ANNEX 14

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International Scientific Committee for Tuna
and Tuna-Like Species in the North Pacific Ocean
Yeosu, Republic of Korea
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STOCK ASSESSMENT OF PACIFIC BLUEFIN TUNA (*Thunnus orientalis*) IN THE PACIFIC OCEAN IN 2018

REPORT OF THE PACIFIC BLUEFIN TUNA WORKING GROUP

July 2018

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Table of Contents

2018 Pacific Bluefin Tuna Stock Assessment
ISC PBFWG

EXECUTIVE SUMMARY MAY 2018

1. Stock Identification and Distribution

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

2. Catch History

While Pacific bluefin tuna (PBF) catch records prior to 1952 are incomplete, there are some PBF landings records dating back to 1804 from coastal Japan and to the early 1900s for U.S. fisheries operating in the EPO. Catch of PBF was estimated to be high from 1929 to 1940, with a peak catch of approximately 47,635 t (36,217 t in the WPO and 11,418 t in the EPO) in 1935; thereafter catches of PBF dropped precipitously due to World War II. PBF catches increased significantly in 1949 as Japanese fishing activities expanded across the North Pacific Ocean. By 1952, a more consistent catch reporting process was adopted by most fishing nations. Estimates of PBF annual catches fluctuated widely from 1952 to 2016 (Figure 1). During this period reported catches peaked at 40,383 t in 1956 and reached a low of 8,653 t in 1990. Catches in 2015 and 2016 were 11,194 t and 13,198 t, respectively, including non-ISC member countries. While a suite of fishing gears has been used to catch PBF, the majority is currently caught in purse seine fisheries (Figure 2). Catches during 1952-2016 were predominately composed of juvenile PBF, but since the early 1990s, the catch of age 0 PBF has increased significantly (Figure 3).

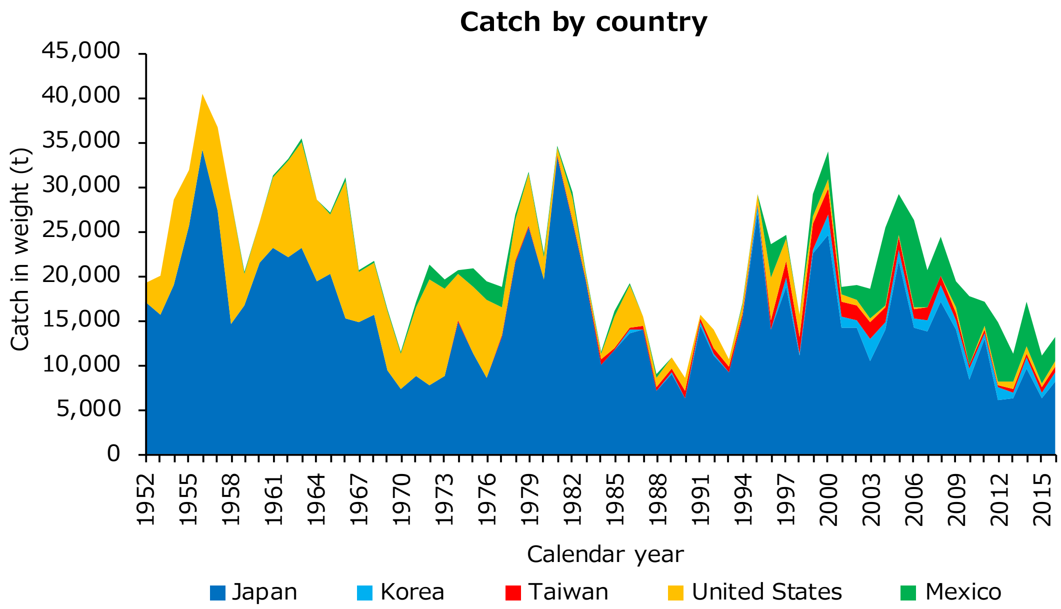

Figure 1. Annual catch of Pacific bluefin (*Thunnus orientalis*) tuna by country from 1952 through 2016 (calendar year).

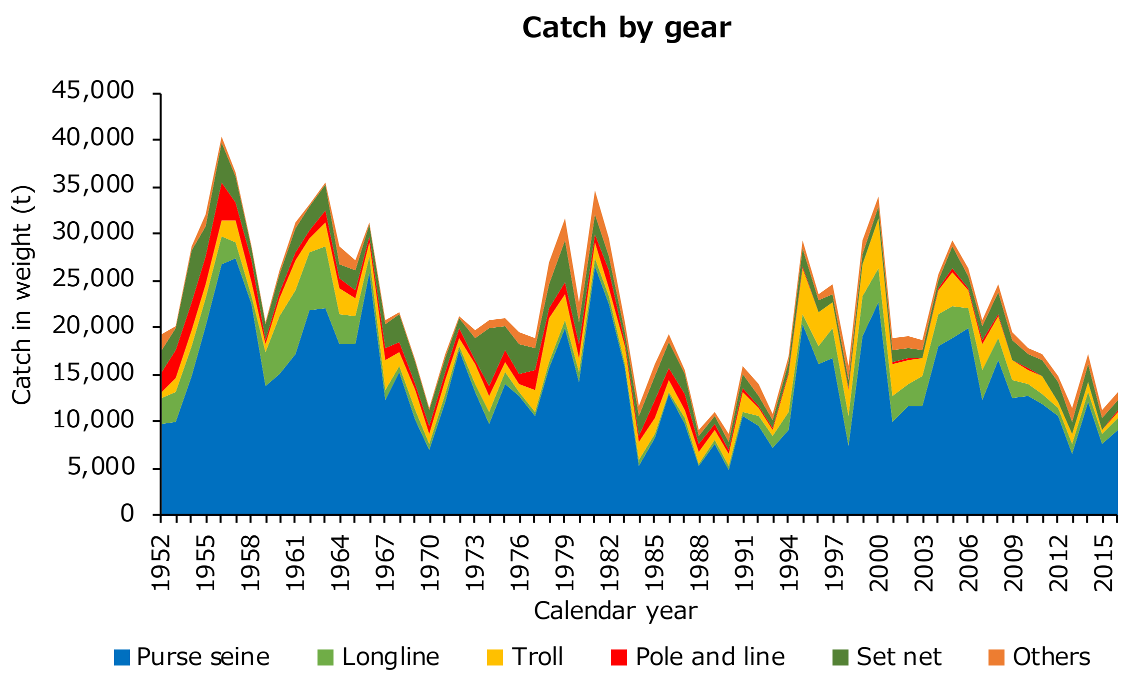

Figure 2. Annual catch of Pacific bluefin tuna (*Thunnus orientalis*) by gear type from 1952 through 2016 (calendar year).

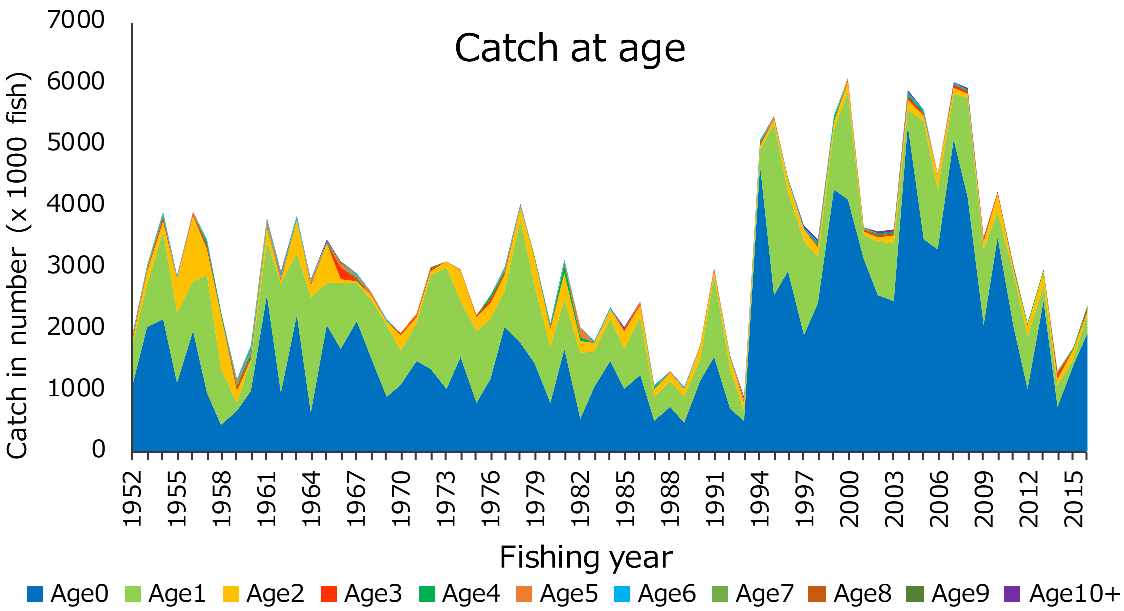

Figure 3. Estimated annual catch-at-age of Pacific bluefin tuna (*Thunnus orientalis*) by fishing year[1] (1952-2016; data for 1952 are incomplete).

3. Data and Assessment

As the 2018 assessment was an update, the basic model construction is the same as that used for the 2016 assessment with data through 2016. Population dynamics were estimated using a fully integrated age-structured model (Stock Synthesis (SS) v3.24f) fitted to catch, size-composition and catch-per-unit effort (CPUE) data from 1952 to 2016 (fishing year), provided by Members of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC), Pacific Bluefin Tuna Working Group (PBFWG) and by non-ISC countries. Life history parameters included a length-at-age relationship from otolith-derived ages, as well as natural

[1] To better describe PBF biology, the fishing year (from July 1 to June 30 of the following calendar year) was used instead calendar year in the modelling context.

mortality estimates from a tag-recapture study and empirical-life history methods.

Nineteen fleets were defined for use in the stock assessment model based on country/gear/season/region stratification. Quarterly observations of catch and size compositions, when available, were used as inputs to the model to describe the removal processes. Annual estimates of standardized CPUE from the Japanese distant water, off-shore and coastal longline fleets, the Taiwanese longline fleets, and the Japanese troll fleets were used as measures of the relative abundance of the population. The Japanese and Taiwanese longline CPUEs (used to inform the trend of adult abundance) showed gradually increasing trends (2014-16) in the updated years while the Japanese troll CPUE (used to inform recruitment) was higher in 2016 than the low level in 2014.

The assessment model was fitted to the input data in a likelihood-based statistical framework. Maximum likelihood estimates of model parameters, derived outputs and their variances were used to characterize stock status and to develop stock projections.

4. Stock Status and Conservation Information

Stock Status

The 2018 base-case model was constructed with minimal modifications relative to the 2016 base-case model. Based on the diagnostic analyses, the model represents the data sufficiently and results were consistent with the 2016 assessment. The 2018 assessment results are considered the best available science information.

The base-case model results show that: (1) spawning stock biomass (SSB) fluctuated throughout the assessment period, (2) the SSB steadily declined from 1996 to 2010; and (3) the slow increase of the stock continues since 2011 including the most recent two years (2015-16). Based on the model diagnostics, the estimated biomass trend for the last 30 years is considered robust although SSB prior to the 1980s is uncertain due to data limitations. Using the base-case model, the 2016 SSB (terminal year) was estimated to be around 21,000 t in the 2018 assessment, which is an increase from 19,000 t in 2014 (Table 1 and Figure 4).

Historical recruitment estimates have fluctuated since 1952 without an apparent trend. The low recruitment levels estimated in 2010-2014 were a concern in the 2016 assessment. The 2015 recruitment estimate is low and similar to estimates of previous years while the 2016 recruitment estimate is higher than the historical average (Figure 4). The uncertainty of the 2016 recruitment estimate is higher than in previous years because it occurs in the terminal year of the assessment model and is mainly informed by one observation from the troll age-0 CPUE index. The troll CPUE series has been shown to be a good predictor of recruitment, with no apparent retrospective error in the recruitment estimates of the terminal year given the current model construction. As the 2016 recruits grow and are observed by other fleets, the magnitude of this year class will be more precisely estimated in the next stock assessment. The magnitude of the estimated 2016 year class had a positive impact on the projection results.

Table 1. Total biomass, spawning stock biomass and recruitment of Pacific bluefin tuna (*Thunnus orientalis*) estimated by the base-case model, where Coefficient of Variation (CV) measures relative variability defined as the ratio of the standard deviation to the mean.

Fishing year	Total biomass (t)	Spawning stock biomass (t)	CV for SSB	Recruitment (x1000 fish)	CV for R
1952	150825	114227	0.51	9305	
1953	146228	107201	0.49	21843	0.17
1954	147385	96239	0.49	34556	0.15
1955	152230	83288	0.50	14106	0.19
1956	169501	76742	0.49	34261	0.11
1957	188830	82975	0.46	12574	0.15
1958	208078	108677	0.41	3436	0.30
1959	214898	147004	0.39	7963	0.22
1960	218055	155183	0.39	7745	0.21
1961	211262	168125	0.39	23323	0.10
1962	197361	151993	0.42	10794	0.18
1963	181329	129755	0.45	27615	0.10
1964	169581	114448	0.45	5827	0.32
1965	159109	100628	0.46	11584	0.35
1966	144866	95839	0.44	8645	0.44
1967	121987	89204	0.44	10803	0.38
1968	107216	83374	0.45	13656	0.24
1969	93223	69074	0.47	6413	0.30
1970	81816	57958	0.48	7120	0.40
1971	71900	49980	0.48	12596	0.34
1972	67819	43035	0.46	22742	0.17
1973	65474	37205	0.44	11058	0.27
1974	65059	29896	0.44	13570	0.17
1975	63515	27733	0.38	11011	0.18
1976	66532	30485	0.30	9171	0.32
1977	64320	36220	0.25	25078	0.17
1978	69199	33382	0.25	15057	0.26
1979	69609	28007	0.29	11509	0.20
1980	71313	30757	0.25	7584	0.27
1981	72109	28867	0.21	11703	0.13
1982	53715	25408	0.21	6965	0.21
1983	31185	15086	0.29	10078	0.15
1984	33147	12813	0.31	9231	0.20
1985	36319	12846	0.28	9601	0.19
1986	35877	15358	0.23	7857	0.19
1987	31609	14632	0.25	6224	0.22
1988	33868	15709	0.25	8796	0.14
1989	38189	15519	0.25	4682	0.28
1990	46388	19468	0.23	18462	0.09
1991	61501	25373	0.21	11803	0.11
1992	70077	32022	0.20	4426	0.17
1993	79910	43691	0.18	4365	0.18
1994	90135	51924	0.19	28350	0.04
1995	103322	67152	0.18	17414	0.09
1996	98854	66841	0.18	17564	0.06
1997	99196	61069	0.19	10919	0.10
1998	95373	60293	0.19	15014	0.08
1999	91963	56113	0.20	23450	0.05
2000	87384	53835	0.21	14335	0.06
2001	76182	50222	0.21	15786	0.05
2002	77727	47992	0.20	13509	0.06
2003	74204	47569	0.19	7769	0.09
2004	68407	40707	0.20	26116	0.04
2005	63042	33820	0.21	14659	0.06
2006	50197	27669	0.23	11645	0.06
2007	43558	22044	0.24	21744	0.04
2008	41169	16754	0.27	20371	0.04
2009	35677	13011	0.27	8810	0.07
2010	33831	12188	0.25	15948	0.05
2011	34983	13261	0.23	13043	0.06
2012	37451	15892	0.20	6284	0.09
2013	39113	18107	0.20	11874	0.06
2014	38918	19031	0.19	3561	0.14
2015	38322	19695	0.20	7765	0.13
2016	41191	21331	0.22	15988	0.21

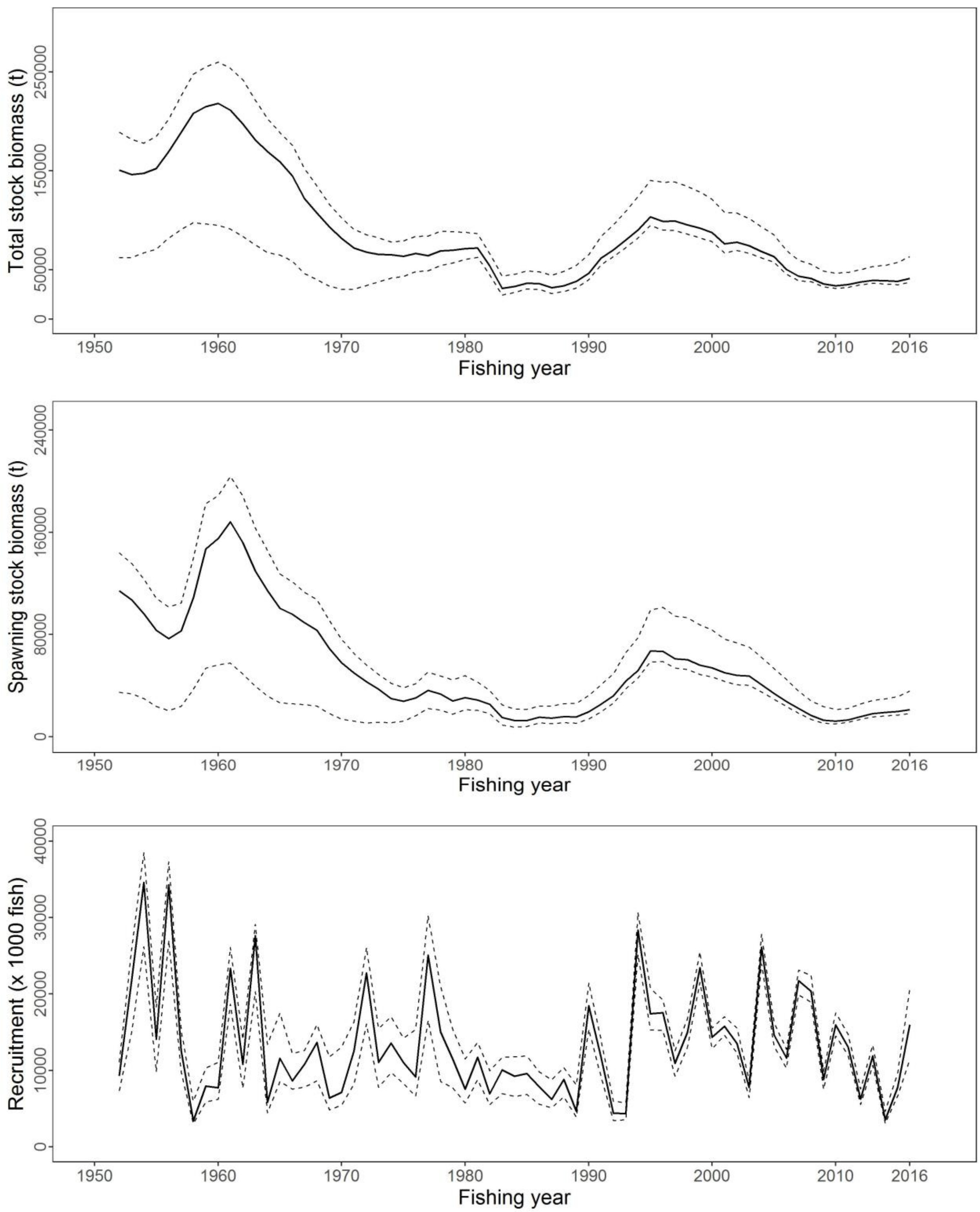

Figure 4. Total stock biomass (top), spawning stock biomass (middle) and recruitment (bottom) of Pacific bluefin tuna (*Thunnus orientalis*) from the base-case model. The solid lines indicate point estimates and the dashed lines indicate the 90% confidence intervals.

Estimated age-specific fishing mortalities (F) on the stock during the periods 2012-2014 and 2015-2016 compared to 2002-2004 estimates (the base period for the WCPFC Conservation and Management Measure) are presented in Table 2 and Figure 5. A substantial decrease in estimated F is observed in ages 0-2 in 2015-2016 from the previous years. Note that stricter management measures in WCPFC and IATTC have been in place since 2015.

Table 2. Changes of estimated age-specific Fs of Pacific bluefin tuna (*Thunnus orientalis*) from 2002-2004 to 2012-2014 and 2015-2016.

	Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Change from	F2012-14	-9%	-42%	24%	-10%	-11%	-25%	-35%	-7%	-3%	-23%	0%	7%	11%	13%	15%	16%	17%	18%	19%	19%	20%
F2002-04 to	F2015-16	-49%	-57%	-21%	25%	56%	34%	18%	-3%	-15%	-24%	-13%	-11%	-8%	-7%	-5%	-4%	-3%	-3%	-2%	-2%	-1%

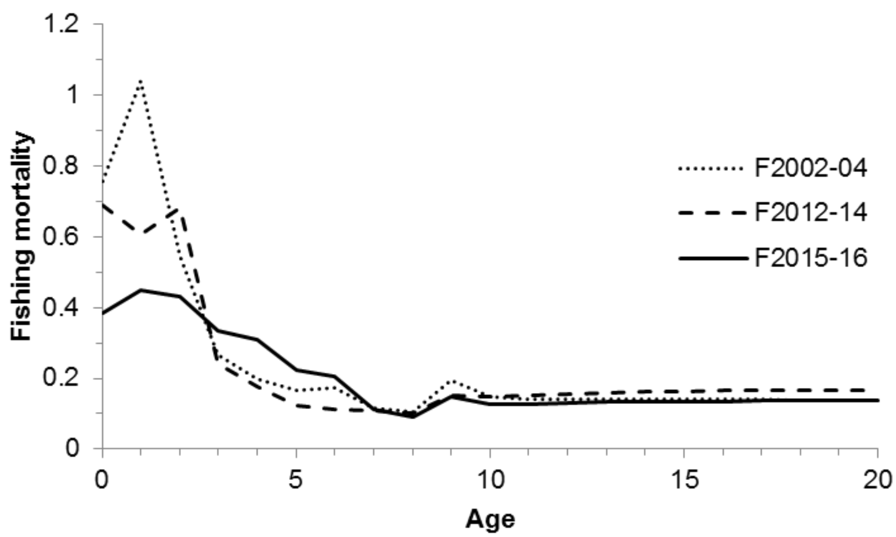

Figure 5. Geometric means of annual age-specific fishing mortalities of Pacific bluefin tuna (*Thunnus orientalis*) in 2002-2004 (dotted line), 2012-2014 (dashed line), and 2015-2016 (solid line).

The WCPFC adopted an initial rebuilding biomass target (the median SSB estimated for the period 1952 through 2014) and a second rebuilding biomass target (20%$SSB_{F=0}$ under average recruitment), without specifying a fishing mortality reference level. The 2018 assessment estimated the initial rebuilding biomass target to be 6.7%$SSB_{F=0}$ and the corresponding fishing mortality expressed as spawning potential ratio (SPR) of $F_{6.7\%SPR}$ (Table 3). Spawning potential ratio (SPR) is the ratio of the cumulative spawning biomass that an average recruit is expected to produce over its lifetime when the stock is fished at the current intensity to the cumulative spawning biomass that could be produced by an average recruit over its lifetime if the stock was unfished. Spawning potential ratio is often used as a measure of fishing intensity when selectivity changes substantially over time, as is the case with Pacific bluefin tuna. $F_{6.7\%SPR}$ describes a fishing mortality and aggregate fishery selectivity pattern that is expected to produce 6.7% of the cumulative unfished spawning biomass; a low number means that fishing mortality on the stock is high for that year. Because the projections include catch limits, fishing mortality is expected to decline, i.e., $Fx_{\%SPR}$ will increase, as biomass increases. The Kobe plot shows that the point estimate of the 2016 SSB was 3.3%$SSB_{F=0}$ and the 2016 fishing mortality corresponds to $F_{6.7\%SPR}$ (Figure 6).

Table 3. Spawning stock biomass and fishing intensity of Pacific bluefin tuna (*Thunnus orientalis*) in 1995 (recent high biomass), 2002-2004 (WCPFC reference year biomass), 2011 (biomass 5 years ago), and 2016 (latest) to those of the adopted WCPFC biomass rebuilding targets. Spawning potential ratio (SPR) is used as a measure of fishing intensity; the lower the number the higher the fishing intensity that year.

	initial rebuilding target	second rebuilding target	1995 (recent high)	2002-2004 (reference year)	2011 (5 years ago)	2016 (latest)
Biomass (%$SSB_{F=0}$)	SSB median 1952-2014 = 6.7%	20%	10.4%	7.1%	2.1%	3.3%
Fishing intensity (SPR)	6.7%	20%	5.1%	3.4%	4.9%	6.7%

Table 4 provides an evaluation of PBF stock status against common reference points. It shows that the PBF stock is overfished relative to biomass-based limit reference points adopted for other species in WCPFC (20%$SSB_{F=0}$) and is subject to overfishing relative to most of the common fishing intensity-based reference points.

Table 4. Ratios of the estimated fishing intensities mortalities (Fs and 1-SPRs for 2002-04, 2012-14, 2015-16) relative to potential fishing intensity-based reference points, and terminal year SSB (t) for each reference period, and depletion ratios for the terminal year of the reference period for Pacific bluefin tuna (*Thunnus orientalis*).

	F_{max}	F0.1	Fmed	Floss	(1-SPR)/(1-SPRxx%)				Estimated SSB for terminal year of each reference period	Depletion ratio for terminal year of each reference period
					SPR10%	SPR20%	SPR30%	SPR40%		
2002-2004	1.77	2.47	1.04	0.78	1.07	1.21	1.38	1.61	40,707	6.3%
2012-2014	1.47	2.04	0.86	0.65	1.05	1.19	1.36	1.58	19,031	3.0%
2015-2016	1.32	1.85	0.78	0.58	1.02	1.15	1.32	1.54	21,311	3.3%

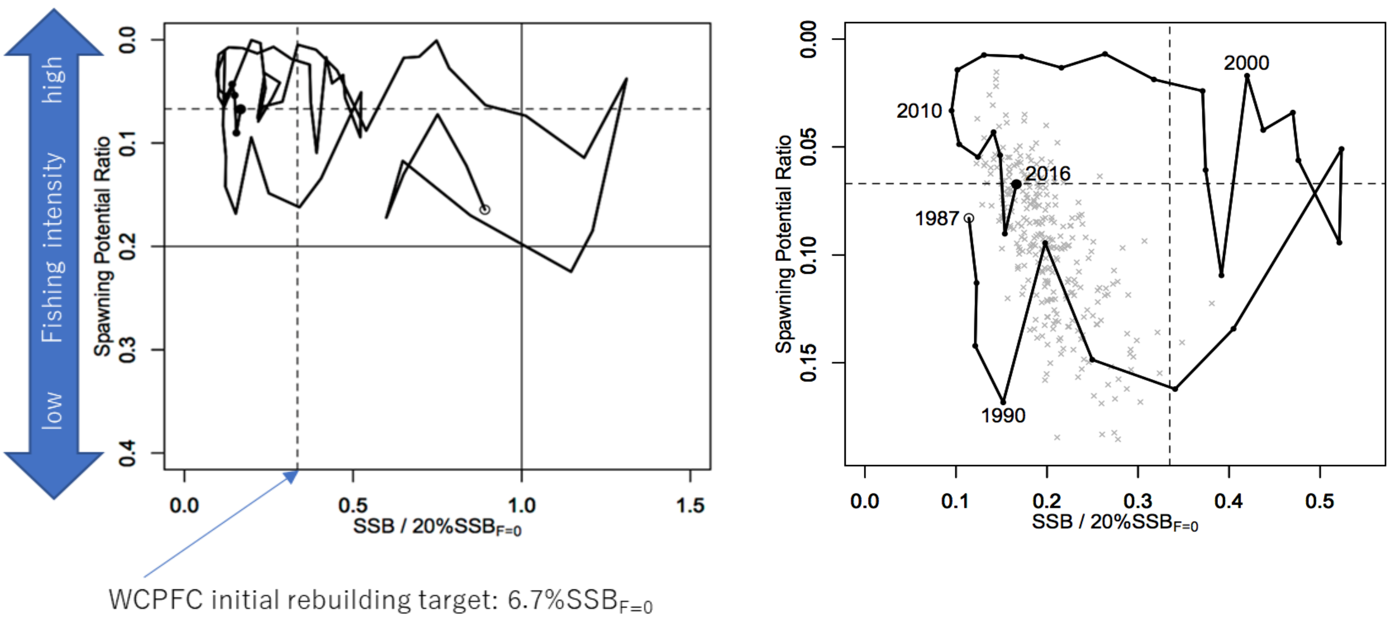

Figure 6. Kobe plots for Pacific bluefin tuna (*Thunnus orientalis*). X axis shows the annual SSB relative to 20%SSB$_{F=0}$ and the Y axis shows the spawning potential ratio as a measure of fishing intensity. Solid vertical and horizontal lines in the left figure show 20%SSB$_{F=0}$ (which corresponds to the second biomass rebuilding target) and the corresponding fishing intensity, respectively. Dashed vertical and horizontal lines in both figures show the initial biomass rebuilding target (SSB_{MED} = 6.7%SSB$_{F=0}$) and the corresponding fishing intensity, respectively. SSB_{MED} is calculated as the median of estimated SSB over 1952-2014. The left figure shows the historical trajectory, where the open circle indicates the first year of the assessment (1952) while solid circles indicate the last five years of the assessment (2012-2016). The right figure shows

the trajectory of the last 30 years, where grey crosses indicate the uncertainty of the terminal year.

Figure 7 depicts the historical impacts of the fleets on the PBF stock, showing the estimated biomass when fishing mortality from respective fleets is zero. Historically, the WPO coastal fisheries group has had the greatest impact on the PBF stock, but since about the early 1990s the WPO purse seine fleets, in particular those targeting small fish (ages 0-1), have had a greater impact, and the effect of these fleets in 2016 was greater than any of the other fishery groups. The impact of the EPO fishery was large before the mid-1980s, decreasing significantly thereafter. The WPO longline fleet has had a limited effect on the stock throughout the analysis period because the impact of a fishery on a stock depends on both the number and size of the fish caught by each fleet; i.e., catching a high number of smaller juvenile fish can have a greater impact on future spawning stock biomass than catching the same weight of larger mature fish.

Based on these findings, the following information on the status of the Pacific bluefin tuna stock is provided:

1. No biomass-based limit or target reference points have been adopted to evaluate the overfished status for PBF. However, the PBF stock is overfished relative to the potential biomass-based reference points evaluated (SSBmed and 20%$SSB_{F=0}$, Table 4 and Figure 6).
2. No fishing intensity-based limit or target reference points have been adopted to evaluate overfishing for PBF. However, the PBF stock is subject to overfishing relative to most of potential fishing intensity-based reference points evaluated (Table 4 and Figure 6).

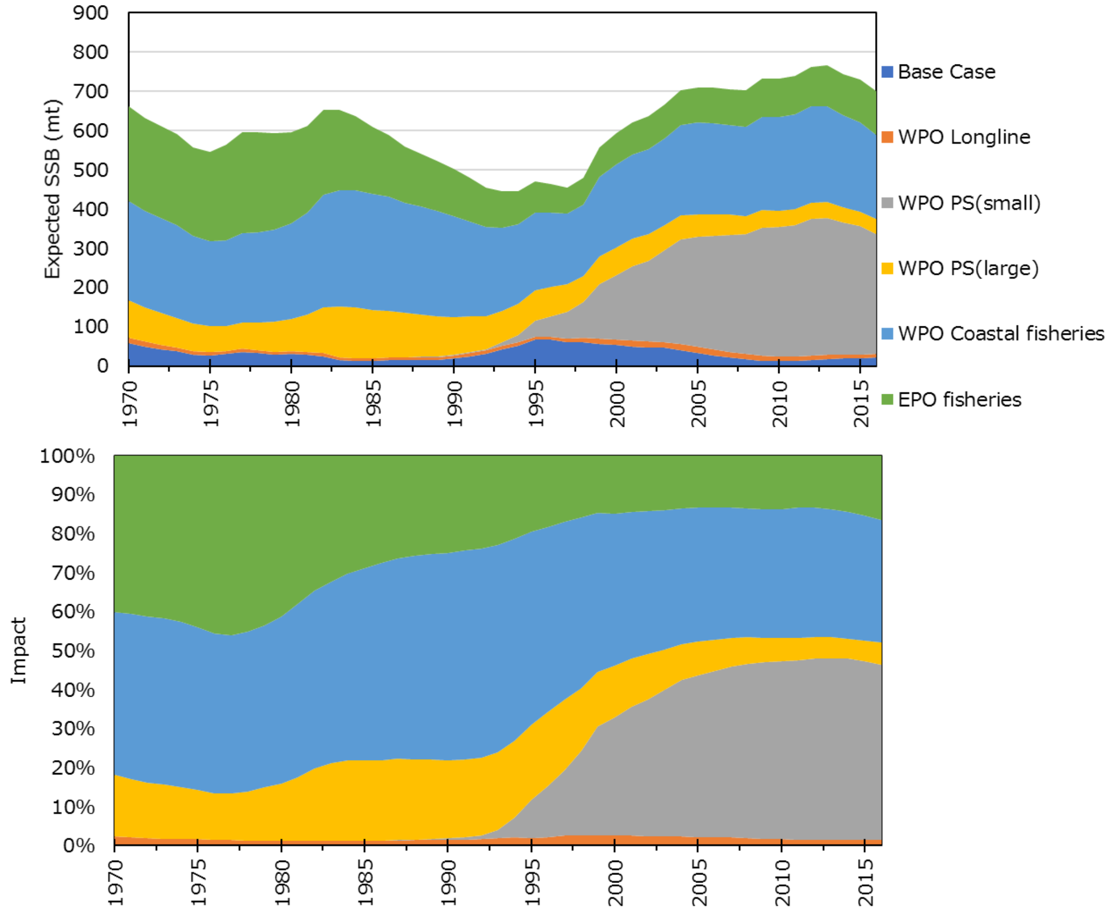

Figure 7. Trajectory of the spawning stock biomass of a simulated population of Pacific bluefin tuna (*Thunnus orientalis*) when zero fishing mortality is assumed, estimated by the base-case model. (top: absolute impact, bottom: relative impact). Fleet definition; WPO longline: F1, F12, F17. WPO purse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

Conservation Information

After the steady decline in SSB from 1995 to the historical low level in 2010, the PBF stock appears to have started recovering slowly. The 2016 stock biomass is below the two biomass rebuilding targets adopted by the WCPFC while the 2015-16 fishing intensity (spawning potential ratio) is at a level corresponding to the initial rebuilding target.

The Harvest Strategy proposed at the Joint WCPFC NC-IATTC WG meeting and adopted by the WCPFC (Harvest Strategy 2017-02) guided which projections the ISC would conduct in order to provide catch reduction options if the projection results indicate that the initial rebuilding target will not be achieved with at least a 60% probability by 2024 or to provide relevant information for a potential increase in catch if the probability of achieving the initial biomass rebuilding target by 2024 exceeds 75% under a low recruitment scenario.

The 2018 base case assessment results are consistent with the 2016 model results. However, the 2018 projection results are more optimistic than the 2016 projections, mainly due to the inclusion of the relatively good recruitment in 2016, which is twice as high as the median of a low recruitment scenario (i.e. that which occurred during1980-1989). Based on the performance analyses of the recruitment estimates using an age-structured production model and the retrospective diagnostics, terminal year recruitment estimates were included in the projections. The magnitude of terminal year recruitment is generally more uncertain than those of other years because it is based on one observation in 2016. As the 2016 year-class is observed in more fisheries in subsequent years, the uncertainty concerning the magnitude of this recruitment will be reduced and the estimated recruitment may differ, which will influence the projections and the probabilities of achieving both rebuilding targets.

