna size composition data for the EPO purse seine fishery. Pacific bluefin tuna size composition data were collected by port samplers from IATTC and national sampling programs. For the most recent Mexican fishery targeting Pacific bluefin tuna 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 75 cm (1-year old fish) before the mid-1980s when the US Pacific bluefin tuna target fishery was operating, there has been a shift towards larger (average size of about 85 cm, 2-year old) fish in more recent years (late 1990s and 2000s), as the Mexican purse seine fishery has targeted Pacific bluefin tuna for farming operations. In 2001, several vessels targeting Pacific bluefin tuna changed their purse seine nets to deeper nets. Since 2002, all vessels targeting PBF have adopted this fishing gear, as this species is usually found in deeper waters. The depth of these purse seine nets ranged from 240 m to about 315 m, deeper than the nets targeting yellowfin tuna (about 210 m). Mexican Pacific bluefin tuna 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).

3.6.10 EPO sports fishery (Fleet 13)

Size composition data for the US sport fishery have been collected by the 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 was similar to the EPO commercial purse seine fishery.

3.6.11 Other fisheries (Fleet 14)

This fishery contains a variety of Japanese gears and fisheries, mainly from Tsugaru Strait. The size composition data were based on weights, and showed a large spike around 10 kg and a long tail up to 250 kg (Abe et al. 2012b). Preliminary analysis indicated that misfits to the size composition data from this fleet strongly influenced the estimated population dynamics, given the model structure. The relative contribution of each gear of this mixed fleet was unknown but likely varied over time.

4.0 MODEL DESCRIPTION

4.1 Stock Synthesis

A seasonal, length-based, age-structured, forward-simulation population model was used to assess the status of Pacific bluefin tuna. The model was implemented using Stock Synthesis (SS) Version 3.23b (Methot 2011; http://nft.nefsc.noaa.gov/Stock_Synthesis_3.htm). Stock Synthesis is a stock assessment model that estimates the population dynamics of a stock through the 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 ageing them to the nearest fractional year based on an assumed biological birth date of May 15th (Shimose and Takeuchi 2012). This relationship was then re- parameterized to the von Bertalanffy growth equation used in SS (Figure 2-3), while adjusting for the birth date used in SS (July 1st, i.e. the first day in 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, L_∞ is the theoretical maximum length, and K is the growth coefficient. The K and L_∞ can be solved based on the length at age and L_∞ was 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 being fixed at 0.1574743 y^{-1} and L_1 and L_2 being fixed at 21.5 cm and 109.194 cm for age 0 and 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+ year fish was fixed at 0.05.

In 2008, when the SS model was used for the first time to assess Pacific bluefin tuna, age of A_2 was manually tuned to optimize model fit ($A_2 = 3$). In the 2008 stock assessment, CV_2 was also manually tuned to optimize 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 current stock assessment 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 natural mortality 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 in cm to weight in kg (Kai 2007). The sex-combined weight-length relationship is,

$$W_t(kg) = 1.7117 \times 10^{-5}(L(cm)^{3.0382}$$

where W_L is weight at length L. This weight-at-length relationship was applied as fixed parameters in the model (Figure 4-1).

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 Pacific bluefin tuna. However, given the lack of sexual dimorphism and a near total lack of recording 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 Pacific bluefin tuna 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 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+ (Figure 2-4).

4.2.6 Recruitment and reproduction

Pacific bluefin tuna spawn throughout spring and summer (April- August), in different areas as inferred from egg and larvae collections and examinations of female gonads. In the SS model, spawning was assumed to occur in 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+. Pacific bluefin tuna ages 0-2 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 (R0), and unfished equilibrium spawning biomass (SSB_0) corresponding to R_0, and was assumed to follow a lognormal distribution with standard deviation σ_R (Methot et al 2011, Methot and Wetzela 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 unbiased.

Recruitment variability (σ_R: the standard deviation of log-recruitment, see Section 4.6.2 for more detail) was fixed at 0.6. The log of R0 and annual recruitment deviates were estimated by the model. The offset for the initial recruitment relative to virgin recruitment, R1, was estimated in the model and found to be small (approximately 0.075, depending on run). Annual recruitment deviates were estimated from 1949 to 2009 (recruitment deviation in 1942-1951 represent deviations from a stable age structure (ages 1-10) in 1952, start year of the stock assessment) and stock-recruitment (S-R) expectations for 2010. Full bias adjustment of recruitment estimates is applied from 1953-2009, 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 et al 2011

Steepness of the stock-recruitment relationship was defined as the fraction of recruitment when the spawning stock biomass was 20% of SSB_0, relative to R0. Previous studies have indicated that h tend to be poorly estimated due to 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 inside 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 because Pacific bluefin tuna is a highly productive species. Independent estimates of steepness that incorporated biological and ecological characteristics of the species (Iwata et al. 2012; 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 estimates were highly uncertain due to the lack of information on early life history stages.

4.2.7 Stock structure

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

4.2.8 Movement

Pacific bluefin tuna is a highly migratory species known to migrate widely in the Pacific Ocean, especially between the EPO and WPO (Section 2.1.3). In this assessment, Pacific bluefin tuna 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) and therefore contained spatial inferences. Instead of explicitly modeling movement, the model used fishery-specific and time-varying selectivity 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 that 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 in the assessment model. Not fitting to the equilibrium catch is equivalent to estimating the catch and therefore the initial fishing mortality rates (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, allowing for model flexibility. In addition, 10 recruitment deviations were estimated prior to the dynamic period to allow the initial population to better match composition information available at the start of the dynamic period of the model.

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 fishery availability (spatial patterns and movement) by spatially and temporally stratifying fisheries . In this assessment, selectivity patterns were estimated for all fisheries with length composition data except for Fleet 14, which was a composite of multiple different gears, 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 the descending limbs of selectivity curves 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 pattern 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 after a specific size. This is a strong assumption 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 the population size. Two parameters described asymptotic selectivity: the length at 50% selectivity, and the difference between the length at 95% selectivity and the length at 50% selectivity, which were estimated in this assessment.

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 fixed to a small value (-15), which caused SS to ignore the first and last size bins and allowed SS to decay the small and large fish selectivity according to parameters of ascending width and descending width, respectively. For some fisheries, the parameter specifying the width of the plateau was often estimated to be very small (-9) and often hit assigned bounds. For these fisheries, the width of the plateau was set to -9. Other parameters describing domed-shape selectivity were estimated by the model, i.e., beginning size for the plateau, ascending width, and descending width.

4.3.4 Special Selectivity- fixed, time varying and mirrored

The selectivities of the Japanese pole-and-line fishery (Fleet 6) and the US recreational fishery (Fleet 13) were mirrored to the selectivities of the Japanese troll fishery (Fleet 5) and the EPO commercial purse seine fishery (Fleet 12), respectively. 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 had similar fishing areas and sizes of fish caught to Fleets 5 and 12. The size composition data of Fleets 6 and 13 were not fitted in the model.

Selectivity of the Japanese Others fishery (Fleet 14), which was a mixed gears fishery, likely varied over time due to the changes in the relative contribution of different gears over time. Given the relatively small catches from this fleet and the difficulties in modeling the selectivity of this fleet, the selectivity of Fleet 14 was fixed with parameters estimated by a preliminary run with lambda=0.1. Due to the fixed parameters, the composition data were not fit in the final model.

Time varying selectivity patterns via blocks of constant selection were employed for the Japanese longline, Japanese tuna purse seine, and EPO purse seine fisheries (Fleet 1, Fleet 3 and Fleet 12). Two periods of selection patterns were estimated for the Japanese longline fishery (Fleet 1: 1952-1992; 1993-2010). These two periods corresponded to a change in fishery operations, separation of CPUE series and a seasonal shift in the timing of fishing. Two periods of selection patterns (1952-2006; 2007-2010) 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 of selection were also assumed for the EPO purse seine fleet (Fleet 12: 1952-2001; 2002-2010). The second block corresponded to a period when the EPO fleet changed gears to target larger fish (Aires-da-Silva and Dreyfus 2012). Therefore, for 2002-2010, it was assumed that the selectivity of Fleet 12 was the same as the earlier period, except that the beginning size of the plateau (peak parameter) was assumed to be 10 cm larger than the earlier period. This resulted in a rightward shift of the selectivity curve by 10 cm in the latter period (Section 3.6.10).

The Japanese set net fishery (Other Area of Japan) (Fleet 9) was divided into two seasonal fleets (quarters 1-3 and quarter 4 of fishing year) and separate selection patterns were estimated for both. 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 the fourth quarter 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 was 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 consisted of likelihoods for data and prior information components. The likelihood components consisted of catch, CPUE indices, size compositions, and recruitment penalty. Model fits to the data and likelihood components were systematically checked.

4.4.1 Observation error model

The observed total catch data were assumed to be unbiased and relatively precise and 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 catch from any fishery.

4.4.2 Recruitment penalty function

The true variability of recruitment in the population, σ_R, constrain the estimates of recruitment deviations and is not affected by data. When data that are informative about recruitment deviations are available, σ_R is partitioned into a signal (the variability among the recruitment estimates) and the residual (the variance of each recruitment estimate).

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

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

4.4.3 Weighting of the data

Two types of weighting were used in the model: (1) relative weighting among length compositions (effective sample size), and (2) weighting of the different data types (sources of information, e.g., length compositions, abundance indices, and conditional age-at-length) relative to each other.

Effective sample sizes, except for Fleets 3 and 12, 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 was scaled by the average sample size of tuna purse seine fleet in the Sea of Japan (Fleet 3) and EPO commercial purse seine fleet (Fleet 12).

Preliminary model runs indicated that the size composition data from Fleet 3 strongly influenced the assessment results. After much discussion, the PBFWG agreed that some of the input sample sizes for Fleet 3 were too large, but did not reach consensus on the appropriate sample sizes to be used in the assessment. As a result, two input sample sizes for Fleet 3 were proposed: 1) set the input sample size for the entire time series to 12.1056, which is the average sample size for the other size composition datasets; and 2) set an upper limit of 51.2 and keep the original effective sample size for other data. Although the Representative Run, from which stock status and management advice was developed, was based on an upper limit of 51.2 for the input sample size (method #2), other plausible model configurations used an input sample size of 12.1056 for the entire time series (method #1) (see section 4.6.2 and Tables 4-3 and 4-3-Appendix).

All size composition data except for Fleets 6, 13 and 14 were fitted in the model with full weight (Section 4.3.4). The CPUE indices of Japanese coastal longline (S1, S2, S3), Japanese coastal troll (S5) and Taiwanese longline (S9) fleets were fitted in 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% (via "jitter" equipped in Stock Synthesis software) and refitting the model.

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, the WG removed up to eight years of data were removed and examined changes in the estimates of SSB and recruitment. The results of this analysis were useful in assessing 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 assumptions or configurations relative to the base case results. The PBFWG examined the sensitivity analyses in Tables 4-2, 4-3, and 4-3-Appendix for this assessment, which were categorized into four themes: 1) CPUE data; 2) effective sample size of Fleet 3 size composition data; 3) fitting different size composition components; and 4) biology. For each sensitivity run, the spawning stock biomass, fits to the data, and changes in the fitted negative log-likelihood values by model component were compared. It was noted that many additional sensitivity runs were conducted in the course of developing of the Representative Run (e.g. fleet definitions, CV for growth curve, alternative data sets etc.) but results from these runs are beyond the scope of this report.

4.6.2.1 CPUE data

4.6.2.1.1 CV for recent Japanese Coastal Longline CPUE (S1).

These sensitivity runs were used to examine the assumptions about the uncertainty of S1. Oshima et al. (2012b) reported a shift of this fishery from targeting Pacific bluefin tuna to targeting yellowfin tuna, which may have increased the uncertainty in the S1 index in recent years. Two methods were proposed to account for this uncertainty: 1) a linear ramp of increasing CV in the index from 2005 (0.24) to 2010 (0.43); and 2) a fixed additive scalar to the estimated observation error so that the average CV of the index equals 0.2 (Table 4-3-Appendix). Sensitivity runs were performed with either CV #1 or CV #2.

4.6.2.1.2 Alternative scenarios for the recent abundance indices for adult PBF.

The purpose of these sensitivity runs was to examine the effect of using either S1 or S9 as the index for mature adults in recent years. A preliminary analysis indicated that the two terminal longline indices (S1 and S9) may provide conflicting information to the model, improving the fit to one index tends to degrade the fit to the other index (Teo and Piner 2012). Sensitivity runs were performed with S1, S9, or both being fitted.

4.6.2.2 Effective sample size of Fleet 3 size-composition data.

These sensitivity runs examined the influence of the assumptions about the input sample size of Fleet 3 size composition data (EffN-F3) on model dynamics. The PBFWG agreed that the size composition data of Fleet 3 were highly influential and that some of the input sample sizes for Fleet 3 were too large. Therefore two alternative effective sample sizes for Fleet 3 were proposed: 1) set the input sample size for the entire time series to 12.1056, which is the average sample size for the other size composition datasets; and 2) set an upper limit of 51.2 and keep the original effective sample size for other data. Sensitivity runs were performed with effective sample sizes for Fleet 3 set with both methods.

4.6.2.3 Effect of fitting to different size composition components.

The effect of fitting different size composition components was examined by several sensitivity runs. A preliminary analysis indicated that the misfit to the size composition data from Fleets 3, 4, 7, 12, and 14 may have degraded the fit to the S1 index (Teo and Piner 2012). It was therefore proposed to examine the effect of not fitting to these size composition components. The selectivity of these fleets were estimated in an initial model run and subsequently fixed. The fit to the size composition was then not included in the calculation of the total likelihood function for the final model run. Sensitivity runs were performed that fit to various size composition components.

4.6.2.4 Biology

4.6.2.4.1 Natural Mortality

Two sensitivity runs were made to examine the effect of natural mortality assumptions on population dynamics, assuming 20% higher and lower natural mortality rates than those used in the Representative Run (Table 4-2).

4.6.2.4.2 Stock recruitment steepness (h)

Two sensitivity runs were conducted assuming higher and lower steepness values (h = 1.0, and 0.8) than the base case (h = 0.999).

4.6.2.4.3 Growth curve

Three sensitivity runs were conducted assuming growth curves from various studies (Shimose et al., 2008; 2009; Shimose and Takeuchi 2012).

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 to generate highly similar results on numbers at age and catch weight by fleets with deterministic future projections generated by SS (Ichinokawa 2012, p.11-12).

The projections were based on the results of the Representative Run. 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 log-normal for CPUE and multinomial for size-composition data. The CVs of abundance indices and effective sample sizes of size compositions for the bootstrap replicates were the CVs and 100*effective sample sizes from the input data of the Representative Run. 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 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 at the starting year of the stock projection and fishing mortalities at age were included.

The future projections started from the 1st quarter (July-September) of 2010 because parameter estimates were highly uncertain for the terminal year. Future recruitments were randomly resampled from the whole stock assessment period (1952-2009), without any spawner-recruitment relationship. This was an adequate assumption because the steepness of the Representative Run was very high (h = 0.999)

The following four harvest scenarios were analyzed:

iii. Constant fishing mortality at current F ($F_{2007-2009}$)
iv. Constant fishing mortality during 2002-2004 ($_{F2002-2004}$)
v. Constant fishing mortality of $F_{2007-2009}$ with catch limitations on purse seine fleets in the EPO and northwestern Pacific.
vi. Constant fishing mortality of $F_{2002-2004}$ with catch limitations on purse seine fleets in the EPO and northwestern Pacific

Catch limitations for purse seine fleets in Scenarios 3 and 4 were 5500, 2000, 500 and 5000 mt for Fleet 2, Fleet 3, Fleet 4 and Fleet 12, respectively. These upper limits were based on regulations currently implemented by IATTC (since 2012 fishing season) and Japan (since 2011 fishing season). The first and second scenarios were used to evaluate effects of only fishing mortality restrictions and the third and fourth scenarios were used to evaluate potential effects of the additional catch limitations on future stock dynamics.

4.6.4 Biological reference points

A suite of candidate F-based biological reference points (F_{max}, $F_{0.1}$, F_{med}, F_{loss} and $F_{10\%-40\%}$) relative to $F_{2007-2009}$ (current F) or $F_{2002-2004}$ (reference year of current WCPFC management measure) were used in this assessment. The estimates were expressed as the ratio of F_{BRP} to $F_{2007-2009}$, which means that when the ratio was less than 1.0, $F_{2007-2009}$ 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 F10-40% reference points are spawning biomass-based proxies of F_{MSY}.

5.0 MODEL RESULTS

5.1 Representative Run results

The dynamics of spawning stock biomass and recruitment during the stock assessment period (1952-2010) are shown in Figure 5-1. Point estimates of the Representative Run indicated that the current levels (2010) of stock biomass and SSB are 53,216 mt and 22,606 mt, respectively. The recent 5-year average of recruitment (2005-2009) was 15.6 million fish.

Fishing mortality dynamics during the stock assessment period (1952-2010) are shown in Figure 5-2. Age-specific fishing mortalities for 2007-2009 were estimated to be 4, 17, 8, 41, and 10% higher than 2002-2004 (reference year of the current WCPFC conservation and management measure) for ages 0, 1, 2, 3 and age 4+, respectively (Figure 5-2).

5.1.1 Model convergence diagnostics

The jitter runs showed that the model likely converged to a global minimum, with no evidence of further improvements to the total likelihood or substantial trends in the scaling parameter (R_0) (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 (S6) and both Japanese longline indices before 1993 (S2 and S3) were fit very well (rmse = 0.21 for all three). However, the fit for Japanese longline index for 1993-2010 (S1) and the Taiwan longline index for 1998-2010 (S9), were relatively poorer (rmse = 0.46 and 0.35 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

The estimated recruitment deviations were relatively precise for both 1996-2010 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_R = 0.6). However, the estimated and input recruitment variability were close enough such that the estimated population dynamics would not be substantially affected.

5.1.4.2. Selectivity

The estimated selectivity curves for the Representative Run are shown in Figure 5-7. Given the model structure, most of the selectivity parameters were relatively well estimated. Importantly, the selectivity parameters for the Taiwan 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 5 parameters). However, it should be noted that the selectivity for Fleet 14 was fixed after the initial run and the size compositions from Fleet 14 were not fitted in the final model due to the large misfits for this data component.

All other selectivities were estimated to be dome-shaped. However, the selectivities 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 adult fish. The parameters for the width of the descending limb for the late period, and the selectivity at the last bins for both early and late periods were not well estimated (CV = 50, 36, and 505%, respectiviely). This was likely due to the small number of observations for this fishery at the largest sizes, which suggests that a low level of selectivity occurs at these large sizes but there was not enough observations to provide a lot of information on the selectivity at large sizes.

The most precise selectivity parameters were generally the parameters for the length at peak selectivity, with CVs ranging from 1 to 10%. The least precise selectivity parameters were generally the width of the plateau, with CVs ranging from 146 to 198%.

5.2 Stock Assessment Results

Results from the Representative Run were used to determine trends in population biomass, spawning biomass, recruitment and fishing intensity for the Pacific bluefin tuna stock during the stock assessment period 1952-2010 (i.e. July, 1952 to June, 2011).

5.2.1 Total and Spawning Stock Biomass

Point estimates of total biomass (age 0+ on July 1) from the Representative Run depicted long-term fluctuations (Table 5-1 and Figure 5-8). In 1952, the starting year of the current stock assessment, stock biomass was 112,268 mt. During the stock assessment period, total biomass reached the historical maximum of 177,000 mt in 1958, and a historical minimum of 40,000 mt in 1983. Total biomass started to increase again in the mid-1980s and reached the second highest peak of 118,000 mt in 1995. Stock biomass has been declining since then to around 52,000 mt for the last 5 years and was 48,000 mt in 2010.

Spawning biomass estimates also exhibited long term fluctuations (Table 5-1 and Figure 5-9). Spawning stock biomass (SSB) relative to unfished SSB has ranged from 0.03 to 0.21 during the assessment period (1952-2010). Estimates of spawning biomass in the beginning of quarter 4 (April-June) in the first five years (1952-1956) of the assessment averaged approximately 70,000 mt. The highest SSB of about 133,000 mt occurred in 1961 while the lowest SSB of about 19,000 mt occurred in 1984. In the 1990s, SSB reached the second highest level of about 83,000 mt in 1995 and declined to about 26,000 mt in recent years (average for 2006-2010) and about 23,000 mt in 2010, which 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 20% on average for 2006-2010, and 23% for 2010.

5.2.2 Recruitment

Recruitment (age-0 fish on July 1st) estimates fluctuated widely with no apparent trend. Recent (since 1990) strong cohorts occurred in 1990 (30 million fish), 1994 (39 million fish), 2004 (37 million fish) and 2007 (24 million fish) (Table 5-1 and Figure 5-10). The average estimated recruitment was approximately 15 million fish for the entire stock assessment period (1952-2010), and 16 million fish for 2000-2009. Estimates were relatively precise for the initial 10 years of the stock assessment, i.e. 1952-1961 (average CV=14%), but were less precise for 1964-1979 (average CV = 31%, maximum CV = 42%). Recruitment estimates became more precise (average CV = 20%, maximum CV = 28%) after 1980, when recruitment indices from the Japanese troll fishery became available. In the most recent period (1995-2007), recruitment estimates have further improved in their precision (average CV = 6% or maximum CV = 9%) due to the comprehensive size data collection for Japanese fisheries that began in 1994. The 2010 recruitment estimate was based on the expected recruitment given the spawner-recruit (SR) relationship and estimated spawning biomass.

5.2.3 Fishing mortality at Age

Annual fishing mortality at age (Figure 5-2 and Table 5-2) 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 Representative Run. Throughout the stock assessment period, average fishing mortality for age 0-3 juveniles (0.54) was higher than that for age 4+ fish (0.11). The F at age 1 started to increase in 1995. The average F of age 1 fish during 1995-2009 was 1.04, while average Fs of ages 0, 2, 3 fish were 0.59, 0.56, 0.26, respectively. The average F of age 4+ fish during the same period was 0.15. In the recent period (2007-2009), average Fs of ages 0-4+ fish were 0.52, 1.02, 0.63, 0.36 and 0.15, respectively. During 2002-2004 (the base period of the current WCPFC management measure), average Fs of age 0-4+ fish were 0.50, 0.88, 0.58, 0.26 and 0.13, respectively. Therefore, the Fs at ages 0-4+ during 2007-2009 were 4%, 17%, 8%, 41%, and 10% higher than in 2002-2004, respectively.

5.2.4 Numbers-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 5-11. Several strong cohorts were apparent (e.g. the 1990 and 1994 year classes in recent years). In general, the estimated numbers-at-age reflect the age structure of Pacific bluefin tuna with fewer older fish expected.

5.3 Retrospective analyses

Retrospective analyses show that SSB estimates tended to increase with the removal of more terminal years (Figure 5 – 12). However, these increases were relatively small compared to the estimated SSB. The terminal SSB estimates also varied with the sequential removal of terminal years, but did not show consistent bias in the terminal SSB estimate. In contrast, all the retrospective analysis runs were similar in the estimates of recruitment, i.e., there is no consistent bias in the terminal estimates of recruitment. Some uncertainty was present in terminal year point estimates of recruitment.

5.4 Sensitivity to alternative assumptions

The WG conducted 20 alternative model runs with plausible alternative model configurations and data (see Section 4.6.2, Table 4-2, Table 4-3, and Table 4-3-Appendix), including the Representative Run (Run 2). For each trial run, trends in estimated SSB and recruitment were compared. In addition, estimates of $F_{2007-2009}$ (current F) or $F_{2002-2004}$ (reference year by current WCPFC Conservation Management Measure) relative to a subset of F-based biological reference points (F_{max}, F_{med}, $F_{20\%}$), the estimated depletion ratio (SSB_{2010} relative to SSB_0), and SSB_{2010} were calculated (Table 5-5).

5.4.1 Alternative model configurations and data

All 20 runs depicted similar trends in SSB, depletion and biological reference point (BRP) ratios, which supported using a single Representative Run to determine stock status and provide management advice. In all trial runs, the estimated SSB showed long term fluctuations with three biomass peaks (Figure 5-13). All 20 runs showed declining SSB over the most recent decade with an estimated SSB in 2010 ranging from 12,838 mt to 33,383 mt (-43% to +48% of the Representative Run estimate). The depletion ratio estimated by those 20 trial models varied from

0.021 to 0.054 (Table 5-5). Although the ratio of current F to BRPs varied somewhat, all trial runs indicated that the current $F_{2007\text{-}2009}$ was above F_{max}, F_{med}, and $F_{20\%}$.

5.4.2 CPUE data

5.4.2.1 CV for recent Japanese Coastal Longline CPUE (S1).

Results indicated that the choice of method used to incorporate uncertainty affected the fit to the S1 index (Figure 5 - 14). The trends in spawning stock biomass (SSB) and recruitment also differed between these runs (Figure 5 - 15). Run 4, with CPUE CV #2, provided a lower SSB and recruitment. The Run 4 SSB in 2010 was approximately 30% less than the Representative Run (Run 2). Recruitments for Run 4 were 2.0% less in 1990 and and 0.3% less in 1994 relative to the Representative Run. In general, modeling the uncertainty as a constant CV (CV#2) rather than increasing CV (CV #1) resulted in a more pessimistic model.

5.4.2.2 Alternative scenarios for the recent abundance indices for adult PBF.

Results showed a large difference in the trends in SSB in recent years between Runs 4 (which used both S1 and S9) and 10 (which used only S9), but a small difference between Runs 4 and 8 (which used only S1) (Figure 5-16). The SSB estimated for 2010 by Runs 8 and 10 were -2.6% and 106% of those estimated by Run 4, respectively. The SSBs estimated by Runs 4 and 8 fit the observed S1 index for the last five years well, relative to Run 10 because Run 10 did not use S1 (Fig. 5-17). Run 4 fit slightly better than Run 8 (2 log-likelihood units for S1).

5.4.3 Effective sample size of Fleet 3 size-composition data.

Results indicated that there was a difference in the model fit to S1 and S5 depending on the weight given to F3 size composition (Figure. 5-18). A lower weight given to F3 composition (run 1; using EffN-F3 #1) resulted in slightly reduced residuals for both indices in recent years and improved model fit (by 5 and 1.5 log-likelihood units for S1 and S5, respectively). Run 1 also resulted in a more diffuse size selectivity for Fleet 3 than the Representative Run, which caused the expected size compositions to be more flat and diffuse (Figure 5-19). The trends in SSB and recruitment were also slightly different between these runs (Figure 5-20). A lower F3 weight (Run 1) resulted in slightly lower SSB and recruitment estimates. The SSB estimated in Run 1 was 11% less in 2010 than the Representative Run, and the estimated recruitments were 17 and 4% lower than the Representative Run in 1990 and 1994, respectively.

5.4.4 Effect of fitting to different size composition components.

The fit to the terminal CPUE indices (S1 and S5) in Run 20 improved relative to the Representative Run (Figure 5-21). The fit to the size composition for Fleet 1 was reasonable for both Run 20 and the Representative Run (Figure 5-22). However, the expected Fleet 3 size compositions for Run 20 were smaller than observed in some years (i.e. 2000 and 2001), while the expected size compositions from the Representative Run were relatively closer to the observed data (Figure 5-23). The SSB estimates from Run 20 were lower than the Representative Run after the 1980s, and the recruitment estimates from Run 20 also tended to be lower. In particular, the recruitment peaks in 1990 and 1994 were 34 and 8.7% lower than the Representative Run, respectively (Figure 5-24). The SSB estimate in 2010 from Run 20 was 20% less than that from the Representative Run.

5.4.5 Biology

5.4.5.1 Natural Mortality

Substantial differences in historical SSB were reported by changing assumed values for M (Teo 2011). The Representative Run did not exhibit the same sensitivity to M as in past assessments (Figure. 5-25). In this stock assessment, recruitment estimates showed greater sensitivity to M than SSB estimates. The 2010 SSB estimates for the lower (-20%) and higher (+20%) M scenarios were -20% and +17% relative to the Representative Run estimates. The recruitments estimates in 1990 were -38% and +68% for the same scenarios. The model fit for the length-composition components favored the lower natural mortality assumption (> 12 log-likelihood units better than high M run). On the other hand, the model fit for the abundance indices component slightly favored the higher M assumption (< 2 log-likelihood units).

5.4.5.2 Stock recruitment steepness (h)

The model, which assumed a lower steepness parameter (h = 0.8), probably did not converge (final gradient is 2860.57). The trends in SSB and recruitment were similar between the Representative Run and the steepness model, which assumed h was 1.0 (Figure 5-26).

5.4.5.3 Growth curve

Model fit for the Representative Run was better than all the runs using alternative growth models. The model using the growth curve from Shimose et al. (2008), did not fit the size composition data for Fleets 2 and 5 (these Fleets catch mainly age 0-1 fish) well. That growth curve underestimated the size of age-0 fish from the commercial catch taken during summer.

The trends in SSB and recruitment were relatively similar between the Representative Run and the runs that assumed growth models from Shimose et al. (2009) and Shimose and Takeuchi (2012). However, the differences between the Representative Run and the run using the Shimose et al. (2008) growth model were substantial (Figure. 5 ‐ 27).

5.5 Future projections

The historical recruitment and SSB estimates from 300 bootstrapped simulations are shown in Figure 5-28. Point estimates of SSB, especially during the 1950s-1970s (Figure 5-28), and some SSB indicators, such as the historical minimum and median (Table 5-6), 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, but the cause is not fully understood.

The four harvest scenarios (see Section 4.6.3) showed clear differences in their expected future stock trajectories (Figure 5-28). At the current F level (F2007-2009), the SSB was expected to decline slightly to about 22,000 mt. If the fishing mortality is at the 2002-2004 level, SSB was expected to increase, with median SSB in 2030 expected to be around 40,000 mt. The effect of catch limits for the purse seine fisheries in the WCPO and EPO were substantial. Regardless of underlying fishing mortality scenarios, the future median SSB should increase substantially (50,000 mt for F2007-2009 and 83,000 mt for F2002-2004).

It should be noted that catch limitations are generally only effective when strong recruitment occurs. This is reflected in the wider 90% confidence intervals observed in the projections with catch limits than in those without catch limits (Figure 5-28). In addition, the probability that future SSB may fall to a level below the historical minimum SSB was higher for runs without catch limits, when fishing mortality was at 2007-2009 levels (Table 5-6). It is also important to note that if recruitment is less favorable, a reduction of F is more effective than catch limits to reduce the risk of the stock declining.

5.6 Biological Reference Points

The ratio of the suite of candidate F-based biological reference points (F_{max}, $F_{0.1}$, F_{med}, F_{loss} and $F_{10\% - 40\%}$) to $F_{2007 - 2009}$ (current F) and $F_{2002 - 2004}$ (reference year of current WCPFC management measure) are shown in Table 5-4. The current level of F was estimated to be higher than all listed BRPs.