The projection based on the base-case model mimicking the current management measures by the WCPFC (CMM 2017-08) and IATTC (C-16-08) under the low recruitment scenario resulted in an estimated 98% probability of achieving the initial biomass rebuilding target (6.7%$SSB_{F=0}$) by 2024. This estimated probability is above the threshold (75% or above in 2024) prescribed by the WCPFC Harvest Strategy (Harvest Strategy 2017-02) (scenario 0 of Table 5-7; Table 5: list of catch scenarios, Table 6: performance of the scenarios, Table 7: expected yield of the scenarios. See also Figure 8). The low recruitment scenario is more precautionary than the recent 10 years recruitment scenario. In the Harvest Strategy, the recruitment scenario is switched from the low recruitment to the average recruitment scenario beginning in the year after achieving the initial rebuilding target. The estimated probability of achieving the second biomass rebuilding target (6.7%$SSB_{F=0}$) 10 years after the achievement of the initial rebuilding target or by 2034, whichever is earlier, is 96% (scenario 1 of Table 5-7; Figure 8 & 9). This estimate is above the threshold (60% or above in 2034) prescribed by the WCPFC Harvest Strategy. However, it should be recognized that these projection results are strongly influenced by the inclusion of the relatively high, but uncertain recruitment estimate for 2016.

Given the low SSB, the uncertainty in future recruitment, and the influence of recruitment on stock biomass, monitoring of recruitment and SSB should be strengthened so that the recruitment trends can be understood in a timely manner.

Table 5. Future projection scenarios for Pacific bluefin tuna (*Thunnus orientalis*).

Scenario #	Fishing mortality*1	WPO Catch limit Japan*2 Small	WPO Catch limit Japan*2 Large	WPO Catch limit Korea Small	WPO Catch limit Korea Large	WPO Catch limit Taiwan Large	EPO*3 Catch limit Commercial Small	EPO*3 Catch limit Commercial Large	EPO*3 Sports	Catch limit Increase WPO Small	Catch limit Increase WPO Large	Catch limit Increase EPO Small	Catch limit Increase EPO Large
0*4	F	4,007	4,882	718		1,700	3,300		-	0%		0%	
1	F	4,007	4,882	718		1,700	3,300		-	0%		0%	

*1 F indicated the geometric mean values of quartaly age-specific fishing mortality during 2002-2004.
*2 The Japanese unilateral measure (transfering 250 mt of catch upper limit from that for small PBF to that for large PBF during 2017-2020) would be reflected.
*3 Fishing mortality for the EPO commercial fishery was asssumed to be enough high to fullfill its catch upper limit (F multiplied by two). The fishing mortality for the EPO recreational fishery was assumed to be F2009-11 average level.
*4 In scenario 0, the future recrutment were assumed to be the low recruitment (1980-1989 level) forever. In other scenarios, recruitment was switched from low recruitemnt to average recruitment from the next year of achieving the initial rebuilding target.

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

Scenario #	Catch limit Increase WPO Small	Catch limit Increase WPO Large	Catch limit Increase EPO Small	Catch limit Increase EPO Large	Initial rebuilding target: The year expected to achieve the target with >60% probability	Initial rebuilding target: Probability of achiving the target at 2024	Initial rebuilding target: Probability of SSB is below the target at 2024 under the low recruitment	Second rebuilding target: The year expected to achieve the target with >60% probability	Second rebuilding target: Probability of achiving the target at 2034	Median SSB (mt) at 2034
0*1	0%		0%		2020	98%	2%	N/A	3%	74,789
1	0%		0%		2020	99%	2%	2028	96%	263,465

*1 In scenario 0, the future recrutment were assumed to be the low recruitment (1980-1989 level) forever. In other scenarios, recruitment was switched from low recruitemnt to average recruitment from the next year of achieving the initial rebuilding target.

Table 7. Expected yield for Pacific bluefin tuna (*Thunnus orientalis*) under various harvesting scenarios based on the base-case model.

Scenario #	Catch limit Increase				Expected annual yield in 2019, by area and size category (mt)				Expected annual yield in 2024, by area and size category (mt)				Expected annual yield in 2034, by area and size category (mt)			
	WPO		EPO		WPO		EPO		WPO		EPO		WPO		EPO	
	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large
0	0%	0%	0%		4,477	4,384	3,530		4,704	6,133	3,457		4,704	6,211	3,451	
1	0%	0%	0%		4,477	4,384	3,530		4,745	6,202	3,665		4,747	6,640	3,703	

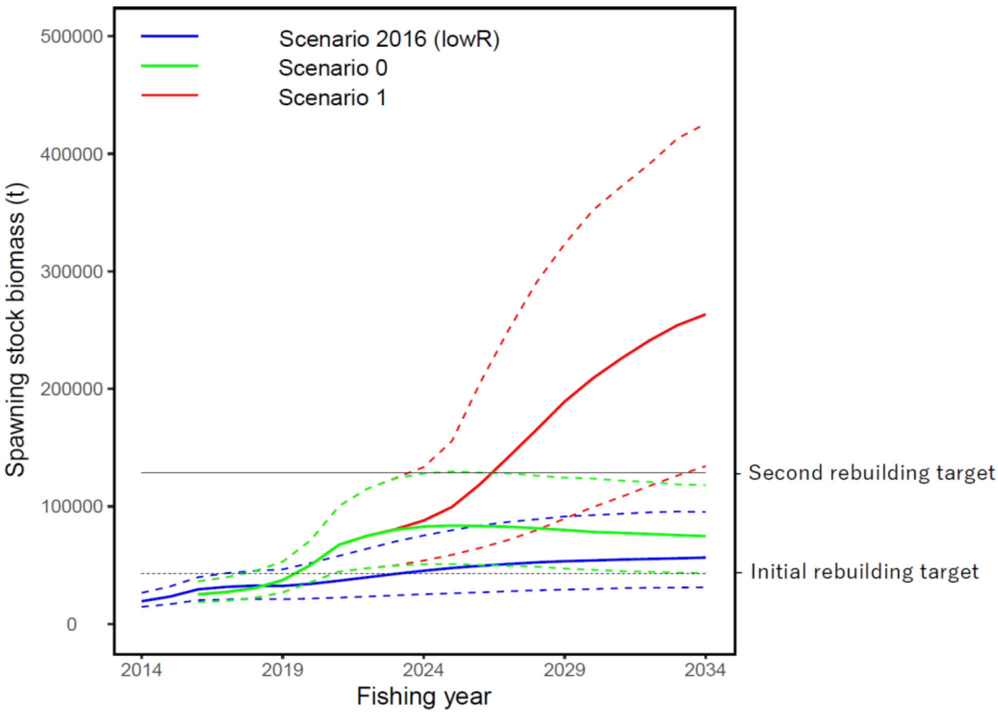

Figure 8. Comparison of future SSB under the current measures by assuming low recruitement using the 2016 assessment (scenario 2016 lowR), assuming low recruitment using the 2018 assessment (scenario 0), and assuming a shift of the recruitment scenario from low to average after achieving the initial rebuilding target using the 2018 assessment (scenario 1).

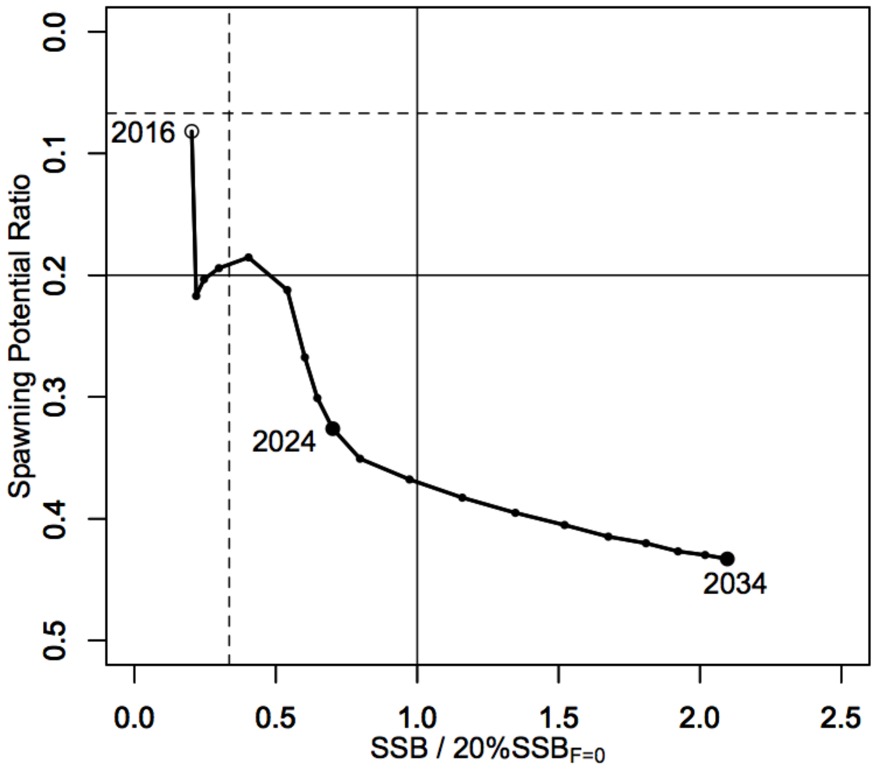

Figure 9. A projection result (scenario 1 from Table 4) for Pacific bluefin tuna (*Thunnus orientalis*) in a form of Kobe plot. X axis shows the relative SSB value to 20%$SSB_{F=0}$ (second rebuilding target) and Y axis shows the spawning potential ratio as a measure of fishing intensity. Vertical and horizontal solid lines indicate the second rebuilding target (20%$SSB_{F=0}$) and the corresponding fishing intensity, respectively, while vertical and horizontal dashed lines indicate the initial rebuilding target (SSB_{MED} = 6.7%$SSB_{F=0}$) and the corresponding fishing intensity, respectively.

1.0 INTRODUCTION

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

The PBFWG completed the benchmark stock assessment in 2016 using fishery data from 1952 through 2014 (ISC 2016a) and concluded that the spawning stock biomass (SSB) fluctuated throughout the assessment period; (2) the SSB steadily declined from 1996 to 2010; and (3) the decline appears to have ceased since 2010, although the stock remains near the historic low. It also reported that the management measures then in place would achieve the initial rebuilding target established by the WCPFC (historical median SSB) even under a pessimistic recruitment scenario.

The 2018 assessment of Pacific bluefin tuna was conducted during 5-12th of March at the Southwest Fisheries Science Center, La Jolla, USA. The assessment in 2018 is an update of the benchmark stock assessment conducted in 2016. Although there is no definition of “update assessment” within the ISC, the PBFWG conducted the 2018 assessment with the same model structure and biological parameters as were in the 2016 assessment. This report summarizes the assessment results using newly available seasonal fishery data (i.e. catch, size composition data) and annual abundance index through 2016 in a length-based, age-structured, and forward-simulation population model (i.e. Stock Synthesis).

In this report, “year” denotes fishing year unless otherwise specified. A fishing year starts on 1st of July and ends on the following 30th of June, and 1st of July is also assumed to be the date of birth for PBF in the models. For example, the 2016 fishing year corresponds to 1st of July, 2016 to 30th of June, 2017. Relationships among calendar year, fishing year, and year class are shown in Table 1-1.

2.0 BACKGROUND ON BIOLOGY AND FISHERIES

2.1 Biology

2.1.1 Stock Structure

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

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

2.1.2 Reproduction

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

2.1.3 Distribution and Movements

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

Although there are large inter-annual variations of movement (numbers of migrants, timing of migration and migration routes), ages 0-1 fish tend to migrate north along the Japanese and Korean coasts in the summer and south in the winter (Inagake et al. 2001, Itoh et al. 2003, Yoon et al. 2012). Depending on ocean conditions, an unknown portion of immature ages 1-3 fish in the WPO make a seasonal clockwise eastward migration across the North Pacific Ocean, spending up to several years as juveniles in the EPO before returning to the WPO (Inagake et al. 2001). It has been suggested that this migration has been driven by inter-annual changes in the abundance of PBF due to the limitation of food sources in the WPO as well as the oceanographic factors (Polovina 1996), however the migration rates have not been quantified. While PBF in the EPO, the juveniles make seasonal north-south migrations along the west coast of North America (Kitagawa et al. 2007, Boustany et al. 2010). In the spring, PBF are resident off the southern coast of Baja California and as the waters warms, PBF move northwest into southern California bight in summer. By fall, PBF are off of central California.

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

2.1.4 Growth

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

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

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

The variance of length composition data for all fisheries were reviewed during the 2016 stock assessment workshop meeting. The possible causes of variance of growth could be from seasonal growth, different birth date, different growth patterns among years, etc. and the actual variance could be the result of mix of many factors. The estimated variance of length data generally constant over ages suggesting that coefficient of variation (CV) of length at age decreases with age 0-3 and seems to be stable from age 3 and above. This CV at age was externally estimated from the daily and annuli rings.

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

2.1.5 Natural Mortality

Estimates and schedules of instantaneous natural mortality coefficient (natural mortality or *M*) used for southern bluefin tuna (*T. maccoyii*) and Atlantic bluefin tuna (*T. thynnus*) stock assessments were compared to *M* used for Pacific Bluefin tuna stock assessments using cohort survival analyses (ISC 2008, Aires-da-Silva et al. 2008). The results suggested that usage of *M* schedules and estimates for southern bluefin tuna and Atlantic bluefin tuna to represent *M* for PBF may not be appropriate due to the difference of life history and longevity assumptions among these species. The *M* schedule used for PBF was evaluated (Aires-da-Silva et al. 2008). Natural mortality was assumed to be age-specific: high at a young age, decrease as fish grow, and constant afterwards (Figure 2-5). Natural mortality for age 0 fish was based on results obtained from PBF conventional tagging studies (Takeuchi and Takahashi 2006, Iwata et al. 2012a, Iwata et al. 2014). In the absence of direct estimates of *M* beyond age 0, natural mortality for age 1 fish was based on length-adjusted *M* estimated from conventional tagging studies on southern bluefin tuna (Polacheck et al. 1997, ISC 2009). This adjustment incorporated the difference of life-history between PBF and southern bluefin tuna. Natural mortality was further derived from the median value obtained across a suite of empirical and life-history based methods to represent age 2+ fish (Aires-da-Silva et al. 2008, ISC 2009). Whitlock et al. (2012) estimated *M* for age 2 and older PBF based on tagging data, however several issues concerning the analysis were noted by the PBFWG so it was then decided not to change *M*. This stock assessment used the same *M* schedule as the 2012, 2014, and 2016 stock assessments. See section 4.2.5 for the actual model setting for *M*.

2.2 Review of Fishery

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

By 1952, a more consistent catch reporting process was adopted by most fishing nations. Estimates indicate that annual catches of PBF by country fluctuated widely from 1952-2016 (Figure 2-6). Five countries mainly harvest these fish but Japan catches the majority, followed by Mexico, the USA, Korea and Chinese Taipei. Catches in tropical waters and in the southern hemisphere are small and sporadic. During this period reported catches peaked at 40,383 t in 1956 and reached a low of 8,653 t in 1990. While a suite of fishing gears has been used to catch PBF, the majority is currently caught in purse seine fisheries (Figure 2-7).

The fisheries of the main PBF fishing nations are reviewed in this section. However, the input data for the assessment are organized by fishery rather than by country. Therefore, the characteristics of the input data are discussed in detail in Sections 3.3 (fishery definitions), 3.4 (catch), 3.5 (abundance indices), 3.6 (size composition data) and 4.3.2 (selectivity).

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

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

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

The Mexican purse seine fisheries are the most important large pelagic fisheries in Mexico and were developed rapidly after Mexico established its EEZ in 1976. The fisheries are monitored by an at-sea observer program with 100% coverage, captains' logbooks, the Vessel Monitoring Systems (VMS), and more recently through stereoscopic cameras at some of the rearing facilities (Dreyfus and Aires-da-Silva 2015, Dreyfus 2018). Most of the purse seine sets target yellowfin tuna (the dominant species in the catch) in tropical waters; PBF are caught near Baja California. Their historical catch had three large annual records (above 7,000 t) in the years 2004, 2006 and 2010.

In Korean waters, PBF are mostly caught by the offshore large purse seine fleets (OLPS) but there is a small amount of catch reported by the coastal fisheries in recent years. The catches of the OLPS fleets were below 500 t until the mid-1990s, increased thereafter with a peak of 2,601 t in 2003, and fluctuated in recent years from 676 t in 2015 to 1,024 t in 2016. The catch of the coastal troll fleets was 0.1 t in 2011 and 1.1 t in 2012, respectively. The main fishing ground of the OLPS fleets is off Jeju Island, but it occasionally expands to the Yellow Sea and the southeastern waters of Korea (Yoon et al. 2014, Lee et al. 2018).

Since 1993, the majority of catch for Taiwanese fisheries is from small-scale longline fleets (<100 gross registered tonnage (GRT)) that target PBF in the spawning ground from April to June. Landing records indicate that small amounts (<300 t) of PBF have been harvested by small-scale longline, purse seine, large-scale pelagic driftnet, set net, offshore and coastal gillnet, and bottom longline gears since the 1960s. Since 1984, the landings started to increase gradually to over 300 t, mostly due to the increased catch by small-scale longline vessels. The observed catch was highest about 3,000 t in 1999, declined rapidly to less than 1,000 t in 2008, and further declined to the lowest level of about 200 t in 2012. The declining trend was ceased and the landing started to increase thereafter. Preliminary estimate of PBF landing in 2016 was 454 t.

3.0 STOCK ASSESSMENT INPUT DATA

3.1 Spatial Stratification

As discussed in the Section 2.1.1, PBF are distributed across the North Pacific Ocean and considered to be a single stock. Juvenile PBF move between the WPO and the EPO (Itoh et al. 2003, Boustany et al. 2010), but it is difficult to use spatial explicit model due to lack of information of annual movement rates. Thus, the previous assessments have been assumed an instantaneously mixed population and incorporated regional selection patterns to account for spatial effects ("areas-as-fleets approach", Waterhouse et al. 2014). A simulation study on how to deal with un-modelled spatial effect due to age-based movement in PBF stock assessment suggested that although the use of alternative model processes in the single area model does not perform as well as the spatially explicit model with estimation of correctly-specified movement rates, the model using areas-as-fleets approach that estimates both length-based and time-varying age-based selectivity is the best choice in the single area model to implicitly account for the contact gear selectivity and annual availability (Lee et al. 2017).

3.2 Temporal Stratification

The time period modeled in the assessment of PBF is 1952-2016 (fishing year), with catch and size composition data compiled quarterly as follows;

Season 1: July-September,

Season 2: October-December,

Season 3: January-March, and

Season 4: April-June.

Recruitment is assumed to occur at the beginning of "Season 1" of fishing year (starting from July) in the assessment model. Data sources and temporal coverage of the available datasets are summarized in Figure 3-1.

3.3 Fishery Definitions

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

Fleet 1: Japanese longline fisheries (JPLL),

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Fisheries with small amount of PBF catch were also included in the stock assessment. As the previous stock assessment (e.g. ISC 2014, ISC 2016a), their catch amounts were included in the fleet with similar catch-at-size, fishing grounds, and seasons. For example, small amount of catch reported by Korea (by trawl, set-net, and troll fisheries) was included in Fleet 3 (KROLPS). Taiwanese purse seine catches were included in Fleet 4, the driftnet catches from both Japan and Taiwan were included in Season 1 of Fleet 7, and the other Taiwanese catches were included in Season 4 of Fleet 7. Japanese miscellaneous catches for Seasons 1-3 and Season 4 were included in Japanese set-net fleets, Fleet 8 and 9, respectively. The other Japanese catches (by trawl and other small longline fisheries other than those from the Tsugaru Strait) were included in Fleet 11. Non-ISC members' catches (i.e. by New Zealand, Australia, etc.) were included in Fleet 12.

3.4 Catch

Although fisheries catching PBF have been operated since at least the beginning of the 20th century in the EPO (Bayliff 1991) and for several centuries in the WPO (Ito 1961), the detailed fishery statistics prior to 1952 -especially from the WPO- were not available. Therefore, the fishing year 1952 has been used as the starting year of the stock assessments.

The majority of PBF is caught by purse seine fisheries (Figure 3-2(a)): The Japanese tuna purse seine fisheries operating off the Pacific coast of Japan (Fleet 5) accounted for a large portion of the catch until the 1990s, then catches of the Japanese small pelagic fish purse seine fisheries operating in the East China Sea (Fleet 2 and 18), and the Japanese tuna purse seine fisheries in the Sea of Japan (Fleet 4) have become relatively larger in WPO. The largest catches in the EPO came from the US and Mexican commercial purse seine fisheries (Fleet 13 and 14).

For the assessment model, the time series of quarterly catch data has been developed on a fleet basis (Table 3-2). In early years, quarterly catches were not directly estimated for some fleets and indirect estimation was used by applying recent quarterly catch proportions to annual catch data; e.g. Fleets 8 and 9 before fishing year 1994 (Kai 2007a), Fleet 5 before fishing year 1971 (Takeuchi 2007), etc.. For other Fleets, recent quarterly catches were directly derived from logbook or landing statistics. Fleet 11 included small-scaled Japanese fisheries (e.g. trawl, small longline, etc.), and their annual total catch was included in Season 2 of fishing year. Size composition data for Fleets 10 and 11 were combined and shared the estimated selectivity information (see section 3.6), thus catches by Fleet 10 were also included in Season 2 of fishing year aggregating their quarterly catch data. Catch data for stock assessment were expressed in metric tonne for all fleets except for Fleet 15 and 16, whose catches were expressed in thousands of fish (Figure 3-2(b)). For the 2018 assessment, the quarterly catch data was updated up to Season 4 of fishing year 2016 (2017 calendar year Quarter 2).

3.5 Abundance Indices

3.5.1 Overview

CPUE-based abundance indices which have been discussed in ISC PBFWG are listed in Table 3-3. These series were derived from fishery-specific catch and effort data which were standardized with appropriate statistical methods (Figure 3-3 and Table 3-4). In the 2016 assessment, the PBFWG used four longline CPUE series as the adult abundance indices (S1, S2, S3, and S9), and a Japanese troll index (S5) as the recruitment index for the base-case model (ISC 2016a). Among them, the temporal coverage of S2 and S3 indices (Japanese offshore and distant water longline CPUE) are early period (1952-1973) and middle period (1974-1992), respectively. For the 2018 assessment, S1 (Japanese coastal longline CPUE from 1993), S5 (Japanese troll CPUE from 1994), and S9 (Taiwanese longline CPUE in southern area from 2000) were updated using the same standardization approaches as the 2016 assessment. The details of those indices were described in following sections.

3.5.2 CV for the CPUE Series

The annual input coefficients of variation (CV) of abundance indices was set 0.2 as a minimum value in the assessment model if the original CV estimated by the statistical model for the standardization was less than 0.2. This is the same approach as used in the previous assessments (ISC 2014, ISC 2016a). Since all of the original CV values for the abundance indices were below 0.2, the base-case model used 0.2 as input CV value for all the abundance indices.

3.5.3 Japanese Longline CPUE (S1, S2 & S3)

Japanese longline CPUE is based on the logbook data. The logbook system for the coastal longline fishery is only available from fishing year 1993. Before fishing year 1993, the logbook-based CPUE for only offshore and distant water longline was available. Because of the change of operational pattern and available dataset (i.e. hooks-per-basket), the offshore and distant-water longline CPUE have to be split up into two time series; fishing year 1952-1973 (S2; Fujioka et al. 2012a) and 1974-1992 (S3; Yokawa 2008).

For the “update assessment”, Japanese coastal longline CPUE (S1; 1993-2016 fishing year) was updated adding most recent 2 years data, using the same standardizing model with the same data filtering and preparing procedure (i.e. clustering method) as used for previous assessment (Sakai and Tsukahara 2018). For the standardization, Zero-Inflated Negative Binomial model (ZINB) has been applied. The updated CPUE showed a consistent increase after 2011 fishing year.

3.5.4 Japanese Troll CPUE (S5)

Catch-and-effort data for coastal troll fisheries targeting age 0 PBF in the East China Sea (coastal waters of western Kyusyu) have been collected primarily from five fishing ports. The troll fisheries operating in this fishing ground dominant share in Japanese troll catch, and they can fish age 0 PBF from both two spawning grounds (around Ryuku Islands and the Sea of Japan) because of the geographical location (Ichinokawa et al. 2012). The units of effort in the catch-and-effort data are the cumulative daily number of unloading troll vessels, which is nearly equivalent to the total number of trolling trips because most troll vessels make one-day trips. This effort data don't include the unloading without PBF catch: no zero-catch data were available. Therefore, a log normal model has been applied for standardization of the CPUE (S5).

For the 2018 assessment, this troll CPUE was updated to the most recent years using exactly the same standardizing model as used in the 2016 assessment (Fukuda et al. 2018). The updated CPUE of recent two years were higher than that of 2014, especially the CPUE of 2016 fishing year exceeded the historical average. Japanese troll fisheries have been separated into 2 fleets by season (Fleet 6 and 19) in the assessment model. The catch and effort for this CPUE contains very few data from Season 1, thus Fleet 6 has been used as the correspondence fleet for the selectivity setting of this CPUE (ISC 2016 a).

3.5.5 Taiwanese Longline CPUE in Southern area (S9)

Taiwanese longline CPUE was developed by the following process; (1) Estimating PBF catch in number from landing weight for 2000-2002 based on an MCMC simulation, (2) Deriving fishing days for 2006-2008 from data of vessel monitoring system (VMS) and voyage data recorder (VDR), (3) Deriving fishing days for 2000-2005 from vessels trip information based on linear relationships between fishing days and at-sea days for a trip, by vessel size and fishing port, during 2006-current, and (4) Estimating and standardizing the CPUE using delta-generalized linear mixed model (catch number per fishing days) for fishing year 2000-2016 (Chang et al. 2017, Chang et al. 2018).

The fishing ground of Taiwanese longline fleet can be separated into southern and northern area. The southern area has been considered as the main fishing ground for the Taiwanese longline fisheries, thus the CPUE in the southern area has been used as the input data for the stock assessment (ISC 2016a). The updated CPUE showed similar trend as the previous work presented in the 2017 PBFWG meeting: the CPUE turned upward after 2011 fishing year (Chang et al. 2018).

3.6 Size Composition Data

3.6.1 Overview and Input Sample Size

Quarterly size composition (length or weight) data for PBF from 1952 to 2016 (fishing year) were used for the 2018 assessment. All length data in the model were measured as "fork length (FL)" to the nearest 1 cm. In the assessment model, the length composition bins of 2, 4, and 6 cm width were used for 16-58, 58-110, and 110-290 cm FL fish, respectively. Weight composition bins were of variable width, ranging from 1 kg to 30 kg (0, 1, 2, 5, 10, 16, 24, 32, 42, 53, 65, 77, 89, 101, 114, 126, 138, 150, 161, 172, 182, 193, 202, 211, 220, 228, 236, 243, and 273 kg), which set two bins for each age between 0 to 15 to minimize the misinterpretation of the data (Fujioka et al. 2012b). The lower boundary of each bin was used to define the bin.

For the 2018 assessment, the size composition data for Fleets 5, 7, 13, and 15 were not updated as in the 2016 assessment (ISC 2016a). Length composition data were updated for Fleets 1-4, 6, 8, 9, 12, 14, 15, and 17-19, while weight composition data were updated for Fleets 10 and 11. Of these, the size compositions for Fleets 2-3 and Fleets 10-11 have been combined to simplify the assessment model (Table 3-5). Fleet 16 was assumed to catch age-0 fish using age selectivity setting, thus their size composition was not required. Figure 3-4 shows the aggregated size compositions, and Figure 3-5 shows the quarterly size compositions for each fleet.

The source of input sample sizes for the size composition data are summarized in Table 3-6. Depending on the corresponding fisheries, the information of sample size was based on four different criteria; “Number of fish measured”, “Number of landing well measured”, “Number of total month of well sampled port”, and “Number of haul well measured”.

3.6.2 Japanese Longline (Fleet 1)

Length-composition data from the Japanese longline fisheries (Fleet 1) are available for the periods of fishing year 1952-1968 and 1994-2016 (Figure 3-5). Until 1960s, the data were collected mainly from the Tsukiji Market. Since the 1990s, size sample and market data have been collected at the major PBF unloading ports, e.g., Okinawa, Miyazaki and Wakayama Prefectures. Length measurements were relatively sparse from 1969 to 1993 (Mizuno et al. 2012), and have not been included in the assessment.

Length compositions for fishing year 1952-1968 were estimated based on the aggregated catch and length measurement data by year, month, and area (5x5 degree cells). Using this stratification, length compositions were raised by catch numbers (Mizuno et al. 2012). Since fishing year 1993, the length compositions were estimated based on the quarterly landing amounts and length measurements in each prefecture. Using quarter and prefecture strata, length compositions were raised by landing weights (Sakai and Tsukahara 2018).

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

Length-composition data for PBF from the Japanese purse seine fisheries in the East China Sea have been developed from length measurements taken at Fukuoka and Matsuura, which are the major landing ports. The data are separated into two Fleets by season (Fleets 2 and 18). The available period for Fleet 2 (Seasons 1, 3, 4) was fishing year 2002-2016, whereas that for Fleet 18 (Season 2) was fishing year 2003-2012, 2014, and 2016. The data in Seasons 3-4 of 2014 for Fleet 2 were not used in the assessment model, because there seems to be bias in the size compositions during this period due to the lack of length measurements of smaller fish mainly for farming (ISC 2015b).

Length composition data from the Korean purse seine fisheries were also available after 2010 fishing year (Kim et al. 2015). The size of fish caught by Korean fleets was similar to the Japanese fleets which were fishing in neighboring waters. Thus the size compositions by both Fleets 2 and 3 have been combined and shared (ISC 2015b: Figures 3-5). Since 2013 fishing year, larger sized fish (> around 70 cm) has been observed in Season 3 for Fleet 3 although there was no new information suggesting the change of operation of this fishery. However, as the 2018 assessment is an update, the same approach of combining the data of Fleets 2 and 3 was used.

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

Length-composition data for PBF from the Japanese purse seine fleets in the Sea of Japan (Fleet 4) have been collected by port samplers in Sakai-minato and were available since 1987 fishing year, except for 1990 when there was no catch (Figure 3-5). Size measurement coverage has been high and most of the landings were sampled. This fleet mainly catches age 3 and older of PBF (Fukuda et al. 2012).

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

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

Although length measurements for this fishery had been made since 1980s, an appropriate method to create catch-at-size data has not yet been established for the entire period. The size composition data for this fishery are highly variable (from 50 cm to very large) and it was recognized the need for further research especially focusing on smaller fish.

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

Japanese troll fisheries were separated into two fleets by season (ISC 2016 a), because the size of fish caught in Season 1 (Fleet 19) is smaller than that of the other seasons (Fleet 6). The length-composition data were estimated as following: 1) Fish lengths were measured at the main unloading ports, 2) The measurement data were pooled by "Area" and "Month" as the minimum spatial and temporal strata, and 3) The pooled measurement data were raised by catch number in corresponding strata (Fukuda et al. 2015a). In this procedure, unless more than 80% of catch have corresponding size data, the estimated quarterly length-composition data will not be allowed to fit in the assessment model. According to this criterion, the length composition data for Season 1 and 3 of 2015 fishing year and Season 3 and 4 of 2016 fishing year were not included in updated data for the 2018 assessment.

The troll fishery and pole-and-line fisheries (Fleet 7) tend to operate in the same area, and the size of their catch is similar (primarily age 0 fish). Thus the selectivity information of Fleet 6 has been mirrored to Fleet 7 in the assessment model due to the relatively poor size sampling for Fleet 7.

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

Size measurement data for PBF from Japanese set-net fleets have been collected since 1993. The catch-at-size data were estimated based on the multi-stratified raising method using the catch weight. Excessive estimation was avoided by the introduction of broad size category stratum (i.e. Small/Medium/Large) and limitation of over-strata calculation (Hiraoka et al. 2018). According to the complexity of the dataset, the set-net fisheries were divided into 3 fleets: Fleet 8 is the Seasons 1, 2, and 3 in all prefectures except for Hokkaido and Aomori, Fleet 9 is the Season 4 from the same areas, and Fleet 10 is all seasons of set-net fisheries in Hokkaido and Aomori (ISC 2015b). For Fleets 8 and 9, the length-composition data were available. The data showed that the catch-at-size of set-net were highly variable from year to year, and quarter and quarter, probably because of the influence of the environmental conditions and migration (Kai 2007a).

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

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

3.6.9 Taiwanese Longline (Fleets 12 and 17)

Length composition data for PBF from the Taiwanese longline fisheries (Fleets 12 and 17) were based on the market landing information and port sampling. Since 2010, additional information has been also available from the catch documentation scheme (CDS) program, which can provide much more size samples with higher quality (Chang et al. 2015b). The Taiwanese longline fisheries were separated into two fleets by fishing area; Fleet 12 for southern area and Fleet 17 for northern area. For the 2018 assessment, the length-composition data for both fleets were updated. The southern area has been the main fishing ground for Taiwanese longliners, and their data period was longer than that of the northern area (Fleet 12: 1992-2016 fishing year, Fleet 17: 2009-2016 fishing year).

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

Length-composition data for PBF from EPO purse seine fisheries were collected by port samplers from IATTC and national/municipal sampling programs (Bayliff 1993, Aires-da-Silva and Dreyfus 2012). Fleet 13 is US dominant & transition period of EPO purse seine fisheriese until 2001. For this fleet, length composition data for US dominant period from 1952 to 1982 have been used to estimate the selectivity pattern for the stock assessment (ISC 2015b). Fleet 14 is Mexico dominant period of EPO purse seine fisheries (2002 onwards). The length composition data for Fleet 14 had been obtained by IATTC at-sea observers and port sampling programs. Since 2013, size data have been measured by stereoscopic cameras (Dreyfus and Aires-da-Silva 2015). For the 2018 assessment, the length composition data for 2014-2016 fishing year were updated, with the new data indicating an increase in the average size of fish caught (Dreyfus 2018).

3.6.11 US Recreational Fishery (Fleet 15)

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

3.6.12 Japanese Troll Fishery for Farming (Fleet 16)

In Japan, lengths of PBF caught by troll for farming are reported to be smaller than those of fish caught by conventional troll. Thus, the stock assessment treats the troll fishery for farming as an age-0 fleet (ISC 2015a) as there is no size composition data for Fleet 16.

4.0 MODEL DESCRIPTION

4.1 Stock Synthesis

An annual (time-step), length-based, age-structured, forward-simulation population model, fit to seasonal data (expectations generated quarterly), was used to assess the status of PBF. The model was implemented using Stock Synthesis (SS) Version 3.24F (Methot and Wetzel 2013; http://nft.nefsc.noaa.gov/Stock_Synthesis_3.htm). SS is a stock assessment model that estimates the population dynamics of a stock through use of a variety of fishery dependent and fishery independent information. Although it was developed for coastal pelagic fishes (sardine and anchovy) and used primarily for ground fishes, it has become a standard tool for tunas and other highly migratory species in the Pacific Ocean (IOTC 2016; IATTC 2017). The structure of the model allows for both maximum likelihood and Bayesian estimation processes with full integration across parameter space using a Monte Carlo Markov Chain (MCMC) algorithm. This application uses maximum likelihood and normal approximation or bootstrapping to estimate parameter uncertainty.