6.0 STOCK STATUS AND CONSERVATION ADVICE FOR PACIFIC BLUEFIN TUNA

6.1 Current stock status

The model configuration associated with Run 2 was chosen as the base-case assessment model to determine stock status and provide management advice, acknowledging that while it represents the general conclusions above, the model was unable to reconcile all key data sources (Figure 5-1). Based on the trajectory of the base-case model stock biomass (age 0+) and SSB are estimated to be 53,216 mt and 22,606 mt, respectively, in 2010. The recent 5-year average level of recruitment (2006-2010, calendar year) was 15.6 million fish. Estimated age-specific fishing mortalities on the stock in the recent period (2007-2009) relative to 2002-2004 (the base period for the current WCPFC conservation and management measure 2010-04) show 4,17, 8, 41 and 10% increases for ages 0,1,2,3 and 4+, respectively (Figure 6-1). Although no target or limit reference points have been established for the Pacific bluefin tuna stock under the auspices of the WCPFC and IATTC, the current F (average 2007-2009) is above all target and limit biological reference points (BRPs) commonly used by fisheries managers (Table 5-4), and the ratio of SSB in 2010 relative to unfished SSB is low (Table 5-5).

Stock projections of spawning biomass and catches of Pacific bluefin tuna from 2011 to 2030 were conducted assuming four alternative harvest scenarios. A quarterly based age-structured simulation model was used for the projections, and included uncertainty in the population size-at-age at the starting year of stock projection (2011), fishing mortality at age, and future recruitment levels. Future recruitments used in the projections were randomly resampled from the dynamic period (1952-2009). Six thousand future projection simulations (300 SS bootstrap runs with 20 stochastic simulations each) were conducted for each of the harvest scenarios.

The four harvest scenarios analyzed were: (1) constant fishing mortality at current *F* (F$_{2007\text{-}2009}$); (2) constant fishing mortality at F$_{2002\text{-}2004}$; (3) constant fishing mortality at F$_{2007\text{-}2009}$ and setting catch limitations on purse seine fleets in the EPO and WPO; and (4) constant fishing mortality at F$_{2002\text{-}2004}$ and setting catch limitations on purse seine fleets in the EPO and WPO. Projection results are shown in Figure 5-28.

The future projections indicate that:

(1) The median SSB is not expected to increase recover substantially from the present median SSB in Scenario (1);

(2) The median SSB is expected to increase to approximately 41,000 mt by 2030 in Scenario (2);

(3) The median SSB is expected to increase to approximately 50,000 mt by 2030 in Scenario (3); and

(4) The median SSB is expected to increase substantially to approximately 83,000 mt by 2030 in Scenario (4).

In summary, based on the reference point ratios, overfishing is occurring (Table 5-4) and the stock is overfished. Model estimates of 2010 spawning stock biomass (SSB) are at or near their lowest level and SSB has been declining for over a decade; however, there is no evidence of reduced recruitment.

6.2 Outlook

Stock projections of spawning biomass and catches of Pacific bluefin tuna from 2011 to 2030 were conducted assuming four alternative harvest scenarios. A quarterly based age-structured simulation model was used for the projections, and included uncertainty in the population size at age in the starting year of the stock projection (2011), fishing mortalities at age, and future recruitment levels. Future recruitments used in the projections were randomly resampled from the dynamic period (1952-2009). Six thousand future projection simulations (300 SS bootstrap runs with 20 stochastic simulations each) were conducted for each of the harvest scenarios.

The four harvest scenarios analyzed were: (1) constant fishing mortality at current F ($F_{2007\text{-}2009}$); (2) constant fishing mortality at $F_{2002\text{-}2004}$; (3) constant fishing mortality at $F_{2007\text{-}2009,}$ with catch limitations on purse seine fleets in the EPO and WPO; and (4) constant fishing mortality at $F_{2002\text{-}2004}$, with catch limitations on purse seine fleets in the EPO and WPO. Projection results are shown in Table 5-6 and Figure 5-28.

The future projections indicated that:

(1) The median SSB is not expected to recover substantially in Scenario (1);
(2) The median SSB is expected to recover to approximately 41,000 mt by 2030 in Scenario (2);
(3) The median SSB is expected to recover to approximately 50,000 mt by 2030 in Scenario (3); and
(4) The median SSB is expected to recover to approximately 83,000 mt by 2030 in Scenario (4).

6.3 Conservation advice

The current (2010) PBF biomass level is near historically low levels and experiencing high exploitation rates above all biological reference points (BRPs) commonly used by fisheries managers. Based on projection results, extending the status quo (2007-2009) fishing levels is unlikely to improve stock status.

Recently WCPFC[3] (entered into force in 2011) and IATTC[4] (entered into force in 2012) conservation and management measures combined with additional Japanese voluntary domestic regulations aimed at reducing mortality[3], if properly implemented and enforced, are expected to contribute to improvements in PBF stock status. Based on those findings, it should be noted that implementation of catch limits is particularly effective in increasing future SSB when strong recruitment occurs. It is also important to note that if recruitment is less favorable, a reduction of F could be more effective than catch limits to reduce the risk of the stock declining.

The ISC requires advice from the WCPFC regarding which reference point managers prefer so that it can provide the most useful scientific advice. Until which time a decision is rendered, the ISC will continue to provide a suite of potential biological reference points for managers to consider.
PBF is currently (2010) near historically low biomass levels and experiencing high exploitation levels above BRPs. Extending the status quo (2007-2009) fishing levels is unlikely to improve the stock condition.

Recently implemented WCPFC (entered into force in 2011) and IATTC (entered into force in 2012) conservation and management measures, if properly implemented and enforced, should contribute to the recovery of the stock.

Additional Japanese domestic regulations aimed at reducing fishing mortality on juveniles are projected to further contribute to the recovery of the stock.

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[3] WCPFC CMM 2010-04 specifies that "… total fishing effort by their vessels fishing for Pacific bluefin tuna in the area north of the 20 degrees north shall stay below the 2002-2004 levels for 2011 and 2012, except for artisanal fisheries. Such measures shall include those to reduce catches of juveniles (age 0-3) below the 2002-2004 levels, except for Korea. Korea shall take necessary measures to regulate the catches of juveniles (age 0-3) by managing Korean fisheries in accordance with this CMM. CCMs shall cooperate for this purpose." For full text see: http://www.wcpfc.int/node/3407

[4] IATTC Resolution C-12-09 specifies that "… 1. In the IATTC Convention Area, the commercial catches of bluefin tuna by all the CPCs during the two-year period of 2012-2013 shall not exceed 10,000 metric tons; 2. The commercial catch of bluefin tuna in the commercial fishery in the Convention Area shall not exceed 5,600 metric tons during the year 2012; 3. Notwithstanding paragraphs 1 and 2, 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." For full text see: iattc.org/PDFFiles2/Resolutions/C-12-09-Conservation-of-bluefin-tuna.pdf

[3] This is described in WCPFC-NC8-2012/DP-01. For full text see;
http://www.wcpfc.int/system/files/documents/meetings/northern-committee/8th-regular-session/delegation-proposals-and-papers/NC8-DP-01-%5BEXPLANATION-AND-IMPLEMENTATION-CMM-2010-04%5D.pdf

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8.0 TABLES AND FIGURES

Table 3-1. Definition of fisheries in the stock assessment.

Serial No.	Fleet No.	Short name	Data type	Available Period	Corresponding Fisheries	Lambda	Size data type (Fishery) or mirroring (CPUE)	Average input sample size or C.V.	Data quality	Document for reference
1	F1	JLL	Fishery	1952–1968, 1994–2009	Japanese Longline	1	Length	12.3	Catch @ length	ISC/12-1/PBFWG/01
2	F2	SPelPS	Fishery	2001–2010	Small pelagic fish purse seine	1	Length	12.1	Catch @ length	ISC/12-1/PBFWG/02
3	F3	TunaPSJS	Fishery	1986–1989, 1991–2010	Tuna purse seine (Sea of Japan)	1	Length	20.3 or 12.1	Catch @ length	ISC/12-1/PBFWG/07
4	F4	TunaPSPO	Fishery	1994–2006	Tuna purse seine (Pacific Ocean)	1	Length	12.1	Catch @ length	ISC/12-1/PBFWG/03
5	F5	JpnTroll	Fishery	1993–2010	Japanese Coastal Troll	1	Length	12.1	Catch @ length	ISC/12-1/PBFWG/04
6	F6	JpnPL	Fishery	1994–1996, 1998–2004, 2005–2010	Japanese Pole-and-line	0	Length, Share Selex with Fleet5	12.1	raw mearsurement	No document
7	F7	JpnSetNet NOJWeight	Fishery	1993–2010	Japanese Set net (northern part of Japan)	1	Weight	12.1	Catch @ weight	ISC/12-1/PBFWG/05
8	F8	JpnSetNet NOJLength	Fishery	1994–2008, 2010	Japanese Set net (Q3-Q4, Hokuriku)	1	Length	12.1	Catch @ length	ISC/12-1/PBFWG/05
9	F9	JpnSetNet OAJLength Q1-3	Fishery	1993–2010	Japanese Set net (other area, Q1-Q3)	1	Length	12.1	Catch @ length	ISC/12-1/PBFWG/05
10	F10	JpnSetNet OAJLength Q4	Fishery	1993–2010	Japanese Set net (Other area, Q4)	1	Length	12.1	Catch @ length	ISC/12-1/PBFWG/05
11	F11	TWLL	Fishery	1992–2010	Taiwanese Longline	1	Length	12.1	raw measurement (high coverage)	No document
12	F12	EPOPS	Fishery	1952–1965, 1969–1987, 1990–2010	Eastern Pacific Ocean Commercial fishery	1	Length	9.3	Catch @ length	ISC/12-3/PBFWG/02
13	F13	EPOSP	Fishery	1993–2003, 2004–2006, 2008–2010	Eastern Pacific Ocean Sports fishery	0	Length	12.1	raw measurement	No document
14	F14	Others	Fishery	1994–2010	Others	0.1	Weight	12.1	Catch @ weight	ISC/12-1/PBFWG/06

Table 3-1 Continued.

Serial No.	Fleet No.	Short name	Data type	Available Period	Corresponding Fisheries	Lambda	Size data type (Fishery) or mirroring (CPUE)	Average input sample size or C.V.	Data quality	Document for reference
15	S1	JpCLL	CPUE	1993-2010	Japanese coastal longline conducting in spawning area and season.	1	F1	0.24 or 0.20	Standerdized	ISC/12-1/PBFWG/08
16	S2	JpnDWLLFujiokaRevto74	CPUE	1952-1973	Japanese offshore and distant water longliners until 1974	1	F1	0.2	Standerdized	ISC/12-1/PBFWG/10
17	S3	JpnDWLLYokawaRevfrom75	CPUE	1974-1992	Japanese offshore and distant water longliners from 1975	1	F1	0.2	Standerdized	ISC/12-1/PBFWG/10
18	S4	TPSJO	CPUE	1987-1989, 1991-2010	Japanese Tuna purse seine in Sea of Japan	0	F3	0.2	Standerdized	ISC/12-1/PBFWG/09
19	S5	JpnTrollChinaSea	CPUE	1980-2010	Japanese troll in Nagasaki (Sea of Japan and East China sea)	1	F5	0.2	Standerdized	ISC/12-1/PBFWG/11
20	S6	JpnTrollPacific	CPUE	1994-2010	Japanese troll combined with Kochi and Wakayama by catch-weighted average	0	F5	0.2	Standerdized and combined by ad-hoc way	ISC/12-1/PBFWG/11
21	S7	JpnTRKochi	CPUE	1981-2010	Japanese troll in Kochi (Pacific)	0	F5	0.2	Standerdized	ISC/12-1/PBFWG/11
22	S8	JpnTRWakayama	CPUE	1994-2010	Japanese troll in Wakayama (Pacific)	0	F5	0.2	Standerdized	ISC/12-1/PBFWG/11
23	S9	TWLL	CPUE	1998-2010	Taiwanese Longline	1	F11	0.2	Standerdized	ISC/12-2/PBFWG/14
24	S10	USPSto82	CPUE	1960-1982	EPO Purse seine during US target fisheries	0	F12	0.93	Standerdized	ISC/12-1/PBFWG/18
25	S11	MexPSto06	CPUE	1999-2010	EPO Purse seine during Mexico operating	0	F12	0.77	Standerdized	ISC/12-1/PBFWG/18

Table 3-2. Abundance indices 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		0.64					0.62	
1981			0.0035		1.11		0.82			0.34	
1982			0.0020		0.57		0.25			0.38	
1983			0.0012		0.87		0.21				
1984			0.0013		0.88		1.14				
1985			0.0012		0.82		0.77				
1986			0.0014		0.93		0.28				
1987			0.0014	709.5	0.67		0.16				
1988			0.0016	353.9	0.76		0.58				
1989			0.0024	598.8	0.61		0.32				
1990			0.0024		1.20		0.64				
1991			0.0038	289.1	1.29		0.58				
1992			0.0041	485.5	0.55		0.30				
1993	1.77			600.3	0.46		0.51				
1994	1.28			2402.0	1.93	2.36	3.20	1.40			
1995	1.60			1169.3	1.05	0.84	1.05	0.78			
1996	1.65			706.3	1.57	0.85	0.90	1.26			
1997	1.46			459.5	0.89	0.46	0.48	0.71			
1998	1.04			550.6	0.81	1.11	1.54	0.55	0.41		
1999	0.80			766.1	1.47	0.25	0.33	0.18	0.34		20.47
2000	0.62			754.8	1.14	0.32	0.32	0.53	0.20		0.56
2001	0.71			438.6	1.15	1.56	2.11	0.94	0.13		0.55
2002	1.18			459.7	0.73	0.67	0.83	0.62	0.18		0.24
2003	1.27			474.9	0.64	0.32	0.40	0.30	0.17		2.38
2004	1.51			752.8	1.27	3.17	3.47	4.37	0.09		1.64
2005	0.74			856.7	1.35	0.87	0.99	1.08	0.11		0.51
2006	1.06			388.4	0.70	0.82	0.93	1.04	0.09		0.29
2007	0.58			865.7	1.38	1.27	1.47	1.51	0.12		0.27
2008	0.37			751.6	1.41	0.68	0.66	1.20	0.09		0.41
2009	0.19			585.1	1.09	0.08	0.08	0.13	0.06		1.64
2010	0.17			603.5	1.07	1.35	1.97	0.40	0.11		3.01

Table 3-3. CVs of abundance indices available for the stock assessment. Only S1, S2, S3, S5, and S9 were used in the assessment model.

	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

(*1) Two scenarios are proposed to quantify uncertainty of Japanese CPUE

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

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

Table 3-5. Input sample size for 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											4.8		
1955	12.0											5.7		
1956	12.8											8.9		
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											19.3		
1964	11.8											11.3		
1965	12.8											25.3		
1966	12.8													
1967	12.8													
1968	12.2													
1969												3.5		
1970												7.0		
1971												2.8		
1972												1.0		
1973												5.5		
1974												3.3		
1975												3.5		
1976												11.3		
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	11.1		7.9	6.6	12.2	12.8	12.4	12.9	12.1	12.1	12.4		13.0	12.6
2000	10.7		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	11.5	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	10.2	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		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		8.3	12.6
2007	11.0	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		13.0	10.5
2009	12.8	12.1	8.9		12.2	12.8	12.4		12.1	12.1	9.6		13.0	12.6
2010		12.1	22.6		12.2	12.5	10.7	12.9	12.1	12.1	12.4		13.0	12.6

Table 4-1. Description of size composition data and the type of the selectivity .

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.
F2	Double normal	lambda=1.
F3	Double normal	Introduce time block during 2007-2010.
F4	Double normal	Eliminate data before 1993 and after 2007, super period combining q1 and q4.
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	weight=1, q1, q4.
F11	Flat top	weight=1.
F12	Double normal	lambda=1, Eliminate data during 1983-2004, 2007. Time block 2002-2010.
F13	Mirror F11 selectivity	lambda=0.
F14	Double normal	lambda=0.

Table 4-2. Biological parameters used for sensitivity runs on natural mortality, steepness, von Bertalanffy growth curve parameters.

Natural mortality

	Age0	Age1	Age2	Age3	Age4+	Assumption
Base	1.6	0.386	0.25	0.25	0.25	
Run1	1.28	0.3088	0.2	0.2	0.2	Lower M
Run2	1.92	0.4632	0.3	0.3	0.3	Higer M

Steepness Parameter

		Assumption
Base	0.999 (Fix)	
Run1	0.8 (fix)	Lower *h*
Run2	1.0 (Fix)	Previous assessment

Growth curve

	K	L∞	t0	L@Amin (0.125)	L@Amax (3.125)	Assumption
Base	0.157			21.5	109.2	
Run1	0.173	249.6	-0.254	15.8	110.5	Shimose (2009)
Run2	0.195	245.4	-0.472	27.0	123.7	Shimose (2008)
Run3	0.165	252.1	-0.259	15.5	107.9	Shimose (2012)

Table 4-3. Model configurations for alternative runs. Run 2 was considered to be the Representative Run. See Table 4-3-Appendix for different CV and Effective sample size (EffN) values used in the model runs.

Run#	CPUE for recent LL	CV for CPUE S1	EffN for F3	Size selectivity estimated	Size composition fitted
1	S1 and S9	CPUE CV #1	EffN #1	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
2	S1 and S9	CPUE CV #1	EffN #2	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
3	S1 and S9	CPUE CV #2	EffN #1	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
4	S1 and S9	CPUE CV #2	EffN #2	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
5	S1	CPUE CV #1	EffN #1	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
6	S1	CPUE CV #1	EffN #2	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
7	S1	CPUE CV #2	EffN #1	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
8	S1	CPUE CV #2	EffN #2	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
9	S9	-	EffN #1	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
10	S9	-	EffN #2	Mirror to other fleet: F6, 13. Fixed: F14. Estimated: The rest of Fleets.	All Fleets except Fleet 6, 13, 14
11	S1	CPUE CV #2	EffN #1	Mirror to other fleet: F6, 13. Estimated: The rest of Fleets.	All fleets except F6, F13
12	S1	CPUE CV #2	EffN #1	Mirror to other fleet: F6, 13. Fixed: F3, 4, 7, 12, 14. Estimated: The rest of Fleets.	All fleets except F3, F4, F6, F7,F12,F13,F14
13	S1	CPUE CV #2	EffN #2	Mirror to other fleet: F6, 13. Fixed: F3, 4, 7, 12, 14. Estimated: The rest of Fleets.	All fleets except F3, F4, F6, F7,F12,F13,F14
14	S9	-	EffN #1	Mirror to other fleet: F6, 13. Fixed: F3, 4, 12, 14. Estimated: The rest of Fleets.	All fleets except F3, F4, F6,F12,F13,F14
15	S9	-	EffN #2	Mirror to other fleet: F6, 13. Fixed: F3, 4, 12, 14. Estimated: The rest of Fleets.	All fleets except F3, F4, F6,F12,F13,F14
16	S9	-	EffN #1	Mirror to other fleet: F6, 13. Estimated: The rest of Fleets.	All fleets except F6, F13
17	S1 and S9	CPUE CV #2	EffN #1	Mirror to other fleet: F6, 13. Estimated: The rest of Fleets.	All fleets except F6, F13
18	S1 and S9	CPUE CV #2	EffN #1	Mirror to other fleet: F6, 13. Fixed: F3, 4, 7, 12, 14. Estimated: The rest of Fleets.	All fleets except F3, F4, F6, F7,F12,F13,F14
19	S1 and S9	CPUE CV #1	EffN #1	Mirror to other fleet: F6, 13. Fixed: F3, 4, 7, 12, 14. Estimated: The rest of Fleets.	All fleets except F3, F4, F6, F7,F12,F13,F14
20	S1 and S9	CPUE CV #1	EffN #2	Mirror to other fleet: F6, 13. Fixed: F3, 4, 7, 12, 14. Estimated: The rest of Fleets.	All fleets except F3, F4, F6, F7,F12,F13,F14

Table 4-3-Appendix. Input values of CV for S1 (Japanese longline CPUE from 1993-2010) and effective sample size (EffN) for Fleet 3 (Japanese purse seine operating in the Sea of Japan) that were used as alternative model configurations in alternative runs detailed in Table 4-3.

	CV for CPUE S1		EffN for Fleet3	
Year	**#1**	**#2**	**#1**	**#2**
1987	-	-	12.11	12.19
1988	-	-	12.11	8.55
1989	-	-	12.11	12.46
1991	-	-	12.11	2.99
1992	-	-	12.11	2.47
1993	0.20	0.23	12.11	1.22
1994	0.20	0.21	12.11	51.20
1995	0.20	0.22	12.11	7.26
1996	0.20	0.20	12.11	51.20
1997	0.20	0.20	12.11	23.21
1998	0.20	0.19	12.11	2.60
1999	0.20	0.19	12.11	7.94
2000	0.20	0.19	12.11	15.66
2001	0.20	0.20	12.11	51.20
2002	0.20	0.19	12.11	11.42
2003	0.20	0.18	12.11	9.78
2004	0.20	0.18	12.11	13.58
2005	0.24	0.19	12.11	51.20
2006	0.28	0.19	12.11	41.13
2007	0.31	0.19	12.11	22.87
2008	0.35	0.20	12.11	35.68
2009	0.39	0.22	12.11	8.95
2010	0.43	0.23	12.11	22.64

Table 5-1. Trends in spawning stock biomass (mt) and recruitment (1000s fish) estimated by the Representative Run.

Year	Total biomass (B in t)	Spawning stock biomass (SSB in t)	StdDev for SSB	Recruitment (R in 1000 fish)	StdDev for R
1952	113476	85488	36134	15766	
1953	116379	75841	32837	38958	4452
1954	126600	67155	29652	19799	3397
1955	137149	60141	27106	21460	2998
1956	155532	64143	27608	32021	2797
1957	168861	77989	31078	11130	1197
1958	177630	106759	38442	2721	627
1959	177621	123349	42530	5502	1094
1960	175163	132216	45622	17120	2139
1961	167191	132742	47214	21939	2410
1962	152774	112631	43764	12962	1883
1963	137790	90911	38817	22953	2366
1964	125442	76975	34237	12804	2309
1965	117988	67735	30414	7893	3293
1966	106399	63978	27749	9121	3711
1967	86423	60444	25607	10963	4322
1968	75748	53419	24037	15268	3994
1969	64790	45353	21450	8131	2757
1970	58070	37708	18611	12310	4693
1971	54134	31723	15602	14196	5074
1972	56350	27508	12605	20501	5201
1973	58515	25831	9914	20385	4738
1974	63748	23543	7690	11428	2950
1975	67987	25695	6764	13166	2916
1976	75386	34852	7612	9548	3087
1977	77829	46549	9599	28361	5655
1978	81747	49065	10366	17018	5213
1979	79583	42519	9707	14551	3309
1980	76878	40355	8691	6770	2026
1981	75746	32173	6295	18839	2263
1982	58767	25878	5103	8379	2240
1983	39892	18900	4376	11709	2295
1984	43204	18502	4193	8661	2241
1985	45729	20600	4152	11227	2166
1986	44513	23708	4517	12175	2178
1987	41051	21846	4630	8206	2155
1988	45090	22052	4878	7830	1841
1989	50231	22703	4988	6232	1487
1990	61904	28983	5667	29074	1848
1991	78099	37970	6567	3726	1050
1992	85420	45146	7154	5891	696
1993	94429	56616	8215	4741	632
1994	107134	67684	9676	38677	1334
1995	118483	83070	11857	11816	1250
1996	114940	76894	11471	18509	973
1997	111947	72161	11066	9240	820
1998	106437	72312	10712	15681	933
1999	99492	68173	10518	21539	1037
2000	90163	59865	9712	16199	828
2001	77419	54464	8817	18031	766
2002	77134	48723	7862	13933	836
2003	74358	46131	7048	10168	835
2004	73187	40603	6358	27424	977
2005	68456	36163	5885	13249	863
2006	57663	32995	5565	9863	846
2007	53187	28168	5203	23878	1265
2008	53050	25085	5020	18786	1361
2009	48591	22680	5057	9059	1225
2010	48949	22606	5305	16348	2968

Table 5-2. Age-specific fishing mortality estimates from the Representative Run.

Year	Age 0	Age 1	Age 2	Age 3	Age 4+
1952	0.34	0.46	0.44	0.24	0.06
1953	0.19	0.49	0.47	0.22	0.05
1954	0.24	0.46	0.46	0.24	0.06
1955	0.29	0.30	0.27	0.24	0.08
1956	0.19	0.35	0.35	0.26	0.09
1957	0.32	0.41	0.38	0.22	0.06
1958	0.74	0.78	0.41	0.17	0.04
1959	0.51	0.72	0.37	0.15	0.06
1960	0.33	0.86	0.79	0.29	0.06
1961	0.27	0.92	1.00	0.37	0.07
1962	0.29	0.69	0.76	0.34	0.08
1963	0.26	0.71	0.79	0.35	0.07
1964	0.29	0.50	0.55	0.30	0.07
1965	0.41	0.78	0.56	0.30	0.07
1966	0.65	1.55	1.39	0.51	0.07
1967	0.67	1.23	0.97	0.45	0.07
1968	0.37	1.49	1.67	0.67	0.09
1969	0.44	1.02	1.05	0.43	0.06
1970	0.36	0.96	0.74	0.36	0.07
1971	0.25	0.83	0.75	0.31	0.06
1972	0.17	0.97	1.14	0.42	0.07
1973	0.23	0.66	0.75	0.31	0.08
1974	0.32	0.56	0.51	0.33	0.11
1975	0.23	0.67	0.48	0.17	0.04
1976	0.64	0.95	0.76	0.29	0.06
1977	0.29	0.75	0.69	0.37	0.08
1978	0.44	0.84	0.63	0.36	0.09
1979	0.44	0.77	0.52	0.31	0.09
1980	0.46	0.72	0.41	0.32	0.10
1981	0.50	0.90	0.66	0.69	0.23
1982	0.27	0.95	1.22	1.10	0.32
1983	0.36	0.56	0.34	0.28	0.15
1984	0.77	0.68	0.34	0.23	0.11
1985	0.45	0.92	0.67	0.39	0.10
1986	0.47	1.03	1.05	0.49	0.15
1987	0.23	0.39	0.41	0.31	0.10
1988	0.36	0.43	0.25	0.19	0.11
1989	0.29	0.36	0.22	0.17	0.09
1990	0.16	0.34	0.23	0.13	0.08
1991	0.51	0.58	0.17	0.13	0.11
1992	0.74	0.95	0.18	0.09	0.09
1993	0.31	0.40	0.19	0.12	0.12
1994	0.37	0.42	0.26	0.15	0.08
1995	0.35	1.08	0.30	0.13	0.11
1996	0.57	0.71	0.50	0.18	0.13
1997	0.64	1.23	0.38	0.13	0.13
1998	0.58	1.09	0.53	0.24	0.18
1999	0.78	0.96	0.35	0.22	0.18
2000	1.15	1.68	0.64	0.25	0.14
2001	0.58	0.59	0.29	0.14	0.11
2002	0.52	0.71	0.39	0.21	0.13
2003	0.46	1.15	0.56	0.20	0.11
2004	0.53	0.83	0.90	0.43	0.17
2005	0.56	1.36	0.78	0.29	0.16
2006	0.52	1.11	0.79	0.35	0.20
2007	0.54	1.08	0.75	0.41	0.16
2008	0.52	1.08	0.67	0.42	0.18
2009	0.51	0.92	0.49	0.28	0.12
2010	0.52	0.52	0.61	0.33	0.09

Table 5-3. Estimated numbers-at-age (1,000s fish) at the beginning of the year from the Representative Run.

Year	Age0	Age1	Age2	Age3	Age4	Age5+
1952	15,766	1,814	232	109	117	812
1953	38,958	2,272	776	117	67	643
1954	19,799	6,527	945	378	73	500
1955	21,460	3,157	2,794	463	232	399
1956	32,021	3,247	1,591	1,655	283	418
1957	11,130	5,329	1,549	870	993	459
1958	2,721	1,634	2,400	824	543	986
1959	5,502	262	509	1,236	542	1,100
1960	17,120	664	87	274	829	1,156
1961	21,939	2,493	192	31	159	1,365
1962	12,962	3,372	672	55	17	1,038
1963	22,953	1,960	1,155	245	31	709
1964	12,804	3,583	658	408	134	511
1965	7,893	1,943	1,470	295	235	440
1966	9,121	1,058	607	655	170	458
1967	10,963	963	153	118	306	421
1968	15,268	1,127	192	45	59	474
1969	8,131	2,133	173	28	18	347
1970	12,310	1,053	524	47	14	257
1971	14,196	1,739	273	194	26	188
1972	20,501	2,228	516	100	110	153
1973	20,385	3,494	571	128	51	180
1974	11,428	3,269	1,226	210	73	159
1975	13,166	1,676	1,265	575	118	150
1976	9,548	2,103	582	611	376	196
1977	28,361	1,015	555	212	356	398
1978	17,018	4,273	325	217	114	480
1979	14,551	2,211	1,257	135	118	383
1980	6,770	1,894	698	584	77	332
1981	18,839	864	629	360	331	267
1982	8,379	2,296	240	255	140	278
1983	11,709	1,287	606	55	66	157
1984	8,661	1,649	500	336	32	141
1985	11,227	811	567	277	208	115
1986	12,175	1,448	219	225	146	198
1987	8,206	1,543	352	60	107	214
1988	7,830	1,312	712	182	34	208
1989	6,232	1,108	581	430	117	163
1990	29,074	943	526	363	283	190
1991	3,726	4,998	456	324	248	338
1992	5,891	450	1,893	301	221	408
1993	4,741	568	118	1,229	214	456
1994	38,677	702	259	76	847	474
1995	11,816	5,382	313	156	51	934
1996	18,509	1,687	1,249	182	106	701
1997	9,240	2,111	564	587	118	583
1998	15,681	982	420	301	400	498
1999	21,539	1,770	225	192	185	605
2000	16,199	2,001	458	123	119	520
2001	18,031	1,040	254	188	75	437
2002	13,933	2,043	393	148	127	365
2003	10,168	1,680	685	207	94	341
2004	27,424	1,298	361	305	133	310
2005	13,249	3,257	384	114	155	286
2006	9,863	1,529	567	137	67	285
2007	23,878	1,181	341	200	75	228
2008	18,786	2,821	273	126	103	197
2009	9,059	2,254	651	109	64	184
2010	16,348	1,096	609	310	64	166

Table 5-4. Ratio of candidate F-based biological reference points to $F_{2007-2009}$ (current F) and $F_{2002-2004}$ (reference year of current WCPFC management measure) for the Representative Run. If the ratio is less than 1.0, the estimated F (F_{0709} or F_{0204}) is higher than the biological reference point.