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

4.2 Biological and Demographic Assumptions

4.2.1 Growth

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

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

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

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

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

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

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

where

L_t = length at age t;
L_∞ = 249.917 cm = theoretical maximum length;
K = 0.188 y^{-1} = growth coefficient or the rate at which L_∞ is asymptotically reached; and
t_0 = -0.4217 (assumed July 1 as birth day, the first day in fishing year) = theoretical age where length is equal to zero.

4.2.2 Ages Modeled

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

4.2.3 Weight-Length Relationship

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

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

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

4.2.4 Sex Ratio

This assessment assumes a single sex. It has been reported that there is potentially sexually dimorphic growth (Shimose and Takeuchi, 2012). However, it is not yet clear the degree of sexual dimorphism and given a near total lack of records of sex in the fishery data, a single sex was assumed.

4.2.5 Natural Mortality

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

4.2.6 Recruitment and Reproduction

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

A standard Beverton and Holt stock recruitment relationship (SR) was used in this assessment. The expected annual recruitment was a function of spawning biomass, a fixed steepness (h), and estimated natural log of unfished recruitment (logR_0). Recruitment deviations from the SR relationship (1953-2016) were estimated and assumed to follow a lognormal distribution with a fixed standard deviation σ (Methot and Taylor 2011, Methot and Wetzel 2013).

Steepness of the stock-recruitment relationship was defined as the fraction of recruitment when the spawning stock biomass is 20% of SSB_0, relative to R_0. Previous studies have indicated that h tends to be poorly estimated due to the lack of information in the data about this parameter

(Magnusson and Hilborn 2007, Conn et al. 2010, Lee et al. 2012). Lee et al. (2012) concluded that steepness was estimable from within the stock assessment models when models were correctly specified for relatively low productivity stocks with good contrast in spawning stock biomass. However, the estimate of *h* may be imprecise and biased for PBF as it is a highly productive species. Independent estimates of steepness that incorporated biological and ecological characteristics of the species (Iwata 2012, Iwata et al. 2012b) reported that mean *h* was approximately 0.999, close to the asymptotic value of 1.0. Therefore, steepness was fixed at 0.999 in this assessment. It was noted that these estimates were highly uncertain due to the lack of information on PBF early life history stages. Therefore, steepness was fixed at 0.999 in this assessment which is similar to the value found when the stock-recruitment relationship (based on assessment model estimates) was analyzed outside of the assessment model (Nakatsuka et al. 2017).

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

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

4.2.7 Stock Structure

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

4.2.8 Movement

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

4.3 Model Structure

4.3.1 Initial Conditions

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

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

4.3.2 Selectivity

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

Our approach to deal with this issue was to use a combination of model process (time varying selectivity) and data weightings to insure adequate fit to fleets that caught high numbers of fish since 1990 and to reduce misfit to size composition which could adversely affect model performance. In general, fleets with large catches of migratory ages, good size composition data, and no CPUE were modelled with time-varying selection (Lee et al. 2017). Fleets taking only age 0 or adults were treated as time-invariant unless fleet fishing patterns changed and blocks of time-invariant selection were used (e.g. Fleet 1). Fleets with small catches or poor size composition data were either aggregated with similar fleets or given low weights.

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

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

Fleets without CPUE were categorized into fleets taking fish of non-migratory ages (age 0 fish or spawners for Fleets 2, 17, and 19) and fleets taking fish of migratory ages (ages 1-5 for Fleets 4, 5, 8, 9, 10, 13, 14, and 18). Non-CPUE fleets taking fish of non-migratory ages were modeled as time-invariant length-based selection patterns to account for the gear contact, assuming that availability was temporally constant. Due to the nature of their size compositions with a single well-behaved mode, functional forms of double normal curves were used. Fleets taking fish of migratory ages and without CPUE, separate length- and age-based selectivity patterns were estimated (Lee et al. 2017). A time-invariant length-based selection pattern was estimated to account for gear selection and time varying age based selection was estimated to approximate the un-modelled process of age-based movement (Fleets 4, 5, and 18). The length-based selection was modeled as asymptotic or dome-shaped while age-based selection was modeled assuming a separate selection parameter for each age. Separate time-varying age selection parameters were estimated for migratory ages. Selection for each fleet is a product of the age and length based selection patterns. Because of the large number of parameters involved, fleets without significant catch (Fleets 8, 9, and 10), did not include the time-varying age-based component. The two EPO fleets (Fleets 13 and 14) were modelled with time-varying length based selection due to changes in the contact selectivity of the gears. Since the 2018 assessment is an update, consistent approach with the 2016 assessment was attempted regarding the selectivity parameter estimates (Fukuda and Sakai. 2018).

4.3.3 Catchability

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

4.4 Likelihood Components

4.4.1 Observation error structure

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

4.4.2 Weighting of the Data

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

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

4.5 Model Diagnostics

4.5.1 Adequacy of fit

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

4.5.2 Retrospective and R_0 profiling analyses

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

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

4.5.3 Convergence Criteria

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

4.5.4 Sensitivity analysis

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

1. Natural Mortality
2. Steepness
3. CPUE based abundance indices from JPLL and TWLL
4. Time-varying selectivity for KOLPS
5. Data-weighting of size composition data

4.6 Projections and Biological Reference Points

4.6.1 Projections

Projections were conducted outside the integrated model using forecasting software assuming age-structured population dynamics with a quarterly time step in a forward direction, based on the results of the stock assessment model using SS3 (Ichinokawa et al. 2012, Akita et al. 2015, 2016, Nakayama et al. 2018). This software provides stochastic projection, which includes parameter uncertainty of stock assessment using SS by conducting base-case model bootstrap replicates followed by stochastic simulations. The base-case model replicates were derived by estimating parameters using SS and fishery data generated with parametric resampling of residuals from the expected values. The same error distributions were assumed with the stock assessment using SS.

Each projection was conducted from 300 bootstrap replicates followed by 20 stochastic simulations based on the different future recruitment time series.

Future recruitment is randomly resampled from the recruitment estimates by each base-case model replicates. For precautionary reasons in the light of current low level of the spawning stock and the possible future low recruitment produced thereby, the future recruitment in the initial rebuilding period (until the stock recovered to the initial rebuilding target with the 60% of its probability) was resampled from relatively low recruitment period (1980-1989). As for the second rebuilding period (from the next year of the stock achieving initial rebuilding target with the 60% of its probability), future recruitment was randomly resampled from whole stock assessment period (1952-2016). This future recruitment assumption is consistent with the guidance for projections from the Joint WCPFC NC-IATTC WG meeting and adopted by WCPFC (Harvest Strategy 2017-02). The PBFWG decided to also examine a future population dynamics under a low recruitment assumption for whole future period to seek the probability achieving initial rebuilding target by the year (2024) prescribed in the WCPFC CMM 2017-08 and IATTC resolution C-16-03.

Several alternative harvest scenarios, including combinations of both a constant effort strategy and a setting catch limit were shown in Table 4-2. Scenario 1 approximates the conservation and management measures which are currently in force in the WCPFC convention area (WCPFC CMM17-08) and IATTC convention area (IATTC Resolution C16-03). For the EPO commercial fishery, since the IATTC Resolution apply only a catch limit, constant catch limit of 3,300 tons with maximum F level twice as much as that in 2002-2004 are assumed in this future projection to consume all the quota. For the WPO fishery, the maximum F level is assumed as 2002-2004 average level as the approximation of the effort control prescribed in the WCPFC CMM.

4.6.2 Biological Reference Points

The WCPFC has adopted the initial rebuilding target (the median SSB estimated for the period 1952 through 2014) and the second rebuilding target (20%$SSB_{F=0}$ under average recruitment) by their CMM prepared by the joint WCPFC-NC and IATTC working group. Although biological reference points have not been formally adopted, the rebuilding targets (within specified time periods) could be considered consistent with an interim biomass-based reference points, and the probabilities of achieving those targets consistent with interim fishing mortality reference points. In addition to these interim reference points, two commonly used biological-based reference points were calculated: (1) equilibrium depletions (terminal SSB/unfished SSB from the base-case model) was used to characterize current stock status and (2) spawning potential ratio (SPR) was used to characterize current fishing intensity. In here, SPR is the cumulative spawning biomass that an average recruit is expected to produce over its lifetime when the stock is fished at the current intensity, divided by the cumulative spawning biomass that could be produced by a recruit over its lifetime when unfished. As it was considered unadvisable to compare the fishing mortality from different years when selectivity changes substantially, it was suggested to use spawning potential ratio as a measure of fishing intensity. Those reference points were calculated for the terminal year of 2018 assessment (2016 FY), the initial and second rebuilding targets, and some historical years.

5.0 STOCK ASSESSMENT MODELLING RESULTS

5.1 Model Convergence

All estimated parameters in the base-case model were within the boundaries and the final gradient of the model was 0.00374. The model hessian was positive-definite and the variance-covariance matrix could be estimated. Based on the results from 149 model runs with the random perturbations of initial values and phasing, the base-case model likely converged to a global minimum with no evidence of further improvements on the total likelihood (Figure 5-1 and Figure 5-2).

5.2 Model Diagnostics

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

Results of the profile of total and component likelihoods over fixed log(R_0) for the base-case model are shown in Figure 5-3. Relative likelihood values represent the degradation in model fit (for each component, negative log-likelihood for each profile run minus the minimum component negative log-likelihood across profiles). A relative likelihood value = 0 indicates that data component was the most consistent with that fixed population scale. The smallest values of log(R_0) for recruitment, all combined CPUEs component, and all combined size composition were 9.60, 9.50, and 9.50, respectively, which were consistent with the smallest values of log(R_0) (9.52) for the total likelihood (Figure 5-3 (A)).

The main data components which strongly influence the global scaling of log(R_0) were the recruitment (low side), size compositions (both low and high side), and abundance indices (high side); however, catch component did not have much impact on log(R_0). The relative likelihood values of combined size composition data were larger than those of abundance indices. The strong influence of recruitment component on the low side of log(R_0) might be influenced by the very strong penalty applied to the difference of log of initial recruitment to log of R0 rather than from the contributions of time series of recruitment deviations.

As for the size composition components, Taiwanese longline composition data (fleet 12) and the purse seine fleets (fleets 4, 13, and 14), had relatively strong impact on the log(R_0) profile. Fleets 1, 2, 9, and 10 were also moderately important for the scaling of log(R_0). The rest of the size composition components did not have much influence on the scaling of log(R_0).

All of the abundance indices provided consistent information on population scale except CPUE for S2 (Japanese longline early period) (Figure 5-3 (C)). The influence of this CPUE to the log(R_0)

was on the low side of scale, while the rest of the CPUEs affected mainly on the high side or both sides.

In general, the base-case model resulted in an internally consistent model regarding population scale, demonstrated by relative likelihood values for composition component < 2 units and those for index component < 1 unit at the log(R_0) when estimated.

5.2.2 Goodness-of-fit to Abundance Indices

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

The model also fit well to the terminal indices of S1 and S9, which were Japanese and Taiwanese longline CPUEs (RMSE ≤ 0.3). Although the model fit to S1 index was slightly worsened from the 2016 assessment, the model could predict the relative trend of the observed abundance indices. Therefore, the base case model was considered to be well informed by the indices.

5.2.3 Goodness-of-fit to Size Compositions

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

However, it should be noted that although the aggregated fits were reasonable, the annual residual plots showed large misfit in some degree (e.g. Fleet 6) (Figure 5-6). In addition, the model could not predict some of the updated observation data (e.g. Fleet 1 and 2). Those misfits to the size composition data may be due to un-modelled migration patterns, variability in the local availability/fishing activity, or the growth patterns. The PBFWG noted that further work on growth as well as fishery are necessary for the improvement of model fits to the size composition data in future assessment (ISC 2016b).

In general, the current base-case model, which incorporated additional model process and detailed fleet definition, could replicate the observed size composition data.

5.2.4 Retrospective Analysis

The retrospective analyses showed no substantial pattern of overestimating or underestimating SSB for recent 3 terminal years, although those of recent 4-9 years tended to be slightly underestimating (Fig. 5-7a). This pattern is likely the result of the retrospective period covering a population inflection period and not due to gross model misspecification. Removal of recent 4-9 years data provided the model with less information on the decreasing biomass and this might cause the small retrospective bias in SSB.

On the other hand, the retrospective analyses showed consistent estimates of the recruitment. This analysis did not indicate substantial pattern of over- or under estimating recruitment for the recent 9 terminal years (Fig. 5-7b). This suggested that the recruitment estimates were strongly informed by the age-0 index from Japanese troll fishery, and the information brought by this index and those by the composition data might be consistent regarding the relative strength of the recruitment.

5.3 Model Parameter Estimates

5.3.1 Recruitment Deviations

A Beverton-Holt relationship based on a steepness value of h=0.999 was used for the base-case model, and stock and recruitment plots are presented in Figure 5-8. The estimated recruitment deviations were relatively precise after 1990 indicating that these periods were well informed by data. The updated two years (2015-2016 FY) of the recruitment deviations were lower and higher from the predictions based on the assumed stock recruitment relationship, respectively. Since the predicted variability of recruitment deviations is lower than assumed recruitment variability (σR = 0.6, RMSE between expected recruitment from stock recruitment curve and predicted recruitment for main recruitment period [1953-2016] was 0.52), the estimated population scale and recruitment would not be substantially affected by the recruitment penalty (σR) or assumptions on steepness.

5.3.2 Selectivity

The estimated selectivity curves by fleet for the base-case model are shown in Figures 5-9 and 5-10. In this assessment, both of the length-based and age-based selectivity were estimated for Fleets 4, 5, 8, 9, 10, and 18. The length-based selections were estimated as asymptotic or dome-shaped while age-based selections were estimated for each age. Temporal variations in the age-based selectivity were captured for Fleets 4, 5, and 18. For the rest of the fleets with estimated length-based selectivity (Fleets 1, 2, 6, 12, 13, 14, 17, and 19), dome-shaped patterns were estimated except for Fleet 12 with logistic pattern. Among these fisheries, temporal variations were captured for Fleets 1, 13, and 14. This configuration was consistent with the 2016 assessment taking into account traits of each fishery given its importance of catch, gear contact and availability, goodness of fit to size composition data, and minimal impact of misfit on size composition data.

In summary, 237 selectivity parameters were estimated in the base-case model. The most of selectivity parameters related to the fishery before 2014 (2016 assessment time period) were consistently estimated with the 2016 assessment. As for the parameters related to the fishery of updated time period (2015-2016 FY), dome-shaped length-based selectivity parameters, beginning size for the plateau of Fleet 14 in blocks of 2014 and 2016 marked higher values (105 and 133 cm) than those of the past years. It would suggest that the larger (older) fish became available in the recent year of EPO. On the other hand, time-varying age based selectivity of the Fleet 4 and 18 in 2015-2016 fluctuated within the variation shown in the past years. It may also indicate the local availability of the species in each fishing ground as well as the relatively stable selection pattern.

5.4 Stock Assessment Results

5.4.1 Total and Spawning Stock Biomass

The update model derived results that were very consistent with the previous assessment, although the estimates of SSB by the base case model were slightly higher than the 2016 assessment. Point estimates of total stock biomass from the base-case model showed long-term fluctuations (Table 5-2 and Figure 5-11) ranging from a low of about 31,185 t in 1983 to a high of about 218,000 t in 1960.

Spawning stock biomass (SSB) estimates also exhibited long term fluctuations which is consistent with that of total stock biomass. Estimates of SSB at the beginning of quarter 4 (April-June) in the first five years (1952-1956) of the assessment period averaged approximately 95,500 t. The highest SSB of about 168,000 t occurred in 1961 while the lowest SSB of about 12,200 t occurred in 2010. In the 1990s, SSB reached its second highest level of about 67,200 t in 1995 and declined until 2010. Since 2011, SSB continued to show a tendency of slight increase, and the SSB of terminal year was estimated to be about 21,300 t.

The quadratic approximation to the likelihood function at the global minimum, using the Hessian matrix, indicated that the CV of SSB estimates was about 22% on average for 1980-2016, and 22% for 2016, although that on average for 1952-1979 was about 42%.

The unfished SSB (SSB_0) was estimated by extrapolating the estimated stock recruit relationship under the equilibrium assumptions to be about 643,000 t (R_0 = 13.7 million fish). The depletion ratios (SSB/SSB_0) of the assessment period ranged from 1.9% to 26.2%. The second peak (1995), a trough in the most recent year (2010) and terminal year (2016) of SSB corresponded 10.4%, 1.9% and 3.3% of the SSB0, respectively.

5.4.2 Recruitment

Recruitment (age 0 fish on July 1st) estimates fluctuated widely without an apparent trend, and were almost identical with the 2016 assessment. Recent strong cohorts occurred in 1994 (28.3 million fish), 1999 (23.4 million fish), 2004 (26.1 million fish) and 2007 (21.7 million fish) (Table 5-2 and Figure 5-11). The average estimated recruitment was approximately 13.4 million fish for the entire stock assessment period (1952-2016). The 2014 recruitment was estimated to be relatively low (3.6 million fish) and the average recruitment level for the last five years (9 million fish) may have been below the historical average level. The recent two years (2015 and 2016) of the recruitments were lower (7.8 million fish) and higher (16 million fish) than the estimated unfished recruitment, respectively. PBFWG acknowledged the higher uncertainty of the 2016 recruitment estimate compared to the previous years because terminal year's recruitment is informed by very little data (except for the Troll age-0 CPUE index). The Troll CPUE series has been shown to be a good predictor of recruitment, and there is no apparent retrospective error in the recruitment estimates of the terminal year. As the 2016 recruits grow and are observed by other fleets, the magnitude of this year class will be more precisely estimated in the next stock assessment. The estimated magnitude of the 2016 year class had a positive impact on projections.

Recruitment estimates were less precise at the start of assessment period to 1970's (average CV = 24%, maximum CV = 44%) and became moderately precise from 1980 to 1993 (average CV = 18%, maximum CV = 28%) when CPUE-based recruitment indices from the Japanese troll fishery became available. After 1994, recruitment estimates had further improved in their precision (average CV = 8%) due to the comprehensive size data collection for Japanese fisheries that began in 1994.

5.4.3 Catch at Age

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

Historically, PBF catches were predominately composed of juveniles (age 0-2), and the estimated number of fish caught showed a fluctuation ranging from a low of one million fish in 1959 to a high of 4 million fish in 1978 during 1950's to early 1990's. However, since the early 1990's, the catch of age 0 PBF has increased significantly, and consequently the estimated number of fish caught were fluctuated around the average of 4 million (Figure 5-12). In the most recent 2 years (2015-2016), when the stricter management measures were in place in both of the WCPO and the EPO, average number of fish caught were lower than the most of the previous years.

5.4.4 Fishing Mortality at Age

Annual fishing mortality-at-age was calculated externally by solving the Baranov catch equation using the estimated numbers of fish-at-age at the beginning of the first quarter and the estimated annual catch-at-age matrix from the base-case model (Figure 5-13 and Table 5-3). Throughout the stock assessment period (1952-2016), fishing mortality for age 0-2 juveniles were higher than those for age 3 and older fish. The average F of age 1 fish during 1995-2014 was 1.08, while that for age 0, 2 and 3 fish were 0.66, 0.55, and 0.17, respectively. The average F of age 4+ fish during the same period was 0.15. As for the F at age of the most recent two years (2015-2016 FY), substantial decrease of F is observed in age-0-2. Note that stricter management measures were in place since 2015.

5.5 Sensitivity Analysis

5.5.1 Natural Mortality

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

5.5.2 Steepness

The base-case model could not converge for lower steepness, indicating that the model is fine-tuned to explain data under current assumption of steepness. The PBFWG does not consider this result as a validation of the assumed steepness value and thus the PBFWG considers the issue a high priority for further investigated (ISC, 2016b).

5.5.3 CPUE based abundance indices from JPLL and TWLL

An alternative assumption if the base-case model is fitted more closely to either of the Japanese or

Taiwanese longline CPUEs was derived by updating only one of those two indices, while another index was kept as it was in the 2016 assessment. There was no significant difference in the estimated SSB and recruitment among the updated model and sensitivity runs with an alternative assumption (Fig. 5-15). The RMSE between observed and predicted abundance indices for those indices were improved by those alternative assumptions (Table 5-4). However, the PBFWG agreed to include both indices in the 2018 assessment as was done in the 2016 assessment because the difference in the results were minor.

5.5.4 Time-varying selectivity for KOLPS

A sensitivity run which assumed time varying selectivity for Korean offshore large purse seine (TVS_KOLPS_run) (Fleet 3) fits better to the Fleet 3 size composition data than the base-case (Fig. 5-16), even though this sensitivity run estimated 27 more parameters than the base-case. There was also no significant difference in the estimated SSB and recruitment between the updated model and this sensitivity run (Fig. 5-17).

5.5.5 Data-weighting of size composition data

An alternative scenario of the data re-weighting for the size composition data did not substantially affect to the estimated spawning biomass as well as the recruitment (Figure 5-19). Although the fits to the historical abundance indices (S2 and S3) might be better in the re-weighting model than the base-case model, the base-case model showed similar fit to the terminal abundance indices. There was also no sign of improvement in the fit to the size composition data. PBFWG considered that the specific method for re-weighting among the size composition data and then with the abundance indices requires further study and discussion. The base-case results were not sensitive to the alternative assumption of relative data weighting and the PBFWG chose same method with the 2016 assessment since the 2018 assessment was just an update.

6.0 Future Projection

The WCPFC and IATTC defined the median SSB point estimates during 1952 to 2014 as the initial rebuilding target and 20% of $SSB_{F=0}$ as the second rebuilding target. Note that the second rebuilding target defined as "20%$SSB_{F=0}$ under average recruitment" by WCPFC Harvest Strategy is calculated differently from the R0 based (expected recruitment at unfished biomass) as had been done by the PBFWG, but the impact of the difference should be minimal. Point estimates of year-specific SSB from the base-case model, especially during 1950s-1970s, were generally above the median estimators from the bootstrap. This discrepancy between point estimates from the assessment and the bootstrap medians were also observed in previous stock assessments as well as the stock assessments of other species (ISC ALBWG, 2017). In the projections reported in this document, the projection SSB estimates are the medians of the 6,000 individual SSB calculated for each 300 bootstrap replicates followed by 20 stochastic simulations based on the different future recruitment time series. Thus, there are a difference between the method to estimate SSB as well as SPR between the assessment period and projection period. Also, additional considerations regarding the calculation of initial rebuilding target include that point estimates of SSB in the base-case model are more uncertain during 1950s-1970s (Figure 5-11) due to the paucity of data prior to 1990 (Figure 3-1). The uncertainty in the estimated spawning biomass in the calculation of empirical biomass based reference points such as the current initial rebuilding target may need to be acknowledged.

7.0 Stock Status and Conservation Advice

7.1 Stock Status

The 2018 base-case model was constructed with minimal modifications relative to the 2016 base-case model. Based on the diagnostic analyses, the model represents the data sufficiently and results were consistent with the 2016 assessment. The 2018 assessment results considered the best available science information and appropriate for developing advice on stock status and conservation for the PBF.

The base-case model results show that: (1) spawning stock biomass (SSB) fluctuated throughout the assessment period, (2) the SSB steadily declined from 1996 to 2010; and (3) the slow increase of the stock continues since 2011 including the most recent two years. Based on the model diagnostics, the estimated biomass trend for the last 30 years is considered robust although SSB prior to the 1980s is uncertain due to data limitations. Using the base-case model, the 2016 SSB (terminal year) was estimated to be around 21,000 t in the 2018 assessment, which is an increased from 19,000 t in 2014 (Table 5-2 and Figure 5-11).

Historical recruitment estimates have fluctuated since 1952 without an apparent trend. The low recruitment levels estimated in 2010-2014 were a concern in the 2016 assessment. The 2018 assessment estimate of 2015 recruitment is low and similar to estimates from previous years while the 2016 recruitment estimate is higher than the historical average (Figure 5-11). The uncertainty of the 2016 recruitment estimate is higher than in previous years because it occurs in the terminal year of the assessment model and is mainly informed by one observation from the troll age-0 CPUE index. The troll CPUE series has been shown to be a good predictor of recruitment, with no apparent retrospective error in the recruitment estimates of the terminal year given the current model construction. As the 2016 recruits grow and are observed by other fleets, the magnitude of this year class will be more precisely estimated in the next stock assessment. The estimated magnitude of the 2016 year class had a positive impact on the projection results.

Comparison of estimated age-specific fishing mortalities (F) on the stock during 2012-2014, 2015-2016, and 2002-2004 (the base period for the WCPFC Conservation and Management Measure) are presented in Table 7-1 and Figure 5-13. A substantial decrease in estimated F is observed in ages 0-2 in 2015-2016. Note that stricter management measures in WCPFC and IATTC have been in place since 2015.

With respect to reference points, the WCPFC adopted an initial rebuilding target (the median SSB estimated for the period 1952 through 2014) and a second rebuilding target (20%$SSB_{F=0}$ under average recruitment), without specifying a fishing mortality reference level. The 2018 assessment estimated the initial rebuilding target to be 6.7%$SSB_{F=0}$ and the corresponding fishing mortality expressed as spawning potential ratio (SPR) to be $F_{6.7\%SPR}$ (Table 7-2). Spawning potential ratio (SPR) is the ratio of cumulative spawning biomass that an average recruit is expected to produce over its lifetime when the stock is fished at the current intensity to the cumulative spawning biomass that could be produced by a recruit over its lifetime when the stock is unfished. Spawning potential ratio is often used as a measure of fishing intensity when selectivity changes substantially over time, as is the case with Pacific bluefin tuna. F6.7%SPR describes a fishing mortality and aggregate fishery selectivity pattern that is expected to produce 6.7% of the cumulative unfished spawning biomass; a low number is consistent with high fishing mortality on the stock. Because the projections contain catch limits, fishing mortality is expected to decline, i.e., $F_{x\%SPR}$ will increase, as biomass increases. The Kobe plot shows that the point estimate of the 2016 SSB was 3.3%$SSB_{F=0}$ and the 2016 fishing mortality corresponds to F6.7%SPR (Figure 7-1). Table 7-3 provides the evaluation of the stock status of PBF against common reference points. It shows that the PBF stock is overfished relative to biomass-based limit reference points adopted for other species in WCPFC (20%$_{SSBF=0}$) and is subject to overfishing relative to most of the common fishing intensity-based reference points.

Figure 7-2 depicts the historical impacts of the fleets on the PBF stock, showing the estimated biomass when fishing mortality from respective fleets is zero. Historically, the WPO coastal fisheries group has had the greatest impact on the PBF stock, but since about the early 1990s the WPO purse seine fleets, in particular those targeting small fish (ages 0-1), have had a greater impact, and the effect of these fleets in 2016 was greater than any of the other fishery groups. The impact of the EPO fishery was large before the mid-1980s, decreasing significantly thereafter. The WPO longline fleet has had a limited effect on the stock throughout the analysis period because the impact of a fishery on a stock depends on both the number and size of the fish caught by each fleet; i.e., catching a high number of smaller juvenile fish can have a greater impact on future spawning stock biomass than catching the same weight of larger mature fish.

Based on these findings, the following information on the status of the Pacific bluefin tuna stock is provided:

1. No biomass-based limit or target reference points have been adopted to evaluate overfished status for PBF. However, the PBF stock is overfished relative to biomass-based reference points adopted by WCPFC for other species (Table 7-3).
2. No fishing intensity-based limit or target reference points have been adopted to evaluate overfishing for PBF. However, the PBF stock is subject to overfishing relative to most of commonly adopted fishing intensity-based reference points (Table 7-3).

7.2 Conservation Advice

After the steady decline in SSB from 1995 to the historical low level in 2010, the PBF stock appears to have started recovering slowly. The stock biomass is below the two rebuilding targets adopted by the WCPFC while the fishing intensity (spawning potential ratio) is at a level corresponding to the initial rebuilding target.

The Harvest Strategy proposed at the Joint WCPFC NC-IATTC WG meeting and adopted by the WCPFC (Harvest Strategy 2017-02) guided projections conducted by the ISC to provide catch reduction options if the projection results show that the initial rebuilding target will not be achieved at least with 60% by 2024 or to provide relevant information for a potential increase in catch if the probability of achieving the initial rebuilding target exceeds 75% by 2024.

The 2018 base case assessment results are consistent with the 2016 model results. However, the 2018 projection results are more optimistic than the 2016 projections, mainly due to the inclusion of the relatively good recruitment in 2016, which is twice as high as the median of assumed low recruitment scenario (1980-1989). Based on the performance analyses of the recruitment estimates using an age-structured production model and the retrospective diagnostics, terminal year recruitment estimates were included in the projections. The magnitude of terminal year recruitment is generally more uncertain than those of other years because it is based on one observation in 2016. As this 2016 year-class are observed in more fisheries in subsequent years, the uncertainty concerning the magnitude of this recruitment will be reduced and the estimated recruitment may differ, which will influence the projections and the probabilities of achieving both rebuilding targets.

The projection based on the base-case model mimicking the current management measures by the WCPFC (CMM 2017-08) and IATTC (C-16-08) under the low recruitment scenario resulted in an estimated 98% probability of achieving the initial rebuilding target by 2024. This estimated probability is above the threshold (75% or above in 2024) prescribed by the WCPFC Harvest Strategy (Harvest Strategy 2017-02) (scenario 0 of Table 6-1: performance of the scenarios, and Table 6-2: expected yield of the scenarios. See also Figure 6-1). The low recruitment scenario is more precautionary than the recent 10 years recruitment scenario. In the Harvest Strategy, the recruitment scenario is switched from the low recruitment to the average recruitment scenario beginning in the year after achieving the initial rebuilding target. The estimated probability to achieve the second rebuilding target was evaluated 10 years after the achievement of the initial rebuilding target or by 2034, whichever is earlier, is 96% (scenario 1 of Table 6-2; Figure 6-1, 7-3). This estimate is above the threshold (60% or above in 2034) prescribed by the WCPFC Harvest Strategy. However, it should be recognized that these projection results are strongly influenced by the inclusion of the relatively high, but uncertain recruitment estimate for 2016.

Since the results of the base-case model projections of the current management measures by the WCPFC (CMM 2017-08) and IATTC (C-16-08) show that the probability of achieving the first and second rebuilding targets exceed the specified thresholds for achieving these targets by 2024 and 2034 (75% and 60%, respectively), the PBFWG conducted additional projections to estimated potential catch limit increases that could be implemented while still achieving the rebuilding targets within the specified timeframes. The results of these projections are reported in Appendix I of this report.

Given the low SSB, the uncertainty in future recruitment, and the influence of recruitment on stock biomass, monitoring recruitment and SSB should be strengthened so that the recruitment trends can to be understood in a timely manner.

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9.0 Table and Figure

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

Fishing year	2014				2015				2016				2017	
Season	Season 1	Season 2	Season 3	Season 4	Season 1	Season 2	Season 3	Season 4	Season 1	Season 2	Season 3	Season 4	Season 1	Season 2
SSB				SSB in 2014				SSB in 2015				SSB in 2016		
Day of birth in SS	Birthday of 2014 yr class				Birthday of 2015 yr class				Birthday of 2016 yr class				Birthday of 2017 yr class	
Recruitment	Recruitment in 2014				Recruitment in 2015				Recruitment in 2016				Recruitment in 2017	
Year class	2014 yr class				2015 yr class				2016 yr class				2017 yr class	
Calender year	2014		2015				2016				2017			
Month	7 8 9	10 11 12	1 2 3	4 5 6	7 8 9	10 11 12	1 2 3	4 5 6	7 8 9	10 11 12	1 2 3	4 5 6	7 8 9	10 11 12

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

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

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

Fleet #	Fleet name	Unit of Catch	Gears included				Abundance index
			Representative component	Component 2	Component 3	Component 4	
Fleet 1	JPLL	Weight	JP Longline				S1, S2, S3
Fleet 2	JSPPS (Seas1, 3, 4)	Weight	JP SPPS (Season 1, 3, 4)				
Fleet 3	KROLPS	Weight	KR OLPS	KR Trawl*1	KR Setnet*1	KR Troll*1	
Fleet 4	JPTPSJS	Weight	JP TPSJS	TW PS*2			
Fleet 5	JPTPSPO	Weight	JP TPSPO				
Fleet 6	JPTroll (Seas2-4)	Weight	JP Troll (Season 2-4)				S5
Fleet 7	JPPL	Weight	JP Pole-and-Line	JP Driftnet*3	TW Driftnet*3	TW Others*4	
Fleet 8	JPSetNet (Seas1-3)	Weight	JP Setnet (Season 1-3)	JP Miscellaneous (Season 1-3)			
Fleet 9	JPSetNet (Seas4)	Weight	JP Setnet (Season 4)	JP Miscellaneous (Season 4)			
Fleet 10	JPSetNet_HK_AM	Weight	JP Setnet in Hokkaido and Aomori				
Fleet 11	JPOthers	Weight	JP Handline & Tsugaru Longline	JP Trawl	JP OtherLL		
Fleet 12	TWLL (South)	Weight	TW Longline (South area)	Out of ISC members (NZ, AU, etc.)*5			S9
Fleet 13	USCOMM (-2001)	Weight	US Commercial Fisheries (PS, Others)	Mex Commercial Fisheries (PS, Others)			
Fleet 14	MEXCOMM (2002-)	Weight	Mex Commercial Fisheries (PS, Others)	US Commercial Fisheries (PS, Others)			
Fleet 15	EPOSP	Number	US Recreational Fisheries				
Fleet 16	JPTroll4Pen	Number	JP Troll for Farming				
Fleet 17	TWLL (North)	Weight	TW Longline (North area)				
Fleet 18	JPSPPS (Seas2)	Weight	JP SPPS (Season 2)				
Fleet 19	JPTroll (Seas1)	Weight	JP Troll (Season 1)				

*1 Catch for KRean Trawl, KRean Setnet and KRean Troll were **not included** in the input data until the 2016 stock assessment.

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

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

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

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

Table 3-2. Quarterly catch of Pacific bluefin tuna (*Thunnus orientalis*) by fleet and fishing year for 1952-2016.

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

Table 3-2. Cont.