	F_{max}	$F_{0.1}$	F_{med}	F_{loss}	$F_{10\%}$	$F_{20\%}$	$F_{30\%}$	$F_{40\%}$
F_{0204}	0.57	0.40	0.91	1.19	0.85	0.58	0.43	0.33
F_{0709}	0.48	0.34	0.73	0.95	0.68	0.47	0.35	0.26

Table 5-5. Ratio of F-based biological reference points (F_{MAX}, F_{MED}, $F_{20\%}$) to $F_{2007-2009}$ and $F_{2002-2004}$, depletion ratio ($SSB_{2010}/SSB_{unfished}$), and SSB at 2010 for 20 alternative runs. Run 2 was considered to be the Representative Run.

	Fmax 02-04	Fmax 07-09	Fmed 02-04	Fmed 07-09	F20P 02-04	F20P 07-09	Depletion Rate	SSB at 2010
Run 1	0.54	0.45	0.90	0.71	0.56	0.45	0.032	20030
Run 2	0.57	0.48	0.91	0.73	0.58	0.47	0.036	22606
Run 3	0.51	0.39	0.88	0.63	0.53	0.38	0.022	13678
Run 4	0.54	0.41	0.89	0.64	0.55	0.40	0.025	15794
Run 5	0.58	0.49	0.93	0.75	0.59	0.48	0.037	23794
Run 6	0.60	0.50	0.97	0.78	0.60	0.49	0.041	25595
Run 7	0.52	0.39	0.90	0.65	0.53	0.39	0.022	13996
Run 8	0.54	0.40	0.90	0.65	0.55	0.40	0.024	15388
Run 9	0.61	0.54	0.94	0.82	0.61	0.53	0.047	30085
Run 10	0.63	0.57	0.96	0.84	0.63	0.55	0.051	32519
Run 11	0.51	0.38	0.92	0.64	0.54	0.38	0.022	13141
Run 12	0.46	0.39	0.82	0.66	0.48	0.39	0.021	13060
Run 13	0.46	0.39	0.82	0.66	0.48	0.38	0.021	12944
Run 14	0.62	0.55	0.98	0.82	0.64	0.54	0.051	31196
Run 15	0.60	0.55	1.04	0.87	0.64	0.54	0.053	32741
Run 16	0.61	0.55	1.04	0.87	0.65	0.55	0.054	33383
Run 17	0.49	0.38	0.91	0.63	0.54	0.37	0.021	12838
Run 18	0.46	0.39	0.81	0.65	0.48	0.39	0.022	13389
Run 19	0.50	0.45	0.83	0.74	0.50	0.45	0.030	18419
Run 20	0.49	0.45	0.82	0.74	0.50	0.45	0.030	18206

Table 5-6. Results of future projections. Numbers in parentheses indicate harvest scenarios in the text. Harvest scenarios 1 and 2 uses F0709 and F0204 as future fishing mortality. Harvest scenarios 3 and 4 imposes additional catch limits on the several commercial purse seine fisheries (Fleets 2, 3, 4, and 12) on to scenarios 1 and 2.

		(1)	(2)	(3)	(4)
F scenario		F0709	F0204	F0709	F0204
Scenarios for capping	F2	-	-	5,500	5,500
	F3	-	-	2,000	2,000
	F4	-	-	500	500
	F12	-	-	5,000	5,000
point estimation	terminal year (2010) SSB	22,613			
	historical median SSB	46,122			
	historical minimum(SSBmin)	18,433			
Future Median SSB	2015	21,585	31,337	24,504	35,988
	2020	21,704	38,723	38,109	63,252
	2025	21,726	40,246	47,699	79,404
	2030	21,742	40,784	50,248	83,071
Prob(SSB_y<SSBmin|y1<=y<y2)	y1-y2				
	2011-2015	23	7	19	7
	2016-2020	35	0	17	0
	2021-2025	37	0	10	0
	2026-2030	37	0	6	0
Total catch 5year average	2011-2015	19,687	18,258	18,808	16,670
	2016-2020	19,994	19,929	19,985	18,668
	2021-2025	19,994	20,406	21,382	20,841
	2026-2030	20,039	20,587	22,016	21,681

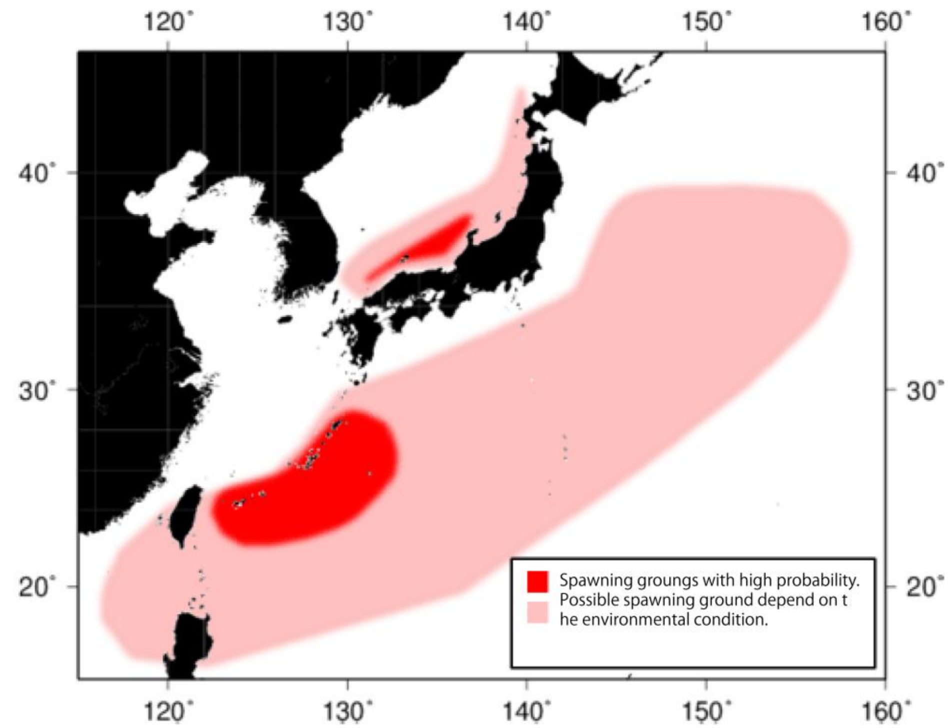


Fig. 2-1. General spawning areas of Pacific bluefin tuna. Red areas represent areas with higher probability of spawning.

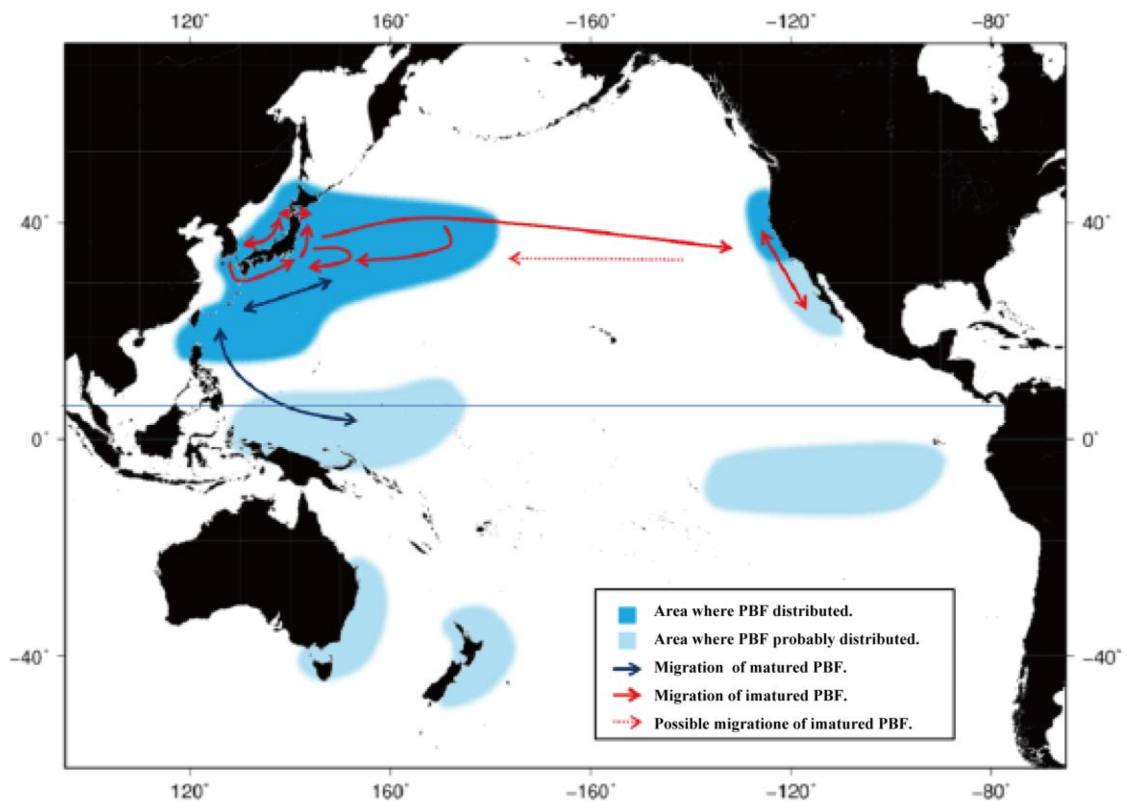


Fig. 2-2.General distribution and migration of Pacific bluefin tuna. Darker areas indicate the main distribution areas.

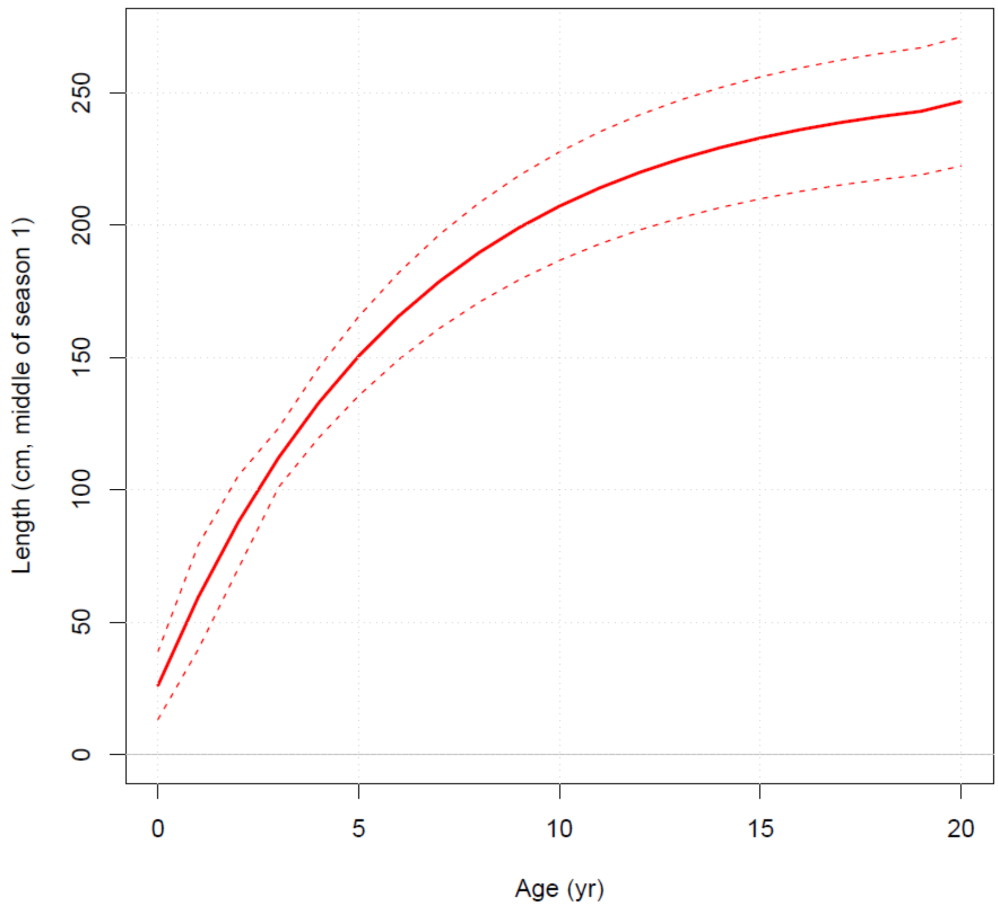


Fig. 2-3.The von Bertalanffy growth curve used in this stock assessment.

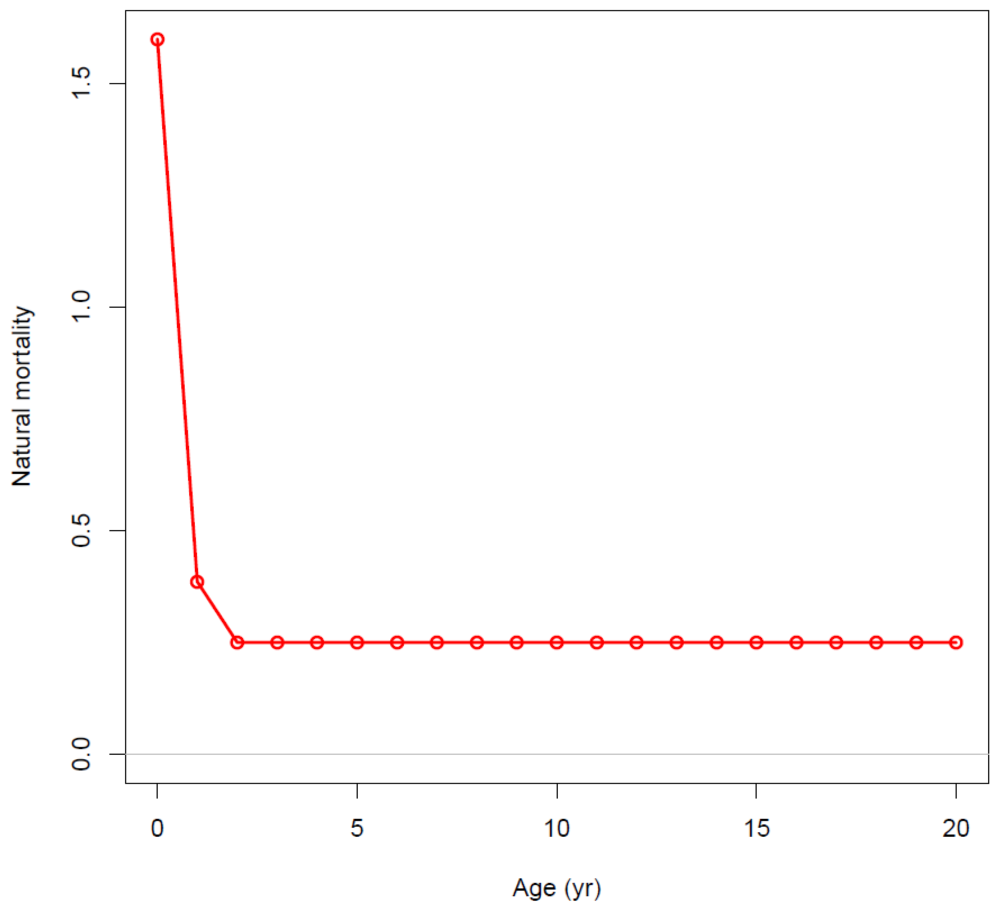


Fig. 2-4. Assumed annual natural mortality in this stock assessment.

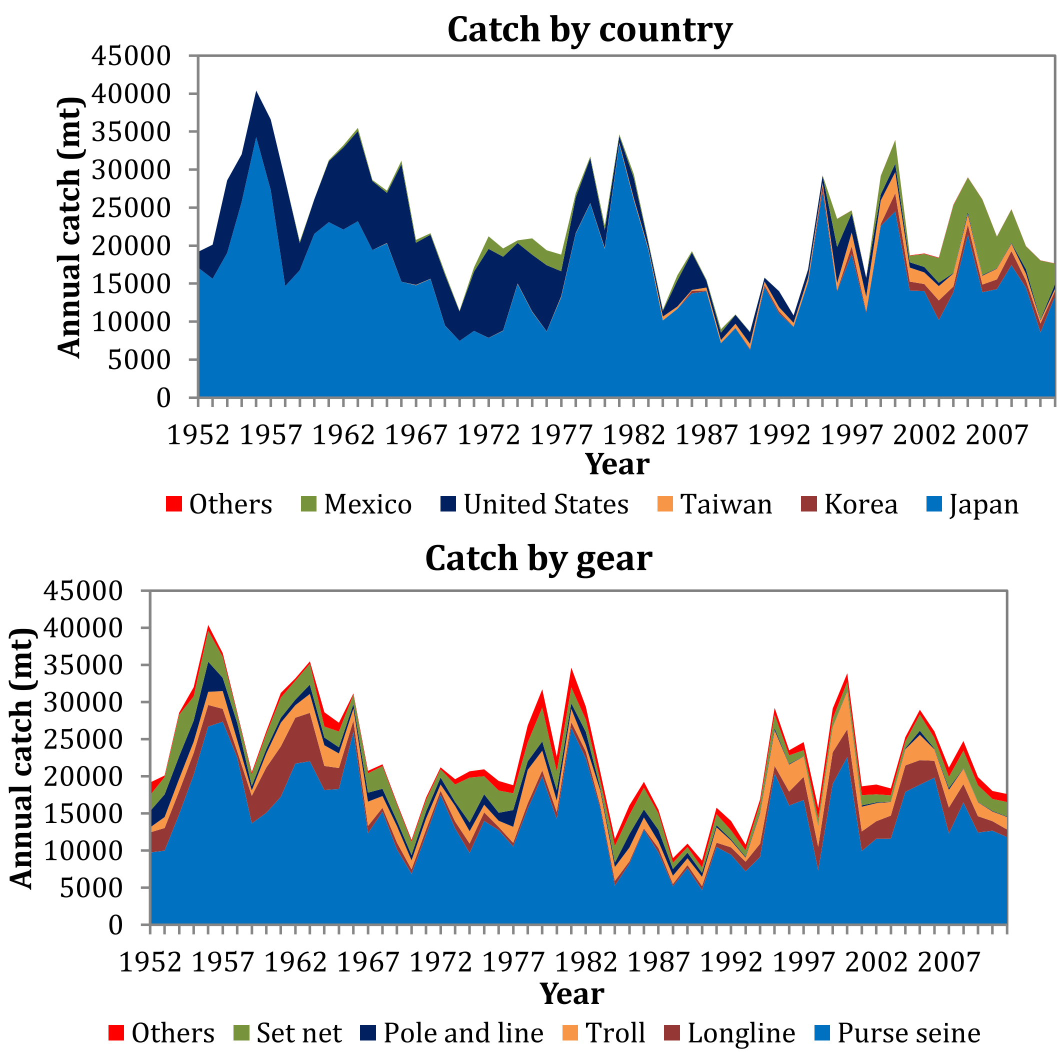


Fig. 2-5. Historical annual catch of Pacific bluefin tuna by country and gear, 1952-2011 (Calendar year). Data for 1952 and 2011 are incomplete.

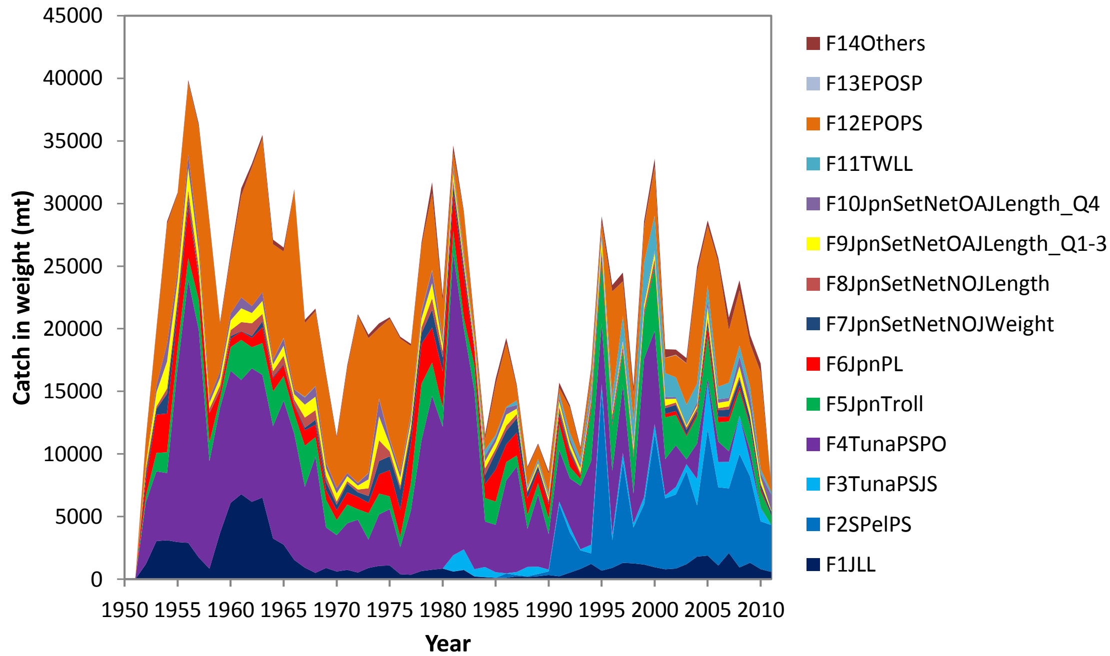


Fig. 3-1. Historical annual catch of Pacific bluefin tuna by fleet 1952-2011 (calendar year). Data for 1952 and 2011 are incomplete..

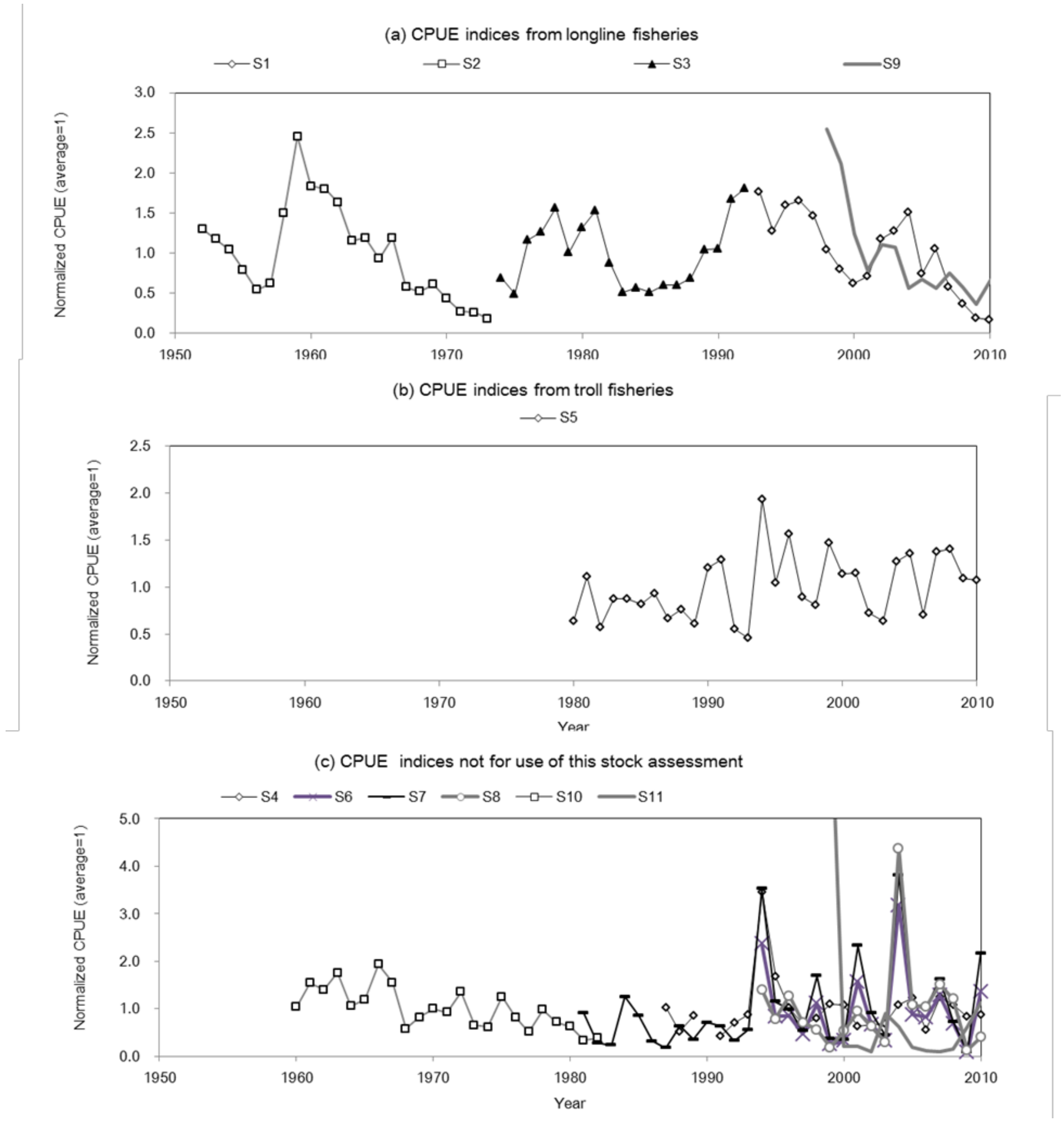


Fig. 3-2. Abundance indices available for this stock assessment: (a) Indices from Japanese (S1, 2, and 3) and Taiwanese (S9) longline fisheries were used to represent adult abundance; (b) Index from the Japanese troll fishery (S5) was used to represent recruit abundance; and (c) Other indices were not used.

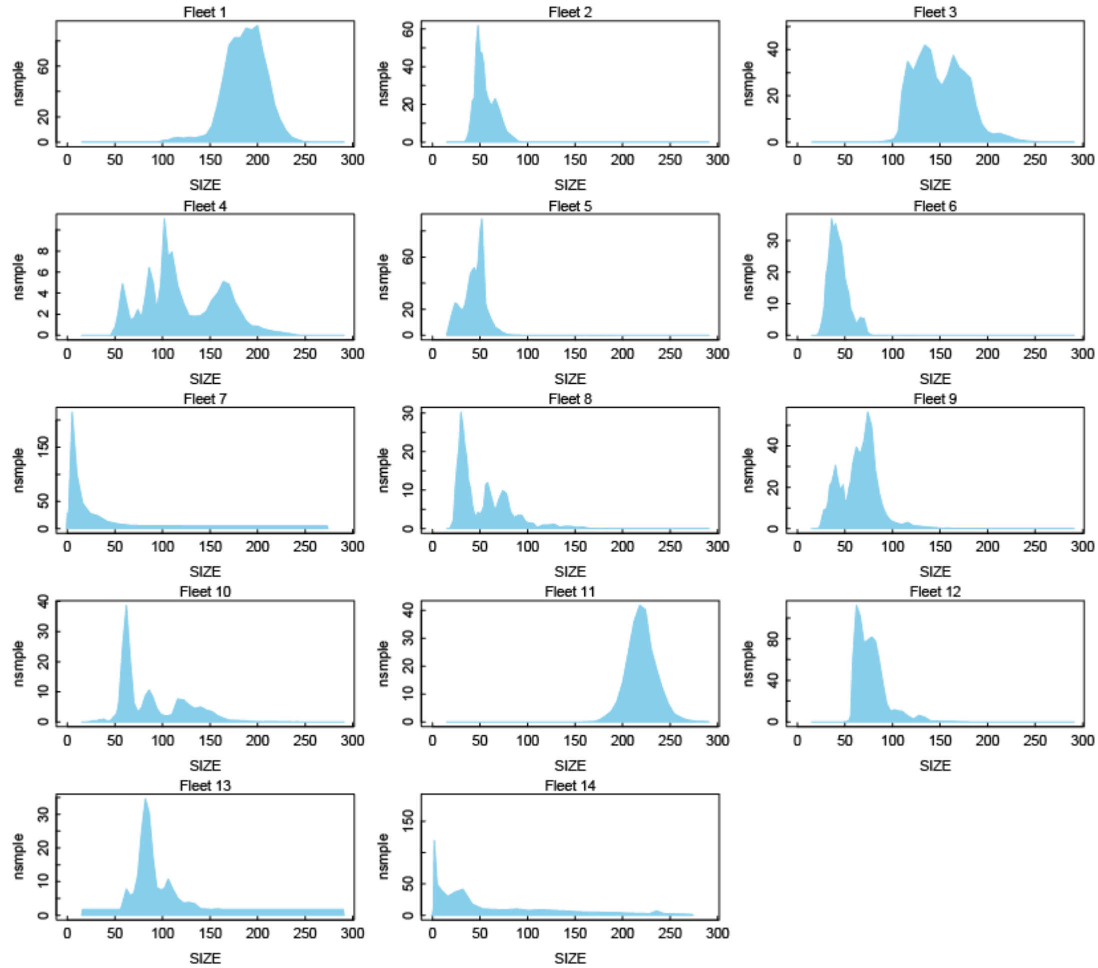


Fig. 3-3. Aggregated size compositions of each fleet in this stock assessment. The data are accumulated through season and years by input sample size (see Section 4.4.3 for explanations). X-axis is in fork length (cm) for all fleets except for fleet 7 and 14, which were in weight (kg).

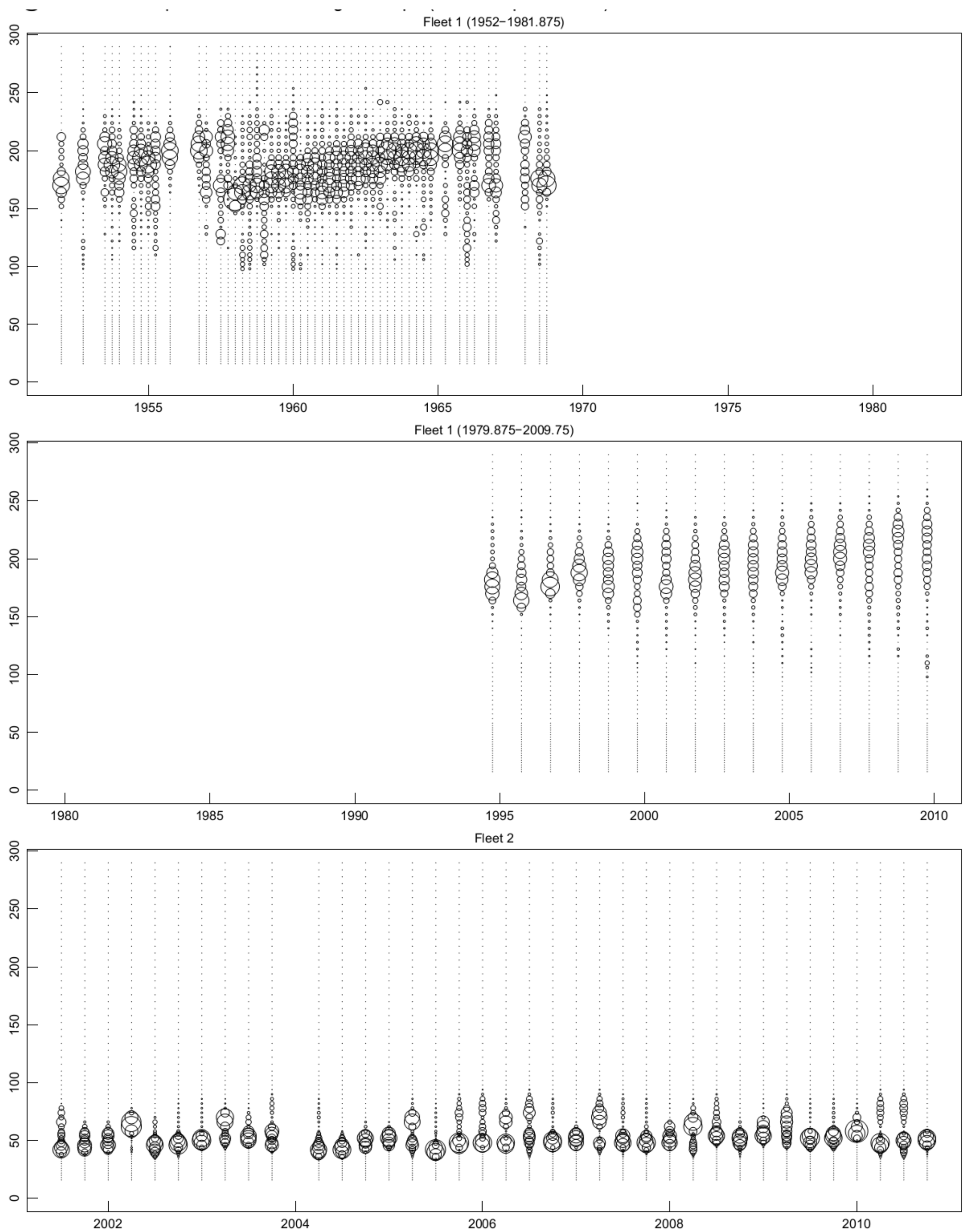


Fig. 3-4. Bubble plots of input size composition data in this stock assessment, by fleet and quarter. Larger circles indicate higher proportions at that size.

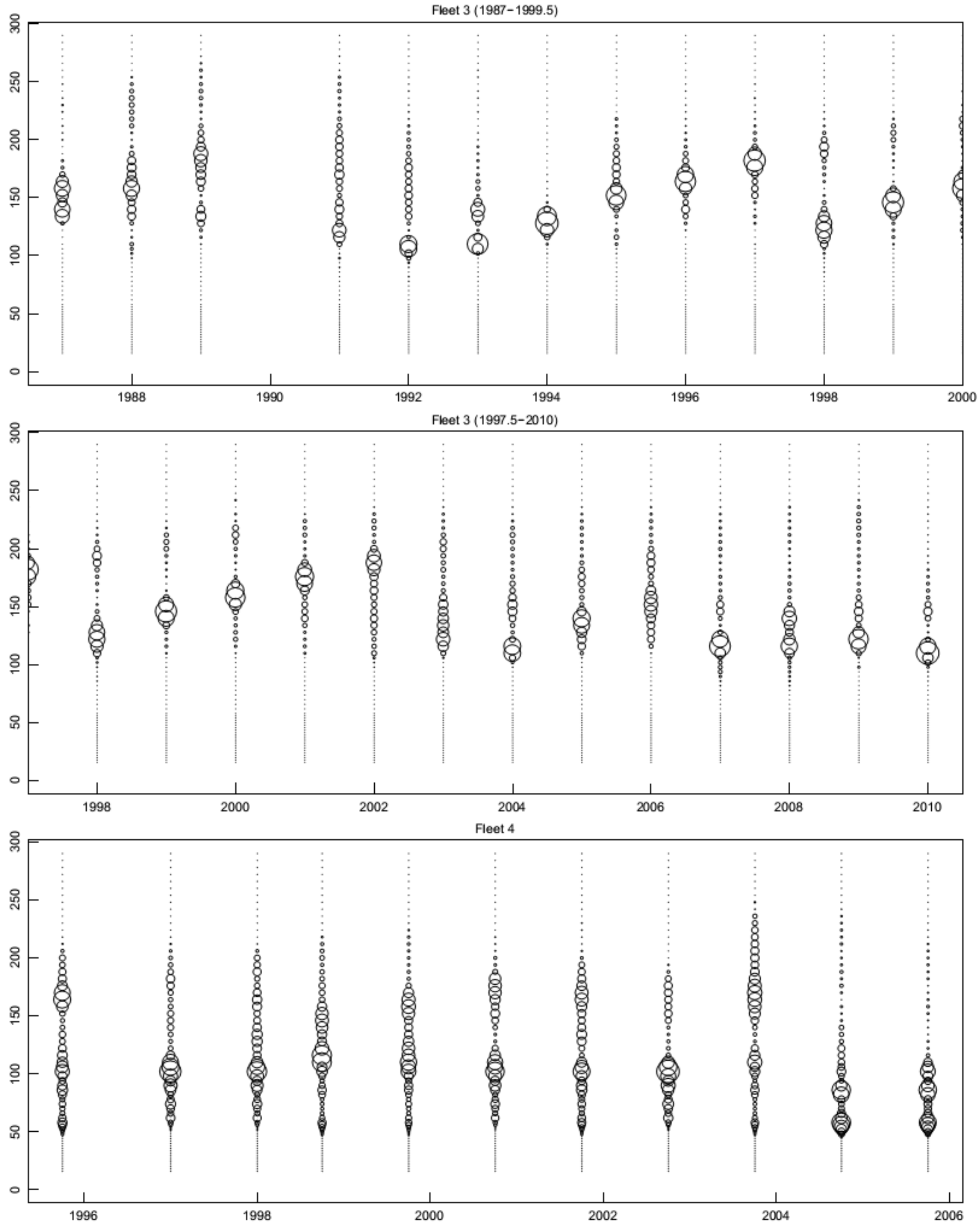
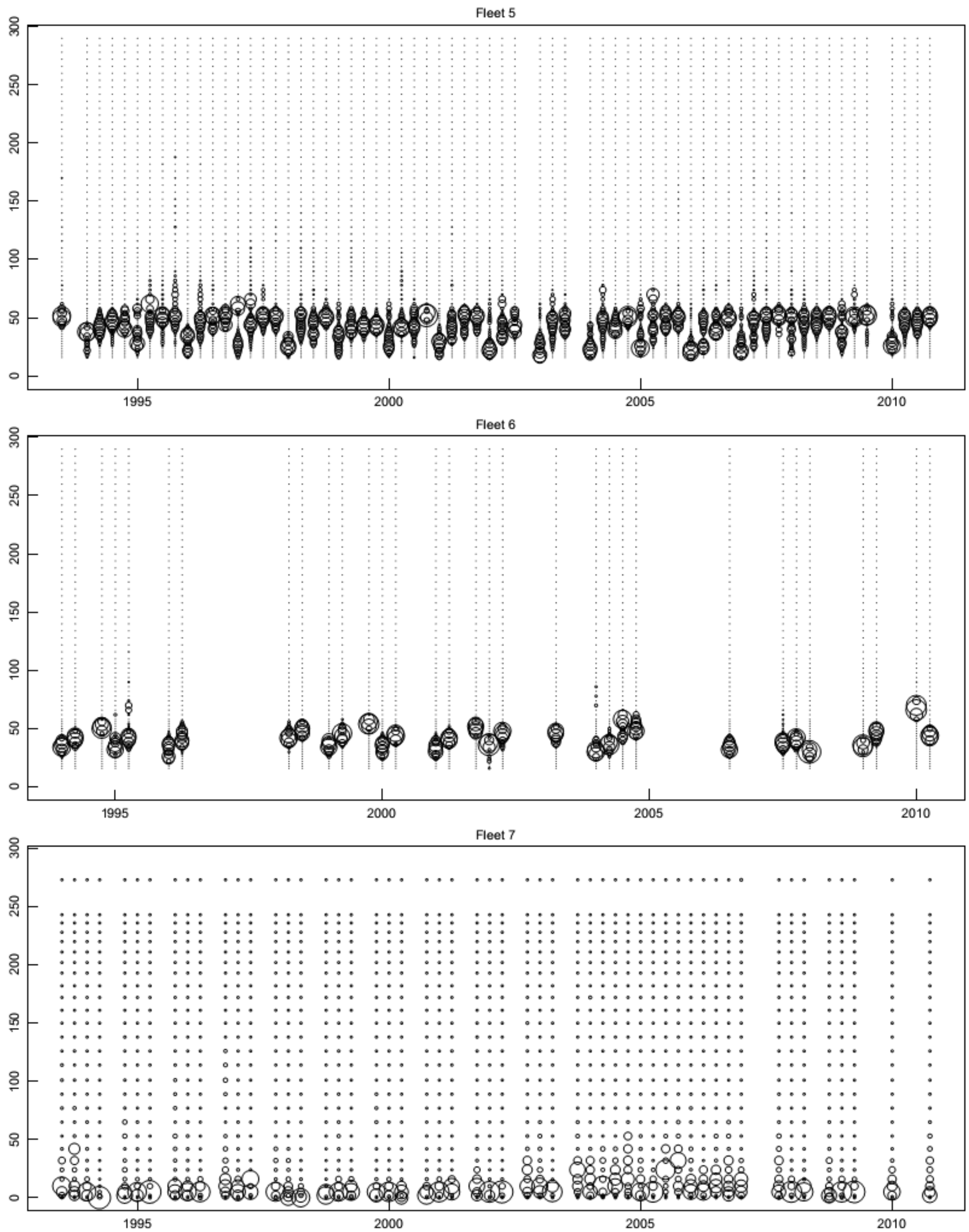


Fig. 3-4. (Continued).



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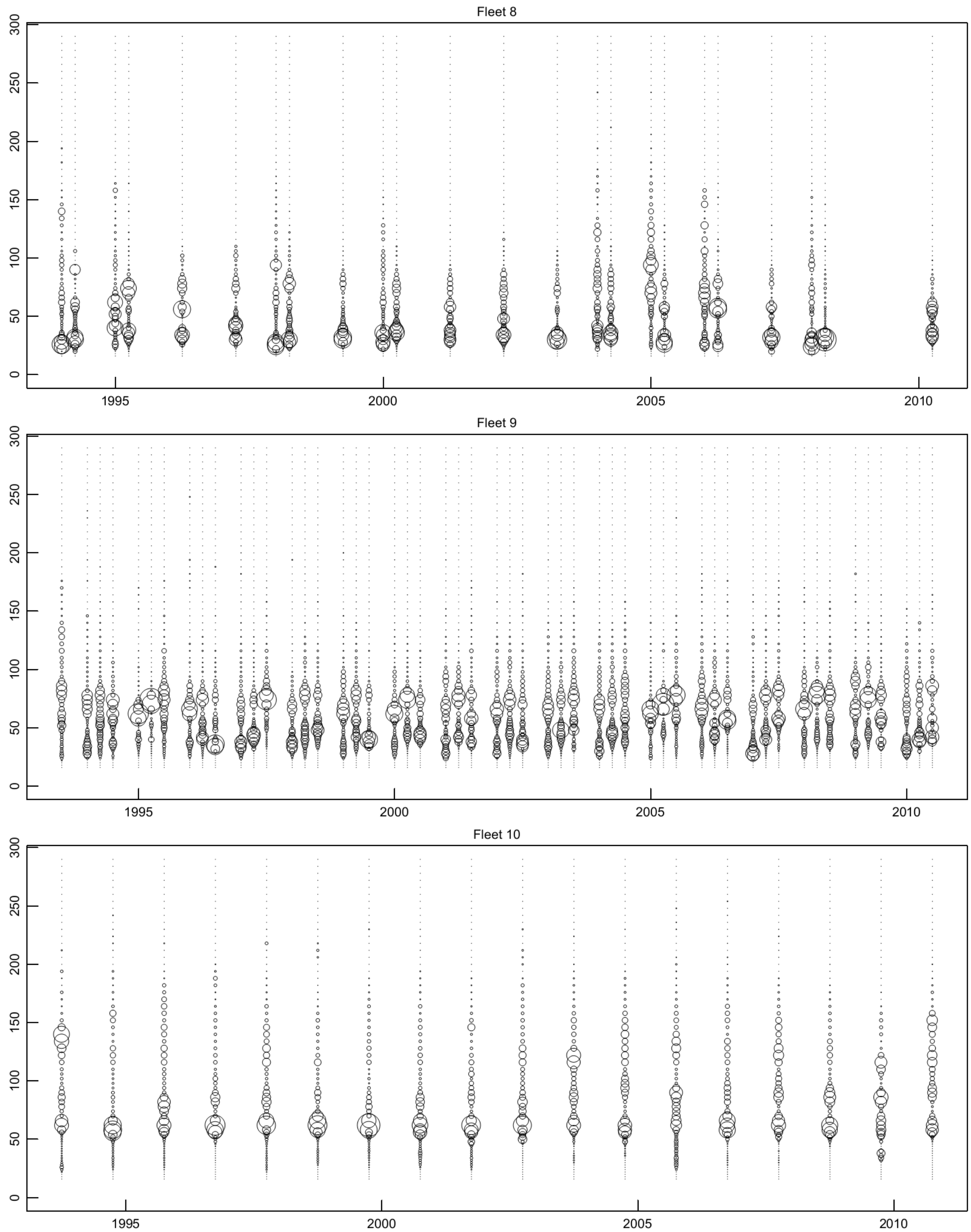


Fig. 3-4. (Continued).

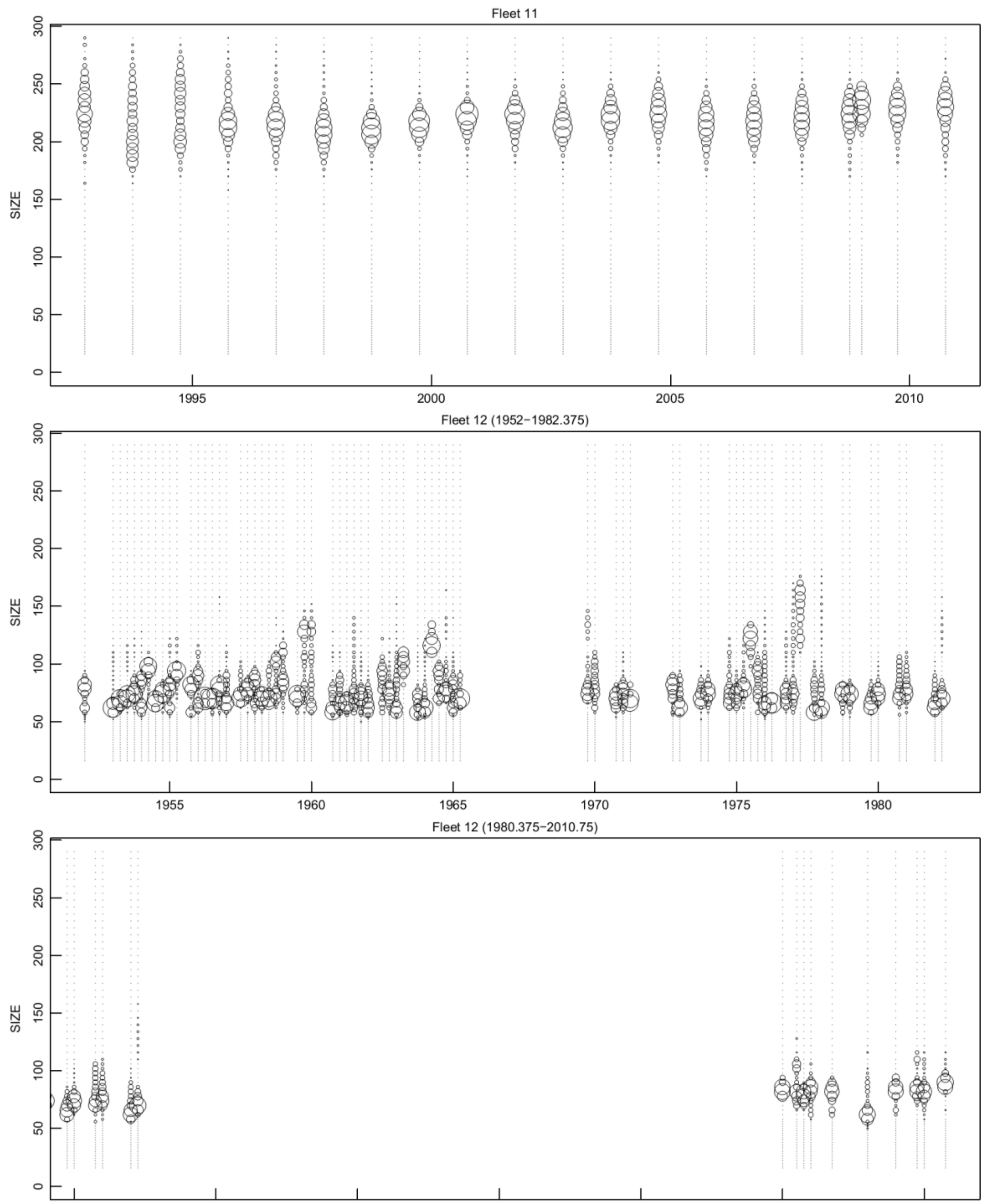


Fig. 3-4. (Continued).

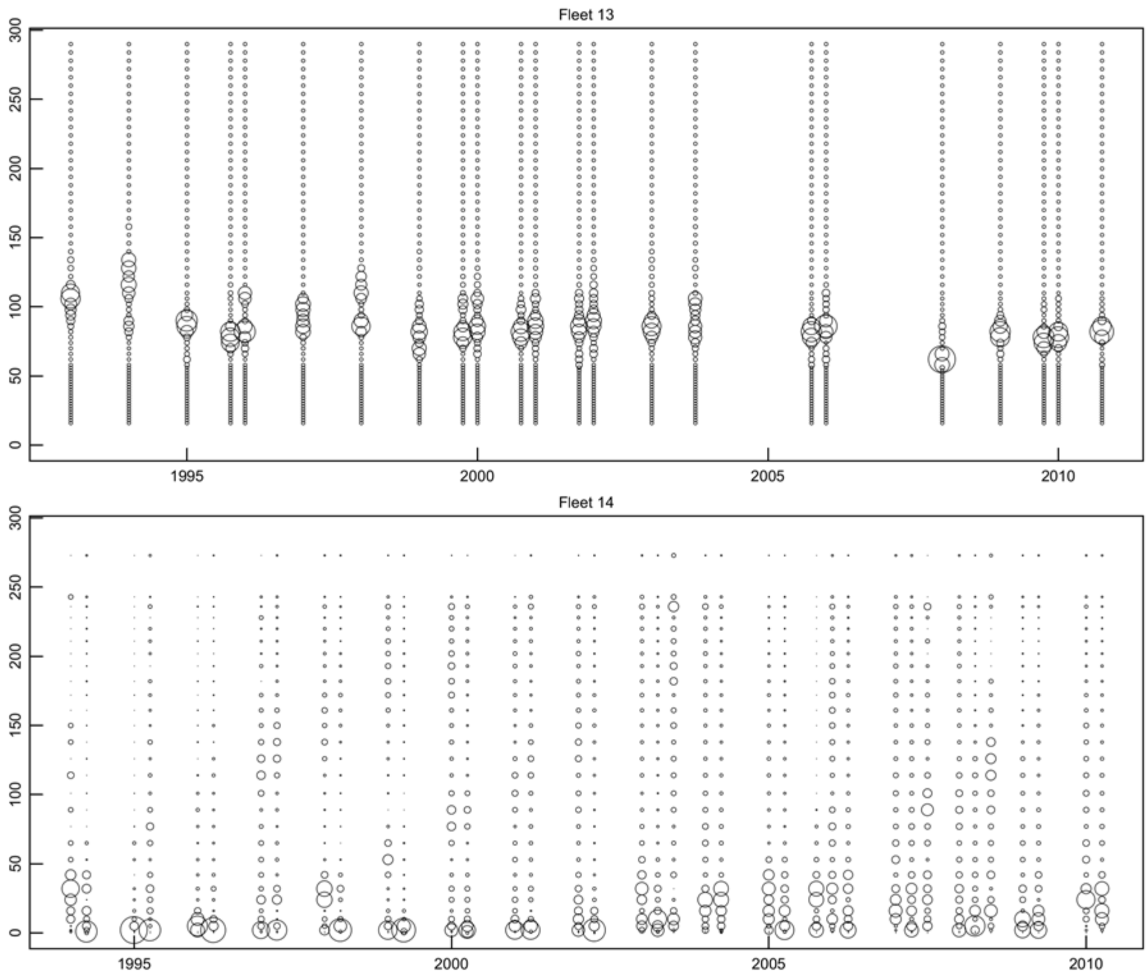


Fig. 3-4. (Continued).

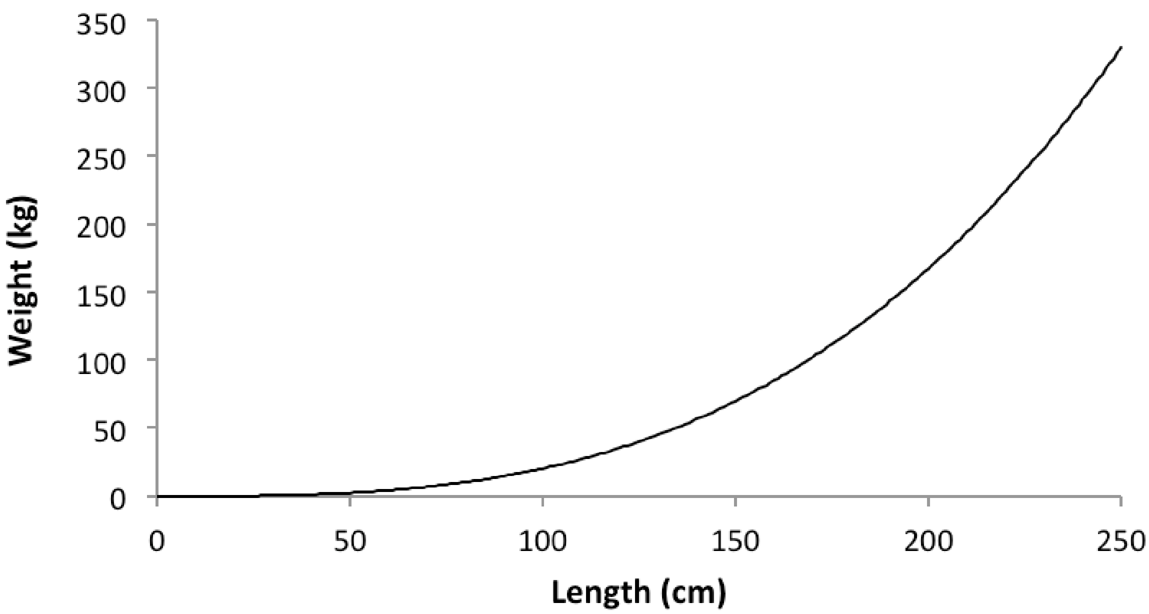


Fig. 4-1. Length-weight relationship used in this stock assessment.

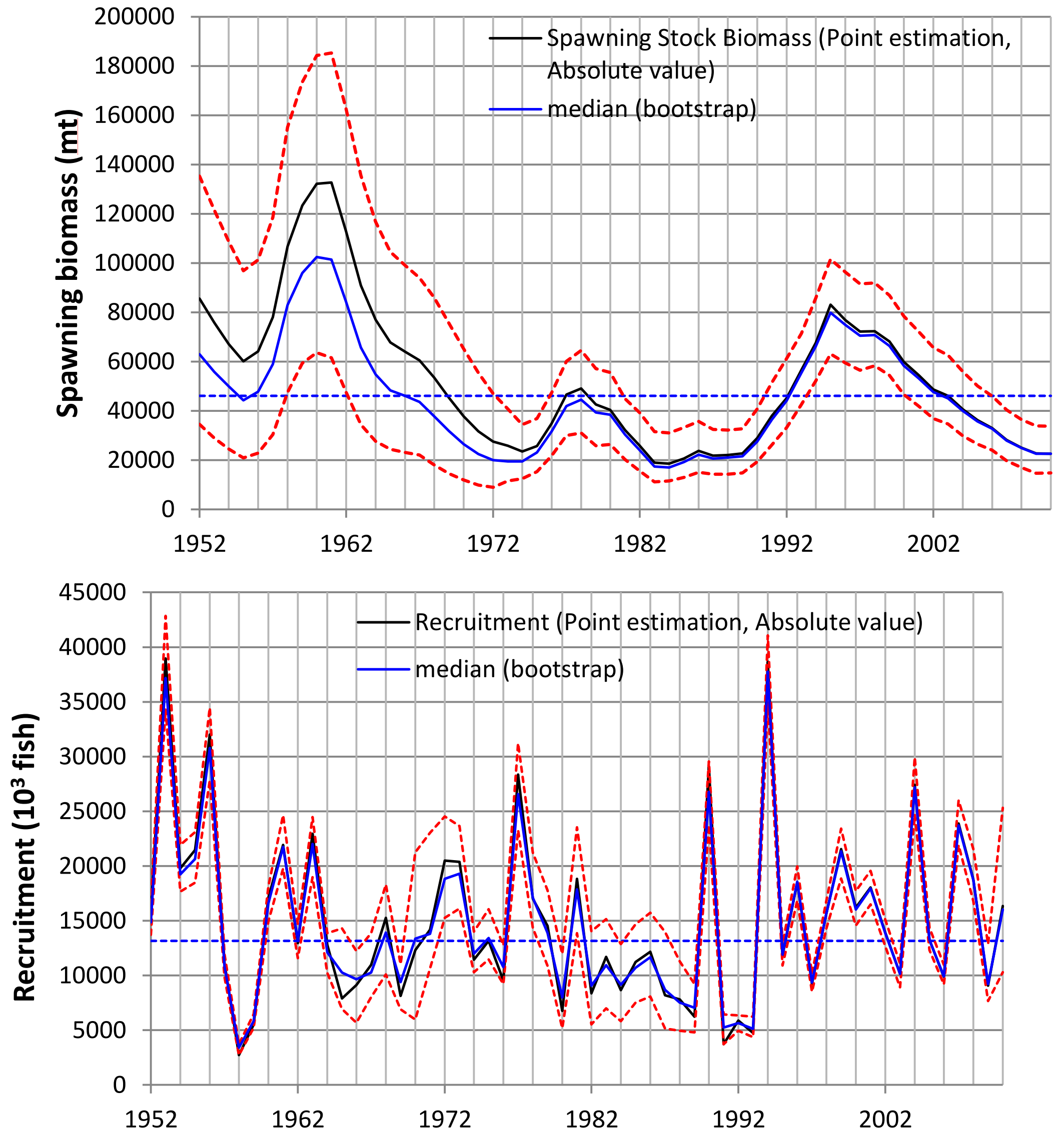
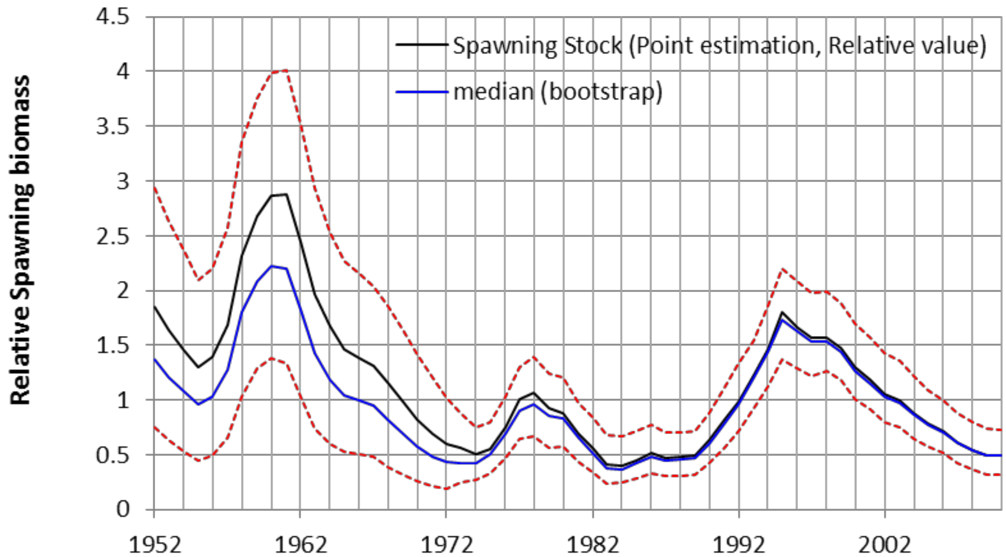


Fig. 5-1. Estimates of spawning stock biomass and recruitment in absolute and relative values from the Representative Run. Broken lines indicate 80% confidence intervals.



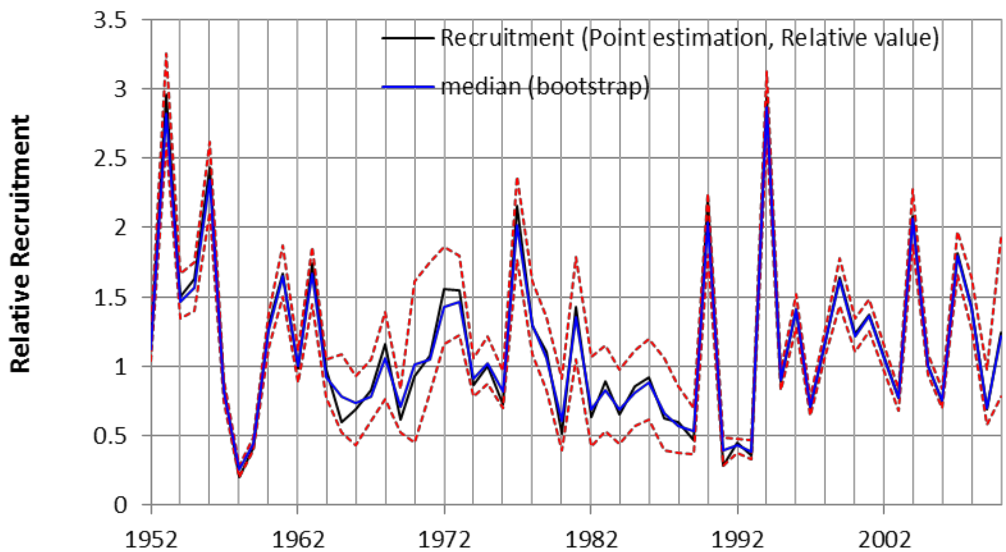


Fig. 5-1. (Continued).