Fishing year	Season	Weight (mt)																	Number (1000 fish)	
		Fleet1	Fleet2	Fleet3	Fleet4	Fleet5	Fleet6	Fleet7	Fleet8	Fleet9	Fleet10	Fleet11	Fleet12	Fleet13	Fleet14	Fleet17	Fleet18	Fleet19	Fleet15	Fleet16
1969	1	109	0	0	0	2061	0	184	294	0	319	0	0	5258	0	0	0	78	1	0
1969	2	54	0	0	0	0	1656	213	426	0	196	160	0	49	0	0	0	0	0	0
1969	3	37	0	0	0	0	230	178	232	0	3	0	0	14	0	0	0	0	0	0
1969	4	524	0	0	0	1274	32	204	0	433	140	0	0	1416	0	0	0	0	0	0
1970	1	23	0	0	0	1633	0	210	282	0	190	0	0	2534	0	0	0	42	1	0
1970	2	35	0	0	0	0	894	194	398	0	99	161	0	2	0	0	0	0	1	0
1970	3	181	0	0	0	0	286	234	163	0	4	0	0	31	0	0	0	0	0	0
1970	4	505	0	0	0	2835	40	269	0	284	171	0	1	4039	0	0	0	0	0	0
1971	1	19	0	0	0	887	0	230	200	0	340	0	0	3349	0	0	0	52	1	0
1971	2	43	0	0	0	0	1114	240	261	0	202	212	0	939	0	0	0	0	0	0
1971	3	47	0	0	0	0	162	297	199	0	3	0	0	3	0	0	0	0	0	0
1971	4	446	0	0	0	2049	23	78	0	215	111	0	14	2879	0	0	0	0	0	0
1972	1	15	0	0	0	2163	0	449	127	0	164	0	0	8861	0	0	0	29	1	0
1972	2	31	0	0	0	0	629	159	233	0	89	124	0	1603	0	0	0	0	0	0
1972	3	57	0	0	0	0	405	73	485	0	2	0	0	11	0	0	0	0	0	0
1972	4	799	0	0	0	464	56	160	0	501	70	0	33	2043	0	0	0	0	2	0
1973	1	21	0	0	0	1803	0	419	359	0	277	0	0	8690	0	0	0	74	4	0
1973	2	25	0	0	0	0	1573	183	514	0	186	286	0	0	0	0	0	0	0	0
1973	3	30	0	0	0	0	318	450	1313	0	4	0	0	0	0	0	0	0	0	0
1973	4	1037	0	0	0	416	44	246	0	1403	155	0	47	1227	0	0	0	0	0	0
1974	1	105	0	0	0	3690	0	483	865	0	546	0	0	4238	0	0	0	58	6	0
1974	2	48	0	0	0	0	1236	363	1424	0	362	368	0	151	0	0	0	0	0	0
1974	3	29	0	0	0	0	198	806	287	0	1	0	0	0	0	0	0	0	0	0
1974	4	891	0	0	0	3415	28	132	0	349	73	0	61	3065	0	0	0	0	0	0
1975	1	121	0	0	0	1077	0	1096	309	0	605	0	0	5748	0	0	0	36	3	0
1975	2	61	0	0	0	0	769	50	378	0	431	132	0	769	0	0	0	0	0	0
1975	3	37	0	0	0	0	159	80	231	0	5	0	0	616	0	0	0	0	0	0
1975	4	298	0	0	0	1122	22	271	0	430	240	0	17	2283	0	0	0	0	0	0
1976	1	54	0	0	0	1026	0	1300	301	0	818	0	0	7250	0	0	0	29	2	0
1976	2	15	0	0	0	0	619	518	431	0	540	152	0	497	0	0	0	0	0	0
1976	3	69	0	0	0	0	416	169	320	0	2	0	0	2	0	0	0	0	0	0
1976	4	244	0	0	0	4063	58	1338	0	411	108	0	131	2015	0	0	0	0	0	0
1977	1	37	0	0	0	1047	0	1258	222	0	485	0	0	3094	0	0	0	76	2	0
1977	2	12	0	0	0	0	1617	377	378	0	331	168	0	348	0	0	0	0	0	0
1977	3	58	0	0	0	0	867	51	377	0	2	0	0	86	0	0	0	0	0	0
1977	4	243	0	0	0	10346	121	426	0	527	107	0	66	704	0	0	0	0	0	0
1978	1	340	0	0	3	78	0	2329	282	0	441	0	0	4403	0	0	0	158	1	0
1978	2	16	0	0	0	0	3372	380	512	0	298	246	0	21	0	0	0	0	0	0
1978	3	55	0	0	0	0	510	454	733	0	2	0	0	11	0	0	0	0	0	0
1978	4	580	0	0	0	11145	71	211	0	1011	115	0	58	2331	0	0	0	0	0	0
1979	1	104	0	0	0	2736	0	1720	527	0	768	0	0	3539	0	0	0	93	1	0
1979	2	24	0	0	0	0	1982	406	861	0	541	888	0	227	0	0	0	0	0	0
1979	3	43	0	0	0	0	294	572	363	0	3	0	0	0	0	0	0	0	0	0
1979	4	749	0	0	0	6168	41	195	0	379	140	0	114	1435	0	0	0	0	0	0
1980	1	20	0	0	0	5159	0	1641	322	0	574	0	0	1439	0	0	0	54	1	0
1980	2	41	0	0	0	0	1143	468	353	0	387	474	0	59	0	0	0	0	0	0
1980	3	185	0	0	0	0	283	85	406	0	1	0	0	0	0	0	0	0	0	0
1980	4	336	0	0	0	6344	0	115	0	404	54	0	179	356	0	0	0	0	0	0
1981	1	56	0	0	1297	17781	0	2382	271	0	352	0	0	742	0	0	0	68	1	0
1981	2	41	0	0	0	0	1426	302	393	0	248	523	0	1	0	0	0	0	0	0
1981	3	63	0	8	0	0	435	336	277	0	2	0	0	0	0	0	0	0	0	0
1981	4	583	0	12	0	5410	53	671	0	341	69	0	207	60	0	0	0	0	0	0
1982	1	73	0	6	1615	12209	0	1905	198	0	300	0	0	2682	0	0	0	5	1	0
1982	2	20	0	5	0	0	370	444	277	0	204	132	0	406	0	0	0	0	0	0
1982	3	38	0	3	0	0	81	31	189	0	1	0	0	91	0	0	0	0	0	0
1982	4	161	0	5	0	11951	0	107	0	207	35	0	175	8	0	0	0	0	0	0
1983	1	8	0	3	570	2262	0	897	143	0	113	0	0	631	0	0	0	21	1	0
1983	2	15	0	2	0	0	1925	131	210	0	74	310	0	125	0	0	0	0	1	0
1983	3	41	0	1	0	0	287	33	380	0	3	0	0	72	0	0	0	0	0	0
1983	4	94	0	2	0	2448	0	116	0	431	138	0	477	144	0	0	0	0	0	0
1984	1	20	0	1	807	1184	0	588	311	0	343	0	0	563	0	0	0	28	3	0
1984	2	9	0	1	0	0	1558	391	413	0	215	336	0	90	0	0	0	0	1	0
1984	3	24	0	0	0	0	538	1011	265	0	3	0	0	62	0	0	0	0	0	0
1984	4	74	0	0	0	2897	135	464	0	358	153	0	210	1572	0	0	0	0	0	0
1985	1	8	0	0	448	889	0	961	229	0	714	0	0	1264	0	0	0	12	5	0
1985	2	8	0	0	0	0	1165	120	352	0	488	447	0	1126	0	0	0	0	0	0
1985	3	19	0	84	0	0	224	74	369	0	3	0	0	109	0	0	0	0	0	0
1985	4	84	0	130	0	6340	0	460	0	547	118	0	70	428	0	0	0	0	0	0

Table 3-2. Cont.

Fishing year	Season	Weight (mt)																	Number (1000 fish)	
		Fleet1	Fleet2	Fleet3	Fleet4	Fleet5	Fleet6	Fleet7	Fleet8	Fleet9	Fleet10	Fleet11	Fleet12	Fleet13	Fleet14	Fleet17	Fleet18	Fleet19	Fleet15	Fleet16
1986	1	8	0	70	16	1072	0	668	375	0	564	0	0	3759	0	0	0	5	1	0
1986	2	5	0	60	0	0	1238	212	553	0	387	403	0	801	0	0	0	0	0	0
1986	3	20	0	22	0	0	354	1089	274	0	2	0	0	93	0	0	0	0	0	0
1986	4	195	0	34	0	4874	15	132	0	299	89	0	365	31	0	0	0	0	0	0
1987	1	20	0	18	250	3550	0	519	193	0	612	0	0	813	0	0	0	6	1	0
1987	2	9	0	15	0	0	505	98	297	0	432	187	0	63	0	0	0	0	1	0
1987	3	19	0	8	0	0	89	146	94	0	1	0	0	0	0	0	0	0	0	0
1987	4	123	16	12	0	1027	0	357	0	113	45	0	108	221	0	0	0	0	0	0
1988	1	35	0	7	742	2010	0	796	87	0	228	0	0	974	0	0	0	15	0	0
1988	2	10	0	6	0	0	1020	42	118	0	157	127	0	227	0	0	6	0	0	0
1988	3	27	3	17	0	0	259	68	86	0	0	0	0	7	0	0	0	0	0	0
1988	4	190	3	27	0	2134	27	356	0	125	24	0	205	0	0	0	0	0	0	0
1989	1	20	88	15	580	3623	0	411	81	0	186	0	0	988	0	0	0	88	5	0
1989	2	4	0	12	0	0	529	146	114	0	132	110	0	130	0	0	20	0	1	0
1989	3	21	0	32	0	0	166	17	165	0	1	0	0	16	0	0	0	0	0	0
1989	4	280	5	50	0	360	92	213	0	133	26	0	189	1	0	0	0	0	0	0
1990	1	24	32	27	149	2474	0	830	64	0	90	0	0	1311	0	0	0	3	4	0
1990	2	10	0	23	0	0	990	47	179	0	60	199	0	194	0	0	118	0	0	0
1990	3	16	99	65	0	0	636	30	421	0	1	0	0	0	0	0	0	0	0	0
1990	4	193	26	100	0	646	161	79	0	288	49	0	342	86	0	0	0	0	0	0
1991	1	14	182	54	224	3466	0	429	123	0	146	0	2	334	0	0	0	82	5	0
1991	2	14	0	46	0	0	1191	103	363	0	95	414	0	5	0	0	5165	0	0	0
1991	3	36	394	71	0	0	274	18	183	0	2	0	0	0	0	0	0	0	0	0
1991	4	462	2061	109	0	1677	0	35	0	332	68	0	464	11	0	0	0	0	0	0
1992	1	10	255	59	469	2183	0	944	173	0	116	0	0	1650	0	0	0	0	8	0
1992	2	20	0	50	0	0	642	65	269	0	66	193	0	328	0	0	198	0	0	0
1992	3	15	582	10	0	0	145	12	102	0	1	0	0	0	0	0	0	0	0	0
1992	4	708	751	15	0	1243	34	38	0	280	27	0	471	45	0	0	0	0	0	0
1993	1	62	99	8	83	3831	0	204	161	0	32	0	6	525	0	0	0	48	10	0
1993	2	37	0	7	0	0	320	36	230	0	16	207	0	113	0	0	12	0	0	0
1993	3	42	25	12	0	0	67	0	70	0	1	0	0	2	0	0	0	0	0	0
1993	4	1085	562	19	0	2677	15	17	0	481	16	0	559	4	0	0	0	0	0	0
1994	1	77	14	10	694	3973	0	206	168	0	36	0	3	967	0	0	0	458	2	0
1994	2	22	0	9	0	0	3570	65	356	0	31	272	0	58	0	0	185	0	0	0
1994	3	11	406	202	0	0	2475	9	132	0	0	0	0	0	0	0	0	0	0	0
1994	4	616	254	309	0	2040	733	136	0	256	23	0	335	0	0	0	0	0	0	0
1995	1	35	4055	168	496	2798	0	143	243	0	213	0	2	716	0	0	0	440	16	0
1995	2	25	0	142	0	0	1130	94	788	0	205	476	0	0	0	0	8860	0	0	0
1995	3	31	1355	25	0	0	136	5	84	0	0	0	0	0	0	0	0	0	0	0
1995	4	827	140	38	0	3124	57	1	0	253	16	0	956	757	0	0	0	0	2	0
1996	1	25	451	21	450	1967	0	90	129	0	142	0	4	7652	0	0	0	256	1	0
1996	2	26	0	18	0	0	3191	66	416	0	110	503	0	0	0	0	158	0	0	0
1996	3	27	594	259	0	0	846	1	114	0	0	0	0	1	0	0	0	0	0	0
1996	4	1215	1113	397	0	1402	550	4	0	199	6	0	1814	61	0	0	0	0	3	0
1997	1	27	3000	215	708	4027	0	113	165	0	20	0	15	2638	0	0	0	224	5	0
1997	2	44	0	183	0	0	1120	25	246	0	53	702	0	41	0	0	2309	0	0	0
1997	3	18	559	46	0	0	605	2	158	0	1	0	0	4	0	0	0	0	0	0
1997	4	1150	518	71	0	13	515	2	0	131	15	0	1910	8	0	0	0	0	1	0
1998	1	53	549	38	326	2376	0	108	114	0	29	0	23	2017	0	0	0	131	21	47
1998	2	46	0	33	0	0	1613	64	359	0	68	609	0	24	0	0	1049	0	1	0
1998	3	33	686	63	0	0	798	10	317	0	1	0	0	0	0	0	0	0	0	0
1998	4	1076	986	96	0	5592	360	2	0	329	32	0	3089	2280	0	0	0	0	1	0
1999	1	25	2228	52	579	5448	0	65	133	0	16	0	26	442	0	0	0	129	35	214
1999	2	41	0	44	0	0	2101	17	391	0	46	482	0	49	0	0	653	0	1	0
1999	3	39	651	747	0	0	1456	1	168	0	0	0	0	0	0	0	0	0	0	0
1999	4	893	2380	1597	0	3403	770	83	0	164	5	0	2780	669	0	0	0	0	8	0
2000	1	15	3214	30	747	4042	0	66	154	0	87	0	29	3204	0	0	0	117	13	382
2000	2	12	0	27	0	0	2780	6	475	0	72	638	0	0	0	0	2048	0	0	0
2000	3	8	898	963	0	0	934	0	358	0	1	0	0	0	0	0	0	0	0	0
2000	4	749	2914	179	0	981	464	4	0	189	45	0	1834	382	0	5	0	0	1	0
2001	1	13	409	9	239	1918	0	167	73	0	174	0	57	821	0	0	0	83	21	549
2001	2	26	0	37	0	0	1847	113	293	0	232	683	0	0	0	0	261	0	1	0
2001	3	76	62	160	0	0	988	17	113	0	0	0	0	0	0	0	0	0	0	0
2001	4	671	2126	175	0	556	697	51	0	117	6	0	1513	0	275	10	0	0	1	0
2002	1	45	959	509	599	2767	0	224	157	0	235	0	61	0	1497	0	0	37	31	716
2002	2	56	0	88	0	0	706	24	231	0	251	409	0	0	0	0	1835	0	2	0
2002	3	95	99	238	0	0	520	11	84	0	0	0	0	0	0	0	0	0	0	0
2002	4	992	1771	394	0	185	824	34	0	87	54	0	1832	0	590	0	0	0	1	0

Table 3-2. Cont.

Fishing year	Season	Weight (mt)																	Number (1000 fish)	
		Fleet1	Fleet2	Fleet3	Fleet4	Fleet5	Fleet6	Fleet7	Fleet8	Fleet9	Fleet10	Fleet11	Fleet12	Fleet13	Fleet14	Fleet17	Fleet18	Fleet19	Fleet15	Fleet16
2003	1	78	783	88	571	200	0	58	96	0	291	0	84	0	2704	0	0	80	21	884
2003	2	85	0	1881	0	0	416	6	156	0	71	403	0	0	0	0	2159	0	1	0
2003	3	116	38	53	0	0	182	5	109	0	3	0	1	0	0	0	0	0	0	0
2003	4	1380	1144	556	0	609	54	15	0	266	47	0	1698	0	3620	0	0	0	1	0
2004	1	154	10	59	2100	2225	0	114	136	0	81	0	93	0	5285	0	0	78	3	1051
2004	2	205	0	105	0	0	1868	94	186	0	68	421	0	0	0	0	2131	0	0	0
2004	3	122	586	720	0	0	1173	164	379	0	15	0	0	0	0	0	0	0	0	0
2004	4	1602	1888	264	0	264	906	321	0	572	217	0	1287	0	1986	43	0	0	0	0
2005	1	106	3280	222	3694	77	0	171	414	0	137	0	71	0	2764	0	0	293	5	908
2005	2	108	0	121	0	0	1034	30	346	0	102	413	0	0	0	0	3029	0	0	0
2005	3	81	59	220	0	0	513	68	284	0	7	0	0	0	640	0	0	0	0	0
2005	4	873	2412	339	0	940	85	23	0	356	135	0	1078	0	4714	49	0	0	5	0
2006	1	115	252	354	2012	692	0	315	148	0	328	0	48	0	4573	0	0	251	2	1265
2006	2	62	0	102	0	0	695	17	229	0	69	331	0	0	1	0	2513	0	0	0
2006	3	61	485	376	0	0	228	32	253	0	10	0	0	0	0	0	0	0	0	0
2006	4	1022	1059	13	0	479	70	15	0	270	127	0	1261	0	1424	95	0	0	0	0
2007	1	66	363	121	2123	364	0	238	150	0	381	0	58	0	2723	4	0	101	1	1753
2007	2	71	0	776	0	0	1985	105	314	0	52	1013	0	0	44	0	1968	0	0	0
2007	3	99	214	581	0	0	619	12	268	0	2	0	0	0	0	0	0	0	0	0
2007	4	802	1610	1003	0	1	220	30	0	844	239	0	784	0	1794	175	0	0	1	0
2008	1	33	3007	62	3028	0	0	287	389	0	186	0	35	0	2613	2	0	72	10	1214
2008	2	40	0	230	0	0	1163	14	455	0	95	797	0	0	1	0	2361	0	0	0
2008	3	39	702	518	0	0	868	1	449	0	1	0	0	0	0	0	0	0	0	0
2008	4	662	2177	213	0	1	241	13	0	1031	276	0	625	0	1209	186	0	0	1	0
2009	1	26	2891	97	1299	828	0	108	180	0	181	0	82	0	2221	3	0	62	12	512
2009	2	23	0	112	0	0	703	43	143	0	106	677	0	0	3	0	181	0	0	0
2009	3	35	718	617	0	0	264	0	342	0	1	0	0	0	0	0	0	0	0	0
2009	4	400	1390	424	0	35	38	36	0	566	264	0	260	0	2447	78	0	0	4	0
2010	1	27	123	26	1052	35	0	179	190	0	79	0	45	0	5300	0	0	20	4	1127
2010	2	10	0	145	0	0	979	44	237	0	9	693	0	0	1	0	388	0	1	0
2010	3	25	67	191	0	0	492	29	374	0	4	0	0	0	0	0	0	0	0	0
2010	4	372	3058	429	0	0	298	34	0	380	384	0	197	0	451	76	0	0	2	0
2011	1	49	611	21	1906	320	0	38	158	0	148	0	48	0	2379	0	0	39	29	808
2011	2	32	0	43	0	0	789	22	217	0	36	567	0	0	19	0	2377	0	1	0
2011	3	20	9	163	0	0	242	70	360	0	5	0	0	0	1	0	0	0	0	0
2011	4	189	530	674	0	3	7	45	0	500	151	0	148	0	1286	50	0	0	4	0
2012	1	24	261	559	841	199	0	103	205	0	514	0	26	0	5421	0	0	2	35	346
2012	2	13	0	28	0	0	233	0	176	0	54	644	0	0	3	0	620	0	1	0
2012	3	28	9	76	0	0	256	2	273	0	4	0	0	0	0	0	0	0	0	0
2012	4	237	743	493	0	12	19	6	0	372	170	0	192	0	1368	123	0	0	3	0
2013	1	28	10	1	1729	268	0	81	132	0	204	0	40	0	1788	0	0	22	57	519
2013	2	15	0	35	0	0	477	3	217	0	82	895	0	0	8	0	2	0	4	0
2013	3	9	79	516	0	0	789	0	306	0	2	0	0	0	2	0	0	0	0	0
2013	4	311	2459	783	0	0	60	43	0	818	285	0	257	0	4036	216	0	0	1	0
2014	1	21	654	6	2203	47	0	125	92	0	231	0	21	0	1228	1	0	40	26	149
2014	2	26	0	6	0	0	97	1	107	0	110	679	0	0	2	0	14	0	2	0
2014	3	36	246	607	0	0	60	7	76	0	1	0	0	0	1	0	0	0	1	0
2014	4	171	519	5	0	567	18	12	0	388	261	0	308	0	3133	237	0	0	2	0
2015	1	26	115	0	1820	372	0	11	88	0	210	0	22	0	43	0	0	19	25	485
2015	2	47	0	65	0	0	233	6	77	0	167	808	0	0	3	0	7	0	0	0
2015	3	69	1	981	0	0	153	4	116	0	0	0	0	0	0	0	0	0	0	0
2015	4	216	762	33	0	796	82	5	0	199	283	0	237	0	2716	215	0	0	2	0
2016	1	86	313	6	1981	490	0	8	135	0	183	0	21	0	329	0	0	224	7	521
2016	2	18	0	9	0	1	213	44	253	0	62	768	0	0	16	0	752	0	2	0
2016	3	35	21	738	0	61	175	30	473	0	1	0	0	0	0	0	0	0	0	0
2016	4	267	651	0	0	890	6	86	0	365	194	0	200	0	3643	148	0	0	0	0

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

CPUE #	Abundance index	Available period (fishing year)	Corresponding fisheries	Corresponding fleet for the selectivity setting	Data quality	Document for reference	Update
S1	Japanese coastal longline CPUE for spawning season.	**1993-2016**	JP Longline	Fleet 1 : JPLL	Standardized by ZINB	ISC/18/PBFWG-1/01	X
S2	Japanese offshore and distant water longliners CPUE	1952-1973	JP Longline	Fleet 1 : JPLL	Standardized by lognormal model	ISC/12/PBFWG-1/10	
S3	Japanese offshore and distant water longliners CPUE	1974-1992	JP Longline	Fleet 1 : JPLL		ISC/08/PBFWG-1/05	
S5	Japanese troll CPUE in the East China sea (coastal waters of western Kyusyu)	**1980-2016**	JP Troll	Fleet 6 : JP Troll (Seas 2-4)	Standardized by lognormal model	ISC/18/PBFWG-1/03	X
S9	Taiwanese longline CPUE (South area)	**2000-2016**	TW Longline	Fleet 12 : TWLL (South)	Standardized by GLMM	ISC/18/PBFWG-1/02	X

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

Fishing year	JP LL			JP Troll	TW LL
	S1	S2	S3	S5	S9
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**			
1961		**0.0193**			
1962		**0.0175**			
1963		**0.0123**			
1964		**0.0128**			
1965		**0.0100**			
1966		**0.0128**			
1967		**0.0062**			
1968		**0.0056**			
1969		**0.0065**			
1970		**0.0046**			
1971		**0.0029**			
1972		**0.0028**			
1973		**0.0019**			
1974		0.0066	**0.0016**		
1975			**0.0011**		
1976			**0.0026**		
1977			**0.0029**		
1978			**0.0035**		
1979			**0.0023**		
1980			**0.0030**	**0.67**	
1981			**0.0035**	**1.18**	
1982			**0.0020**	**0.62**	
1983			**0.0012**	**0.92**	
1984			**0.0013**	**0.94**	
1985			**0.0012**	**0.87**	
1986			**0.0014**	**0.99**	
1987			**0.0014**	**0.72**	
1988			**0.0016**	**0.83**	
1989			**0.0024**	**0.65**	
1990			**0.0024**	**1.28**	
1991			**0.0038**	**1.34**	
1992			**0.0041**	**0.58**	
1993	**2.31**		0.0051	**0.49**	
1994	**1.48**		0.0037	**2.02**	
1995	**2.33**		0.0059	**1.10**	
1996	**2.00**		0.0066	**1.62**	
1997	**1.80**		0.0053	**0.95**	
1998	**1.33**		0.0045	**0.83**	
1999	**1.18**		0.0039	**1.52**	
2000	**0.84**		0.0032	**1.16**	**2.56**
2001	**0.97**		0.0030	**1.16**	**1.06**
2002	**1.26**			**0.75**	**1.86**
2003	**1.50**			**0.65**	**1.95**
2004	**1.72**			**1.30**	**1.37**
2005	**0.81**			**1.44**	**1.43**
2006	**0.88**			**0.74**	**1.02**
2007	**0.67**			**1.43**	**0.87**
2008	**0.36**			**1.46**	**0.82**
2009	**0.21**			**1.16**	**0.41**
2010	**0.23**			**1.13**	**0.39**
2011	**0.19**			**0.98**	**0.35**
2012	**0.30**			**0.49**	**0.36**
2013	**0.30**			**0.88**	**0.55**
2014	**0.34**			**0.44**	**0.62**
2015	**0.43**			**0.51**	**0.62**
2016	**0.57**			**1.20**	**0.74**

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

Fleet #	Fleet name	Catch-at-size data (Size bin definition)	Size data included		Available period (Fishing year)	Source of sample size	Update
			Component 1	Component 2			
Fleet1	JPLL	Length bin	JPLL		1952-1968, 1993-2016	Scaled Number of fish measured	X
Fleet2*1	JPSPPS (Seas1, 3, 4)	Length bin	JPSPPS (Season 1, 3, 4)	KROLPS	2002-2016	Number of landing well measured	X
Fleet3*1	KROLPS	Length bin	KROLPS		2010-2016		X
Fleet4	TPSJS	Length bin	JP TPSJS		1987-1989, 1991-2016	same velue with the last assessment	X
Fleet5	TPSPO	Length bin	JP TPSPO		1995-2006	Number of landing well measured	
Fleet6	JP Troll (Seas2-4)	Length bin	JP Troll (Season 2-4)		1994-2016	Total month of well sampled port	X
Fleet7*2	PL	Length bin	JP Pole-and-Line		1994-1996, 1998-2004, 2006-2010		
Fleet8	SetNet (Seas1-3)	Length bin	JP Setnet (Season 1-3)		1993-2016	Total month of well sampled port	X
Fleet9	SetNet (Seas4)	Length bin	JP Setnet (Season 4)		1993-2016	Total month of well sampled port	X
Fleet10*3	SetNet_HK_AM	Weight bin	JP Setnet in Hokkaido and Aomori	JP Handline & Tsugaru Longline	1994-2016	Total month of well sampled port	X
Fleet11*3	JP Others	Weight bin	JP Handline & Tsugaru Longline		1994-2016	Total month of well sampled port	X
Fleet12	TWLL (South)	Length bin	TWLL (South area)		1992-2016	Scaled Number of fish measured	X
Fleet13	USCOMM (-2001)	Length bin	US Commercial Fisheries (PS)		1952-1965, 1969-1982	Number of haul well measured	
Fleet14	MXCOMM (2002-)	Length bin	MX Commercial Fisheries (PS)		2005-2006, 2008-2016	Number of haul well measured	X
Fleet15*4	EPOSP	Length bin	US Recreational Fisheries		1993-2003, 2005-06, 2008-11, 2014-16		X
Fleet16*5	Troll4Pen	Age (age-0 only)					
Fleet17	TWLL (North)	Length bin	TWLL (North area)		2009-2016	Scaled Number of fish measured	X
Fleet18	JPSPPS (Seas2)	Length bin	JPSPPS (Season 2)		2003-2012, 2014, 2016	Number of landing well measured	X
Fleet19	JP Troll (Seas1)	Length bin	JP Troll (Season 1)		1994-2004, 2006-2011, 2016	Total month of well sampled port	X

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

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

Fleet #	Fleet name	Ages of fish caught	Priority for size data	Type of size data	Sampling quality	CPUE index	Catch in number	Length-based contact selectivity	Age-based availability	Time-varying process
Fleet 1	JPLL	Spawners in WPO	High*	Length	Good	Yes	Low	Dome-shaped (double normal)	None	Constant on length-based
Fleet 2	JSPPS (Seas1, 3, 4)	Age 0 fish in WPO	Medium*	Length	Good	-	High	Dome-shaped (double normal)	None	Constant on length-based
Fleet 3	KROLPS	Age 0 fish in WPO	Medium**	Length	Fair (opportunistically sampling was conducted for 2004-2009, systematically since 2010)	-	Med	Mirror to Fleet 2		
Fleet 4	JPTPSJS	Migratory ages (ages 1-5)	High*	Length	Very Good	-	High	Asymptotic (logistic)	Age-specific (ages 3-9)	Constant on length-based; time-varying on ages 3-7 for 2000-2016
Fleet 5	JPTPSPO	Migratory ages (ages 1-5)	Medium*	Length	Fair	-	High-historic	Asymptotic (logistic)	Age-specific (ages 1-10)	Constant on length-based; time-varying on ages 1, 5-7 for 2004-2005
Fleet 6	JPTroll (Season2-4)	Age 0 fish in WPO	High*	Length	Good	Yes	High	Dome-shaped (double normal)	None	Constant on length- and age-based
Fleet 7	JPPL	Age 0 fish in WPO	Low	Length	Bad	-	Historic	Mirror to Fleet 6		
Fleet 8	JPSetNet (Season1-3)	Migratory ages (ages 1-5)	Low*	Length	Fair	-	Med	Asymptotic (logistic)	Age-specific (ages 1-4)	Constant on length-based;
Fleet 9	JPSetNet (Season4)	Migratory ages (ages 1-5)	Low*	Length	Fair	-	Low	Asymptotic (logistic)	Age-specific (ages 1-5)	Constant on length-based;
Fleet 10	JPSetNet_HK_AM	Migratory ages (ages 1-5)	Medium*	Weight	Good	-	Low	Asymptotic (logistic)	Age-specific (ages 1-3)	Constant on length-based;
Fleet 11	JPOthers	Migratory ages (ages 1-5)	Medium**	Weight	Good	-	Low	Mirror to Fleet 10		
Fleet 12	TWLL (South)	Spawners in WPO	High*	Length	Very Good	Yes	Low	Asymptotic (logistic)	None	Constant on length- and age-based
Fleet 13	USCOMM (-2001)	Migratory ages (ages 1-5)	Medium*	Length	Fair (many samples)	-	High-historic	Dome-shaped (double normal)	None	Time–varying on length-based for 1954-1981
Fleet 14	MEXCOMM (2002-)	Migratory ages (ages 1-5)	High*	Length	Fair (improvement after 2013 due to the stereo-camera)	-	High	Dome-shaped (double normal)	None	Time–varying on length-based for 2006-2016
Fleet 15	EPOSP	Migratory ages (ages 1-5)	Low	Length	Fair (Good samples are available for recent years)	-	Low	Mirror to Fleet 13		
Fleet 16	JPTroll4Pen	Age 0 fish in WPO	Low	Converted length	Catch in # of Age-0 fish are available	-	Med	None	100% selected at age 0	Constant on age-based
Fleet 17	TWLL (North)	Spawners in WPO	Low*	Length	Fair	-	Low	Dome-shaped (double normal)	None	Constant on length-based
Fleet 18	JPSPPS (Season2)	Migratory ages (ages 1-5)	Medium*	Length	Good	-	High	Dome-shaped (double normal)	Age-specific (age 1)	Constant on length-based; Time–varying on age-based for 2004-2012
Fleet 19	JPTroll (Season1)	Age 0 fish in WPO	Medium*	Length	Good	-	High	Dome-shaped (double normal)	None	Constant on length-based

* Fleets whose size data were fitted.

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

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

Scenario #	Fishing mortality*1	WPO					EPO*3			Catch limit Increase			
		Catch limit					Catch limit						
		Japan*2		Korea		Taiwan	Commercial		Sports	WPO		EPO	
		Small	Large	Small	Large	Large	Small	Large		Small	Large	Small	Large
0[*4]	F	4,007	4,882	718		1,700	3,300		-	0%		0%	
1	F	4,007	4,882	718		1,700	3,300		-	0%		0%	

*1 F indicated the geometric mean values of quartaly age-specific fishing mortality during 2002-2004.
*2 The Japanese unilateral measure (transfering 250 mt of catch upper limit from that for small PBF to that for large PBF during 2017-2020) would be reflected.
*3 Fishing mortality for the EPO commercial fishery was asssumed to be enough high to fullfill its catch upper limit (F multiplied by two). The fishing mortality for the EPO recreational fishery was assumed to be F2009-11 average level.
*4 In scenario 0, the future recrutment were assumed to be the low recruitment (1980-1989 level) forever. In other scenarios, recruitment was switched from low recruitemnt to average recruitment from the next year of achieving the initial rebuilding target.

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

Fleet	Number of observations	Mean input N after var adj	Mean *effN*	Harmonic mean *effN*	Mean (*effN*/inputN)
Fleet 1	73	8.5	56.2	26.8	9.7
Fleet 2	39	10.9	22.5	13.3	4.3
Fleet 4	29	20.0	36.1	16.1	2.5
Fleet 5	11	9.6	49.9	42.3	9.4
Fleet 6	52	9.8	30.5	14.7	3.5
Fleet 8	70	6.6	18.9	12.1	3.3
Fleet 9	24	7.0	21.1	15.4	3.1
Fleet 10	23	9.0	32.0	15.7	3.8
Fleet 12	25	12.8	94.7	36.6	9.7
Fleet 13	50	14.5	19.1	6.2	2.6
Fleet 14	14	10.4	24.4	15.8	6.2
Fleet 17	8	2.6	71.7	57.7	28.8
Fleet 18	12	11.3	23.8	13.5	4.2
Fleet 19	18	7.2	27.1	12.2	5.0

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

Fishing year	Total biomass (t)	Spawning stock biomass (t)	CV for SSB	Recruitment (x1000 fish)	CV for R
1952	150825	114227	0.51	9305	
1953	146228	107201	0.49	21843	0.17
1954	147385	96239	0.49	34556	0.15
1955	152230	83288	0.50	14106	0.19
1956	169501	76742	0.49	34261	0.11
1957	188830	82975	0.46	12574	0.15
1958	208078	108677	0.41	3436	0.30
1959	214898	147004	0.39	7963	0.22
1960	218055	155183	0.39	7745	0.21
1961	211262	168125	0.39	23323	0.10
1962	197361	151993	0.42	10794	0.18
1963	181329	129755	0.45	27615	0.10
1964	169581	114448	0.45	5827	0.32
1965	159109	100628	0.46	11584	0.35
1966	144866	95839	0.44	8645	0.44
1967	121987	89204	0.44	10803	0.38
1968	107216	83374	0.45	13656	0.24
1969	93223	69074	0.47	6413	0.30
1970	81816	57958	0.48	7120	0.40
1971	71900	49980	0.48	12596	0.34
1972	67819	43035	0.46	22742	0.17
1973	65474	37205	0.44	11058	0.27
1974	65059	29896	0.44	13570	0.17
1975	63515	27733	0.38	11011	0.18
1976	66532	30485	0.30	9171	0.32
1977	64320	36220	0.25	25078	0.17
1978	69199	33382	0.25	15057	0.26
1979	69609	28007	0.29	11509	0.20
1980	71313	30757	0.25	7584	0.27
1981	72109	28867	0.21	11703	0.13
1982	53715	25408	0.21	6965	0.21
1983	31185	15086	0.29	10078	0.15
1984	33147	12813	0.31	9231	0.20
1985	36319	12846	0.28	9601	0.19
1986	35877	15358	0.23	7857	0.19
1987	31609	14632	0.25	6224	0.22
1988	33868	15709	0.25	8796	0.14
1989	38189	15519	0.25	4682	0.28
1990	46388	19468	0.23	18462	0.09
1991	61501	25373	0.21	11803	0.11
1992	70077	32022	0.20	4426	0.17
1993	79910	43691	0.18	4365	0.18
1994	90135	51924	0.19	28350	0.04
1995	103322	67152	0.18	17414	0.09
1996	98854	66841	0.18	17564	0.06
1997	99196	61069	0.19	10919	0.10
1998	95373	60293	0.19	15014	0.08
1999	91963	56113	0.20	23450	0.05
2000	87384	53835	0.21	14335	0.06
2001	76182	50222	0.21	15786	0.05
2002	77727	47992	0.20	13509	0.06
2003	74204	47569	0.19	7769	0.09
2004	68407	40707	0.20	26116	0.04
2005	63042	33820	0.21	14659	0.06
2006	50197	27669	0.23	11645	0.06
2007	43558	22044	0.24	21744	0.04
2008	41169	16754	0.27	20371	0.04
2009	35677	13011	0.27	8810	0.07
2010	33831	12188	0.25	15948	0.05
2011	34983	13261	0.23	13043	0.06
2012	37451	15892	0.20	6284	0.09
2013	39113	18107	0.20	11874	0.06
2014	38918	19031	0.19	3561	0.14
2015	38322	19695	0.20	7765	0.13
2016	41191	21331	0.22	15988	0.21

Table 5-3. Geometric means of annual age-specific fishing mortalities of Pacific bluefin tuna (*Thunnus orientalis*) for 2002-2004, 2012-2014, and 2015-2016.