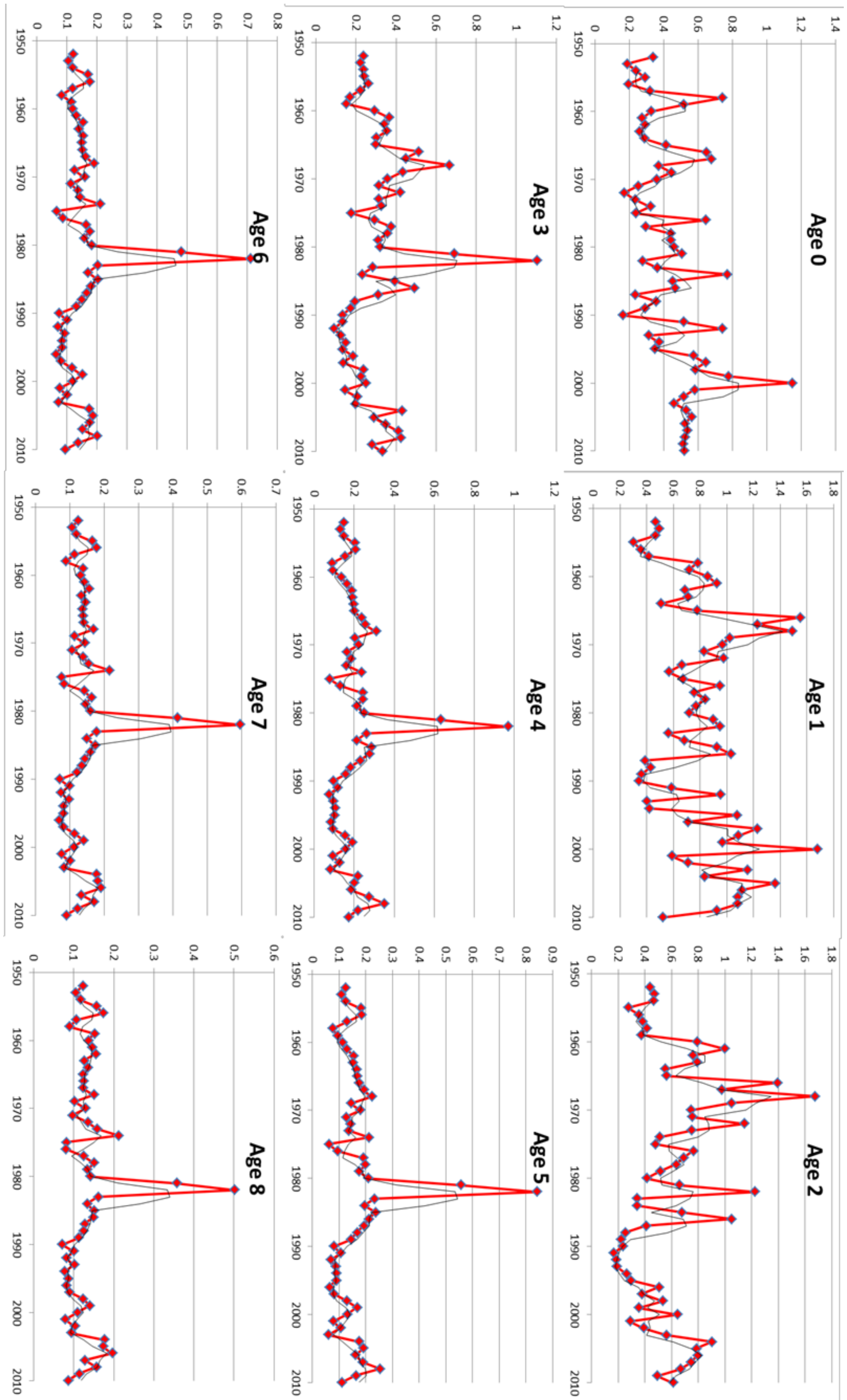


Fig. 5-2. Estimated age-specific fishing mortality for 1952-2010. Red lines represent annual fishing mortality. Gray lines represent the three year moving average fishing mortality.

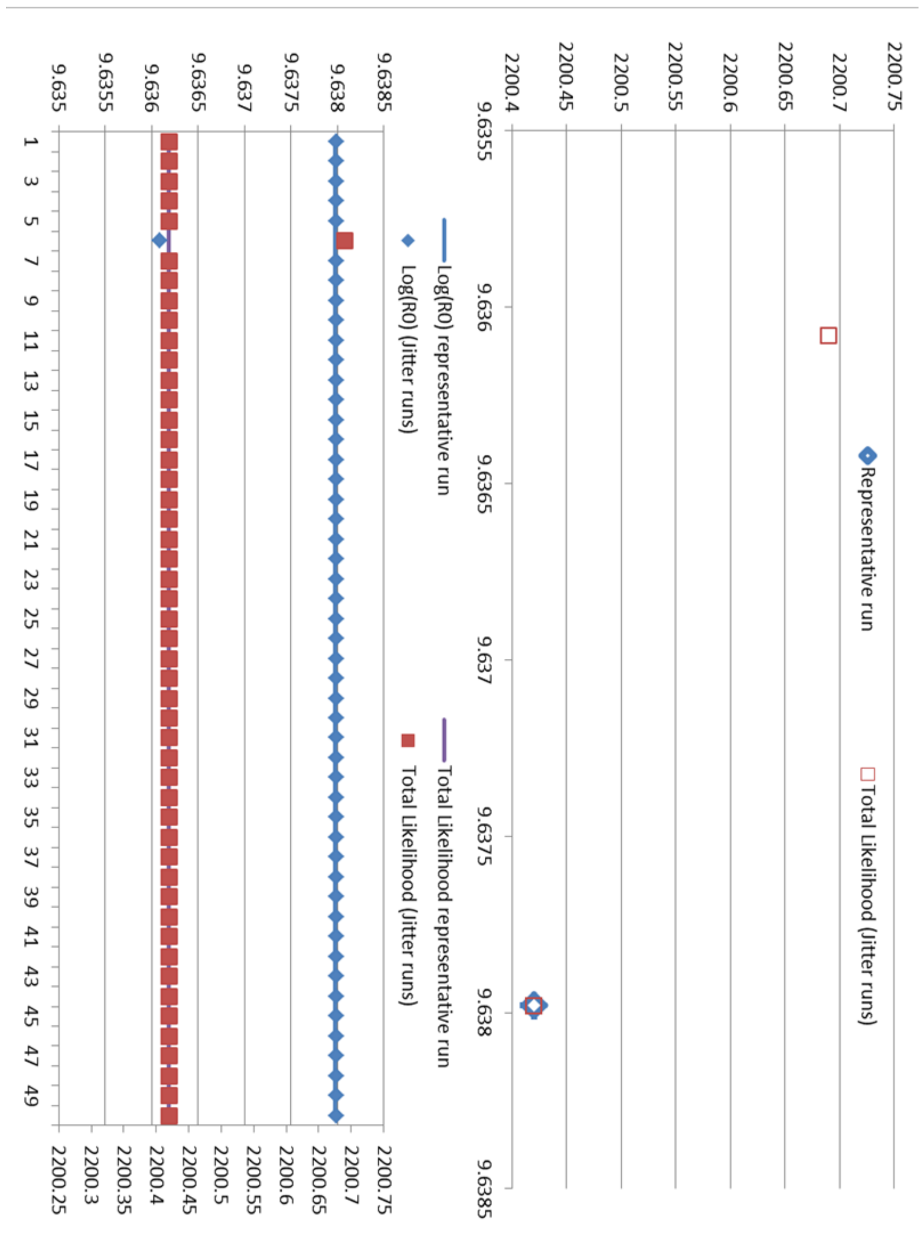


Fig. 5-3.Total likelihood (upper panel) and estimated Log(R0) (lower panel) for the Representative Run (triangles) and 50 jitter runs (squares).

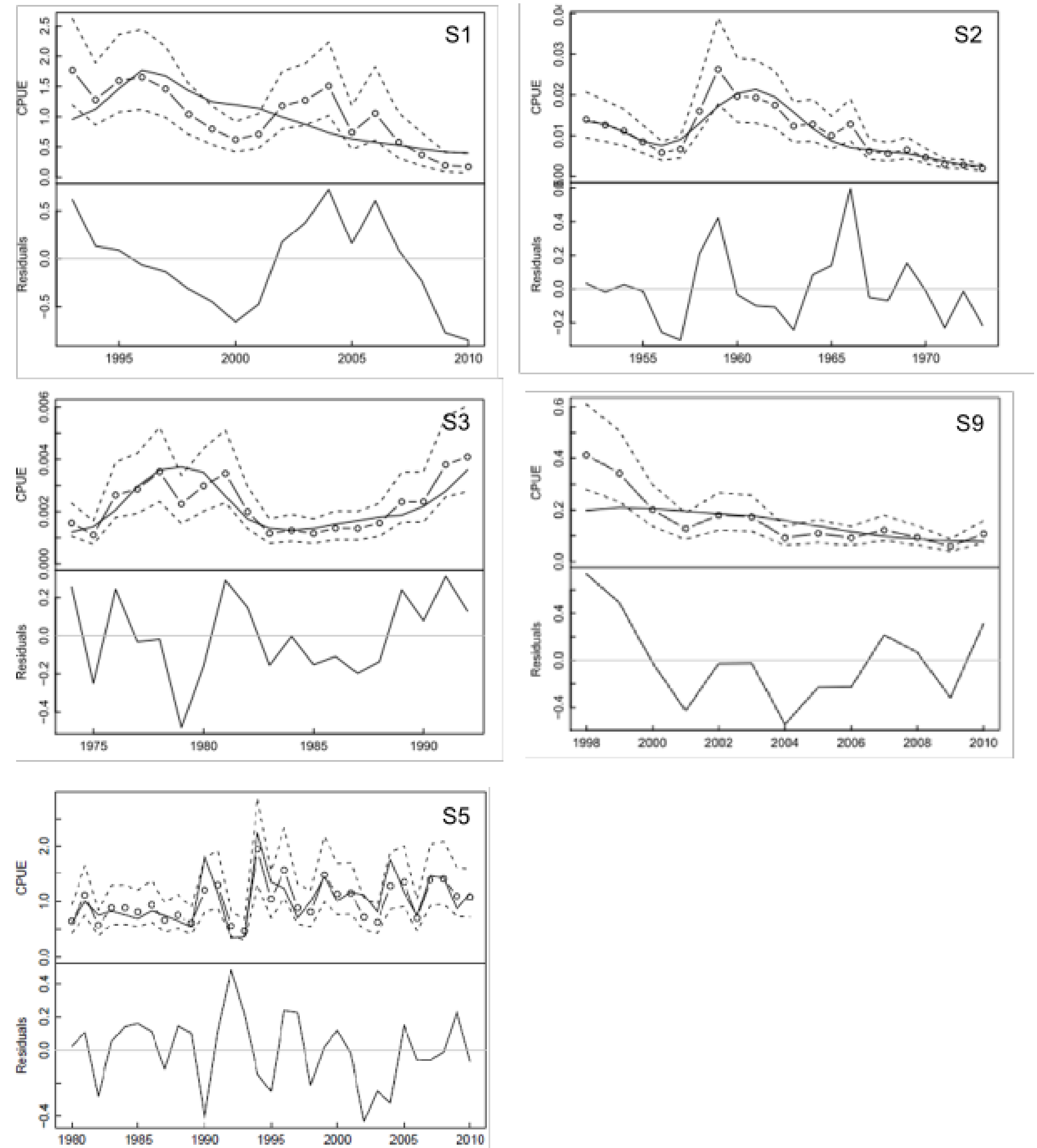


Fig. 5-4.Expected (line) and observed (line and circle) CPUEs, and residuals (observed – expected) for the Representative Run.

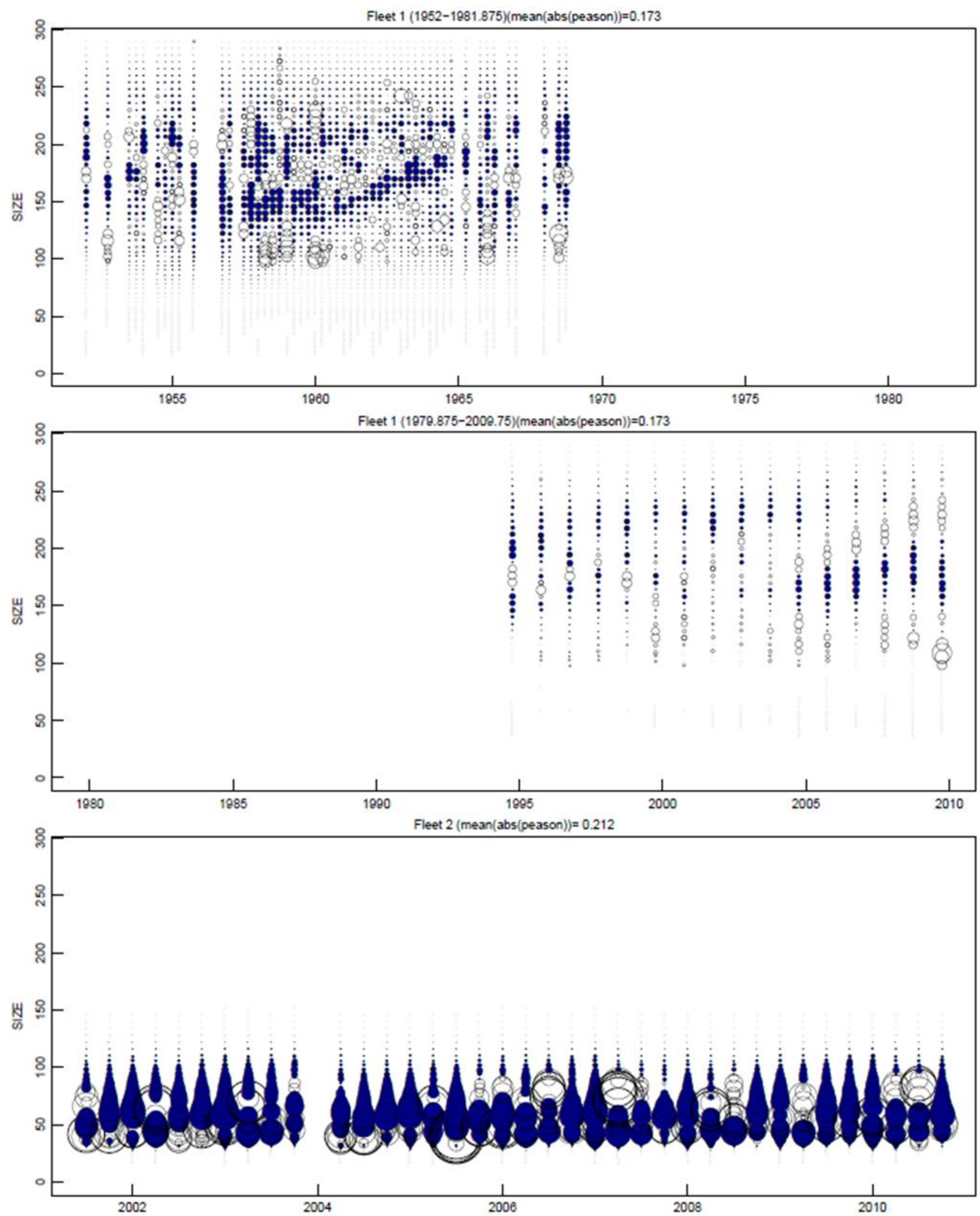


Fig. 5-5. Pearson residuals of model fits to size composition data for the Representative Run. Dark blue circles indicate negative residuals (observation value < expected value), while white circles indicate positive residuals (expected value > observation value).

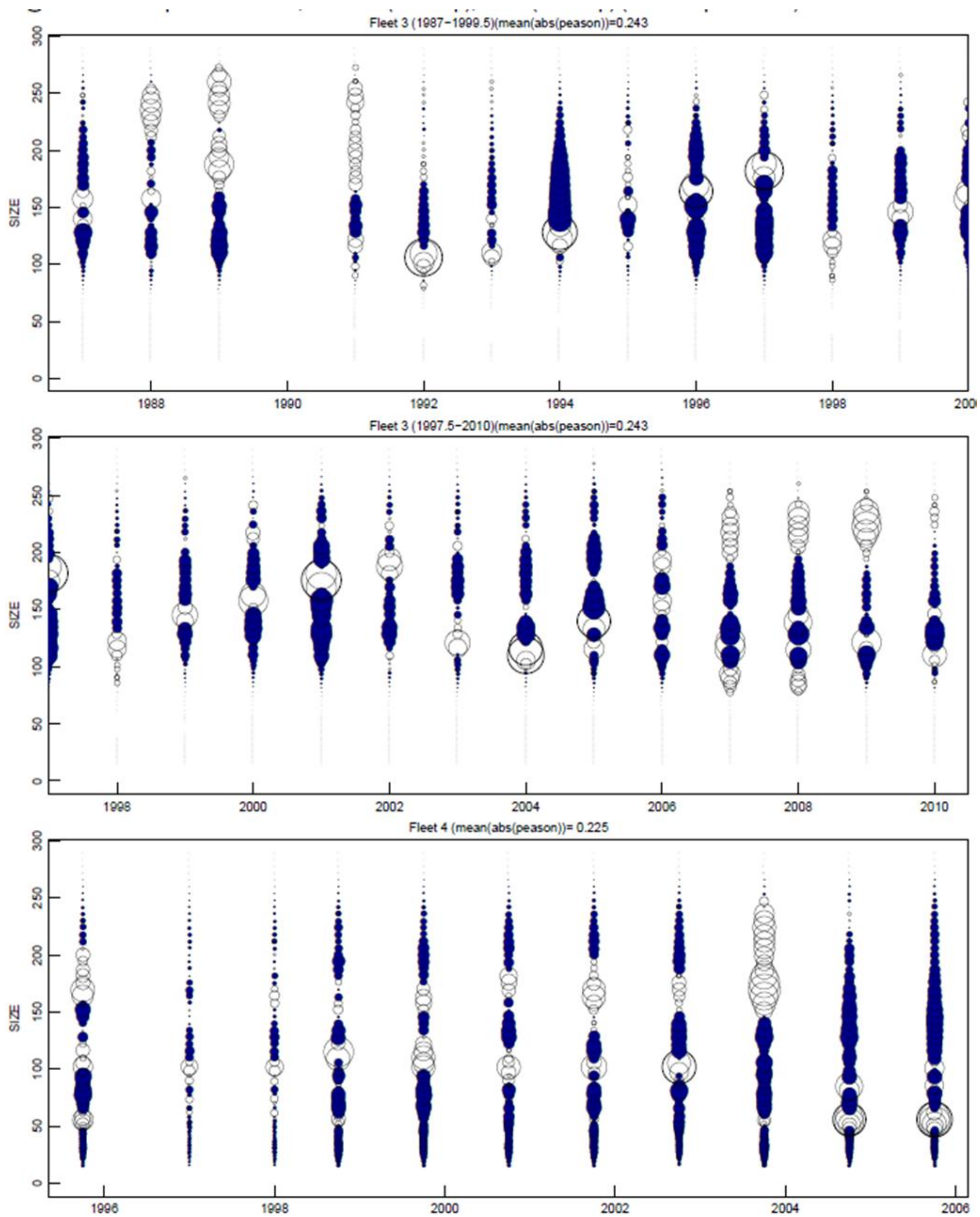


Fig. 5-5. (Continued).

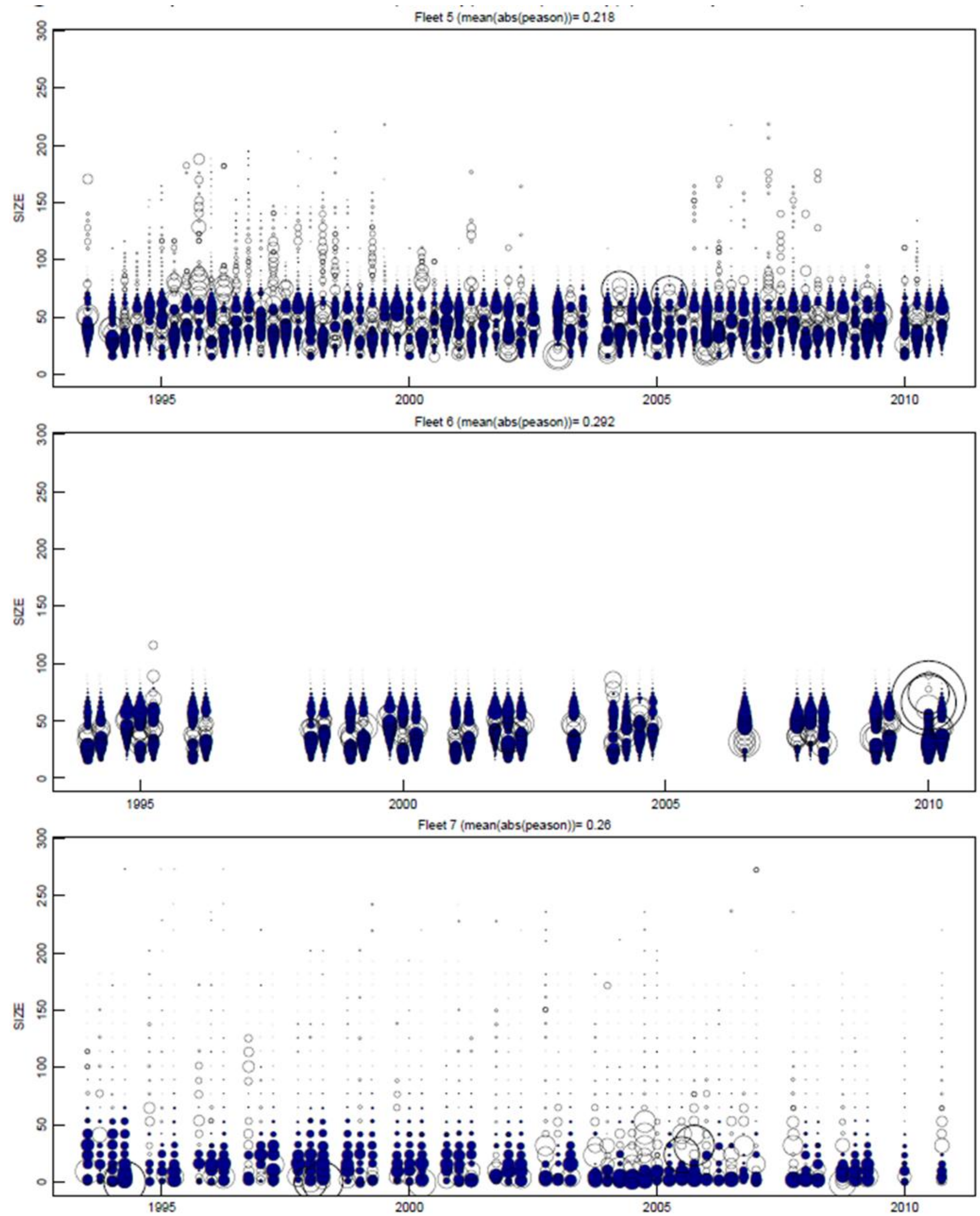


Fig. 5-5. (Continued).

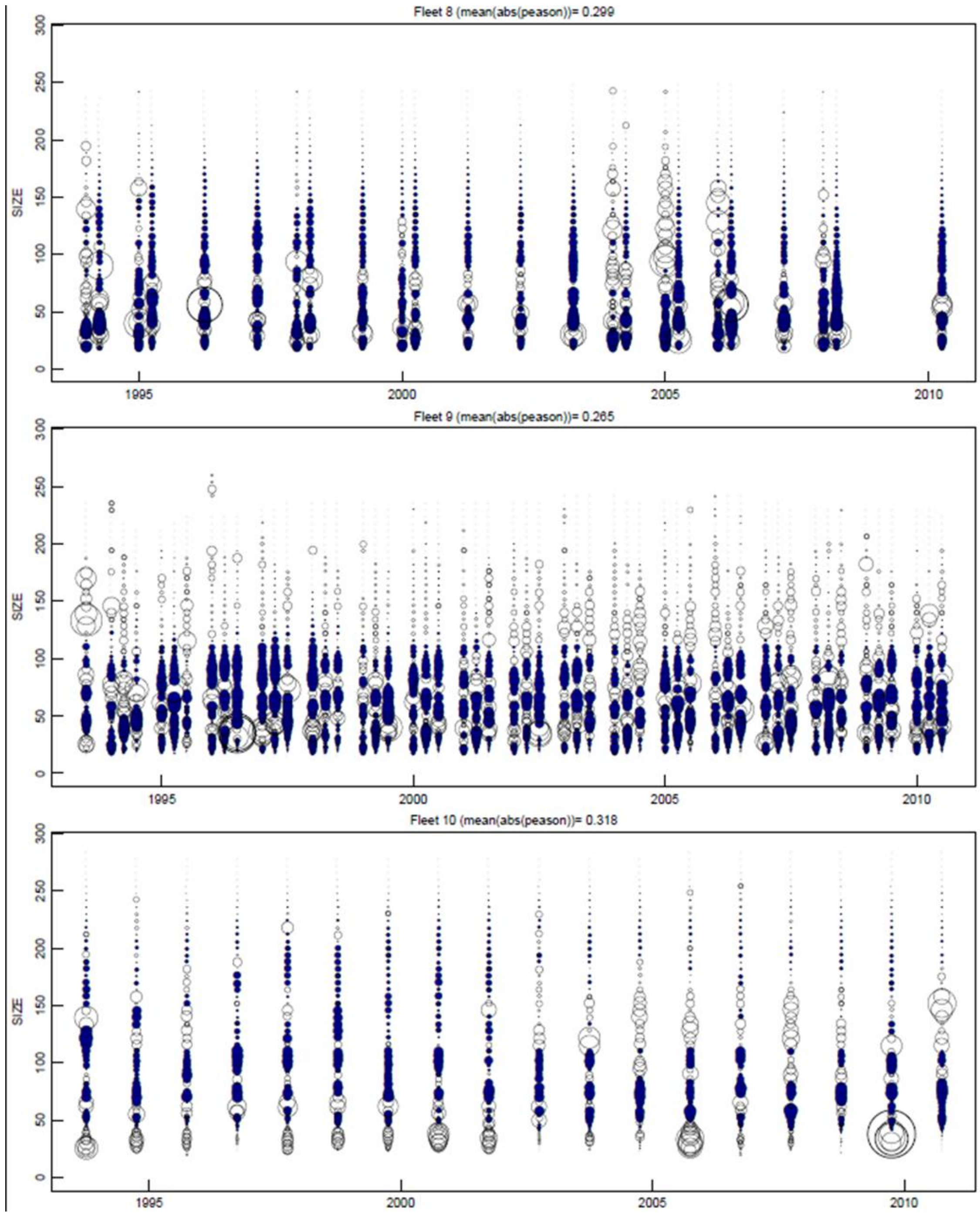


Fig. 5-5. (Continued).

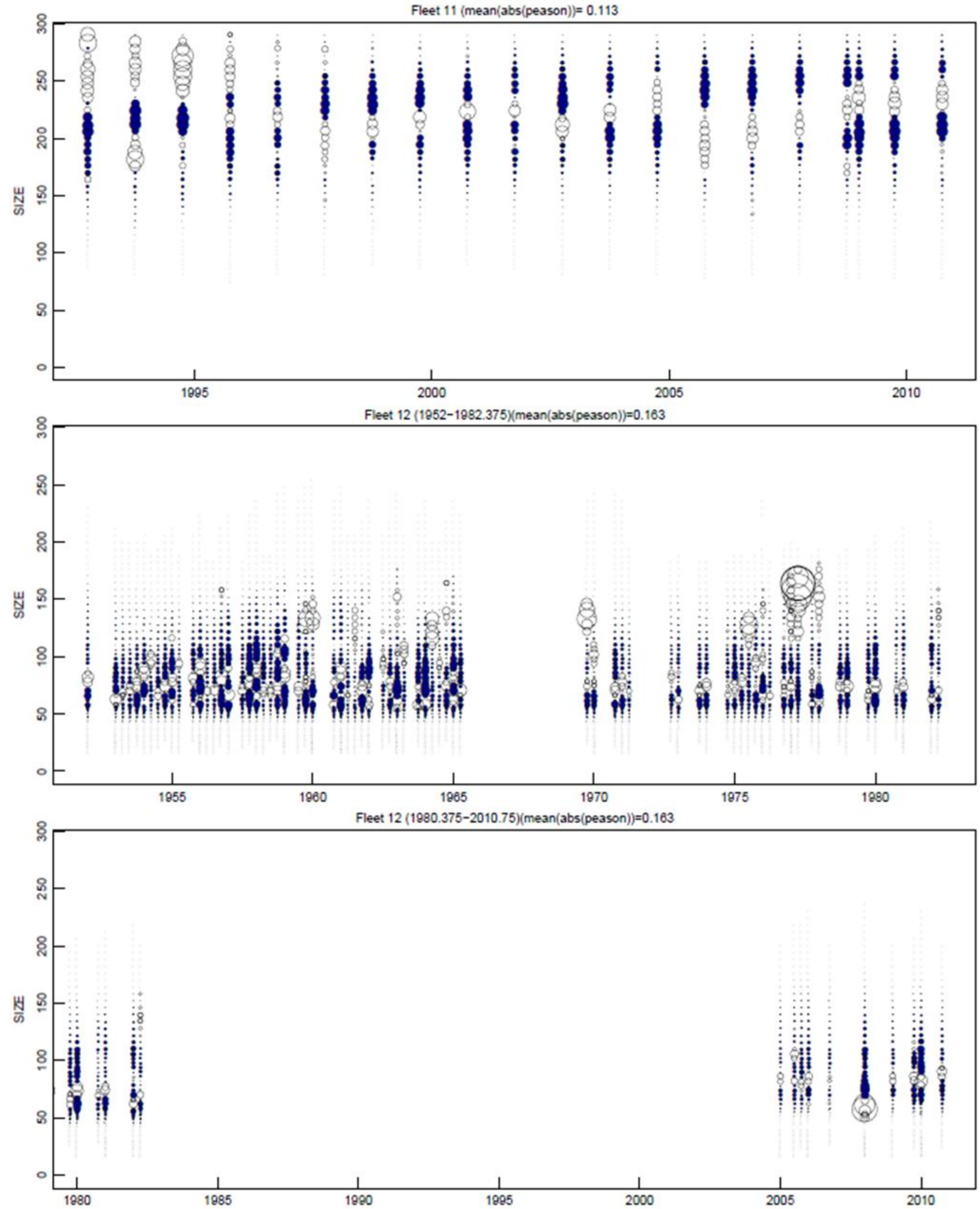


Fig. 5-5. (Continued).