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
F2002-04	0.76	1.04	0.55	0.27	0.20	0.17	0.17	0.12	0.11	0.19	0.15	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
F2012-14	0.69	0.61	0.68	0.24	0.18	0.12	0.11	0.11	0.10	0.15	0.15	0.15	0.16	0.16	0.16	0.16	0.16	0.17	0.17	0.17	0.17
F2015-16	0.38	0.45	0.43	0.34	0.31	0.22	0.21	0.11	0.09	0.15	0.13	0.13	0.13	0.13	0.13	0.14	0.14	0.14	0.14	0.14	0.14

Table5-4. RMSE between observed and predicted abundance indices for the base case model and sensitivity runs.

Model	S1 JPLL late	S2 JPLL early	S3 JPLL middle	S5 JP Troll	S9 TWLL(South)
Base Case	0.302	0.212	0.151	0.188	0.289
Fit JPLL run	0.268	0.211	0.149	0.190	0.273
Fit TWLL run	0.306	0.211	0.149	0.189	0.280

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

Scenario #	Catch limit Increase				Initial rebuilding target			Second rebuilding target		Median SSB (mt) at 2034
	WPO		EPO		The year expected to achieve the target with >60% probability	Probability of achiving the target at 2024	Probability of SSB is below the target at 2024 under the low recruitment	The year expected to achieve the target with >60% probability	Probability of achiving the target at 2034	
	Small	Large	Small	Large						
0*1	0%		0%		2020	98%	2%	N/A	3%	74,789
1	0%		0%		2020	99%	2%	2028	96%	263,465

*1 In scenario 0, the future recrutment were assumed to be the low recruitment (1980-1989 level) forever. In other scenarios, recruitment was switched from low recruitemnt to average recruitment from the next year of achieving the initial rebuilding target.

Table 6-2. Expected annual yield for Pacific bluefin tuna (*Thunnus orientalis*) under various harvesting scenarios based on the base-case model.

Scenario #	Catch limit Increase				Expected annual yield in 2019, by area and size category (mt)				Expected annual yield in 2024, by area and size category (mt)				Expected annual yield in 2034, by area and size category (mt)			
	WPO		EPO		WPO		EPO		WPO		EPO		WPO		EPO	
	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large
0	0%	0%	0%		4,477	4,384	3,530		4,704	6,133	3,457		4,704	6,211	3,451	
1	0%	0%	0%		4,477	4,384	3,530		4,745	6,202	3,665		4,747	6,640	3,703	

Table 7-1. Change of estimated age-specific fishing mortalities (Fs) of Pacific bluefin tuna (*Thunnus orientalis*) from 2002-2004 to 2012-2014 and 2015-2016.

	Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Change from	F2012-14	-9%	-42%	24%	-10%	-11%	-25%	-35%	-7%	-3%	-23%	0%	7%	11%	13%	15%	16%	17%	18%	19%	19%	20%
F2002-04 to	F2015-16	-49%	-57%	-21%	25%	56%	34%	18%	-3%	-15%	-24%	-13%	-11%	-8%	-7%	-5%	-4%	-3%	-3%	-2%	-2%	-1%

Table 7-2. Comparison of spawning stock biomass and fishing intensity of Pacific bluefin tuna (*Thunnus orientalis*) in 1995 (recent biomass high), 2002-2004 (WCPFC reference year), 2011 (5 years ago), and 2016 (latest) to those of rebuilding targets. SPR refers to Spawning Potential Ratio, which is used as a measure of fishing intensity.

	initial rebuilding target	second rebuilding target	1995 (recent high)	2002-2004 (reference year)	2011 (5 years ago)
Biomass (%$SSB_{F=0}$)	SSB median 1952-2014 = 6.7%	20%	10.4%	7.1%	2.1%
fishing intensity (SPR)	6.7%	20%	5.1%	3.4%	4.9%

Table 7-3. Ratios of the estimated fishing mortalities F2002-2004, F2012-2014 and F2015-2016 relative to computed fishing intensity-based biological reference points and SSB (t) and depletion ratio for the terminal year of the reference period for PBF.

	F_{max}	F0.1	Fmed	Floss	(1-SPR)/(1-SPRxx%)				Estimated SSB for terminal year of each reference period	Depletion ratio for terminal year of each reference period
					SPR10%	SPR20%	SPR30%	SPR40%		
2002-2004	1.77	2.47	1.04	0.78	1.07	1.21	1.38	1.61	40,707	6.3%
2012-2014	1.47	2.04	0.86	0.65	1.05	1.19	1.36	1.58	19,031	3.0%
2015-2016	1.32	1.85	0.78	0.58	1.02	1.15	1.32	1.54	21,311	3.3%

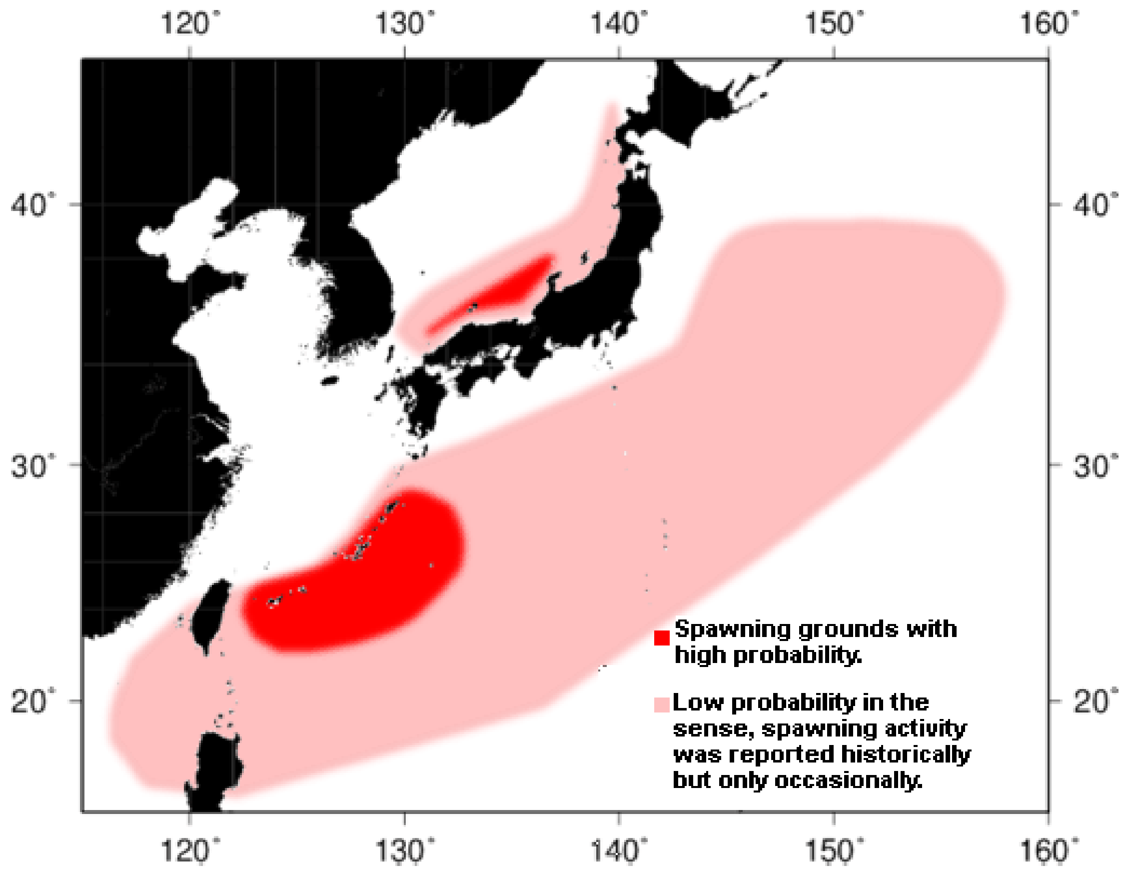


Figure 2-1. Generalized spawning grounds for Pacific bluefin tuna (*Thunnus orientalis*). Red areas represent higher probability of spawning.

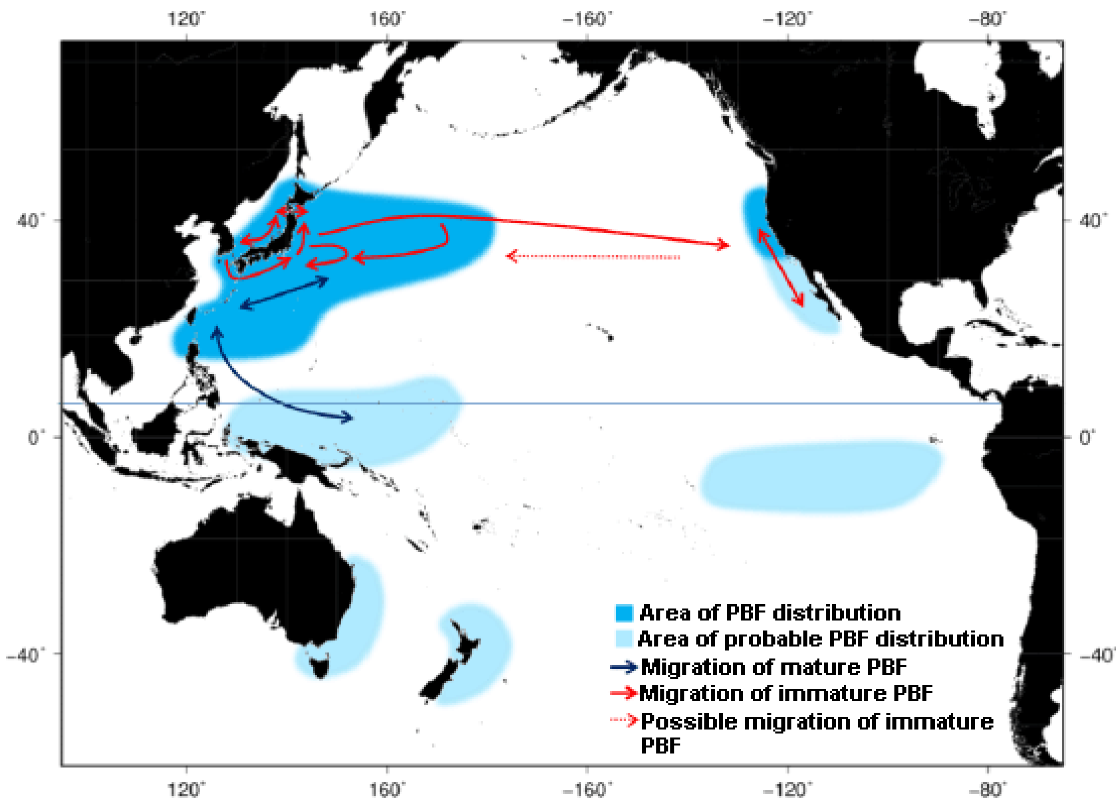


Figure 2-2. Generalized distribution of Pacific bluefin tuna (*Thunnus orientalis*). Darker areas indicate the core habitat.

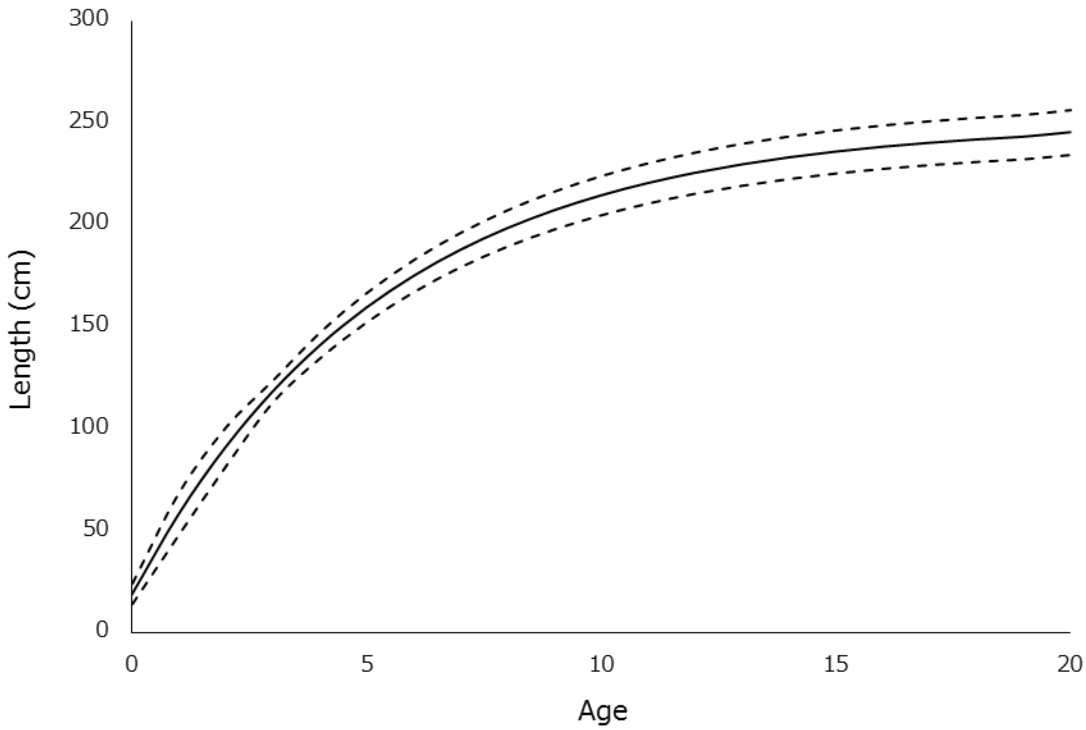


Figure 2-3. The von Bertalanffy growth curve for Pacific bluefin tuna (*Thunnus orientalis*) used in this stock assessment. Integer age (0,1,2,3,…) corresponds to the middle of first quarter of each fishing year (i.e., August 15 in the calendar year).

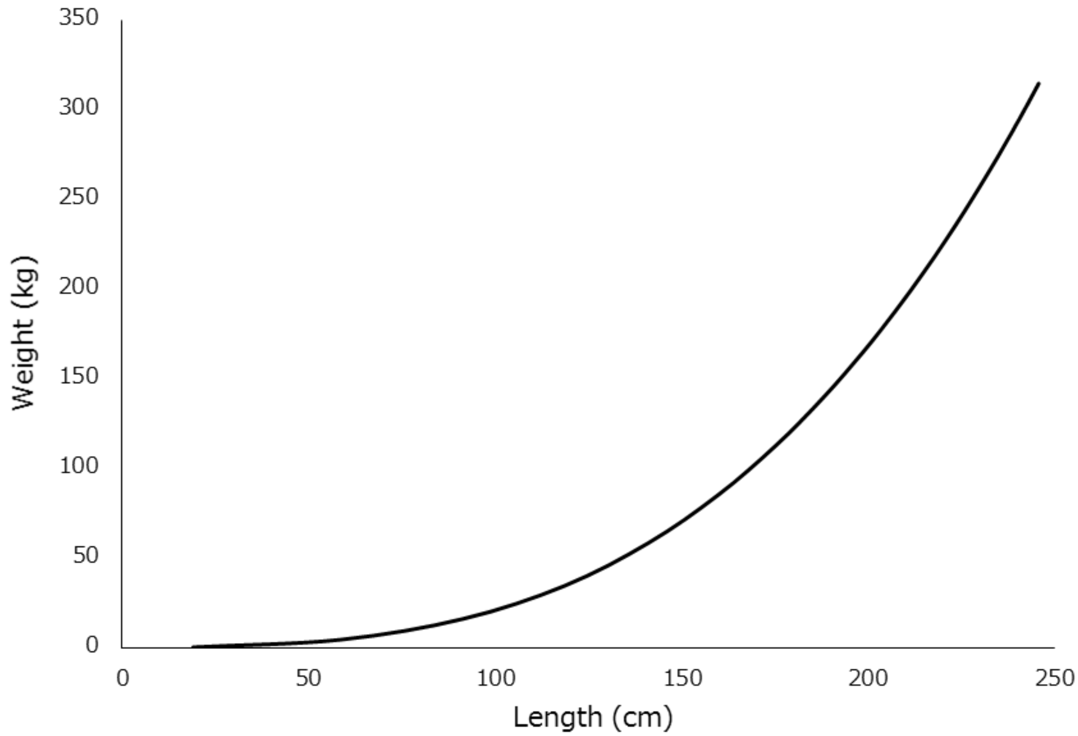


Figure 2-4. Length-weight relationship for Pacific bluefin tuna (*Thunnus orientalis*) used in this stock assessment.

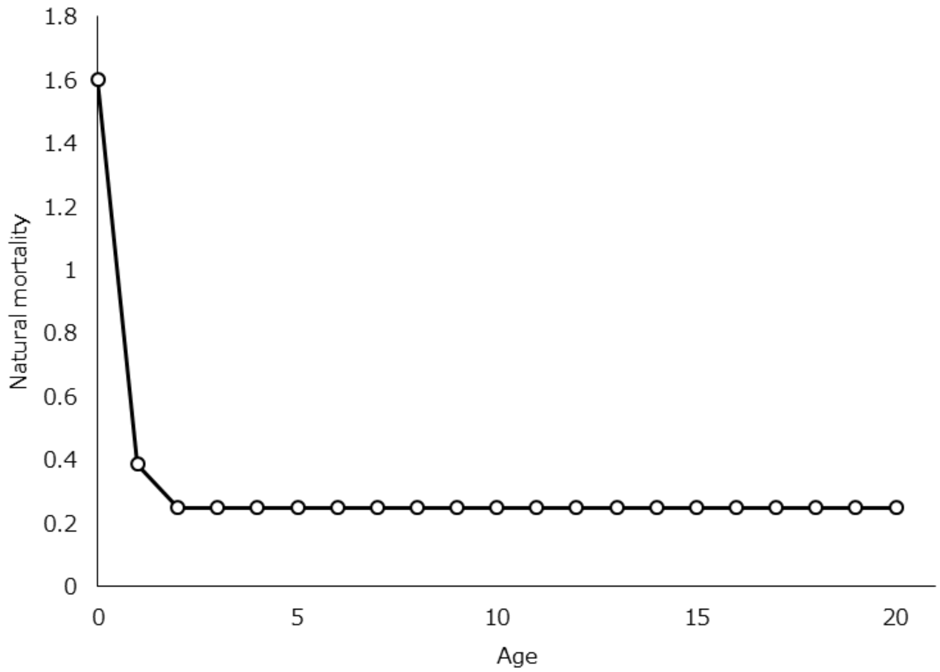


Figure 2-5. Assumed natural mortality (*M*) at age of Pacific bluefin tuna (*Thunnus orientalis*) used in this stock assessment.

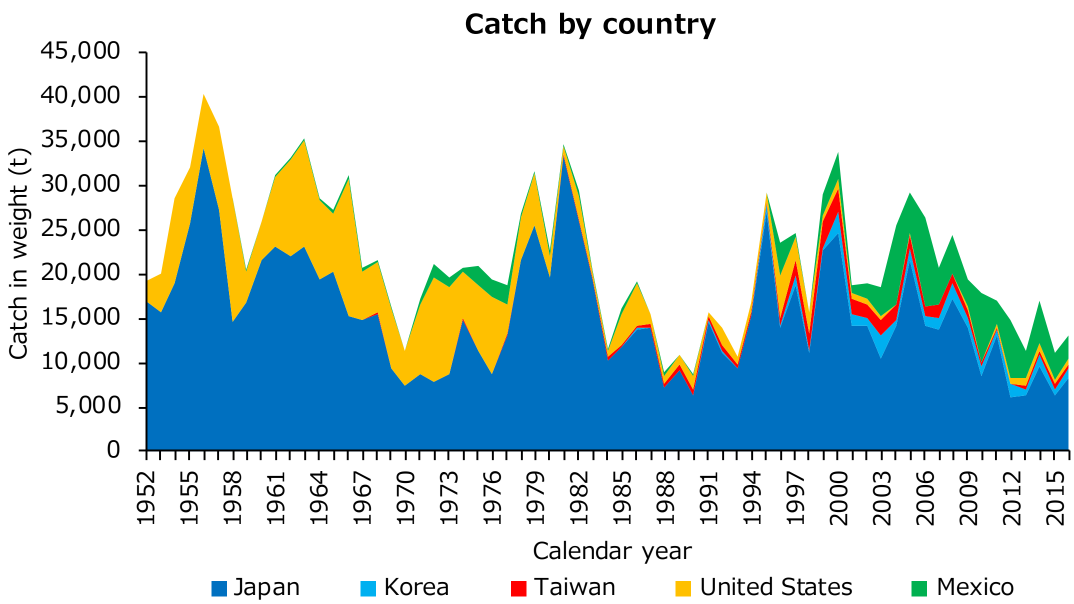


Figure 2-6. Annual catch of Pacific bluefin tuna (*Thunnus orientalis*) by country from 1952 through 2016 (calendar year).

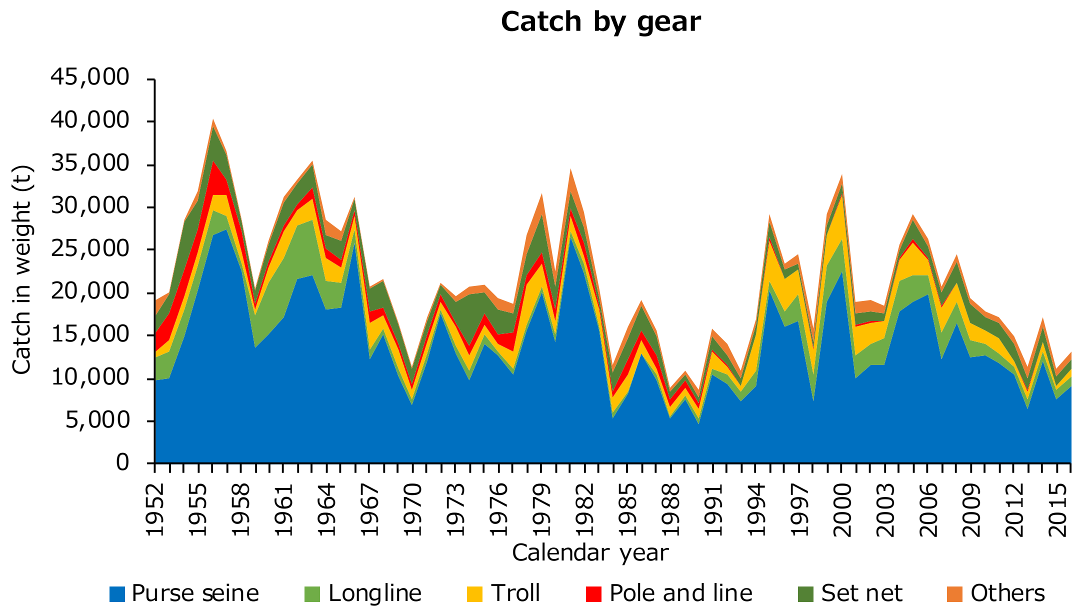


Figure 2-7. Annual catch of Pacific bluefin tuna (*Thunnus orientalis*) by gear type from 1952 through 2016 (calendar year).

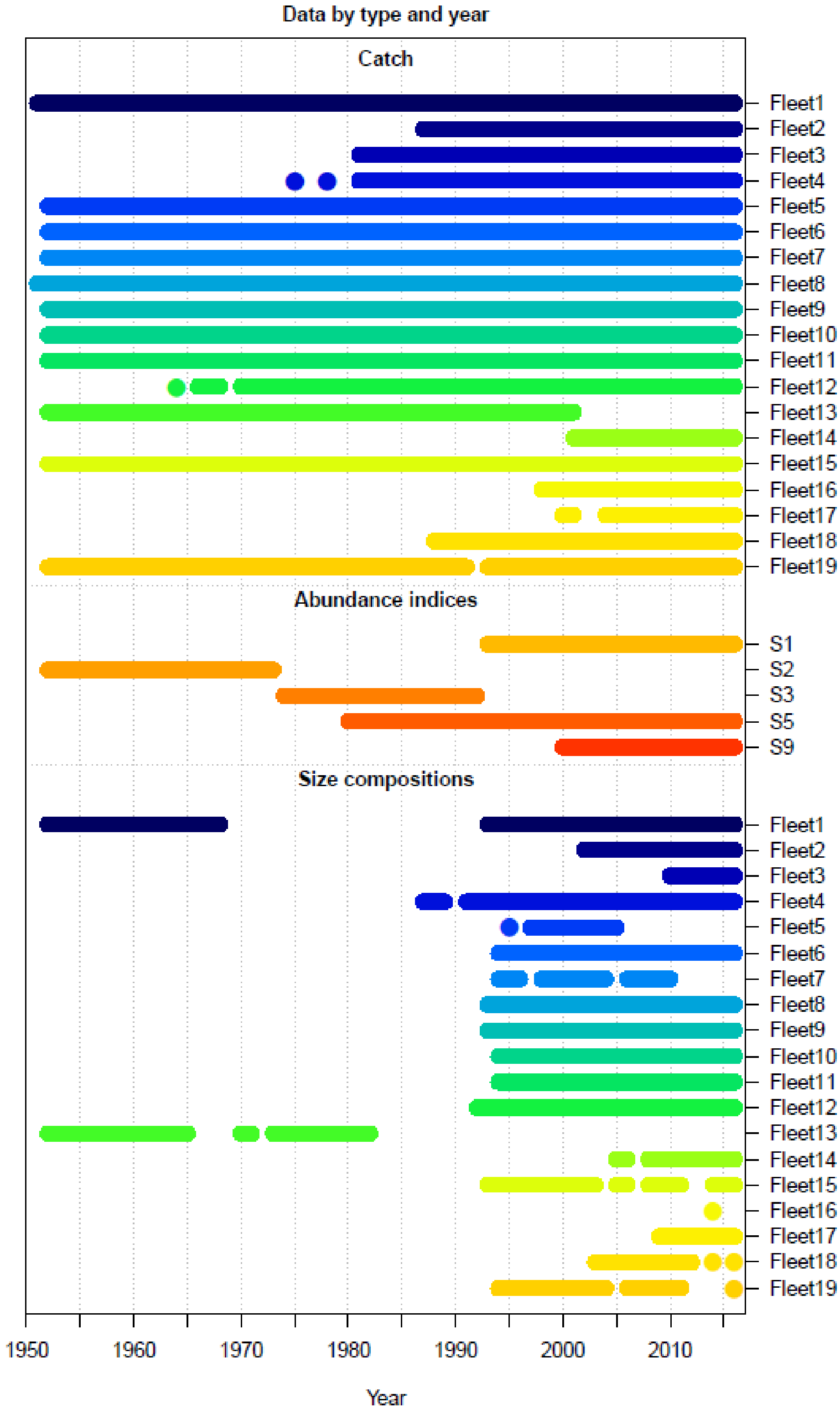
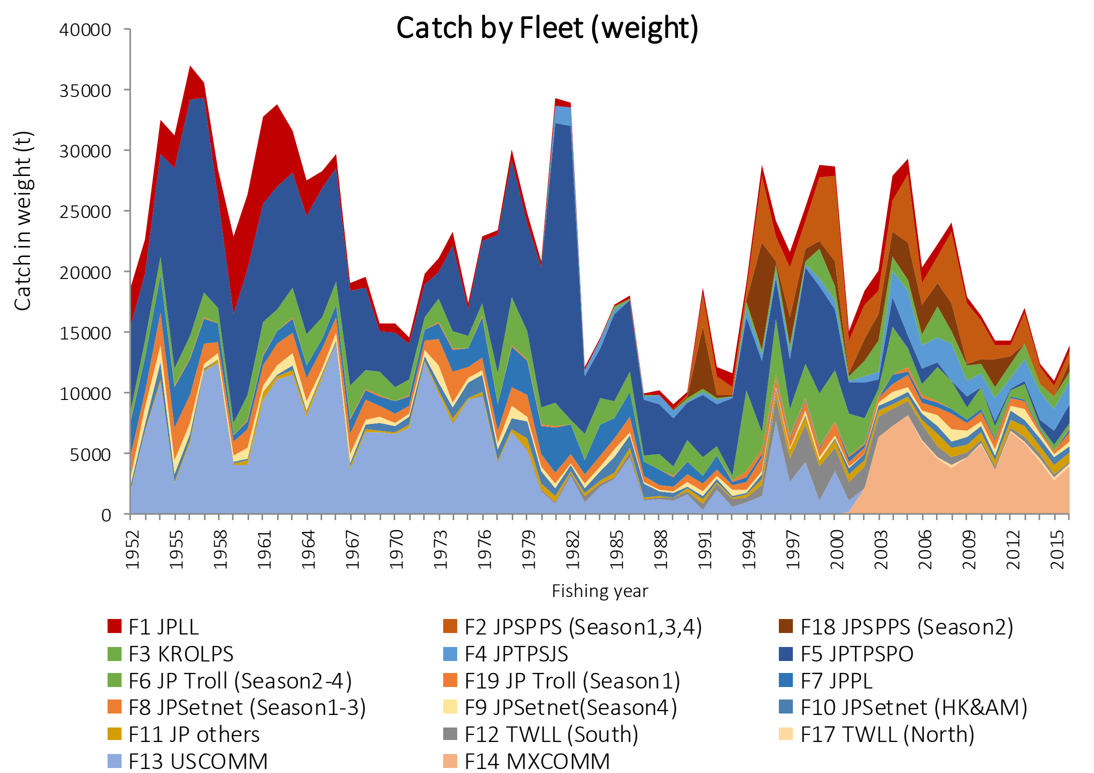


Figure 3-1. Data sources and temporal coverage of catch, abundance indices, and size

composition data used in the stock assessment of Pacific bluefin tuna (*Thunnus orientalis*).

(a)


Catch by Fleet (weight)
Catch in weight (t)
40000
35000
30000
25000
20000
15000
10000
5000
0
Fishing year
F1 JPLL
F2 JPSPPS (Season1,3,4)
F18 JPSPPS (Season2)
F3 KROLPS
F4 JPTPSJS
F5 JPTPSPO
F6 JP Troll (Season2-4)
F19 JP Troll (Season1)
F7 JPPL
F8 JPSetnet (Season1-3)
F9 JPSetnet(Season4)
F10 JPSetnet (HK&AM)
F11 JP others
F12 TWLL (South)
F17 TWLL (North)
F13 USCOMM
F14 MXCOMM

(b)

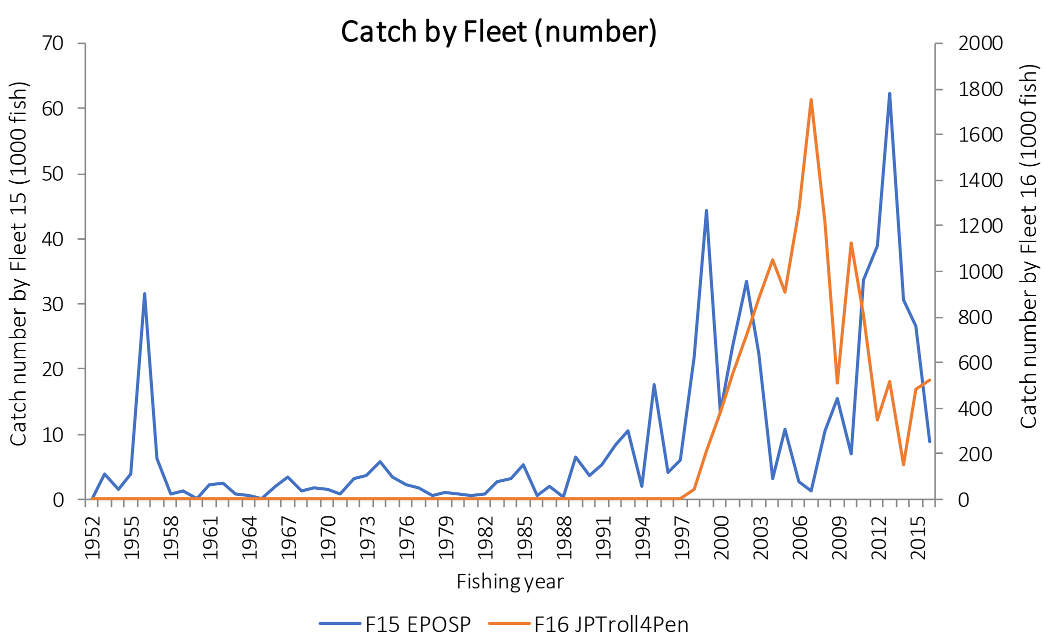

Catch by Fleet (number)
Catch number by Fleet 15 (1000 fish)
Catch number by Fleet 16 (1000 fish)
Fishing year
F15 EPOSP
F16 JPTroll4Pen

Figure 3-2. Annual catch in (a) weight and (b) number of Pacific bluefin tuna (*Thunnus orientalis*) by fleet from 1952 through 2016 (fishing year).

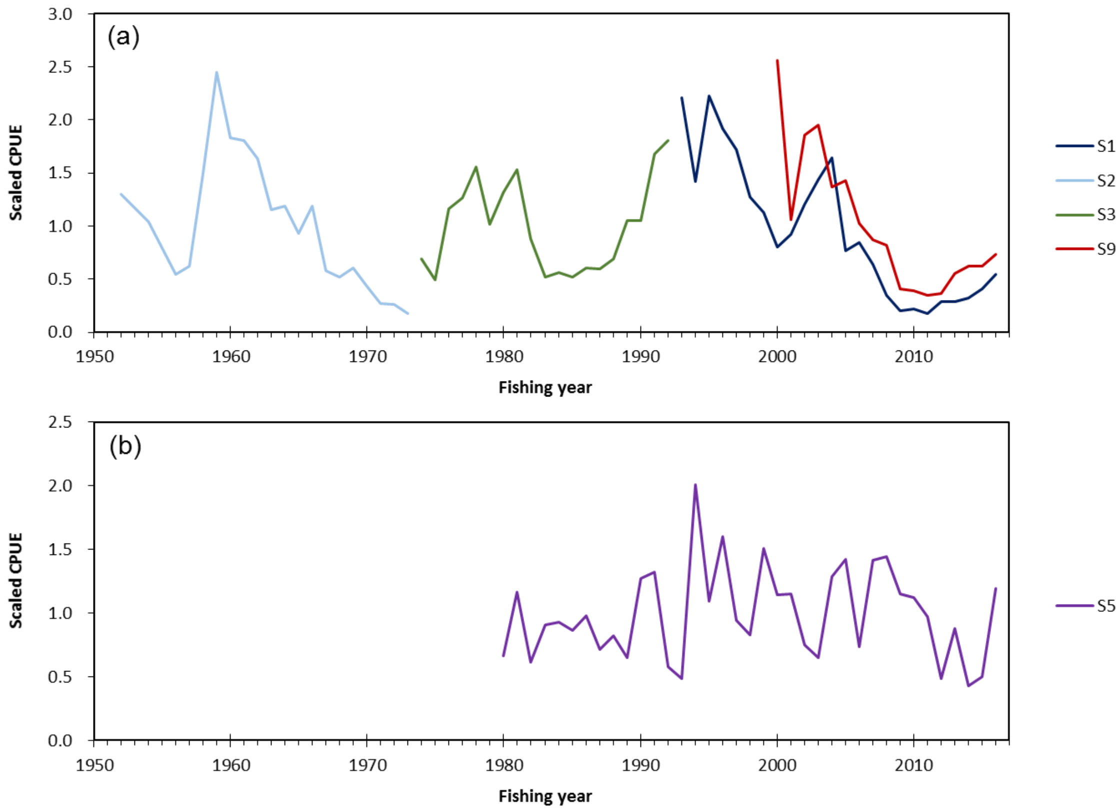


Figure 3-3. Abundance indices of Pacific bluefin tuna (*Thunnus orientalis*) submitted to ISC PBFWG, where (a) the longline indices of Japanese fisheries (S1, S2, and S3) and Taiwanese longline fishery in the southern area (S9) were used to represent adult abundance, (b) the index of Japanese troll fishery (S5) was used to represent recruitment (age 0) abundance.