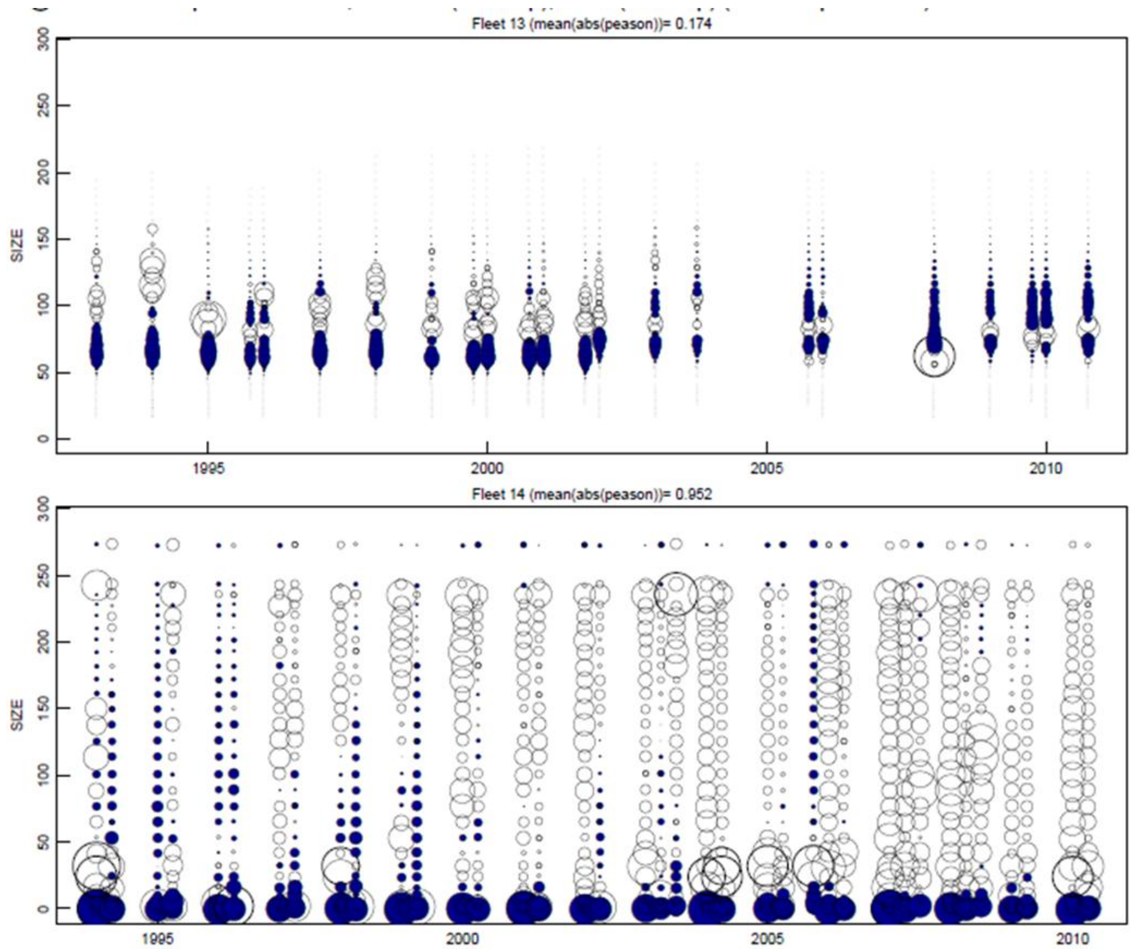


Fig. 5-5. (Continued).

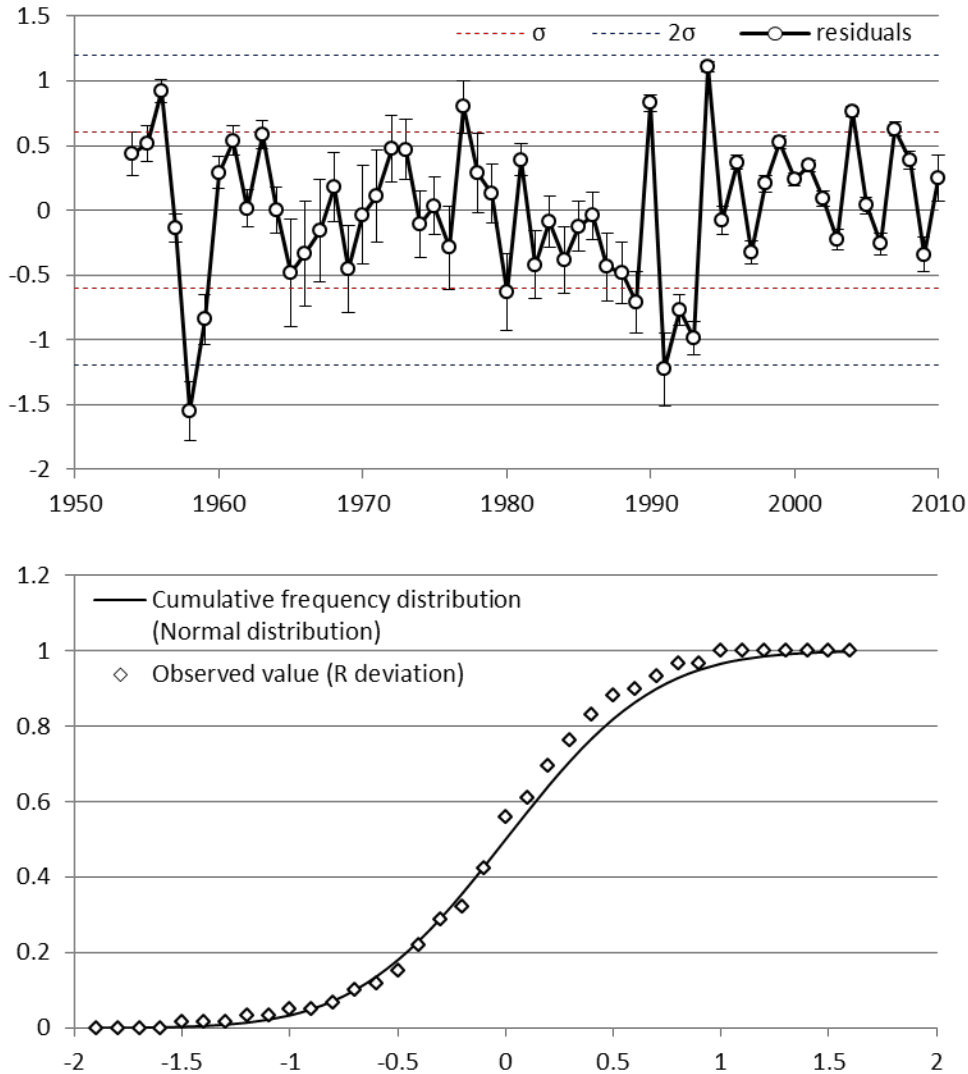


Fig. 5-6. Estimated recruitment deviates (top panel) and cumulative distribution function of recruitment deviates and hypothetical normal distribution with mean=0 and SD=0.6 (bottom panel).

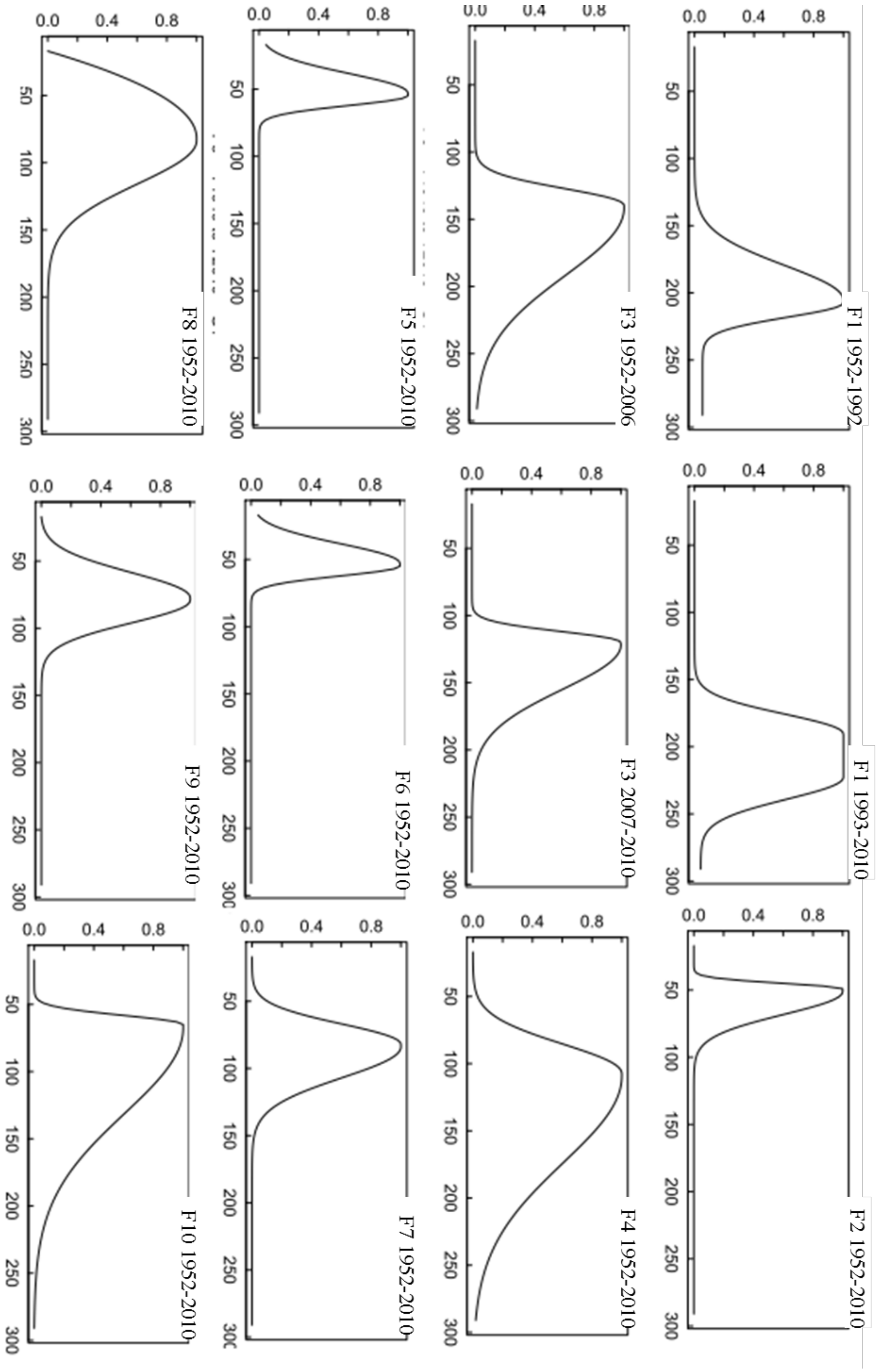


Fig. 5-7.Estimated length-based selectivity curves by fleet from the Representative Run.

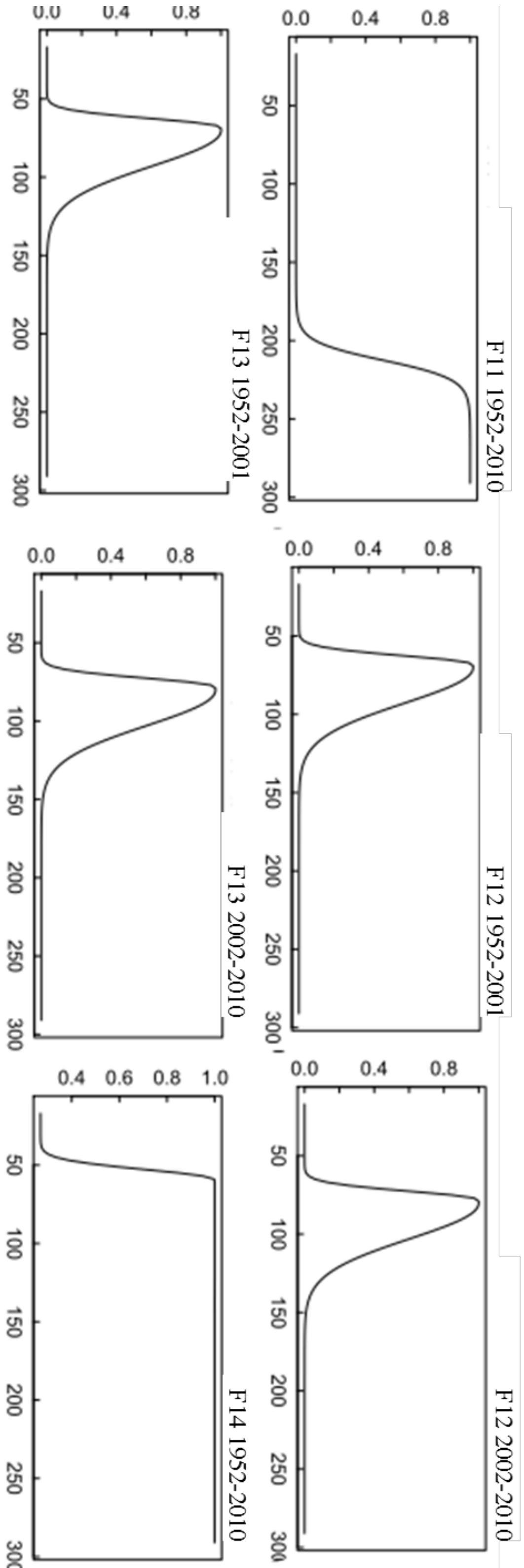


Fig. 5-7. (Continued).

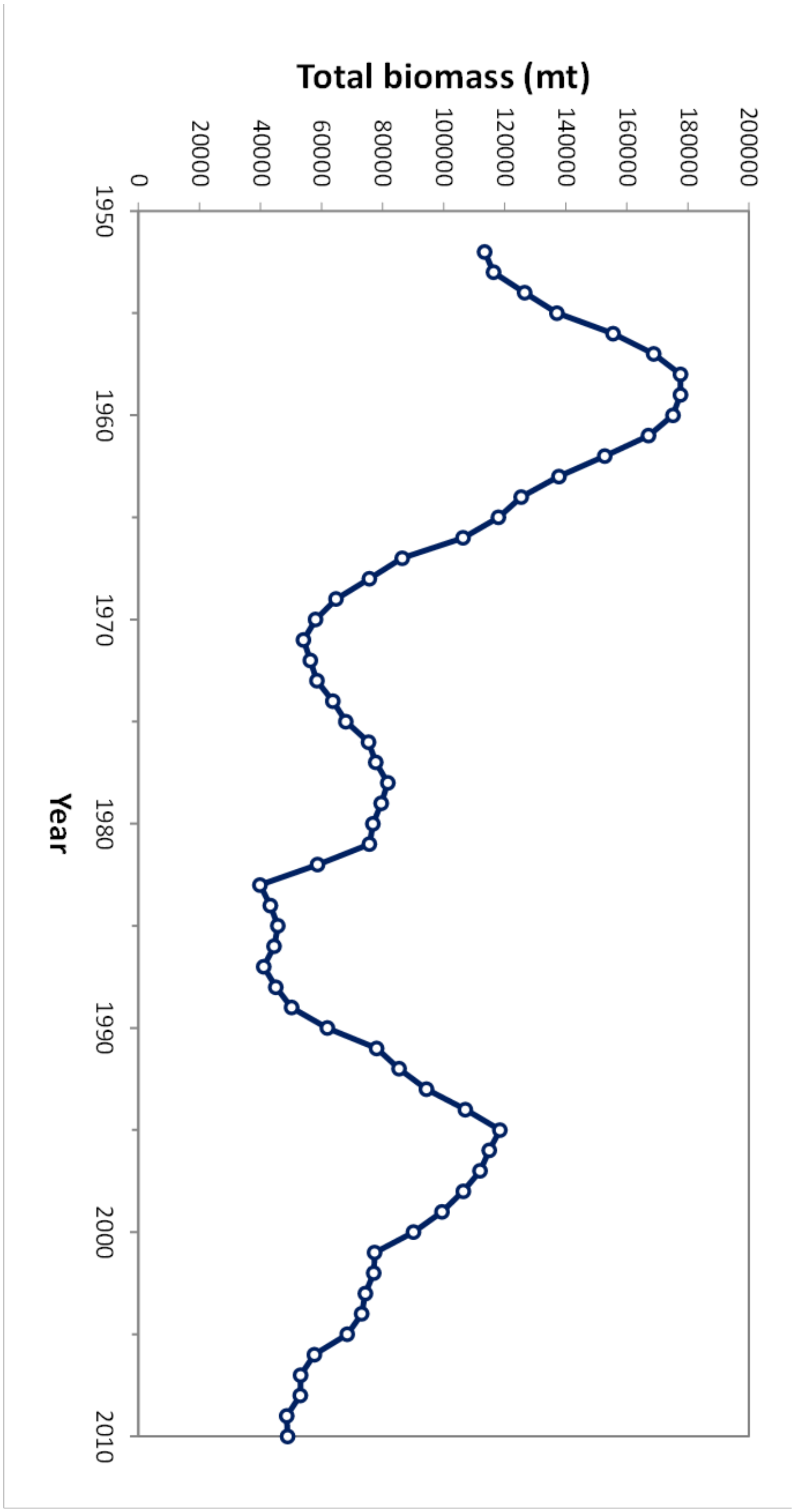


Fig. 5-8.Estimated total biomass (age 0+ on July 1st) from the Representative Run.

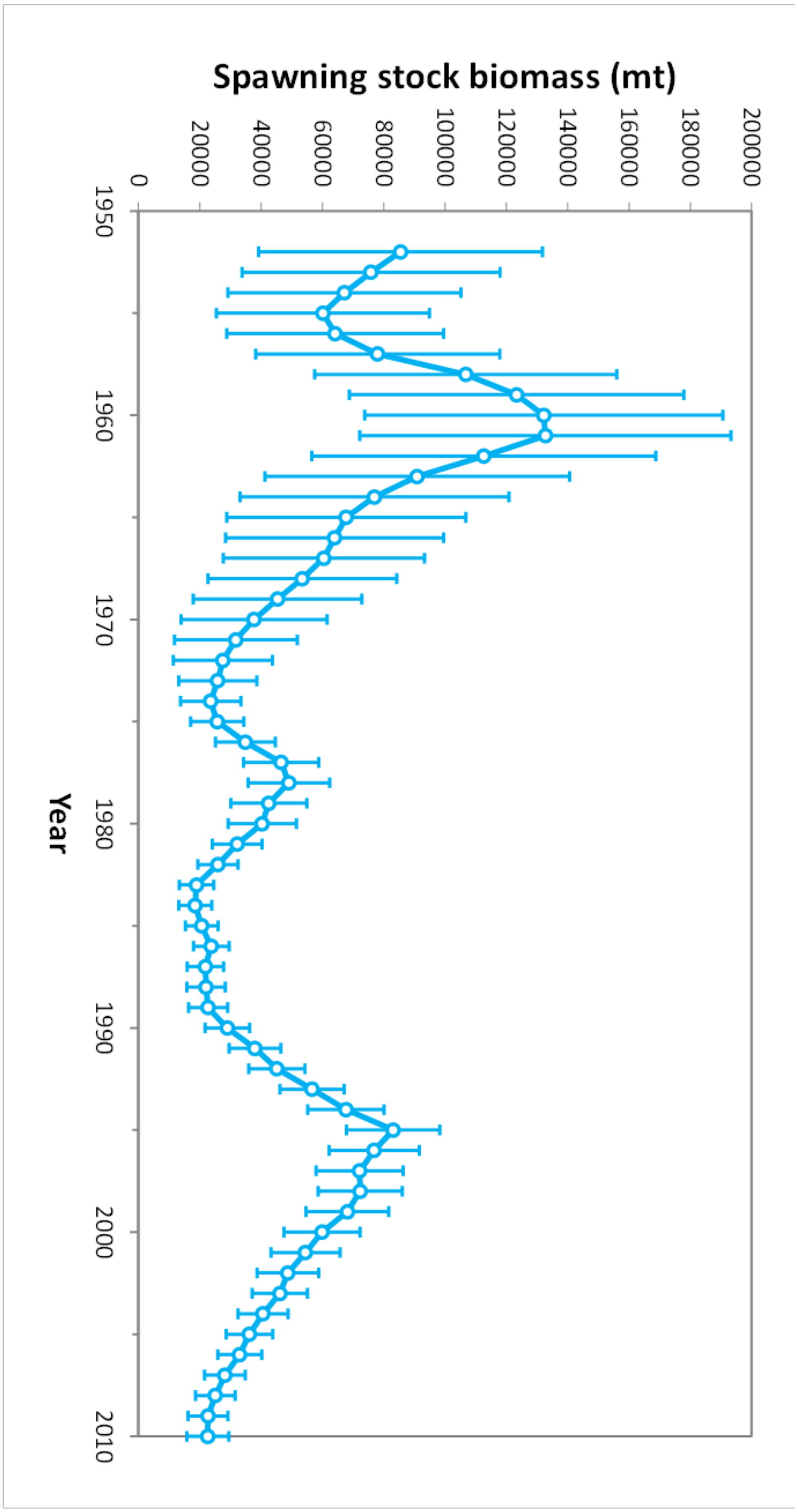


Fig. 5-9. Estimated spawning biomass from the Representative Run. Vertical bars indicate 80% confidence intervals.

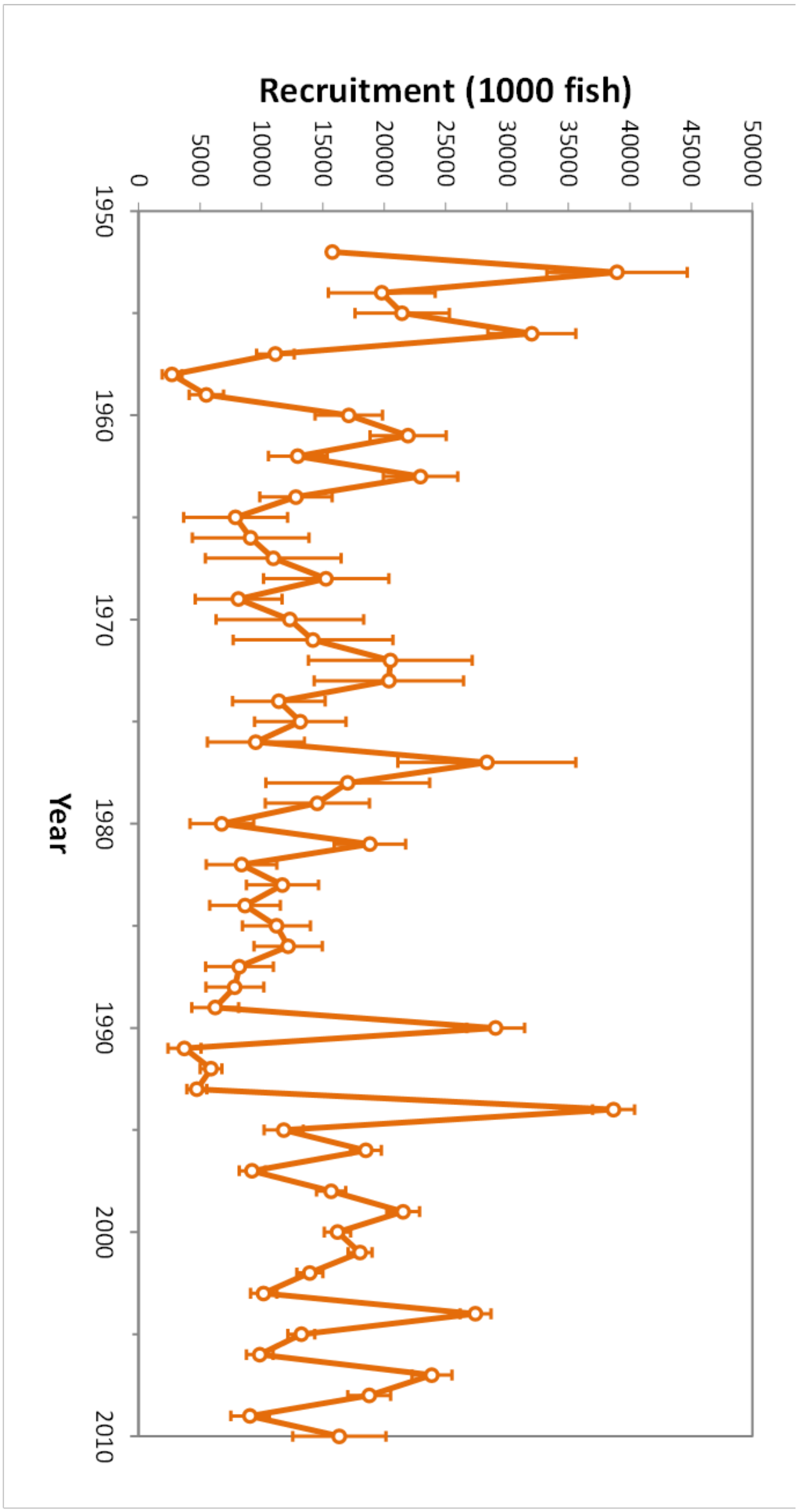


Fig. 5-10. Estimated recruitment from the Representative Run. Bars indicate 80% confidence intervals.

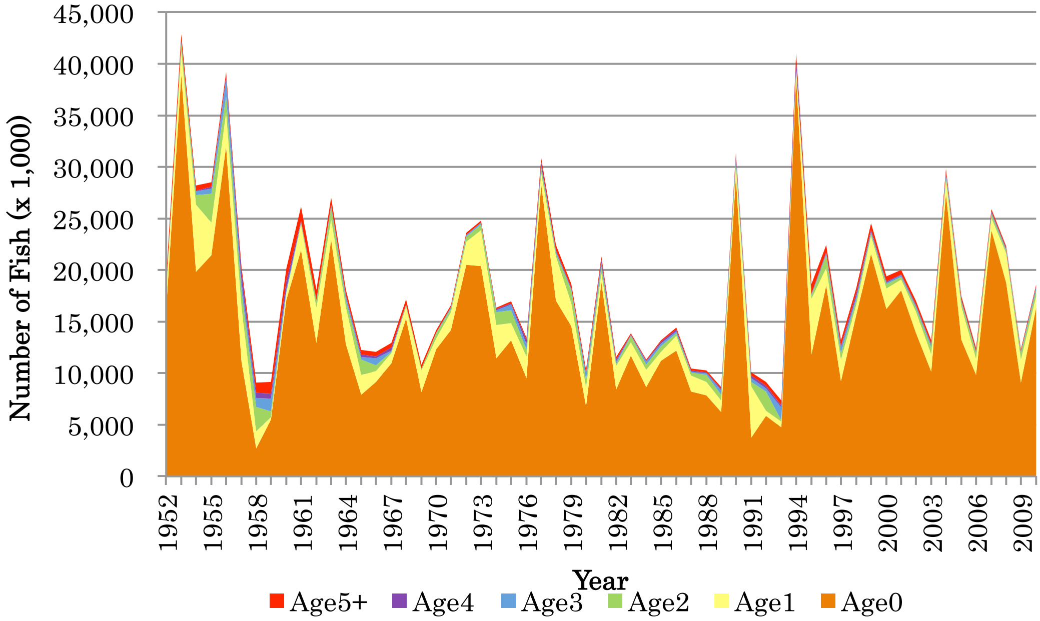


Fig. 5-11. Annual numbers-at-age estimated by the Representative Run at the start of the year.

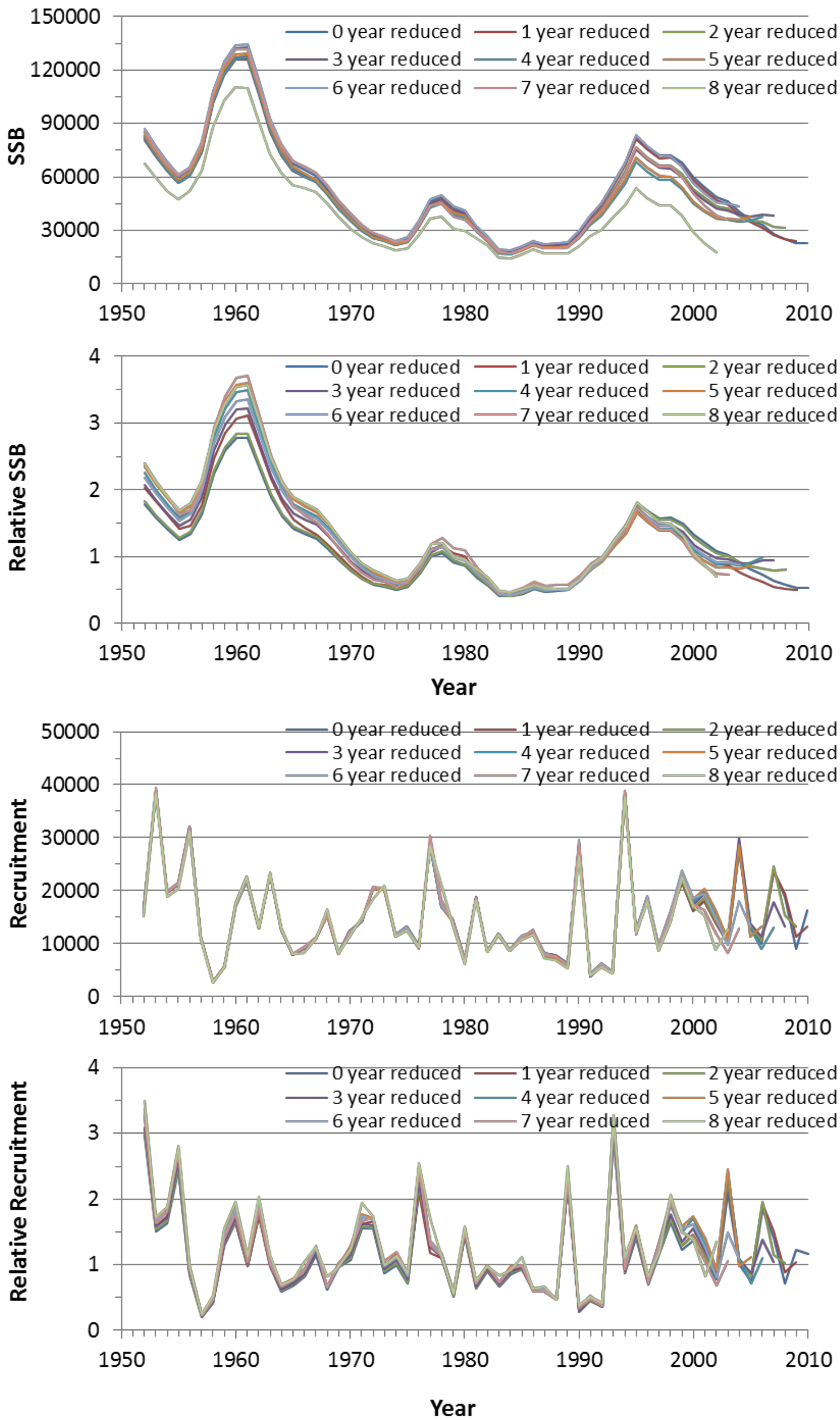


Fig. 5-12.Relative and absolute spawning stock biomass (mt) and recruitment (1000s fish) from the retrospective analysis.