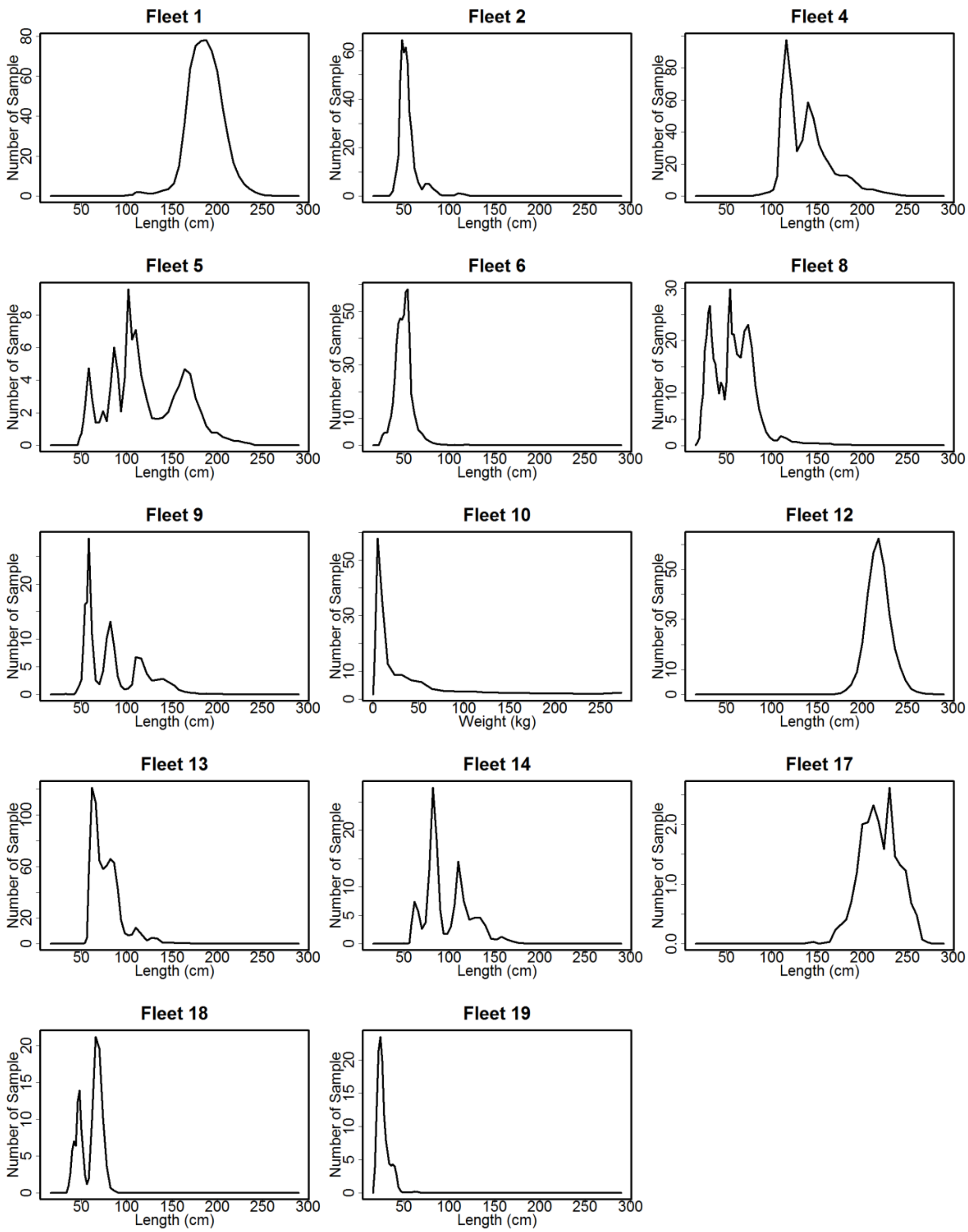
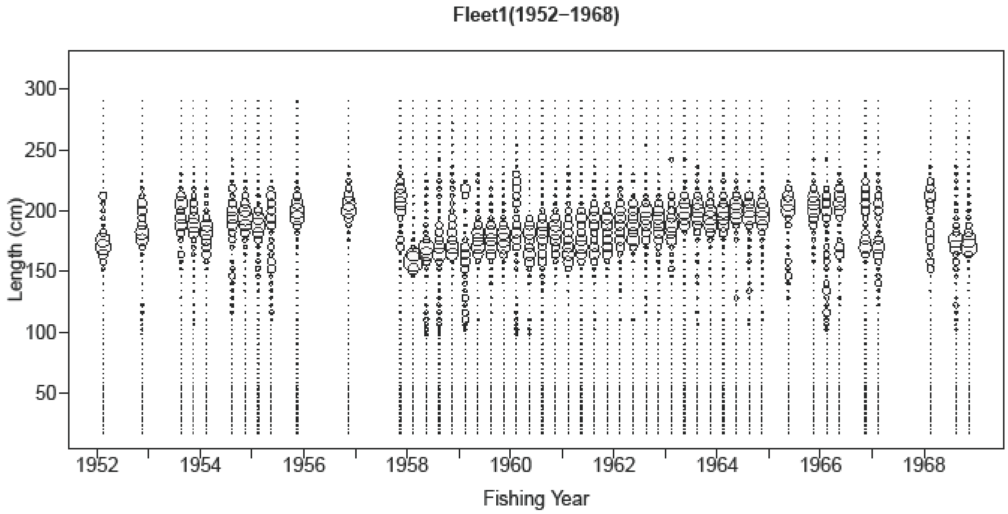


Figure 3-4. Aggregated size compositions of Pacific bluefin tuna (*Thunnus orientalis*) for each fleet used in the stock assessment. The data were aggregated across seasons and years after being

scaled by fleet size. The x-axis is in fork length (cm) for all fleets except for Fleet 10 in weight (kg).

a) Fleet 1



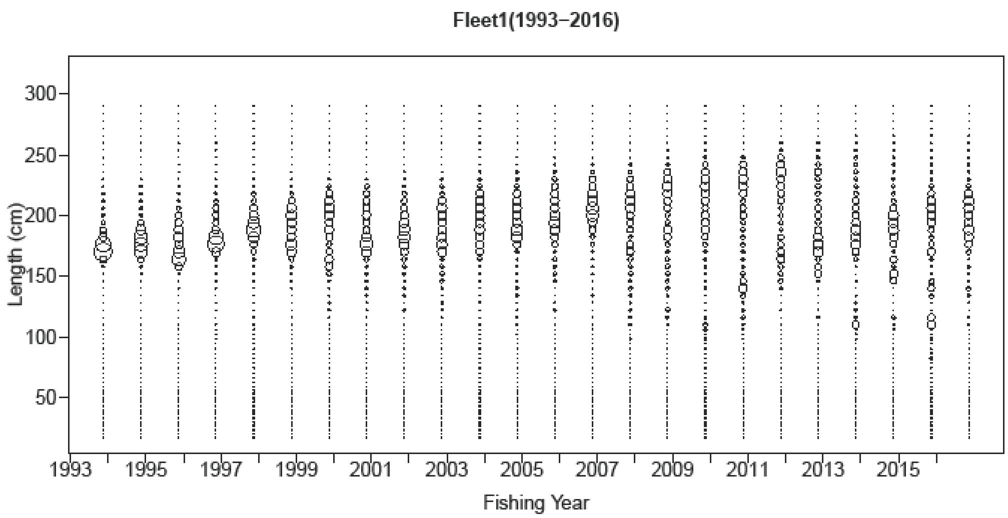
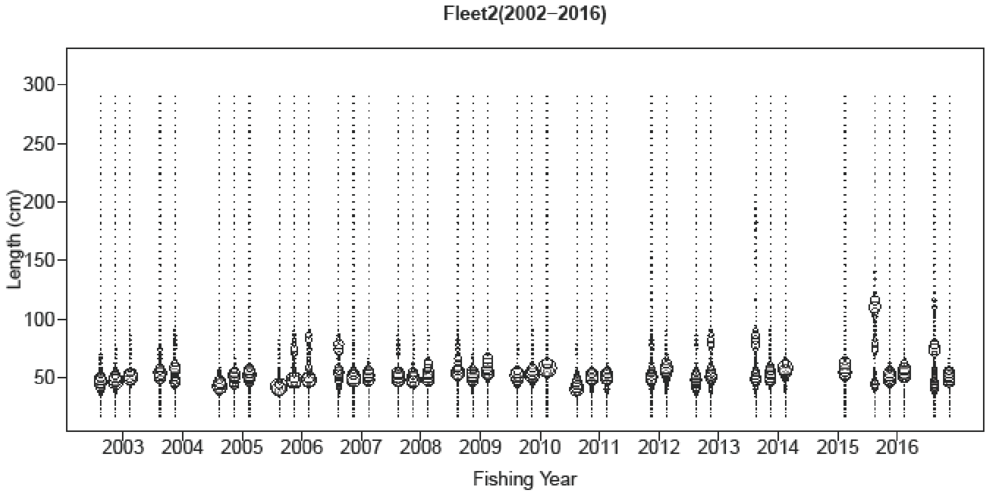


Figure 3-5. Size composition data by fleet and season used in the stock assessment model for Pacific bluefin tuna (*Thunnus orientalis*). Larger circles indicate higher proportions of observation.

b) Fleet 2



c) Fleet 4

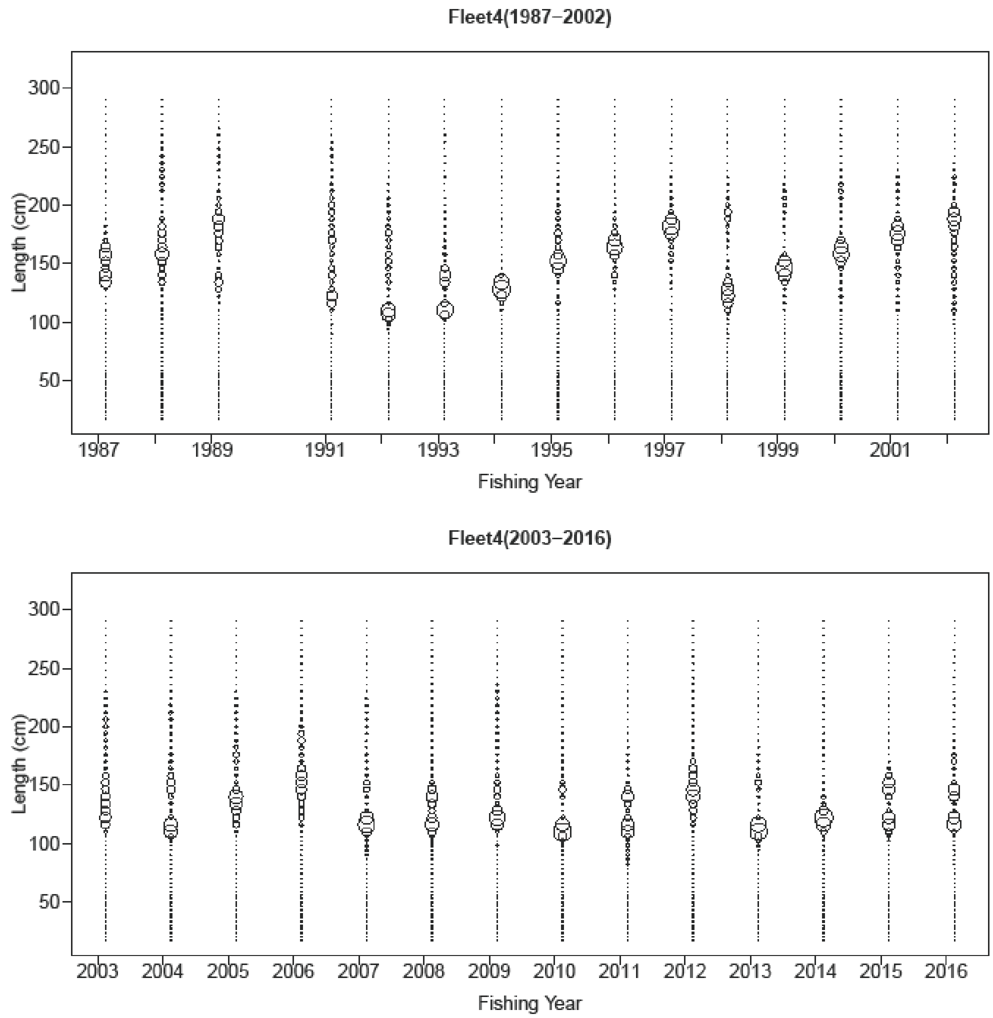
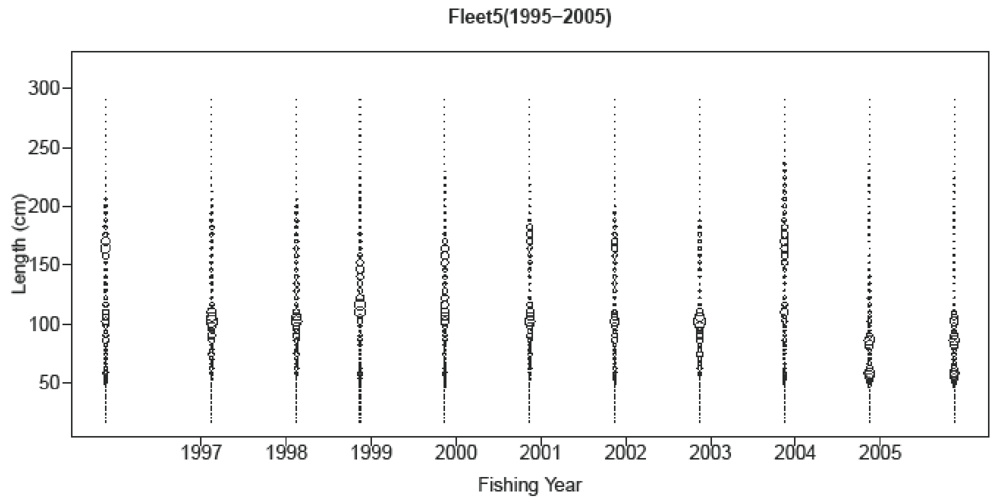
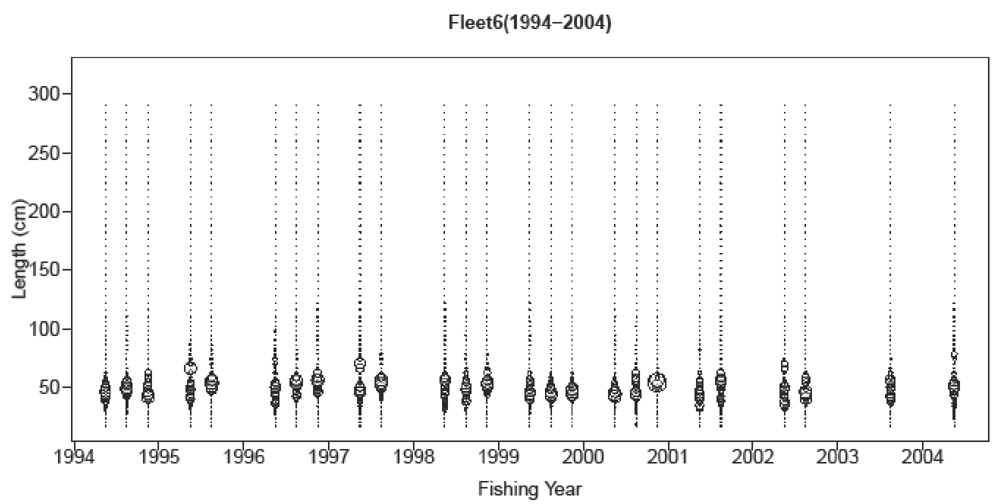


Figure 3-5. Cont.

d) Fleet 5


Fleet5(1995–2005)
Length (cm)
Fishing Year
300
250
200
150
100
50
1997
1998
1999
2000
2001
2002
2003
2004
2005

e) Fleet 6


Fleet6(1994–2004)
Length (cm)
Fishing Year
300
250
200
150
100
50
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004

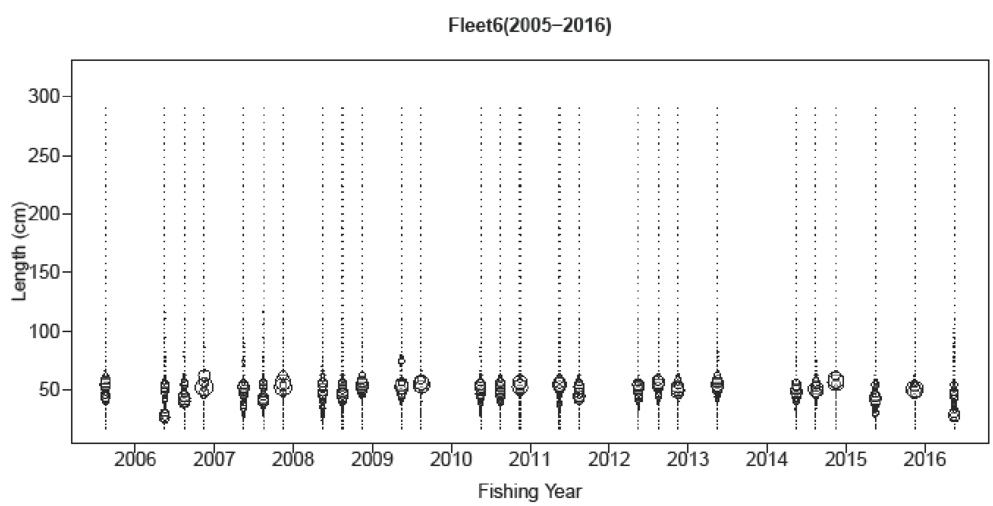
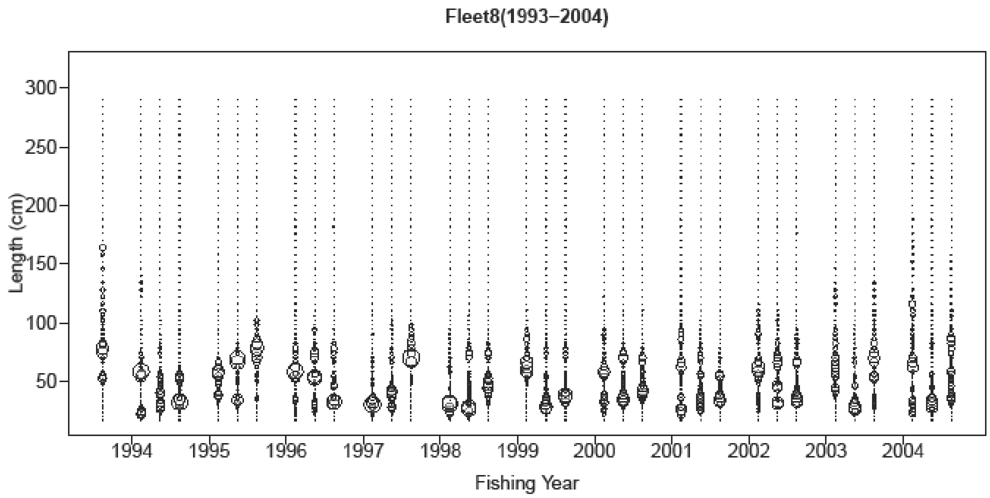
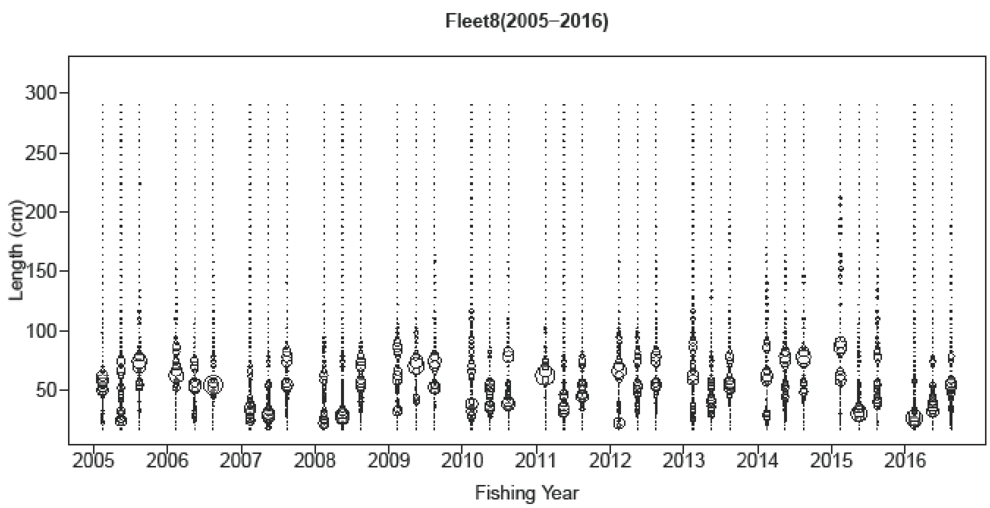

Fleet6(2005–2016)
Length (cm)
Fishing Year
300
250
200
150
100
50
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

Figure 3-5. Cont.

f) Fleet 8





g) Fleet 9

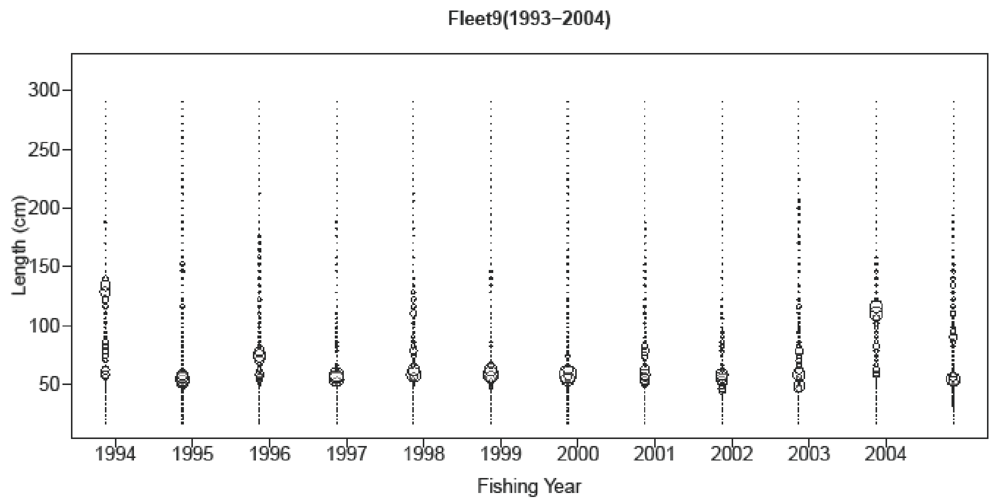
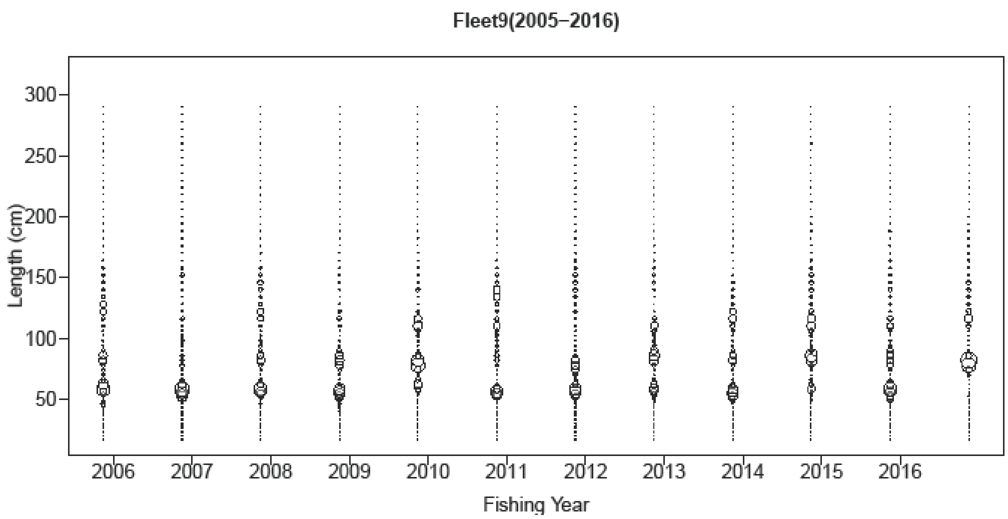


Figure 3-5. Cont.



h) Fleet 10

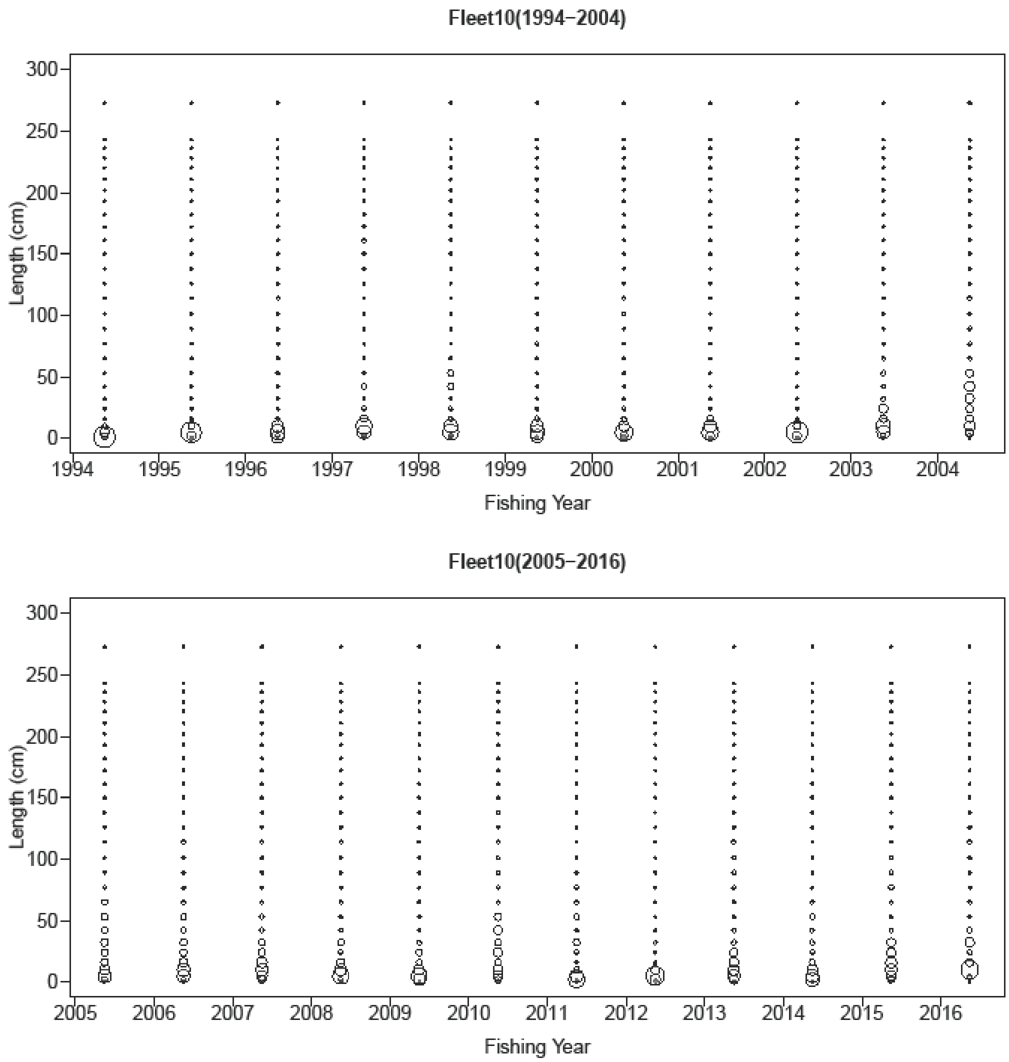
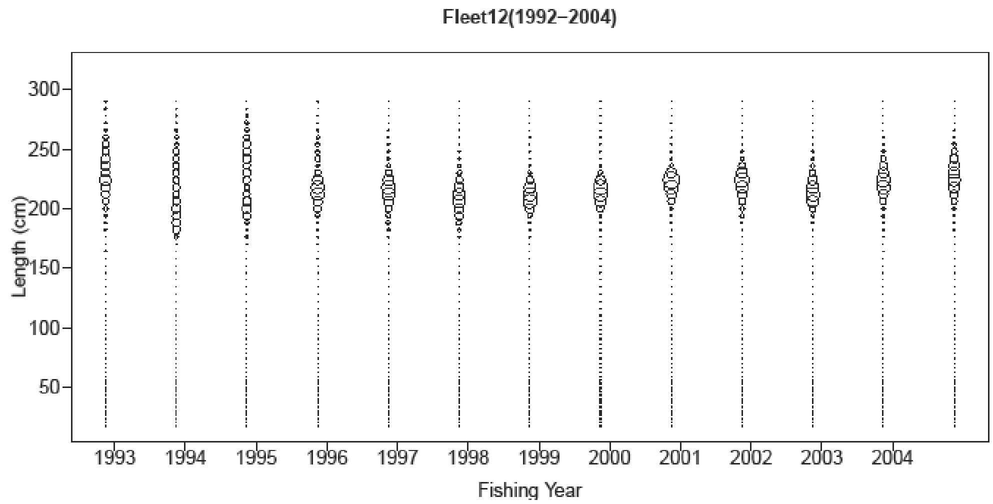
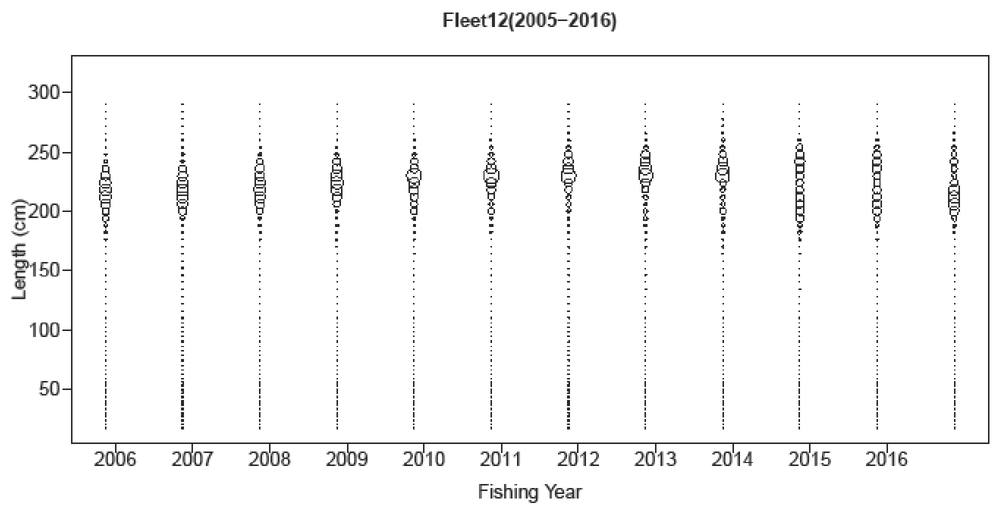


Figure 3-5. Cont.

i) Fleet 12


Fleet12(1992–2004)
Length (cm)
300
250
200
150
100
50
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
Fishing Year


Fleet12(2005–2016)
Length (cm)
300
250
200
150
100
50
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
Fishing Year

j) Fleet 13

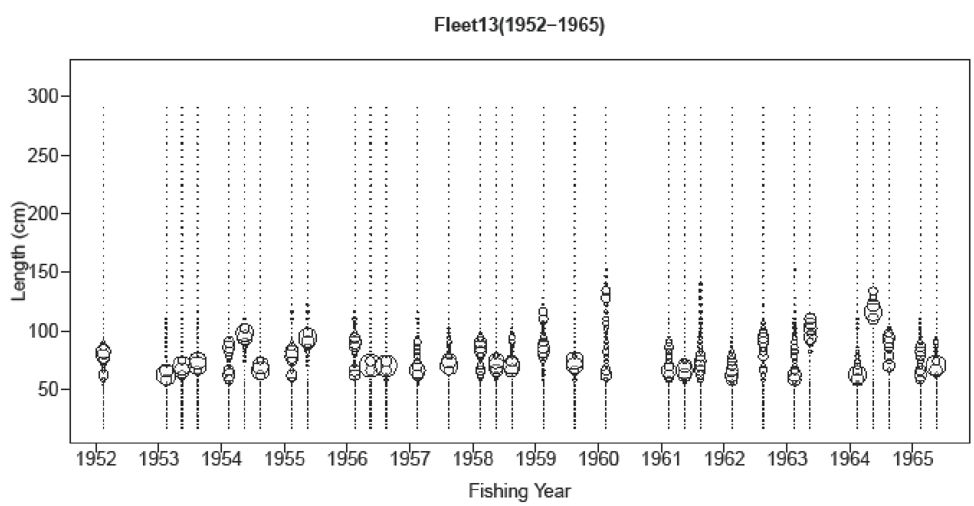
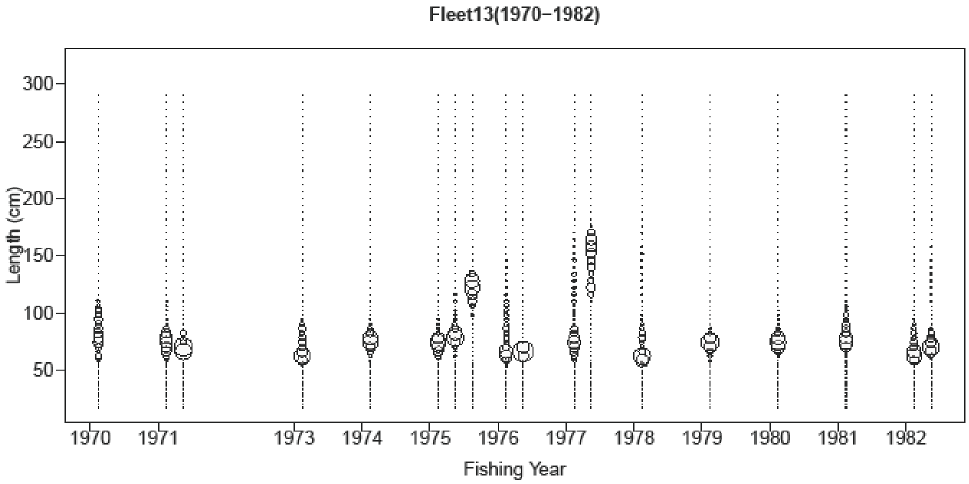
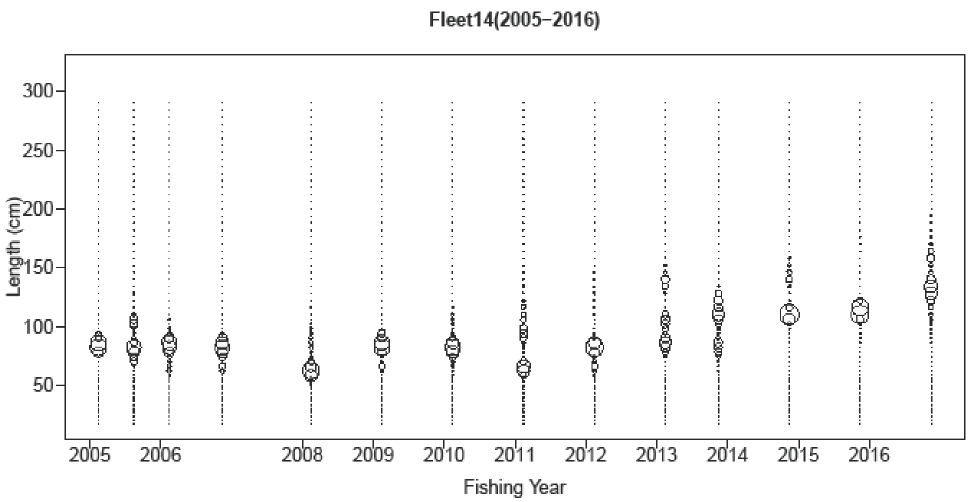