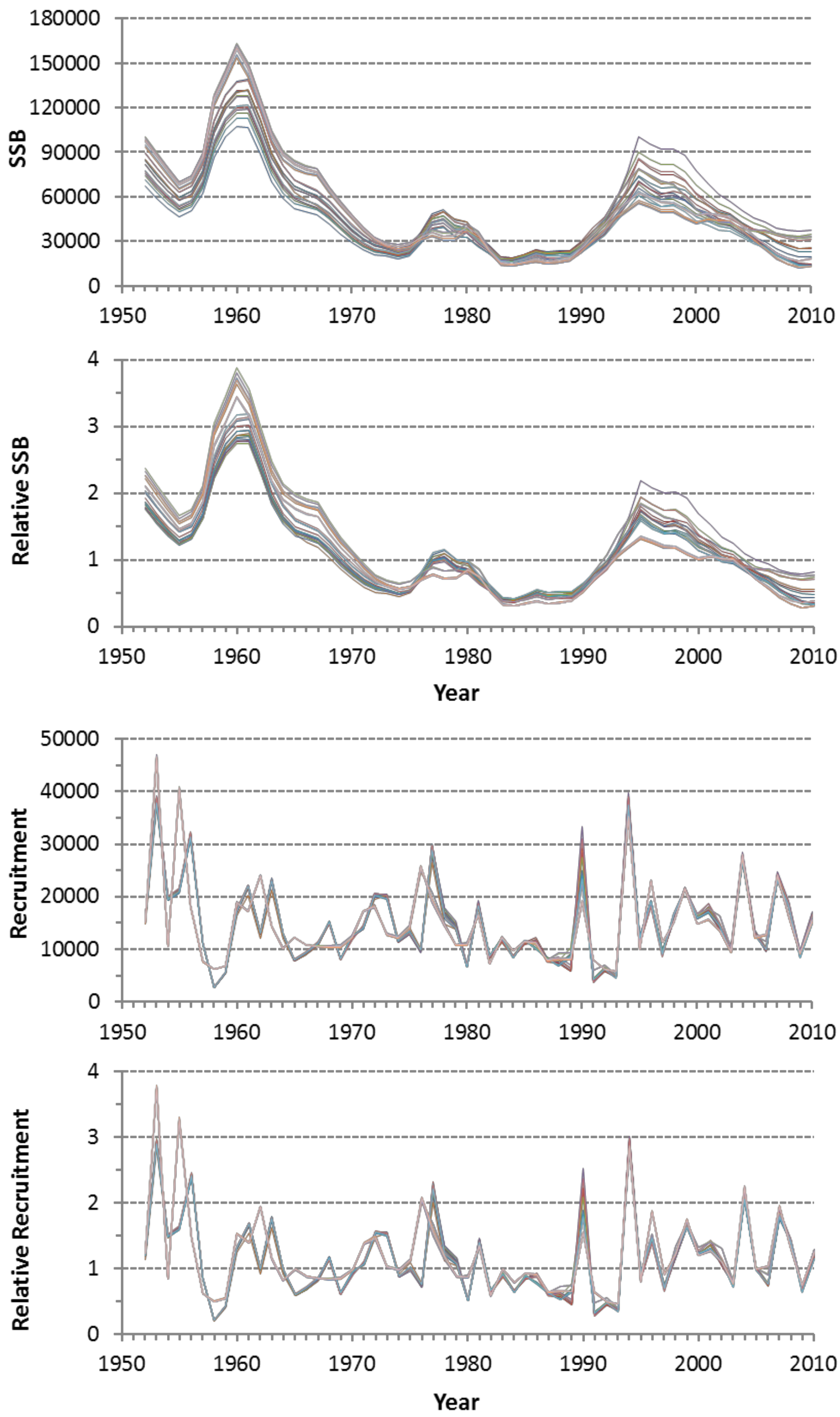


Fig. 5-13.Relative and absolute spawning stock biomass (mt) and recruitment (1,000 fish) from 20 alternative runs (defined in Table 4.3) with different model configurations.

Fig. 5-14. Expected abundance trends (line) and observed indices (line and circle) for S1 index using an alternative CV model (CV #2 of CPUE S1, run4; red) and the Representative Run (CV #1 of CPUE S1, black) (top panel).Residuals (observed minus expected) of S1 CPUE of Run 4 (red) and the representative run (black) are shown on the bottom panel.

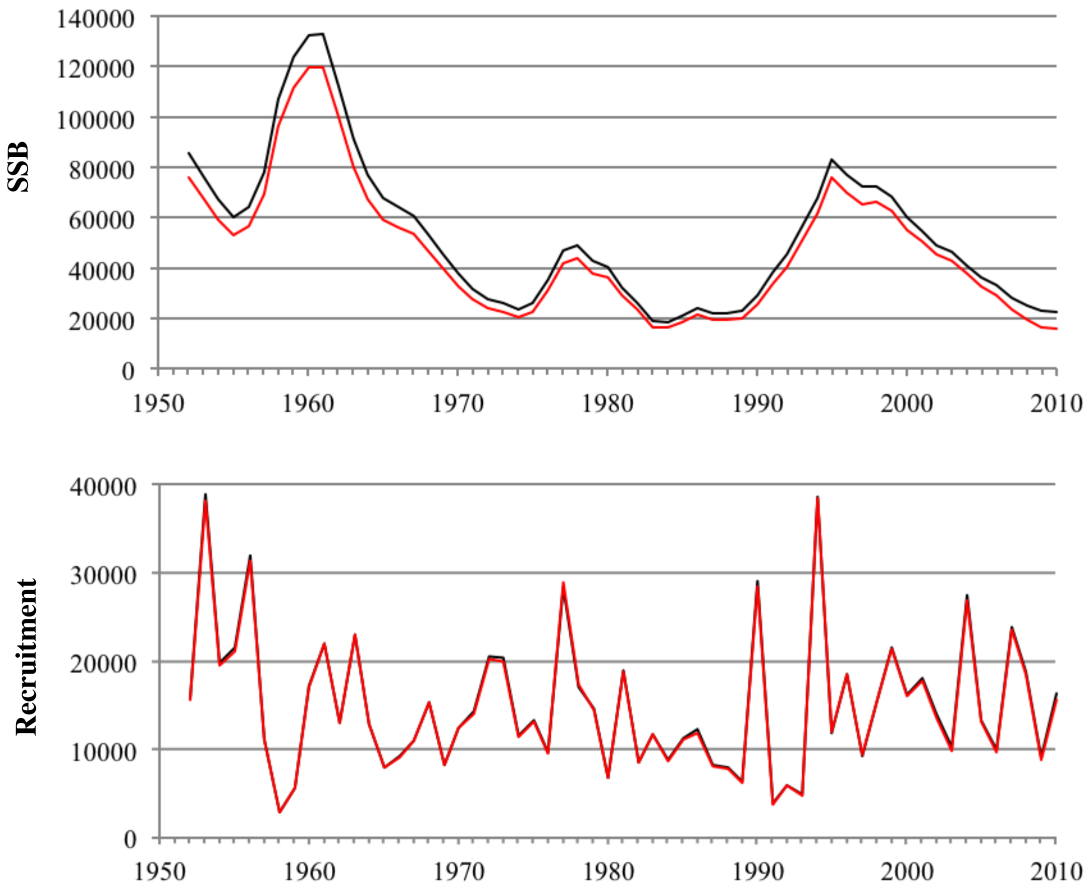


Fig. 5-15. Estimated spawning biomass (mt) and recruitment (1000 fish) from the Representative Run (black) and the alternative CV model (Run 4; red).

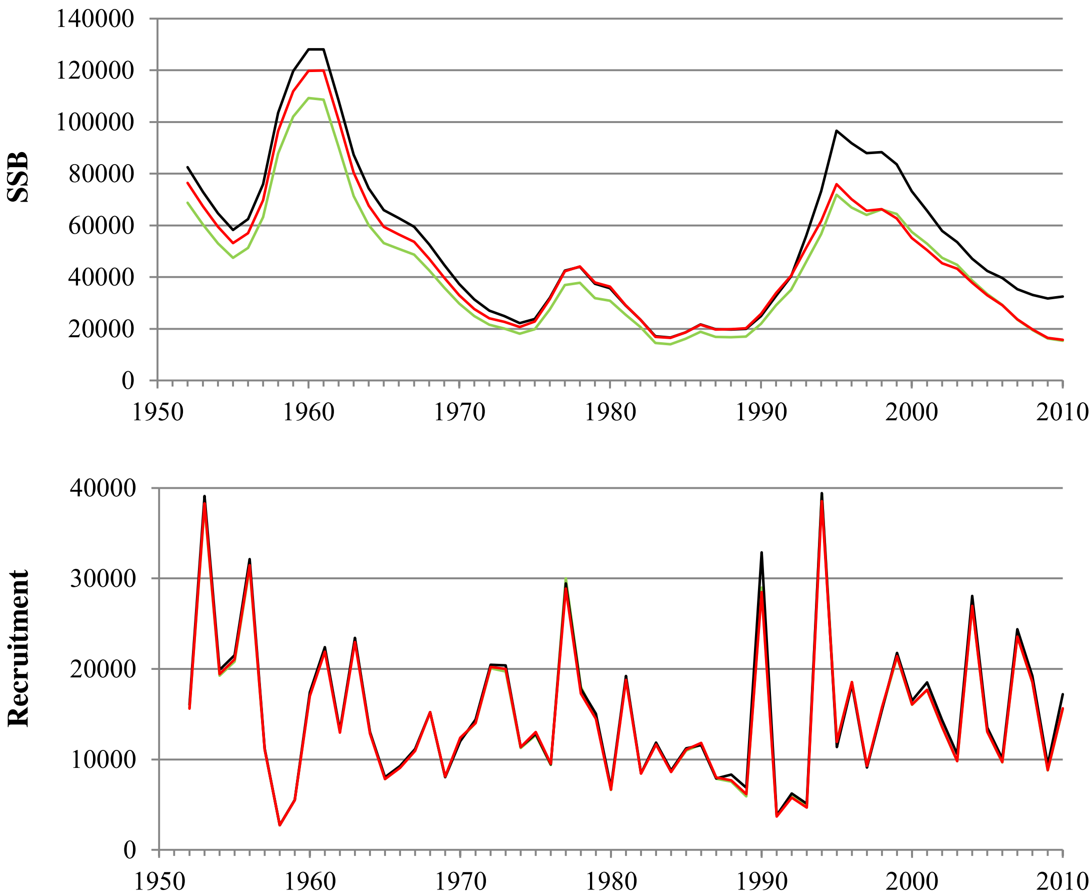


Fig. 5-16.Estimated spawning biomass (mt) and recruitment (1000 fish) from alternative model runs using different longline indices: Run 10 (S9 only; black), Run 8 (S1 only; green), and Run 4 (S1 and S9; red).

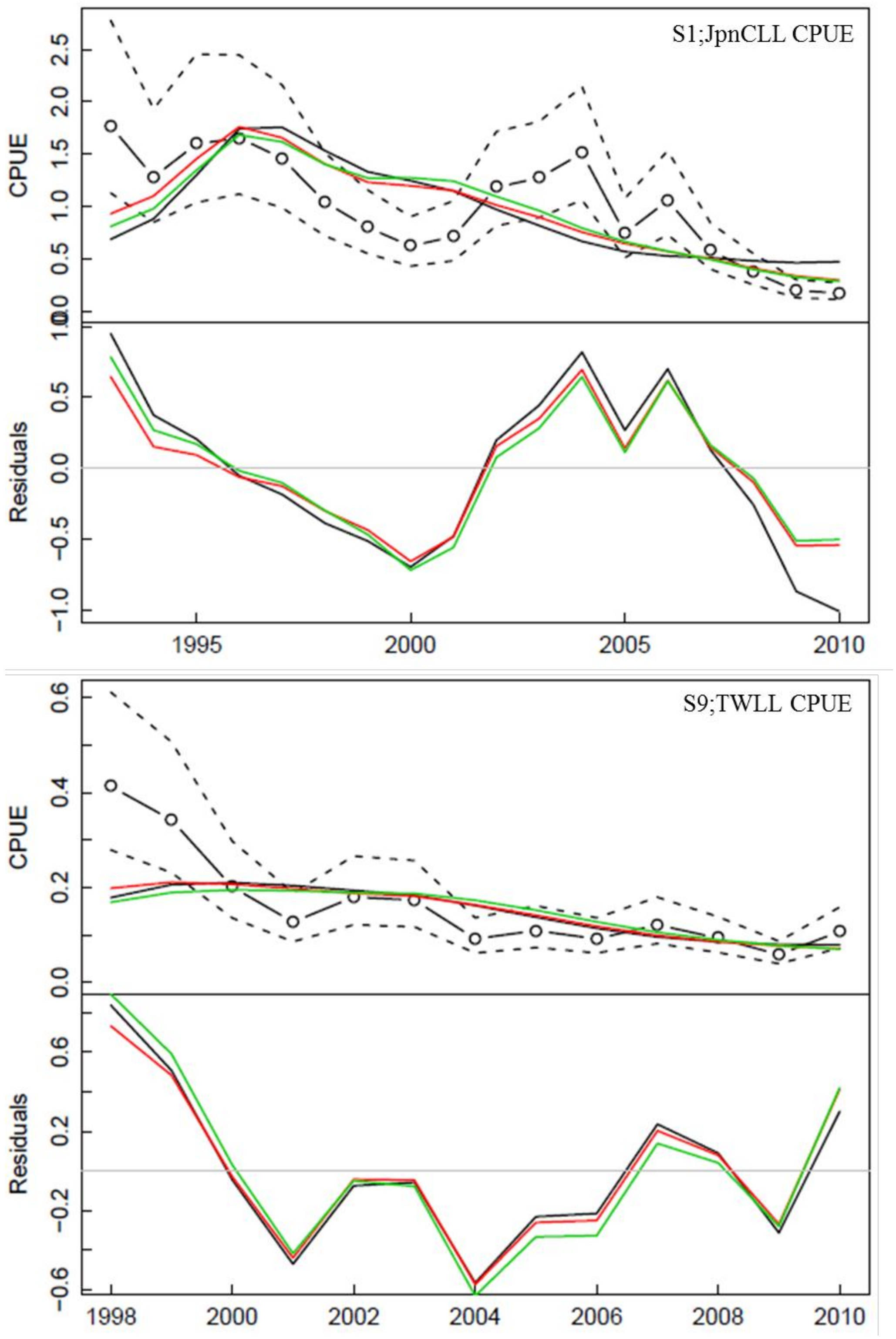


Fig. 5-17. Expected abundance trends (line) and observed indices (line and circle) for S1 (top) and S9 (bottom) indices using alternative indices: Run 10 (S9 only; black), Run 8 (S1 only; green), and Run 4 (S1 and S9; red) and residuals of the fits.

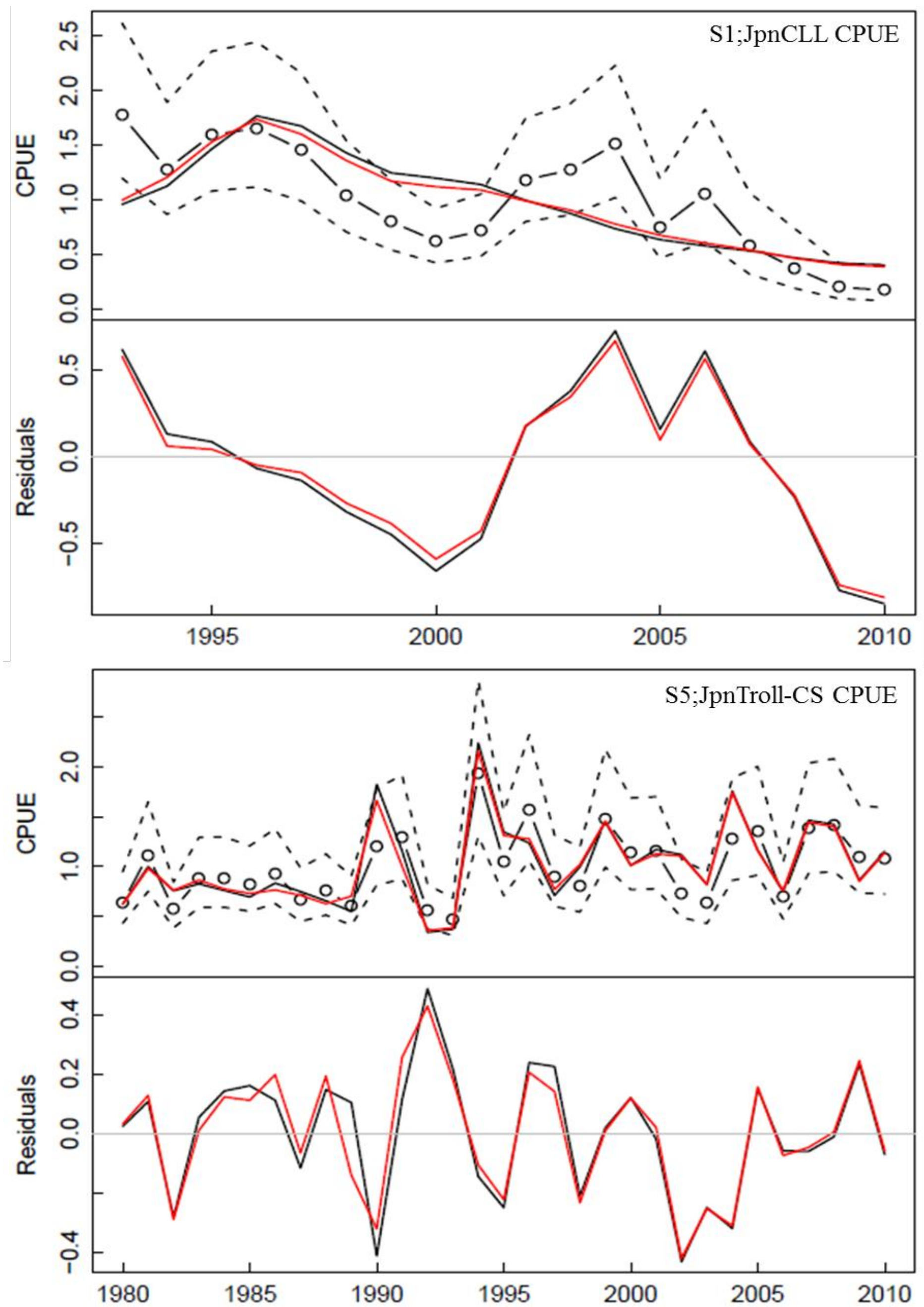


Fig. 5-18.Expected abundance trends (line) and observed indices (line and circle) for S1 (top) and S5 (bottom) indices using alternative weightings for Fleet 3 size composition data: Run 1 (EffN #1; red), and Representative Run (EffN #2; black) and residuals of the fits.

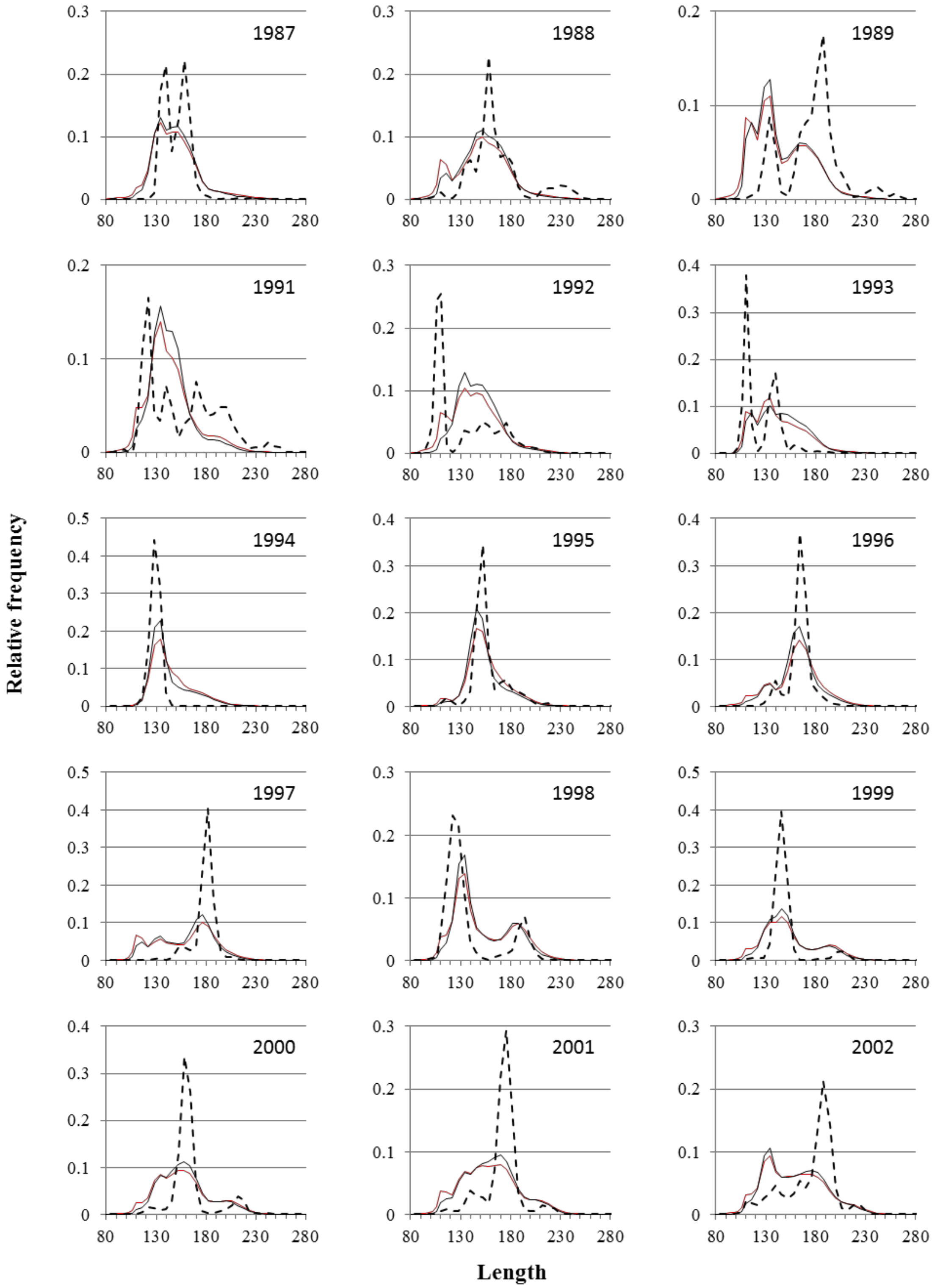


Fig. 5-19.Expected (solid lines) and observed (broken lines) size compositions of Fleet 3 using alternative weightings for Fleet 3 size composition data: Run 1 (EffN #1; red), and Representative Run (EffN #2; black).

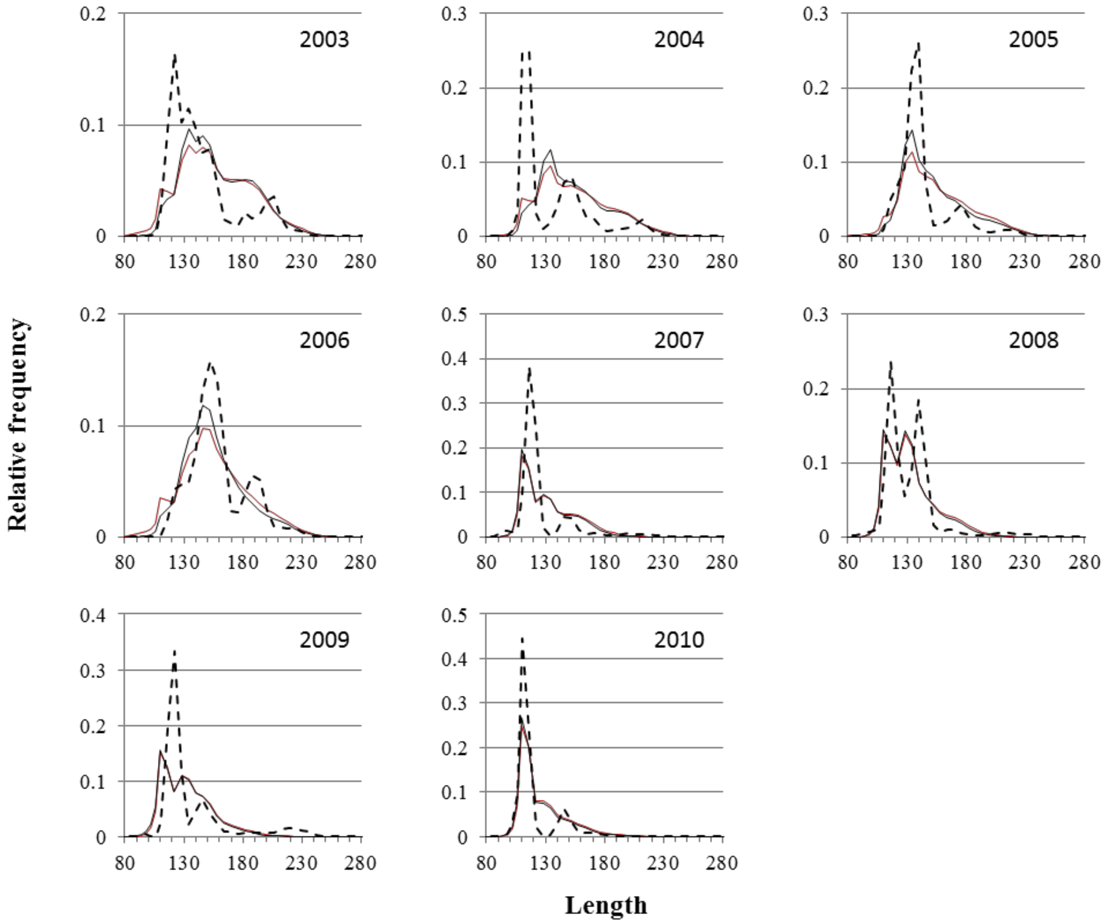


Fig. 5-19. Continued.

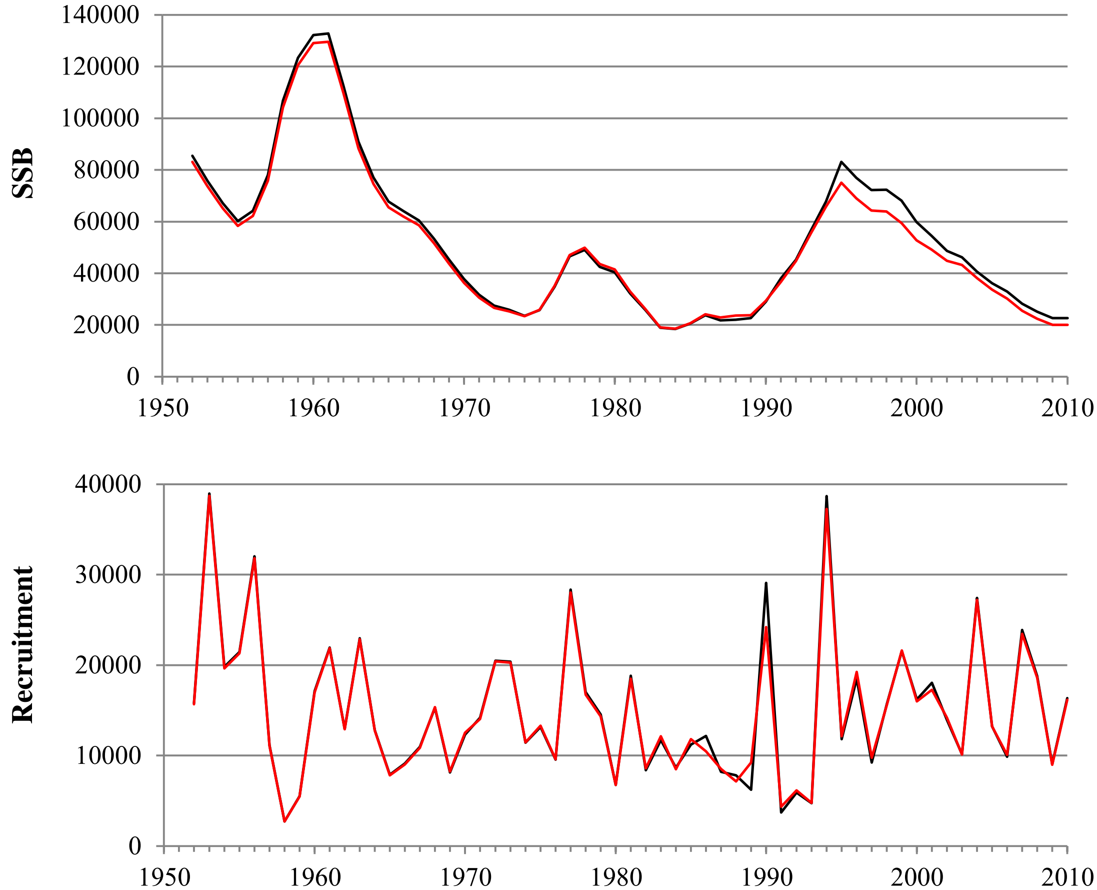


Fig. 5-20. Estimated spawning biomass (mt) and recruitment (1000 fish) using alternative weightings for Fleet 3 size composition data: Run 1 (EffN #1; red), and Representative Run (EffN #2; black).