Fleet13(1952–1965)
Length (cm)
300
250
200
150
100
50
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
Fishing Year

Figure 3-5. Cont.



k) Fleet 14



l) Fleet 17

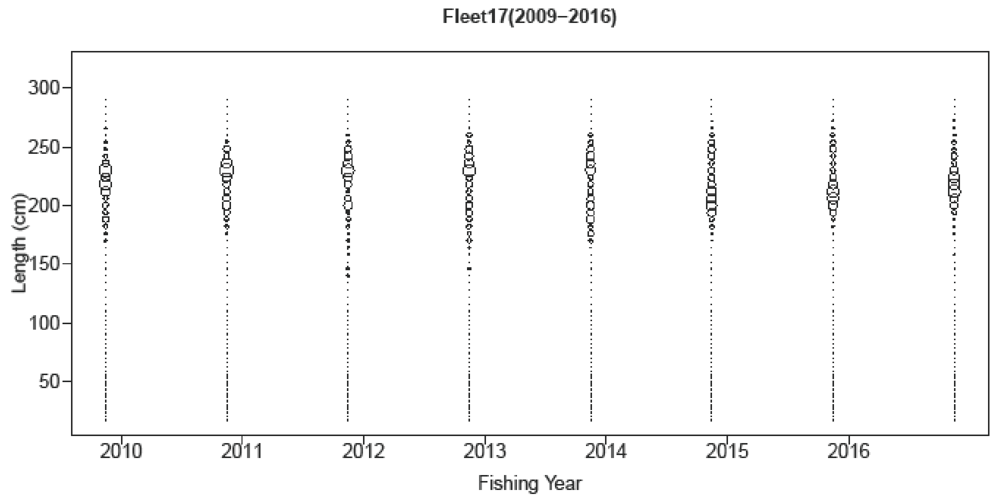
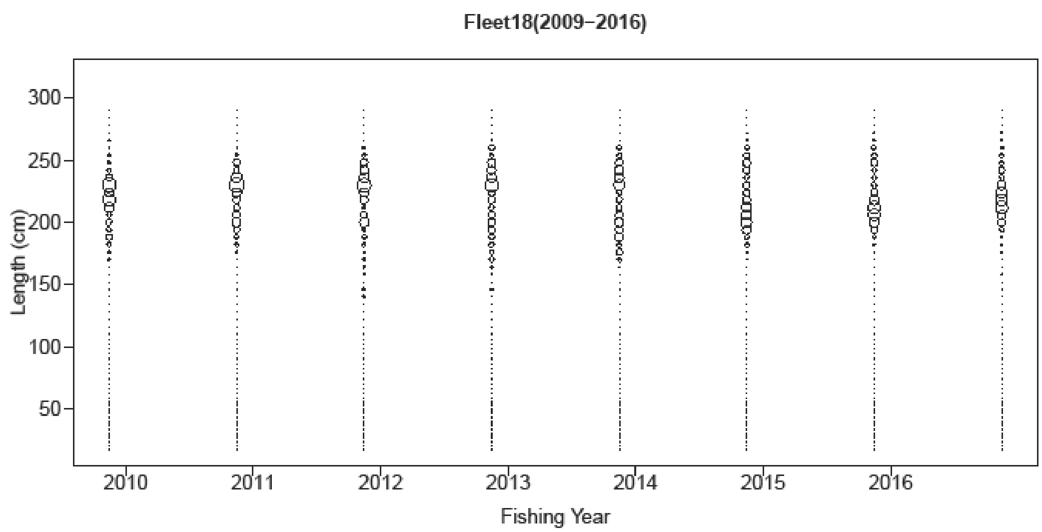


Figure 3-5. Cont.

m) Fleet 18



n) Fleet 19

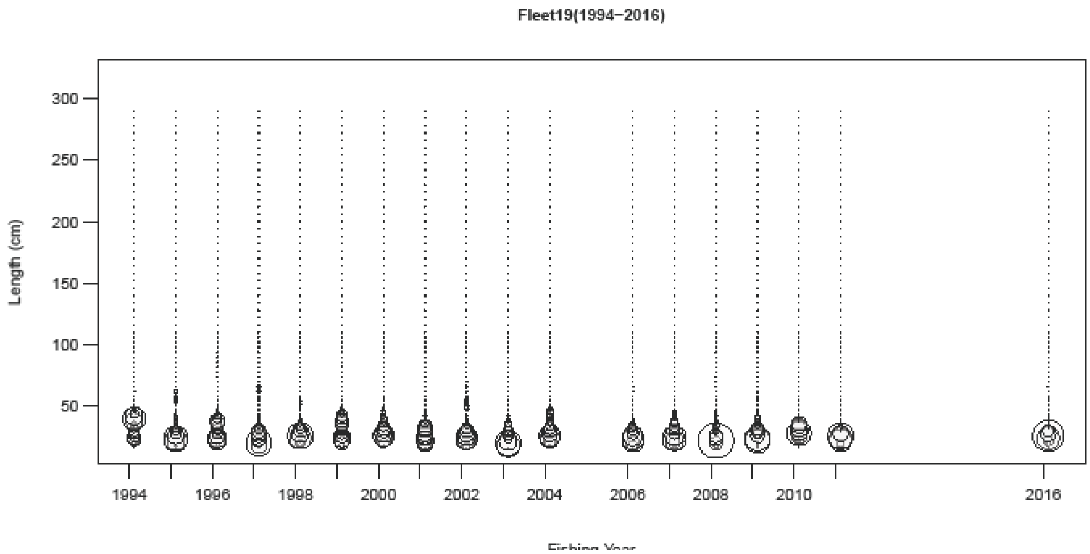


Figure 3-5. Cont.

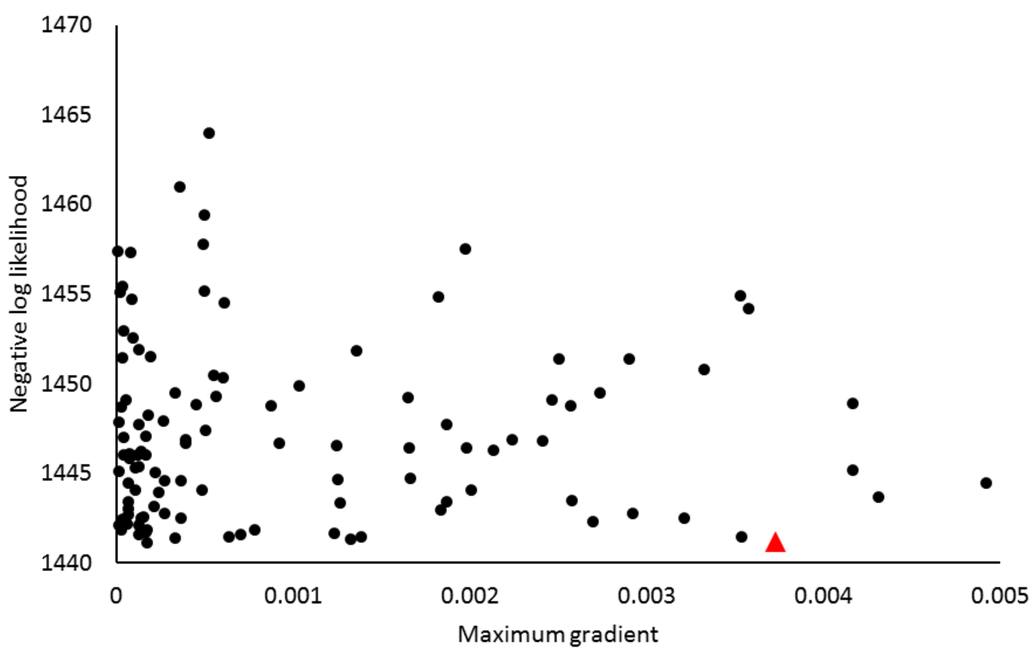


Figure 5-1. Effects of random perturbations of initial values and phasing on maximum gradient and total likelihood by the base-case model for Pacific bluefin tuna (*Thunnus orientalis*). Red triangle represents the value of the base-case model.

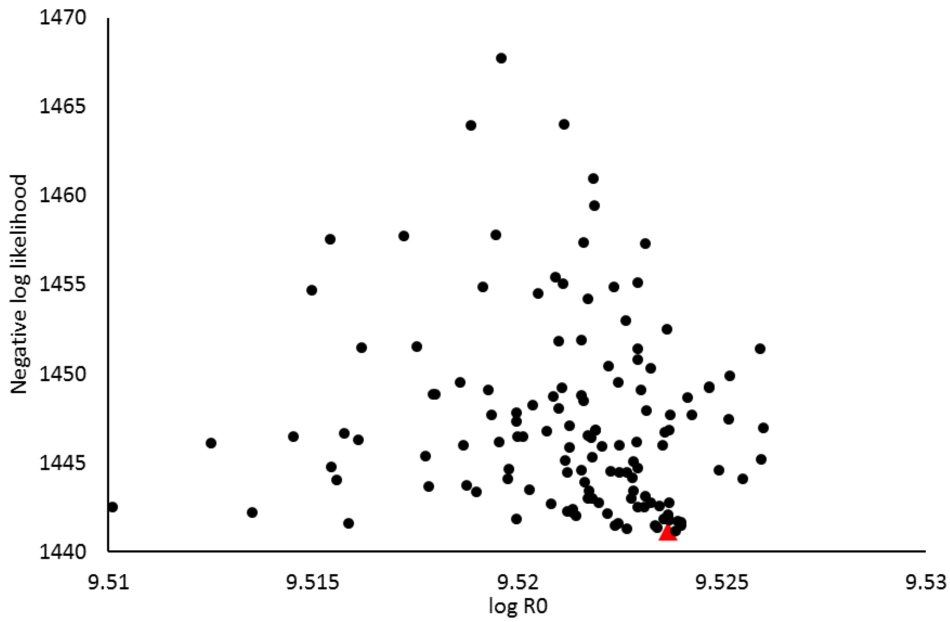


Figure 5-2. Effects of random perturbations of initial values and phasing on log(R_0) and total likelihood by the base-case model for Pacific bluefin tuna (*Thunnus orientalis*). Red triangle represents the value of the base-case model.

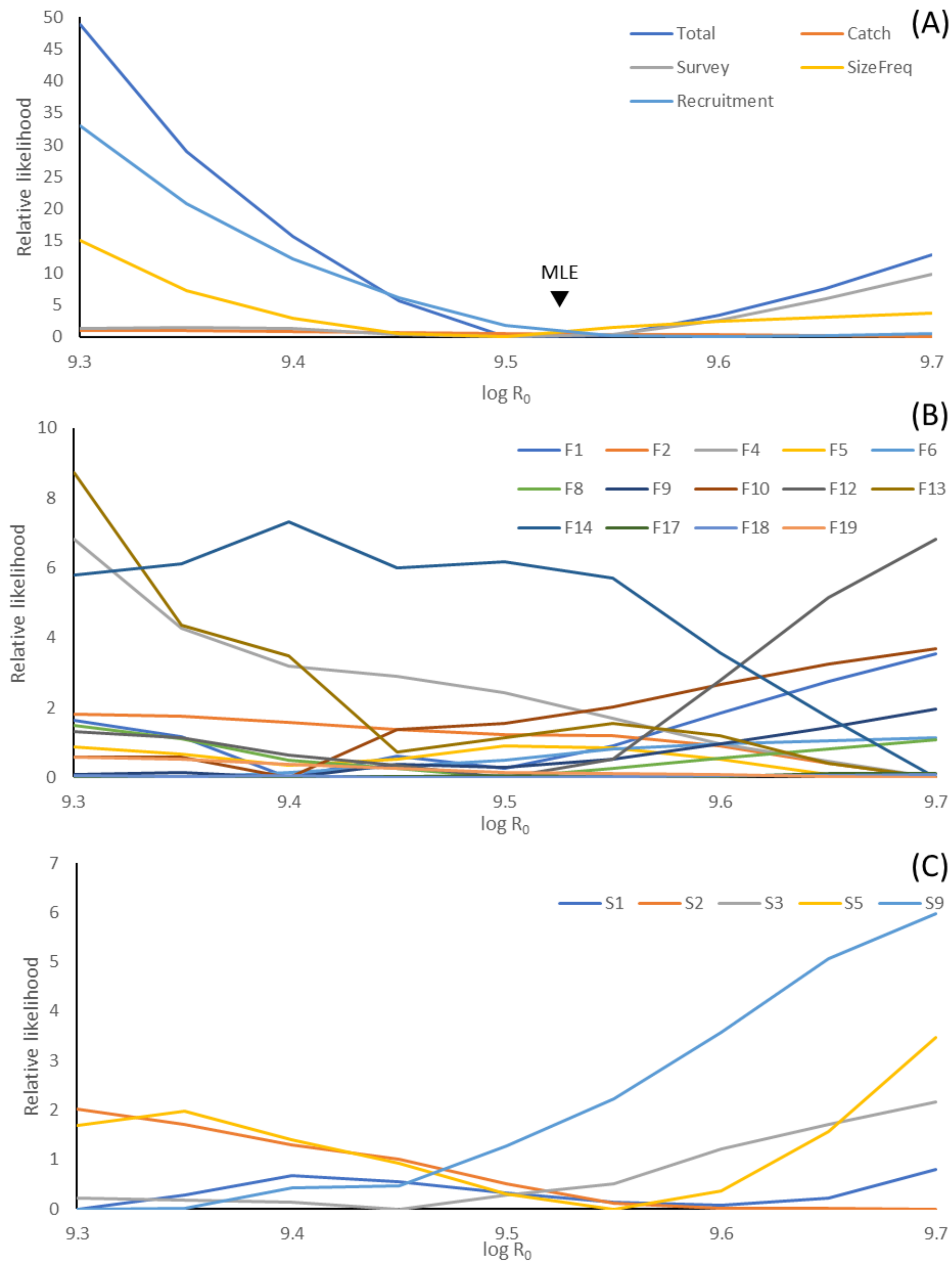


Figure 5-3. Profiles of (A) total and component likelihoods (B) likelihood for each size composition component and (C) likelihood for each index component over fixed log(R_0) for the base-case model of Pacific bluefin tuna (*Thunnus orientalis*).

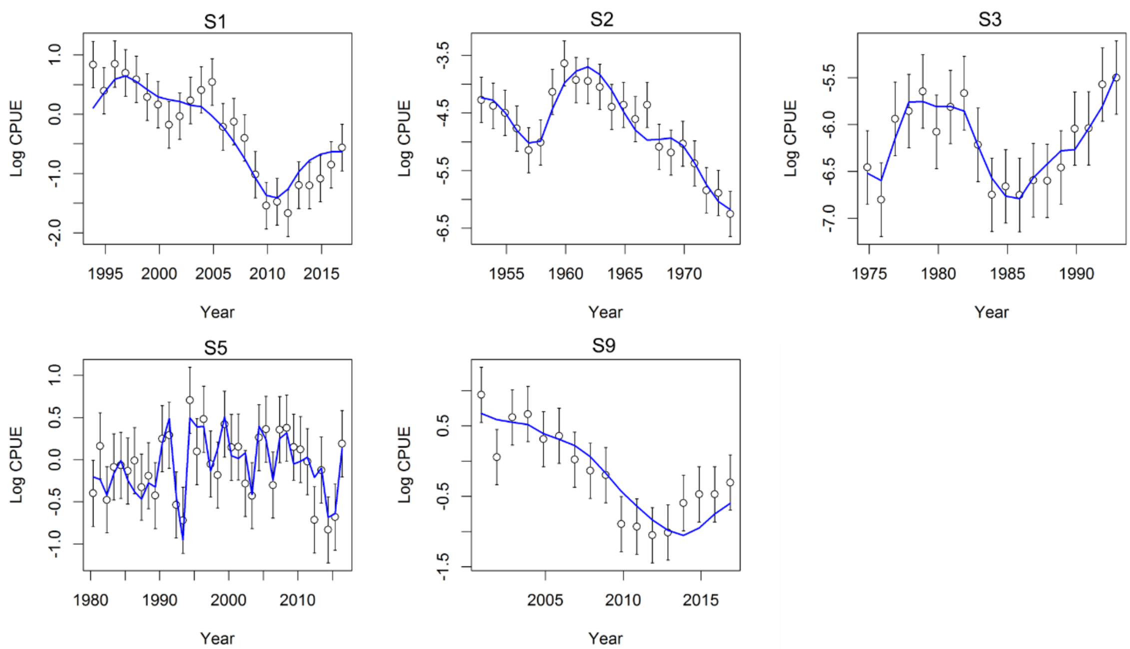


Figure 5-4. Predicted (blue lines) and observed (open dots) abundance indices by fishery for the base-case model of Pacific bluefin tuna (*Thunnus orientalis*), where vertical lines represent the 95% CI of observations.

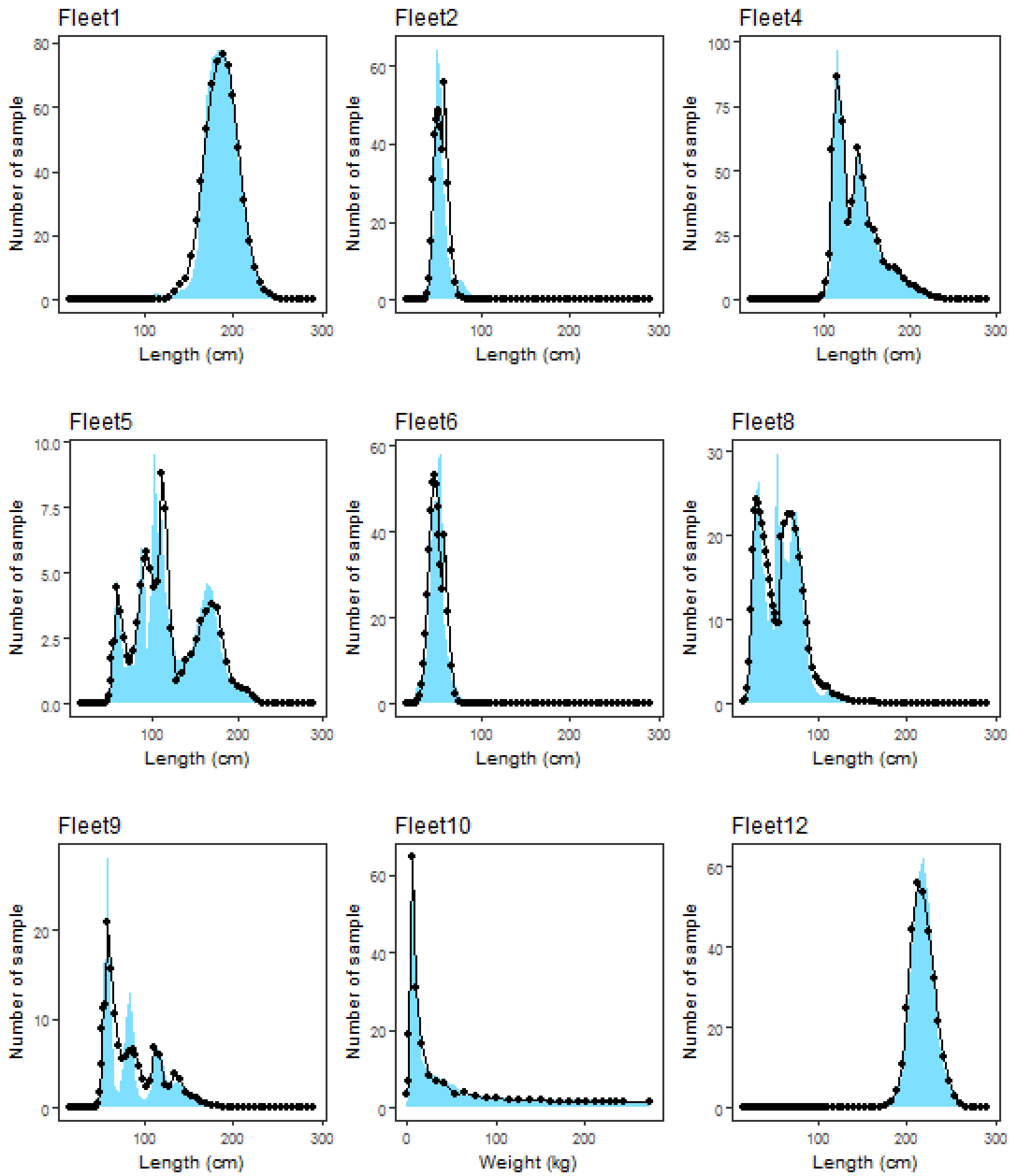


Figure 5-5. Overall fits (black lines with dots) to the size compositions by fleet across seasons in the base-case model for Pacific bluefin tuna (*Thunnus orientalis*), where blue areas indicate the observations.

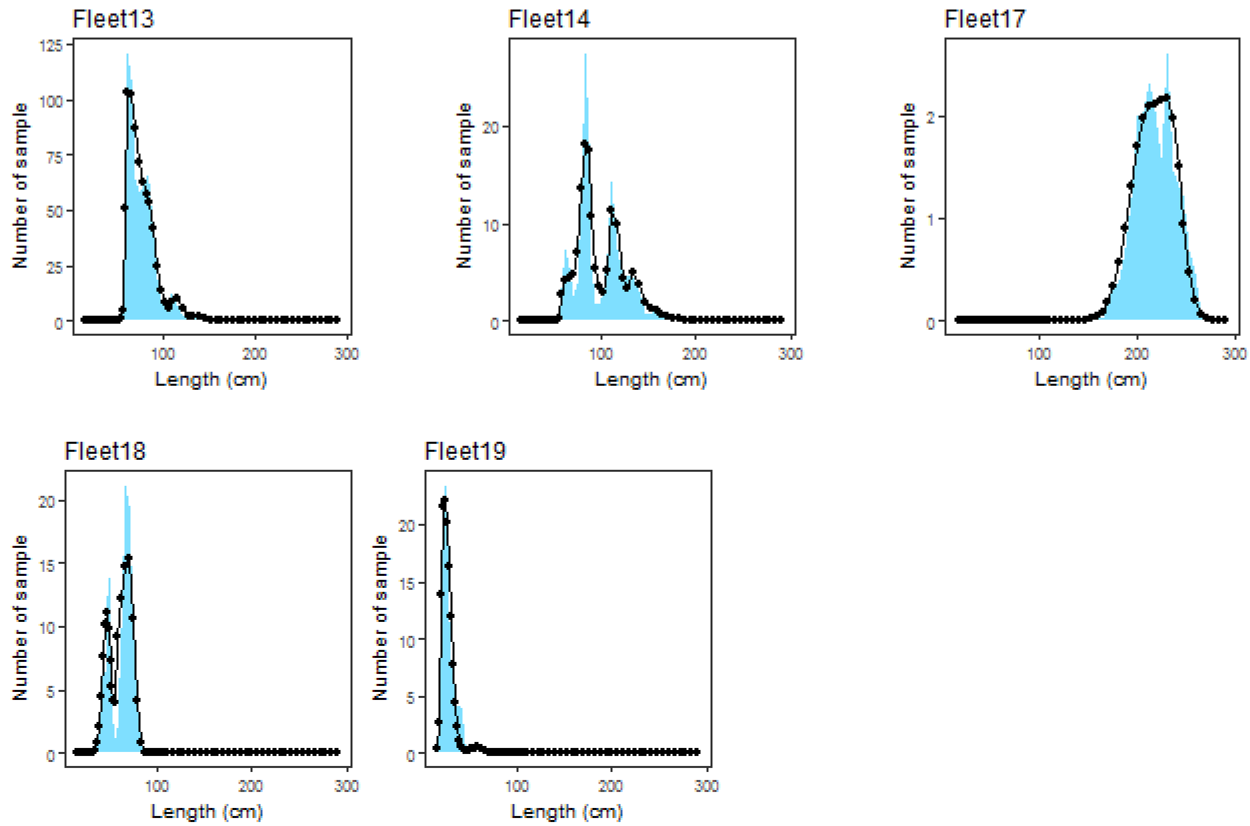


Figure 5-5. Cont.

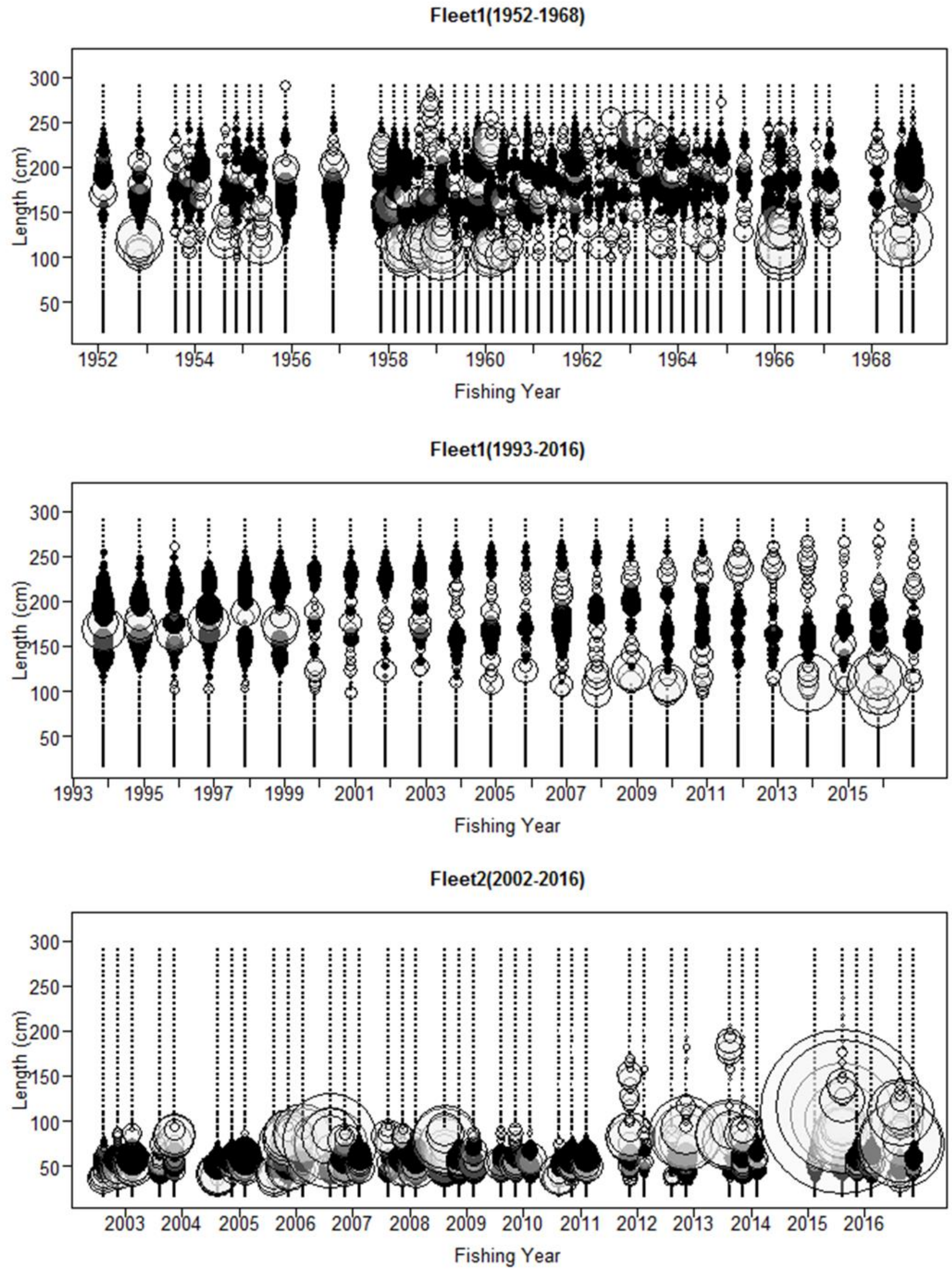


Figure 5-6. Pearson residual plots of model fits to the size composition data of Pacific bluefin tuna (*Thunnus orientalis*) by fishery. The hollow and filled circles represent observations that are higher and lower than the model predictions, respectively. The areas of the circles are proportional to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

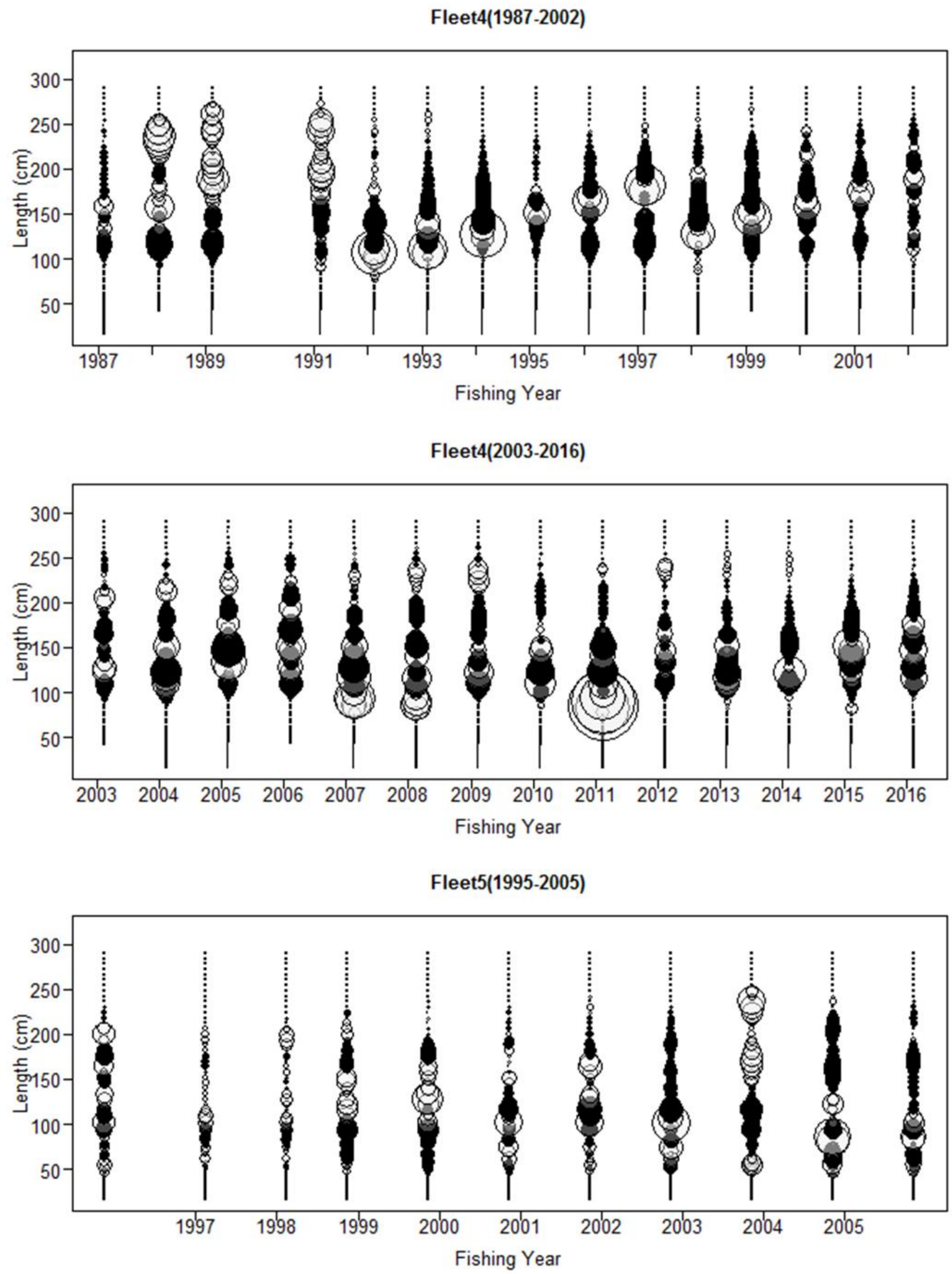


Figure 5-6. Cont.

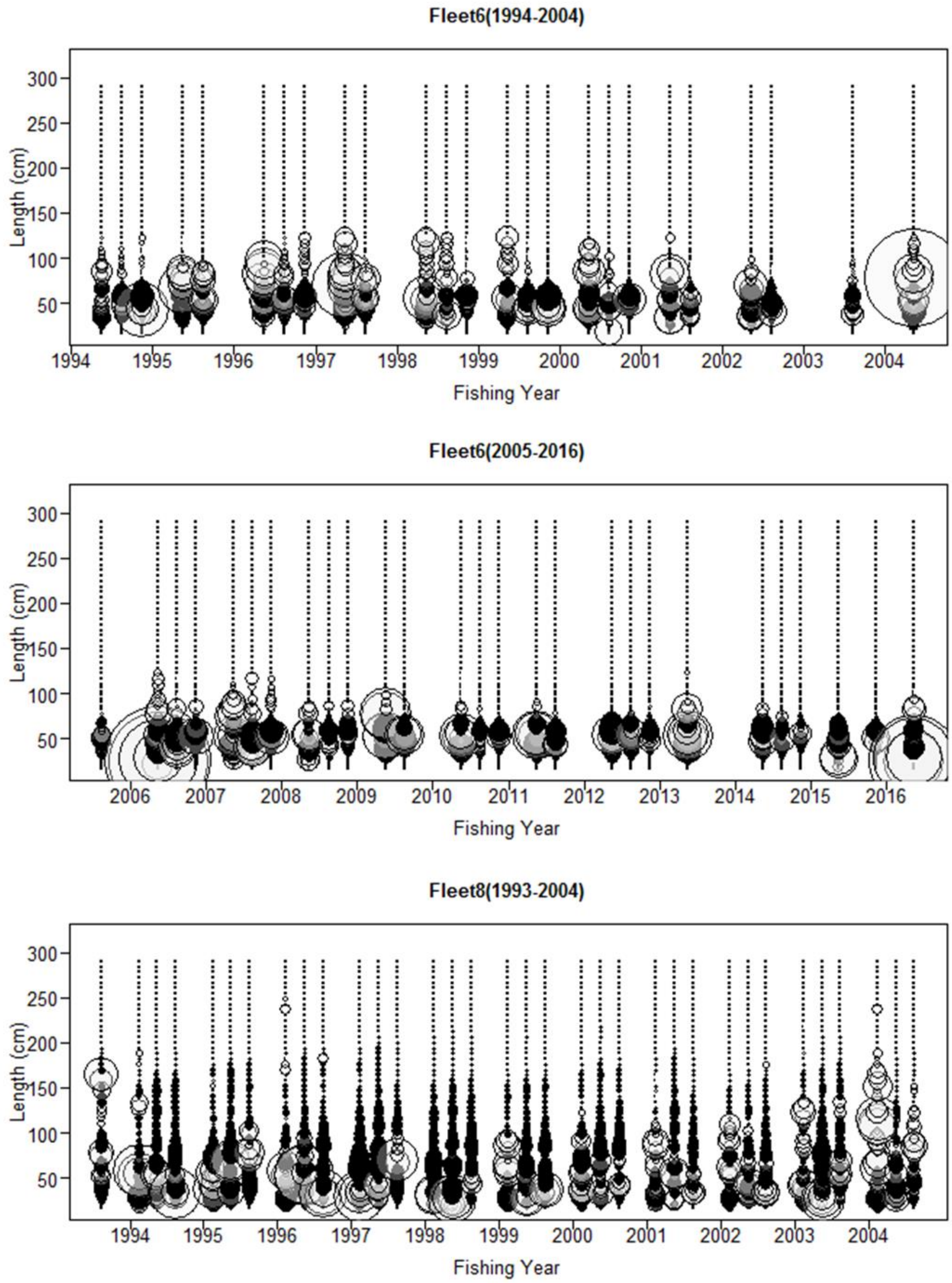


Figure 5-6. Cont.