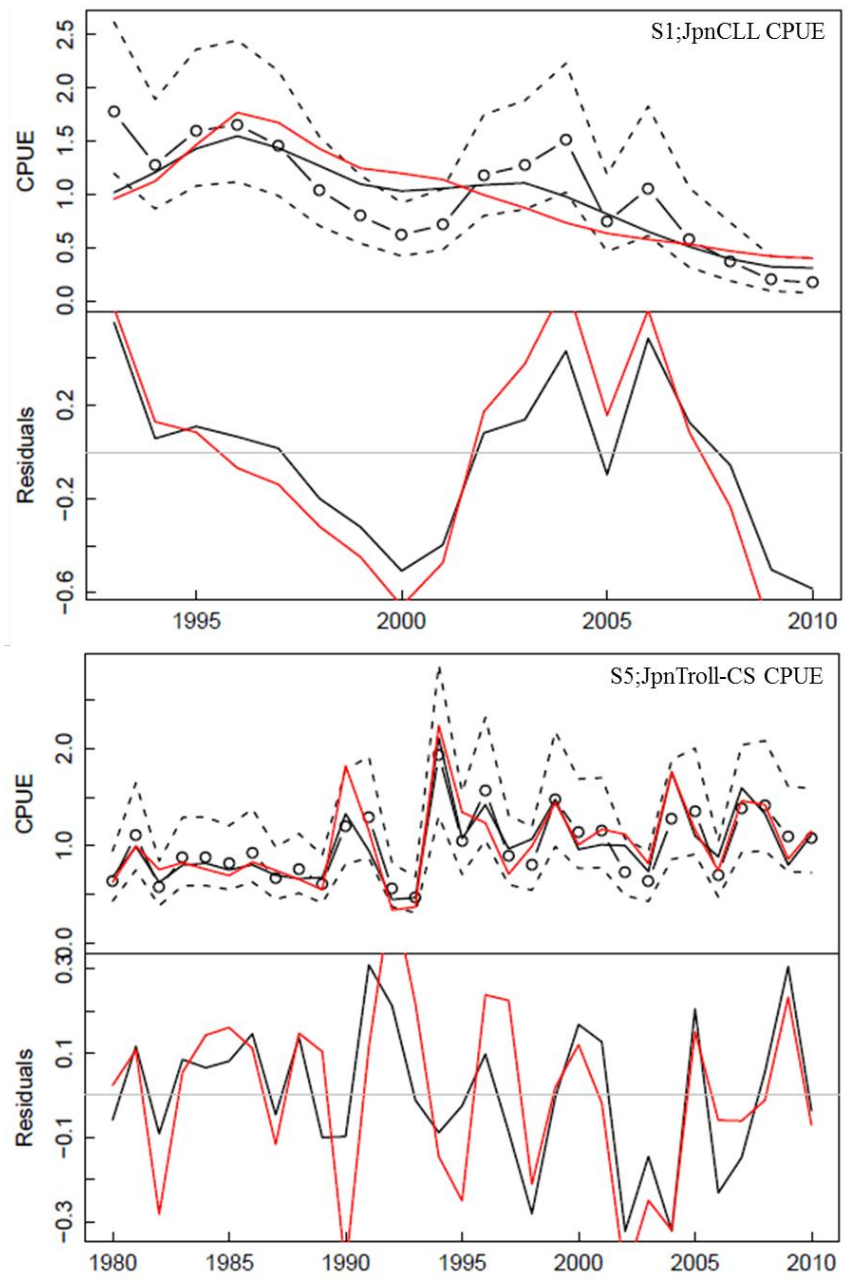


Fig. 5-21. Expected abundance trends (line) and observed indices (line and circle) for S1 (top) and S5 (bottom) indices using alternative models that fit to different size composition components: Run 20 (black), and Representative Run (red) and residuals of the fits.

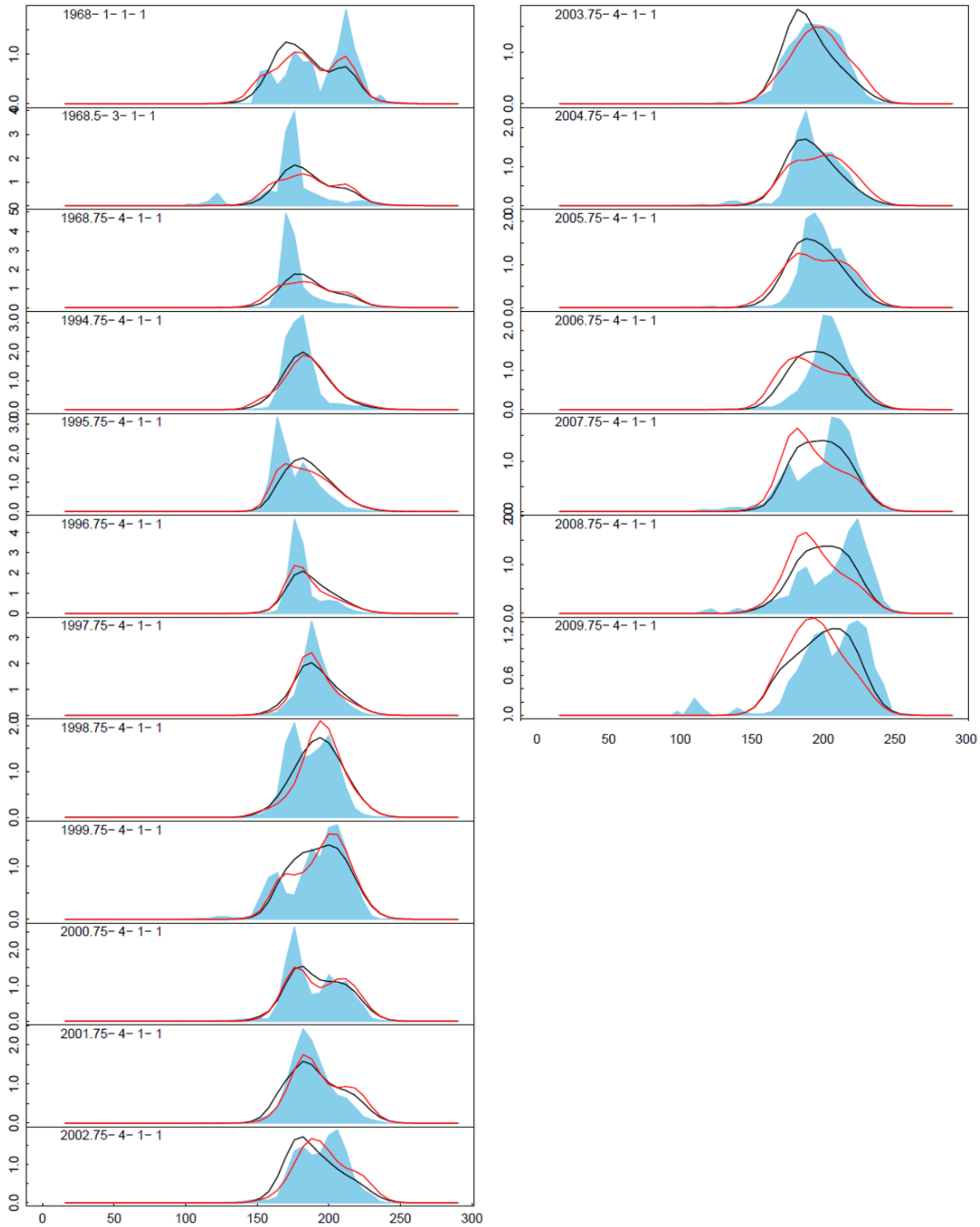


Fig. 5-22.Expected (solid lines) and observed (blue area) size compositions of Fleet 1 using alternative models that fit to different size composition components: Run 20 (black), and Representative Run (red).

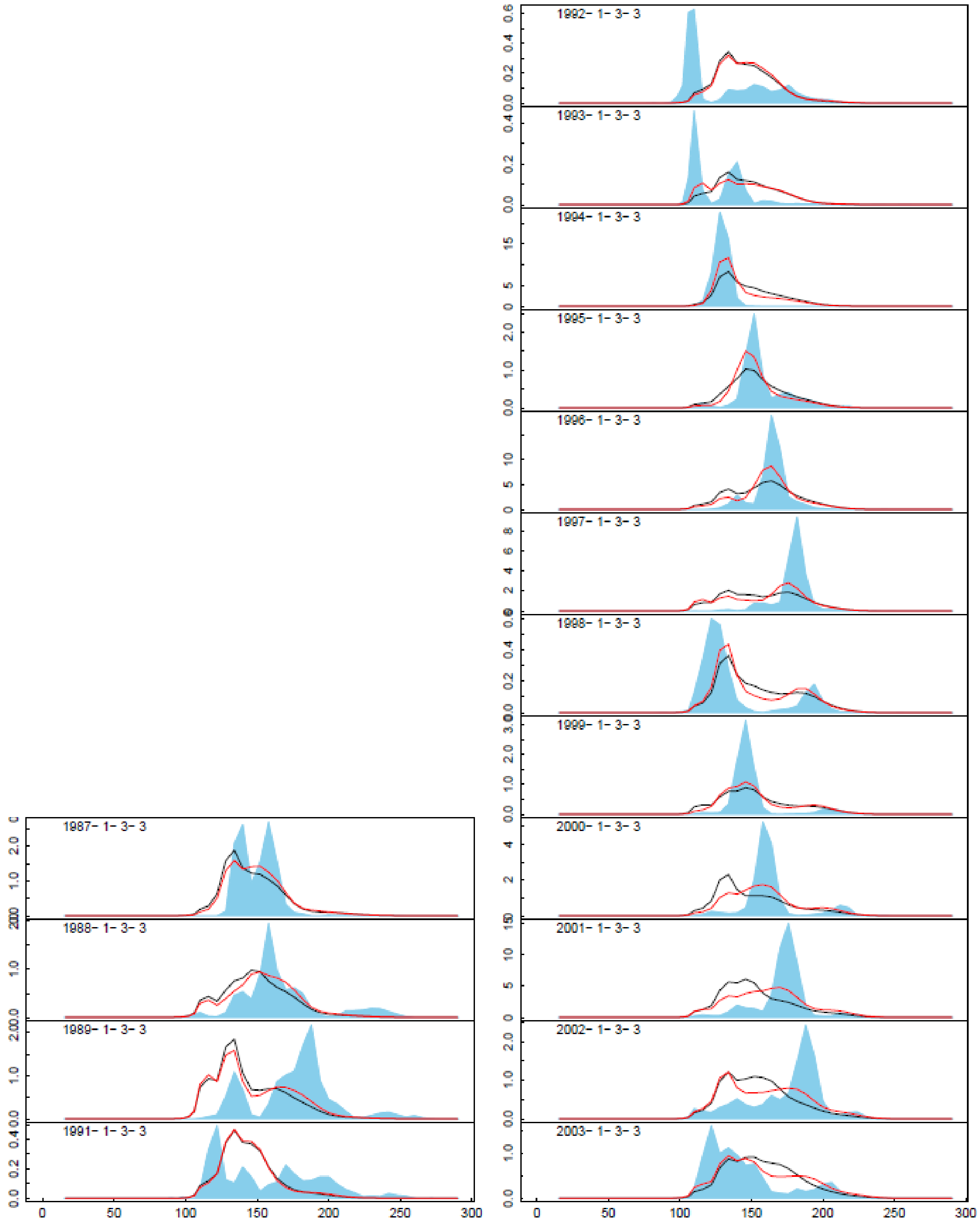
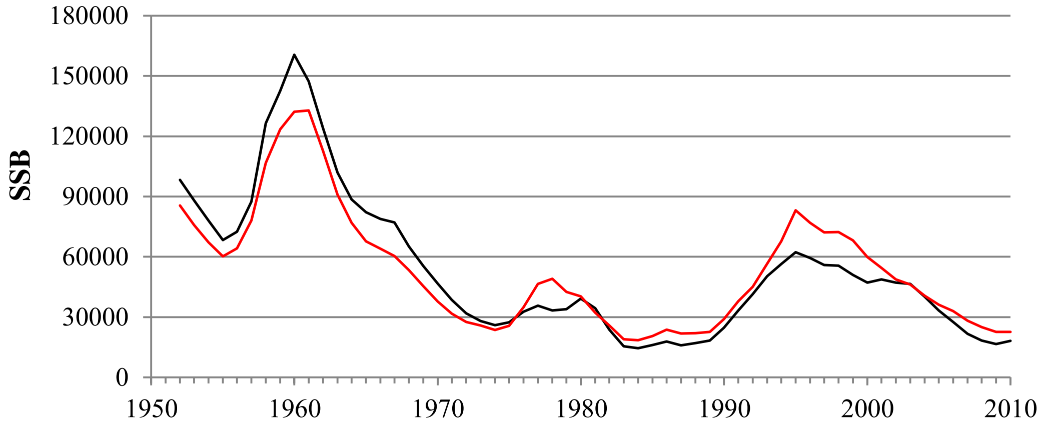


Fig. 5-23.Expected (solid lines) and observed (blue area) size compositions of Fleet 3 using alternative models that fit to different size composition components: Run 20 (black), and Representative Run (red).



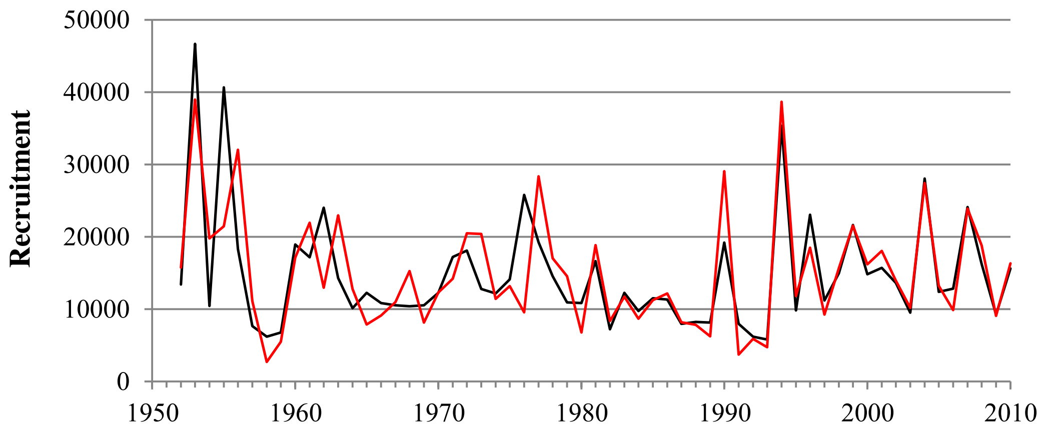


Fig. 5-24.Estimated spawning biomass (mt) and recruitment (1000 fish) using alternative models that fit to different size composition components: Run 20 (black), and Representative Run (red).

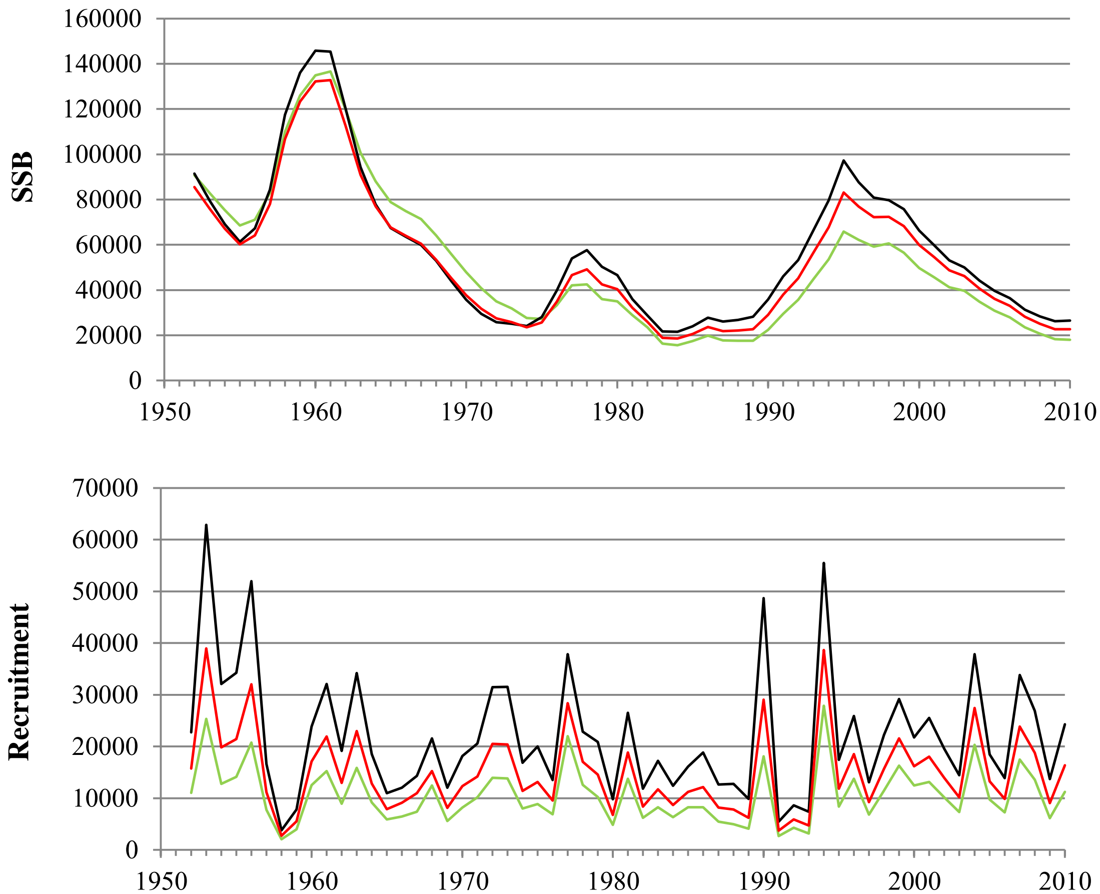


Fig. 5-25. Estimated spawning biomass (mt) and recruitment (1000 fish) using alternative natural mortality assumptions: high M (+20%; black), low M (-20%; green), and Representative Run (red).

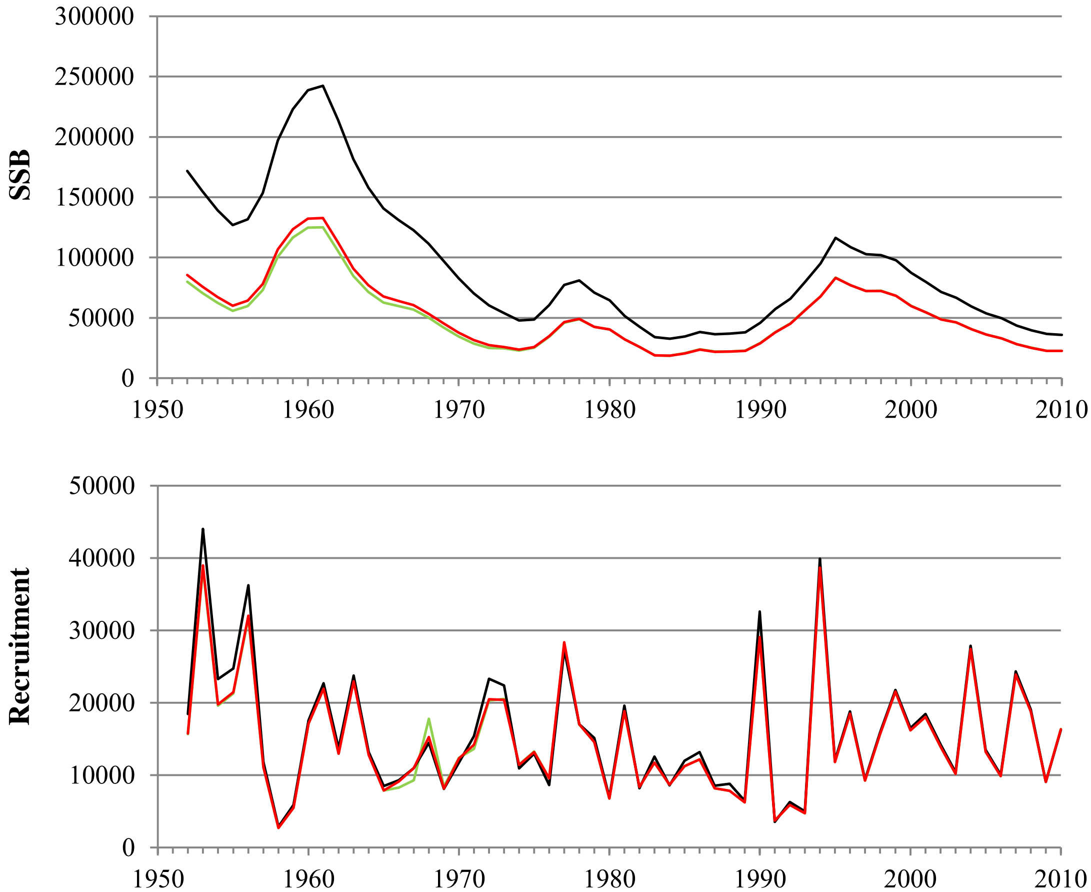


Fig. 5-26. Estimated spawning biomass (mt) and recruitment (1000 fish) using alternative steepness assumptions: low h (0.8; black), high h (1.0; green), and Representative Run (red).

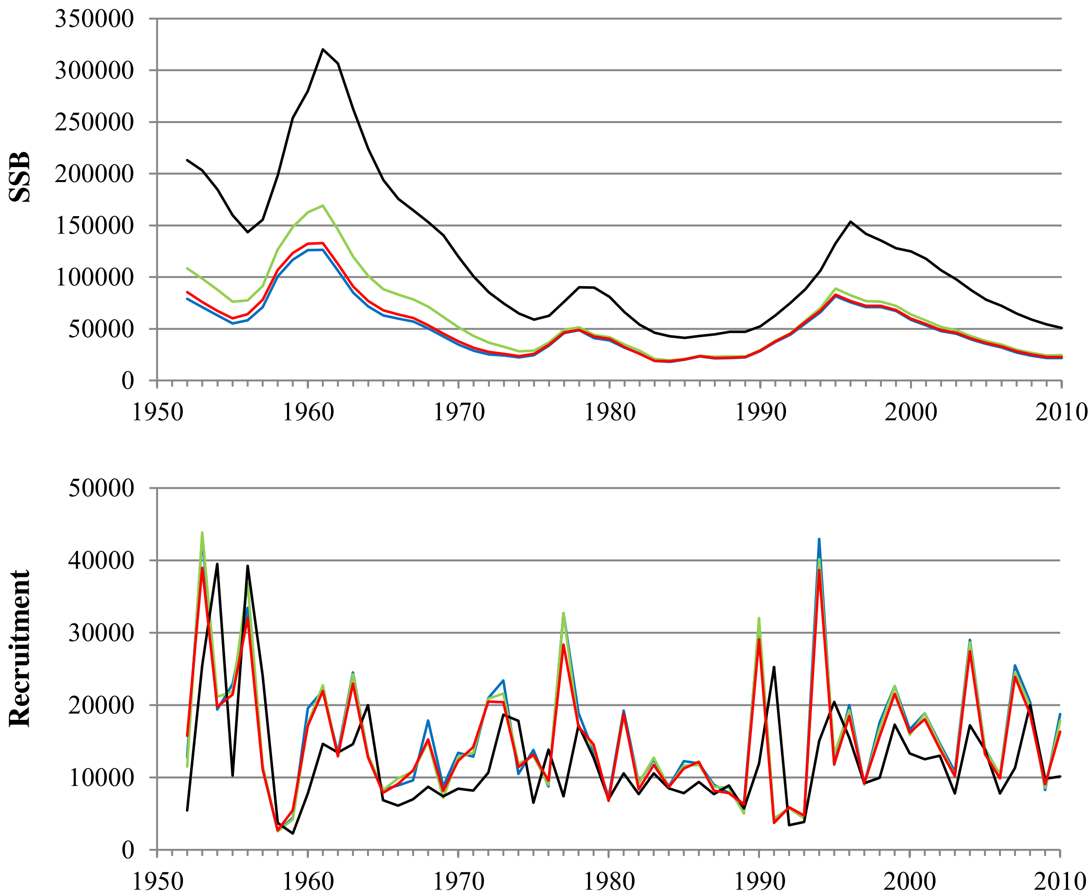


Fig. 5-27. Estimated spawning biomass (mt) and recruitment (1000 fish) using alternative growth curve assumptions from different studies: (ISC08/PBFWG01/08 (black), Shimose et al., 2009 (green), ISC09/PBFEG/01/12 (blue), and Representative Run (red).

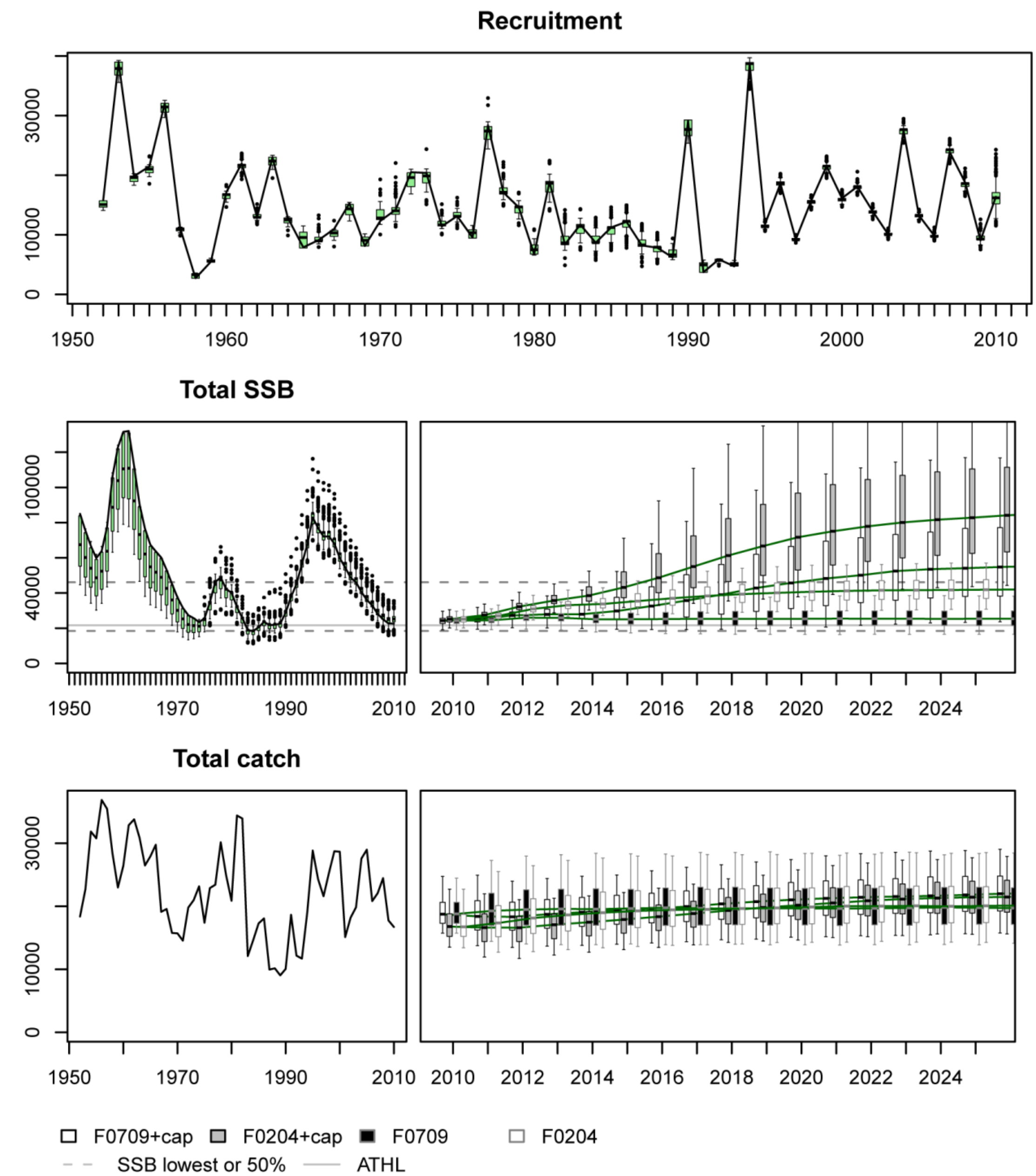


Fig. 5-28. Expected recruitment, spawning biomass, and total catch from 2011 to 2030, based on future projections. Four scenarios were used in the projections: (1) $_{F2007\text{-}2009}$; (2) $F_{2002\text{-}2004}$; (3) $F_{2007\text{-}2009}$ with catch limits on purse seine fleets in EPO and WPO; and (4) $F_{2002\text{-}2004}$ with catch limits on purse seine fleets in EPO and WPO. Bars indicate 80% confidence intervals.

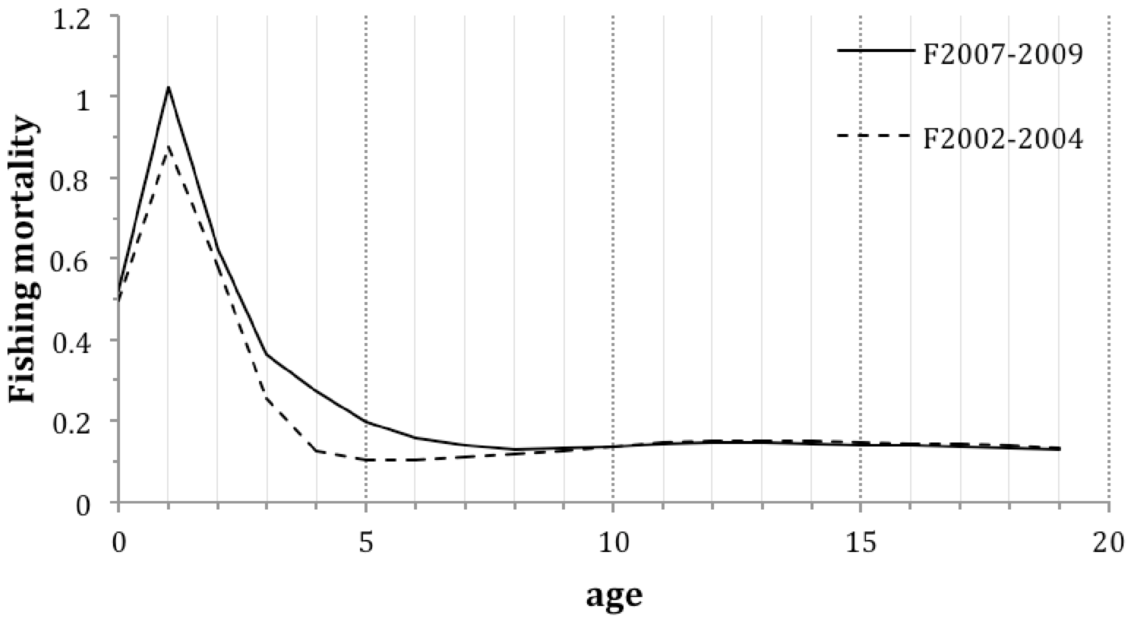


Fig. 6-1. Geometric mean annual age-specific fishing mortalities for 2002-2004 (broken line) and 2007-2009 (solid line).