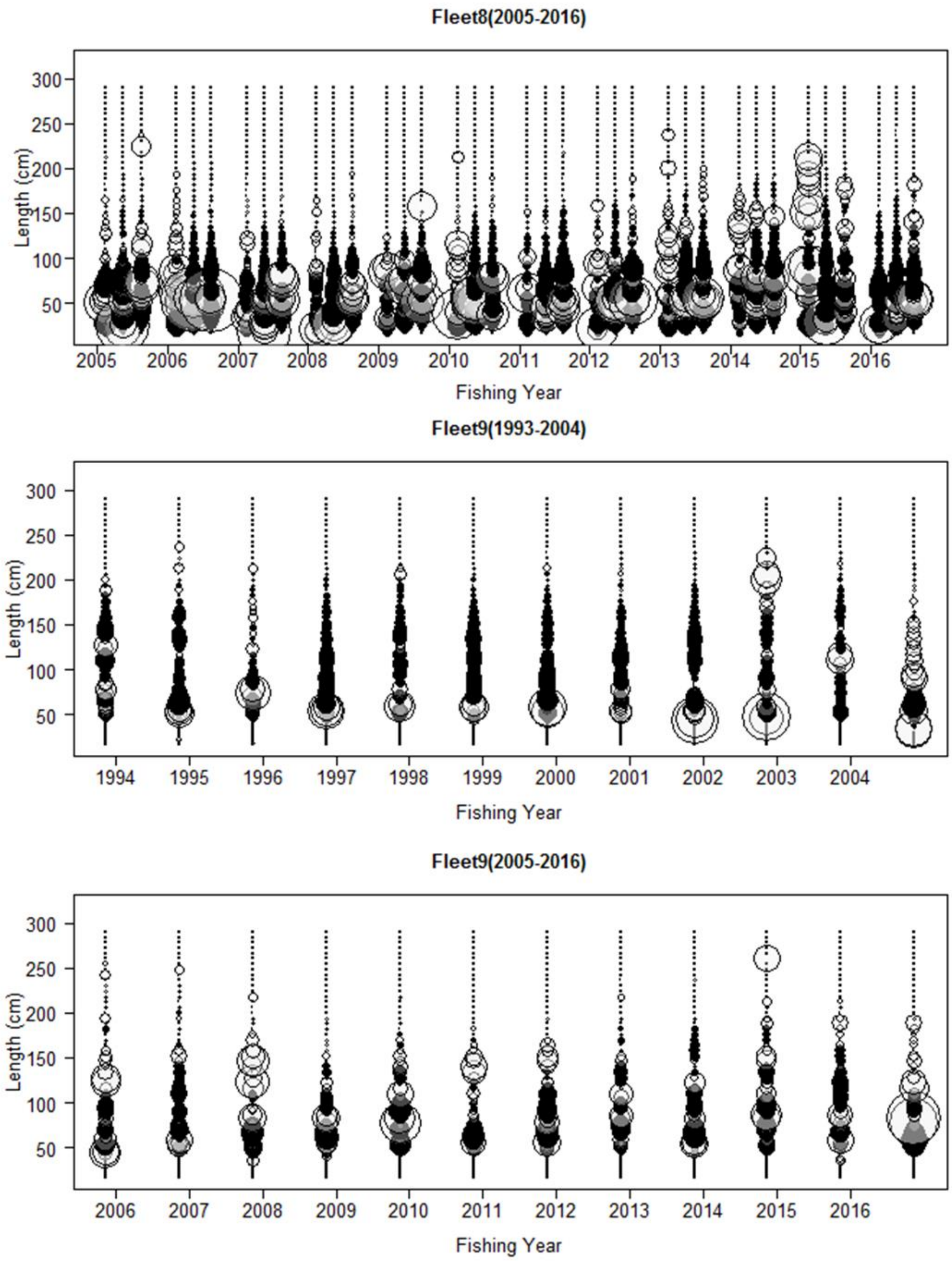


Figure 5-6. Cont.

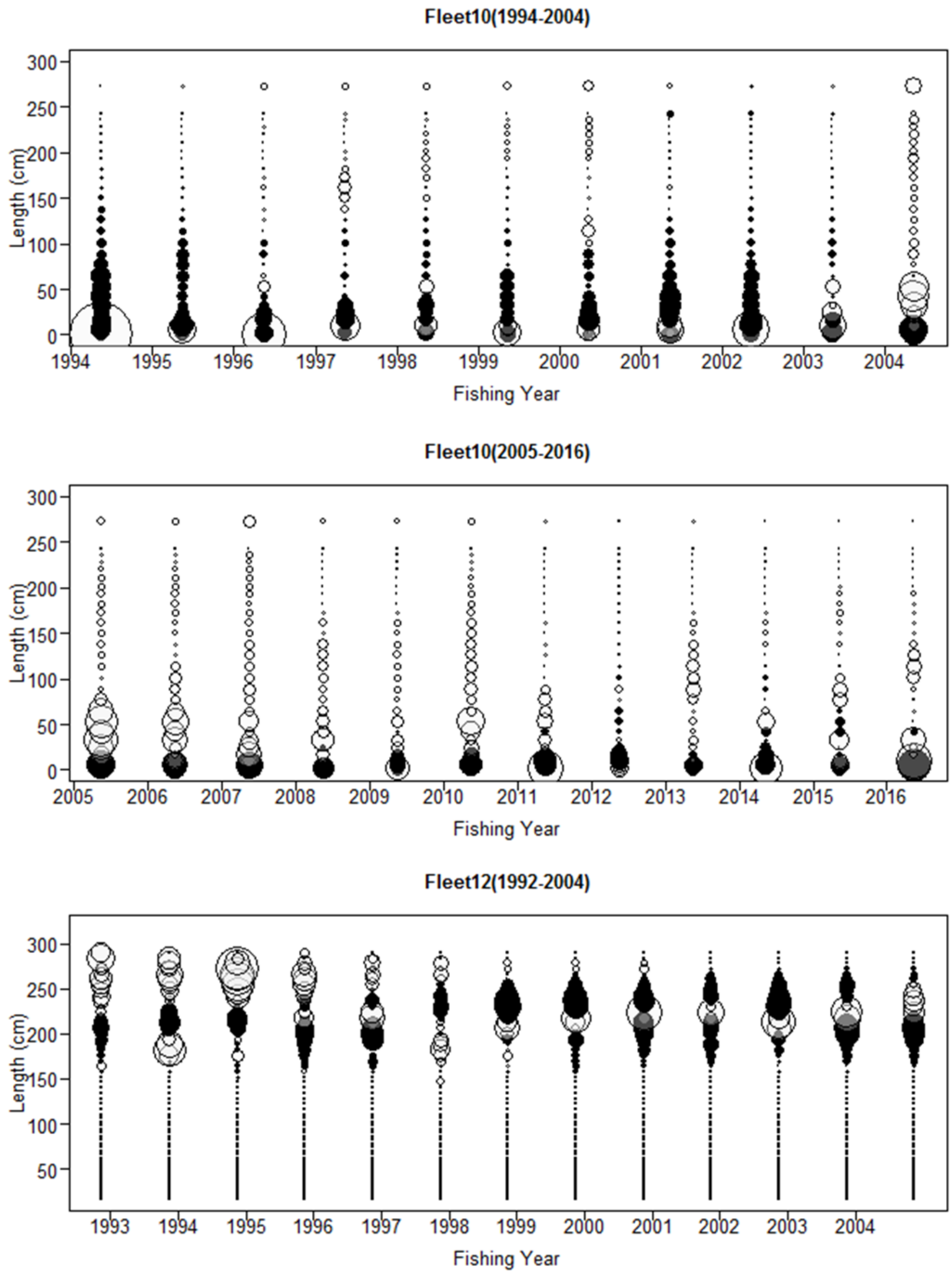
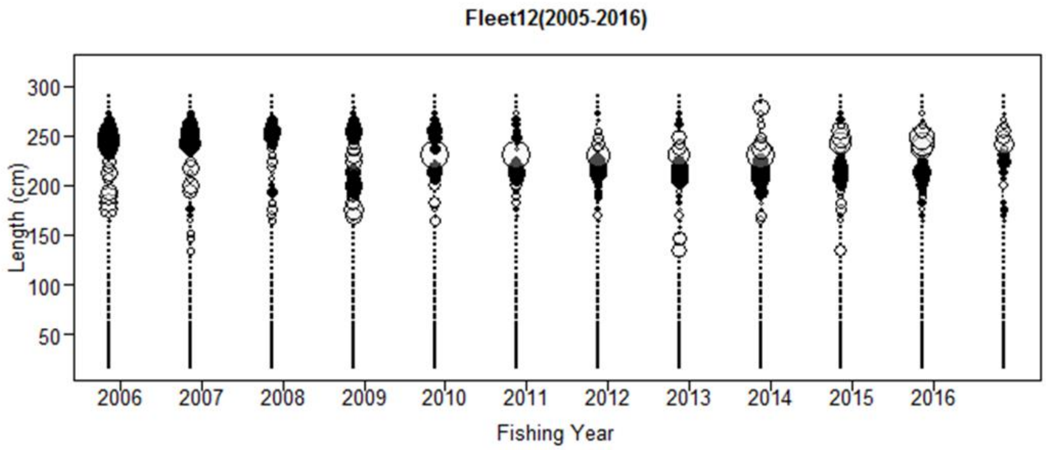
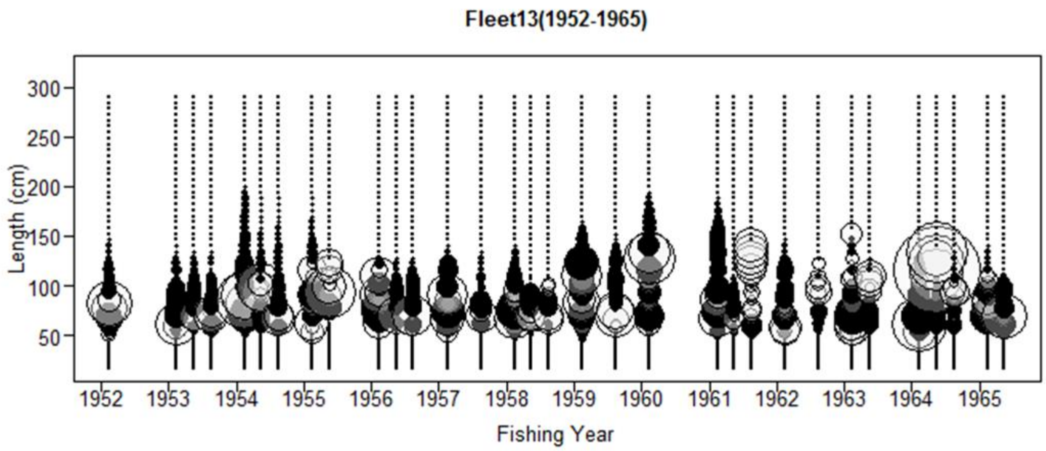


Figure 5-6. Cont.





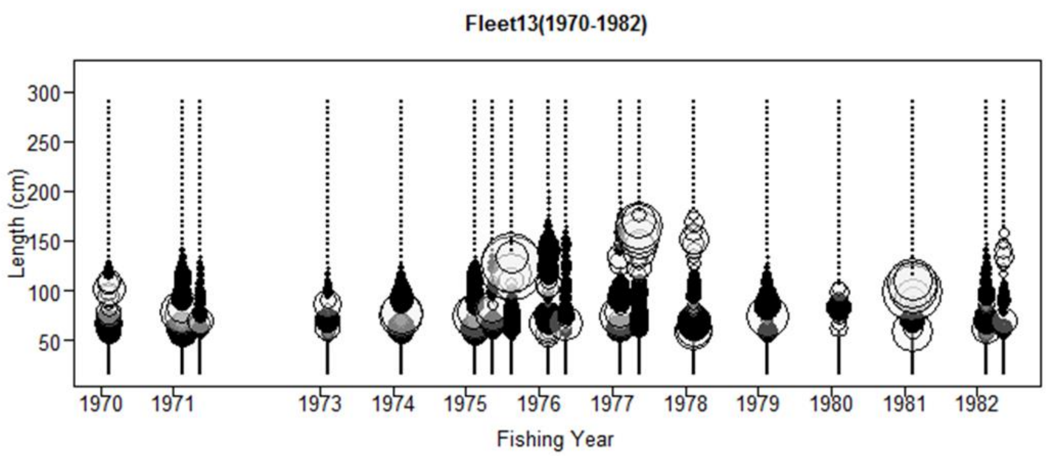


Figure 5-6. Cont.

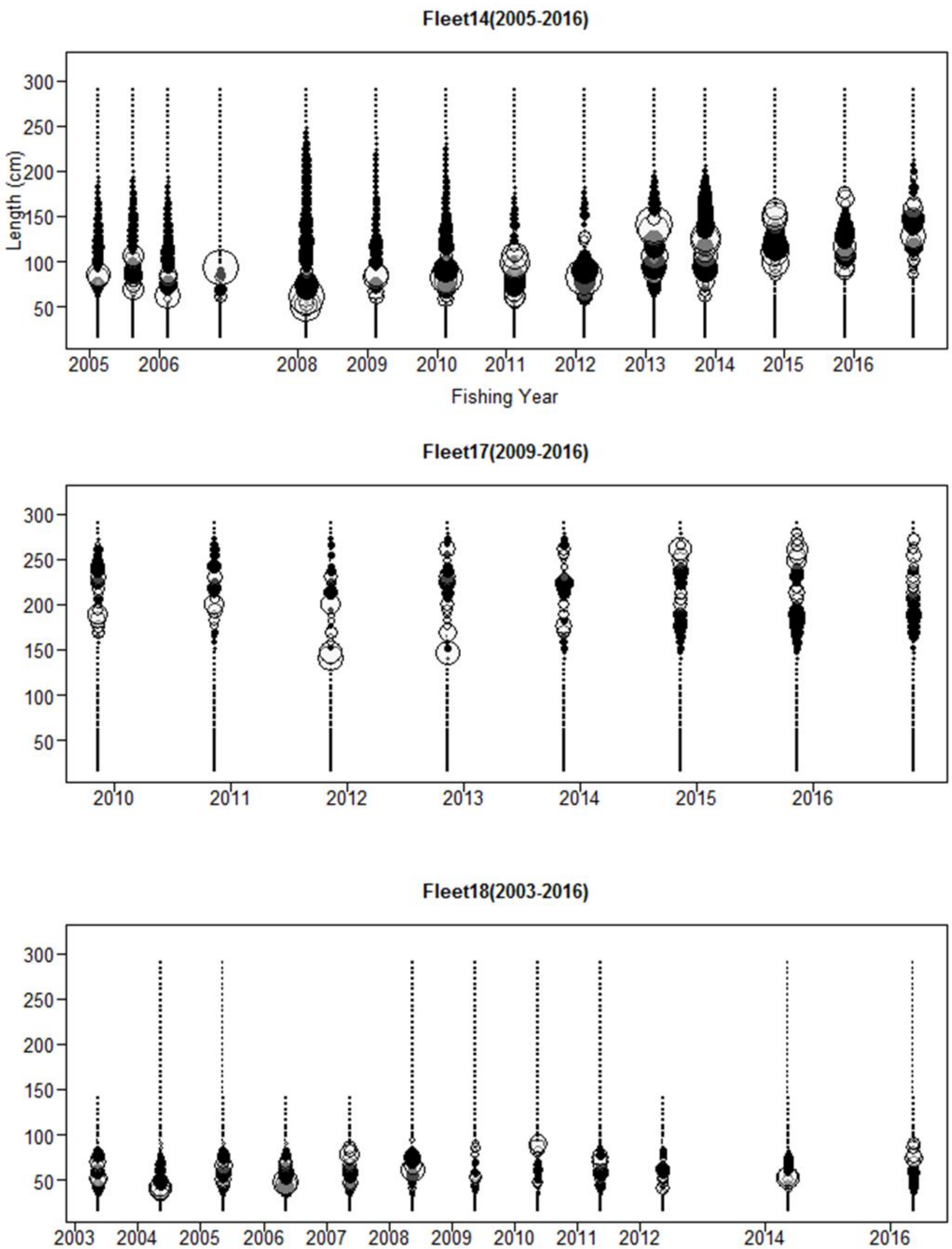


Figure 5-6. Cont.

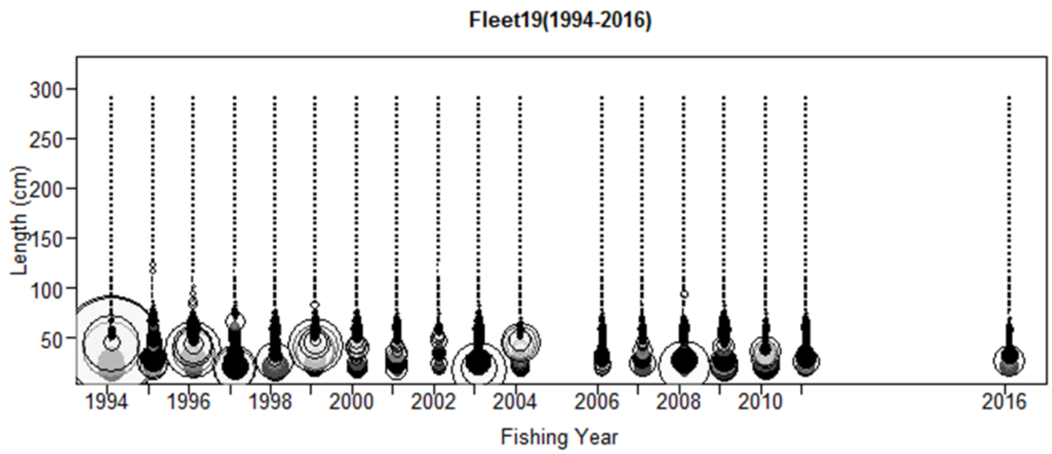


Figure 5-6. Cont.

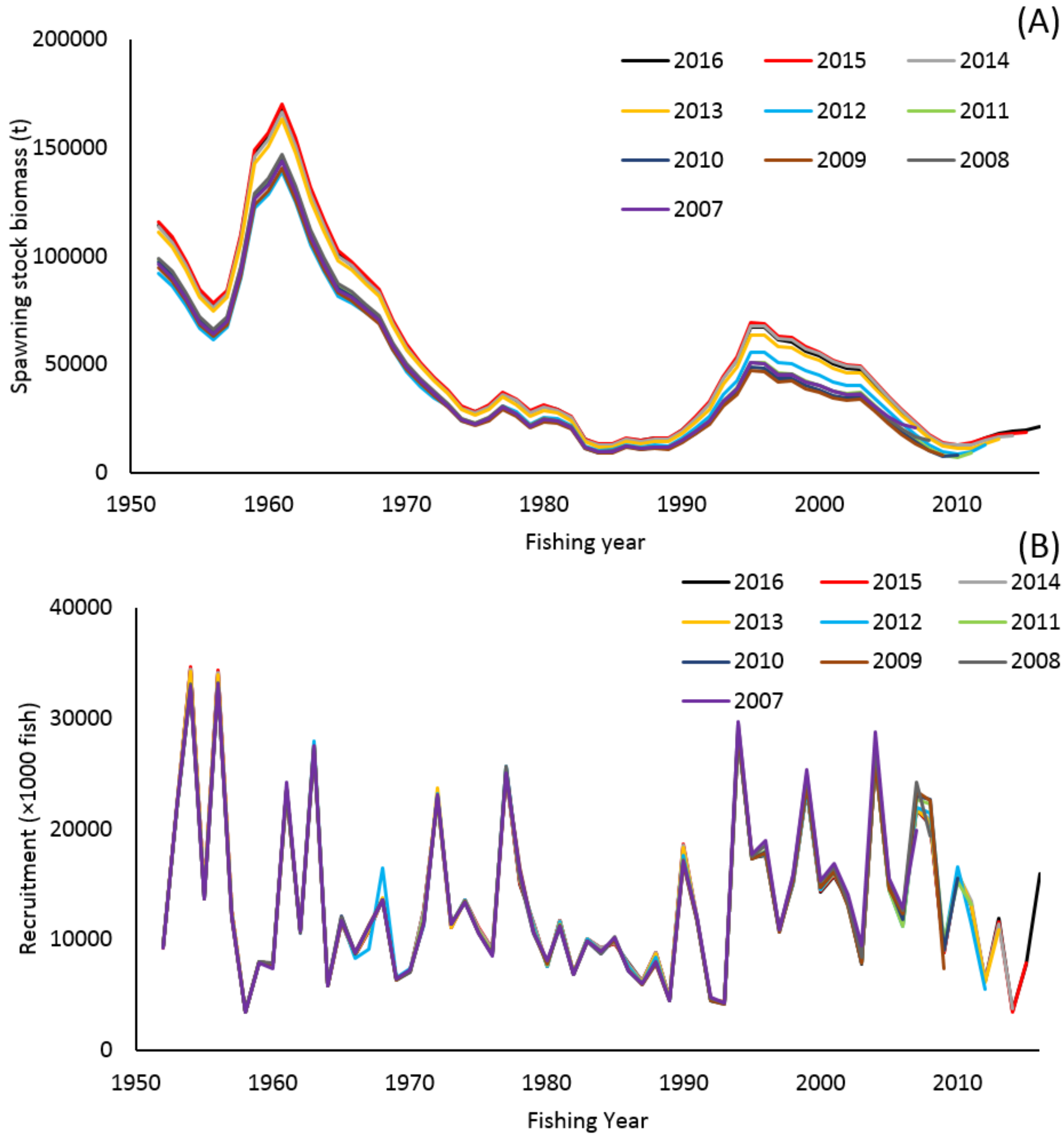


Figure 5-7. Nine-year retrospective analysis of the (A) spawning stock biomass and (B) Recruitment of Pacific bluefin tuna (*Thunnus orientalis*).

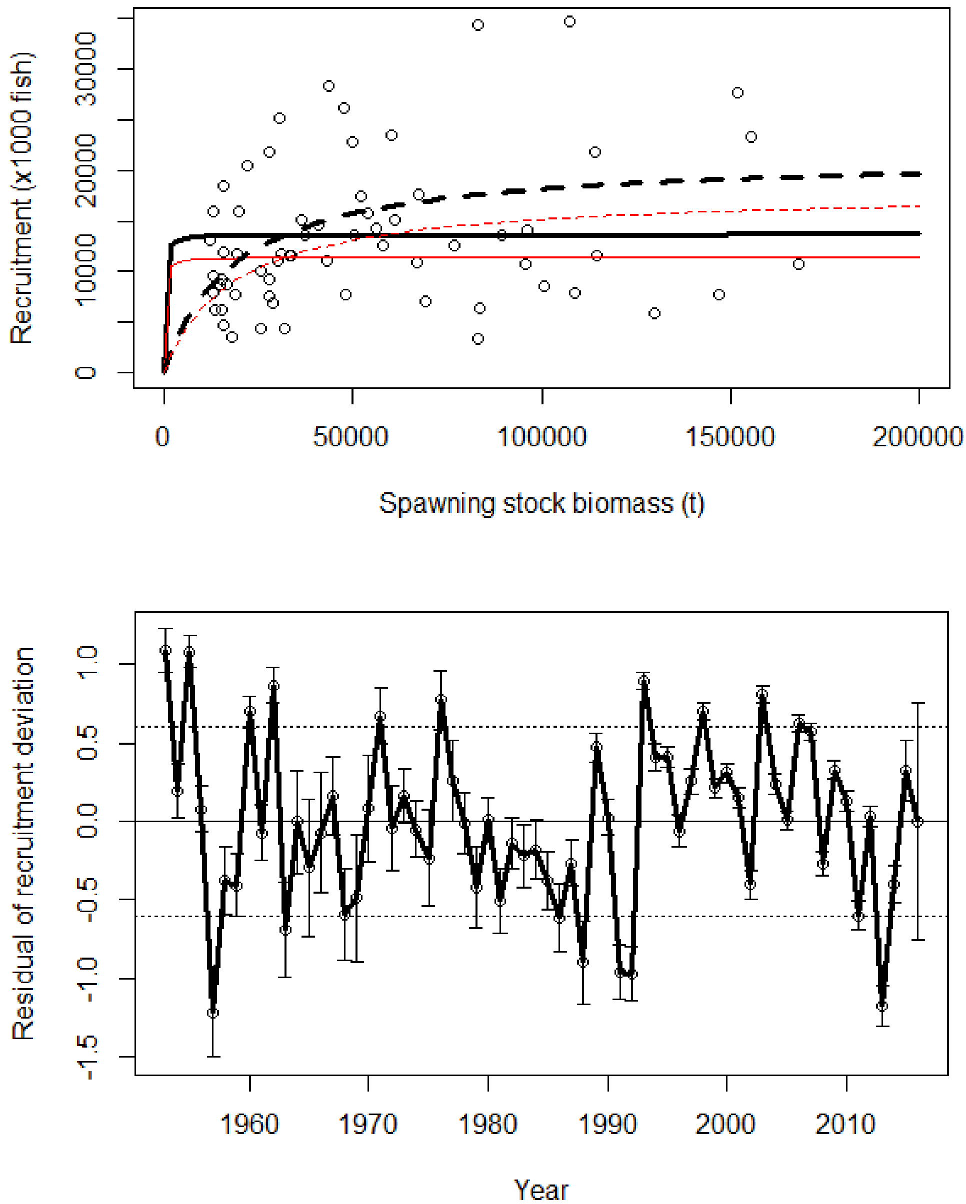


Figure 5-8. Time series of recruitment deviations in log space (upper panel) and spawning stock-recruitment relationship (lower panel) in the base-case stock assessment model for Pacific bluefin tuna (*Thunnus orientalis*). In the upper panel, open circles are the estimated recruitment deviations, vertical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

expected recruitment after bias adjustment corresponding to above two relationships.

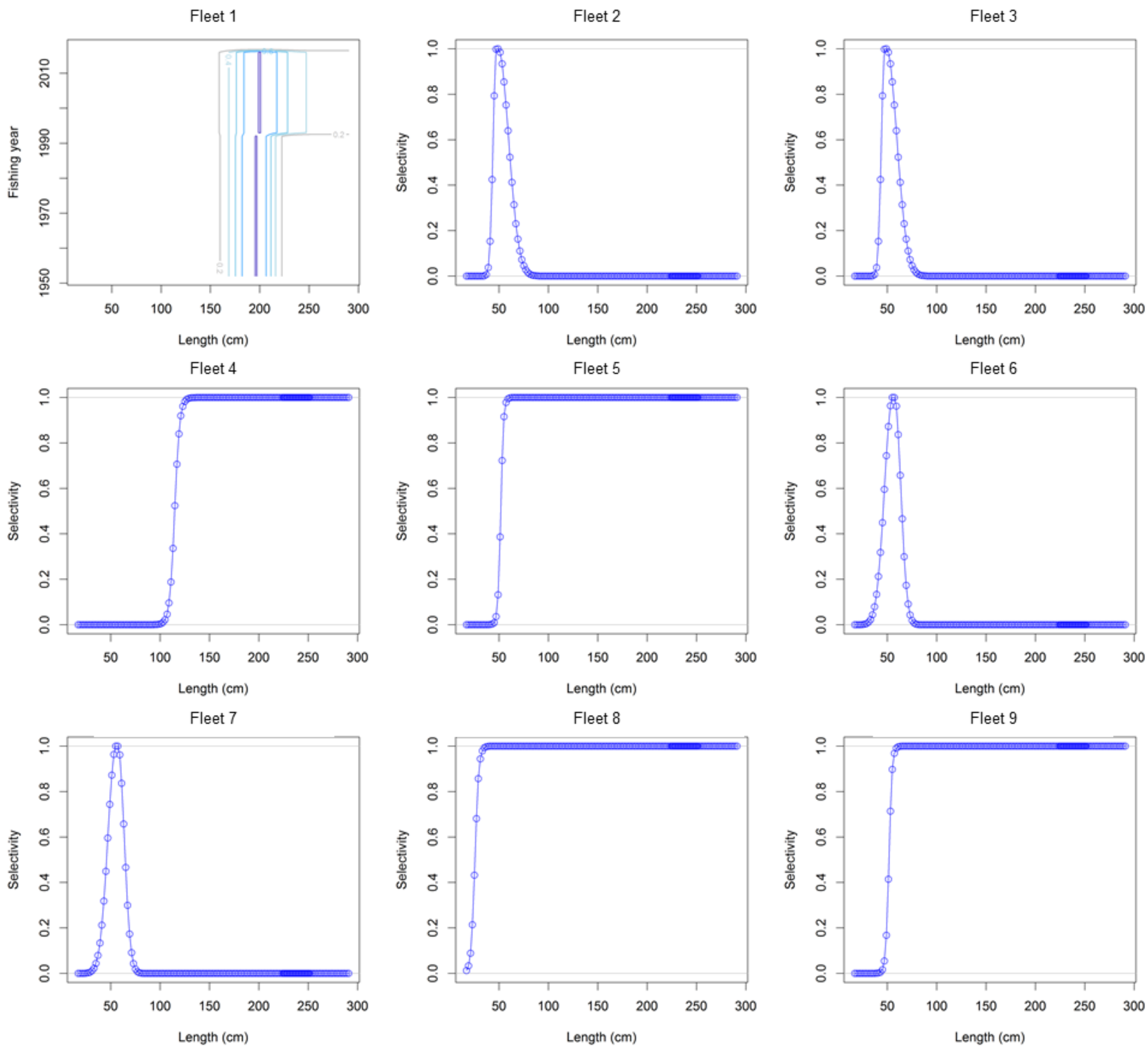


Figure 5-9. Size selectivity for Pacific bluefin tuna (*Thunnus orientalis*) by fishery. Fisheries with time-varying selectivity patterns are displayed in contour plots.

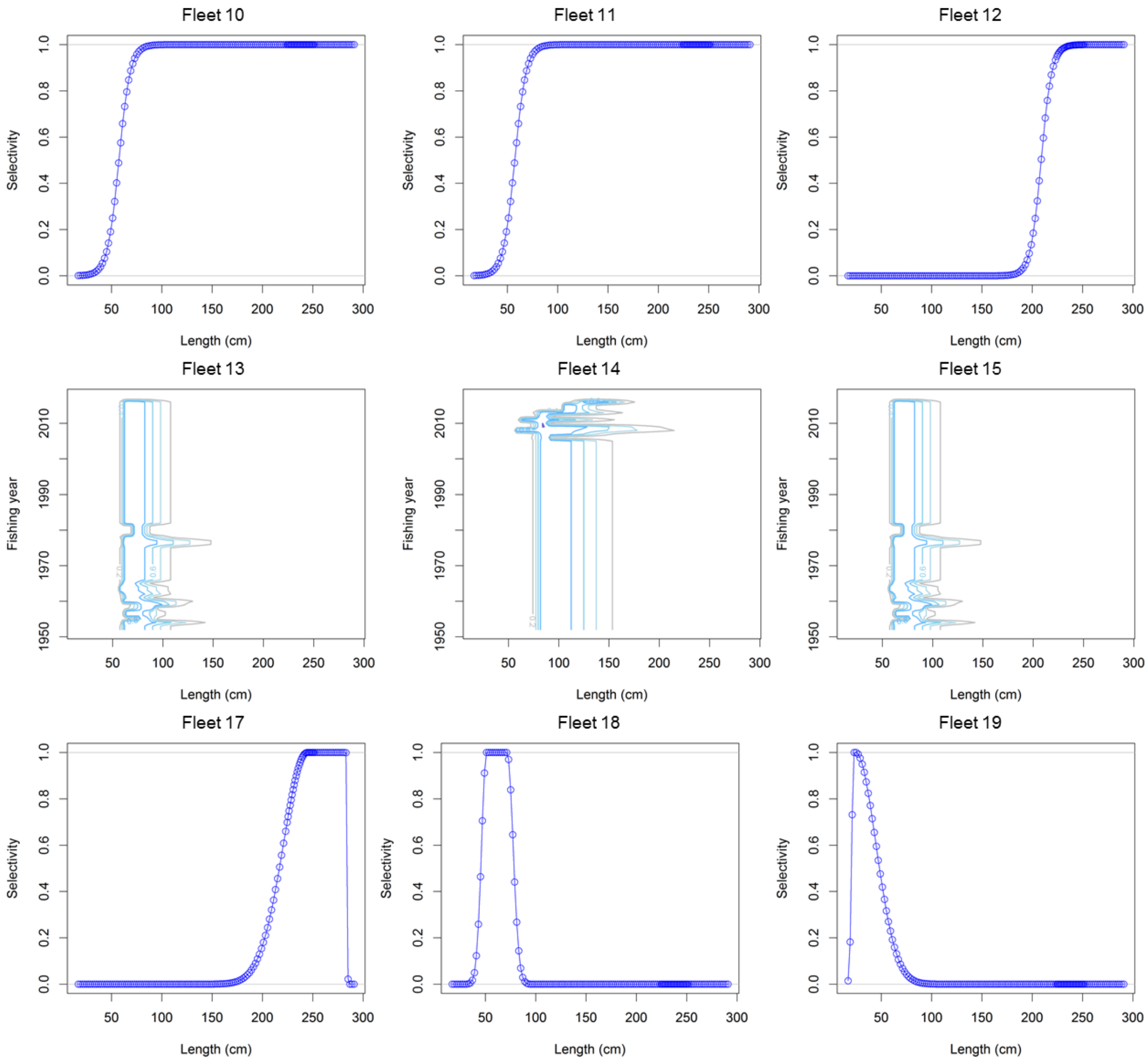


Figure 5-9. Cont.

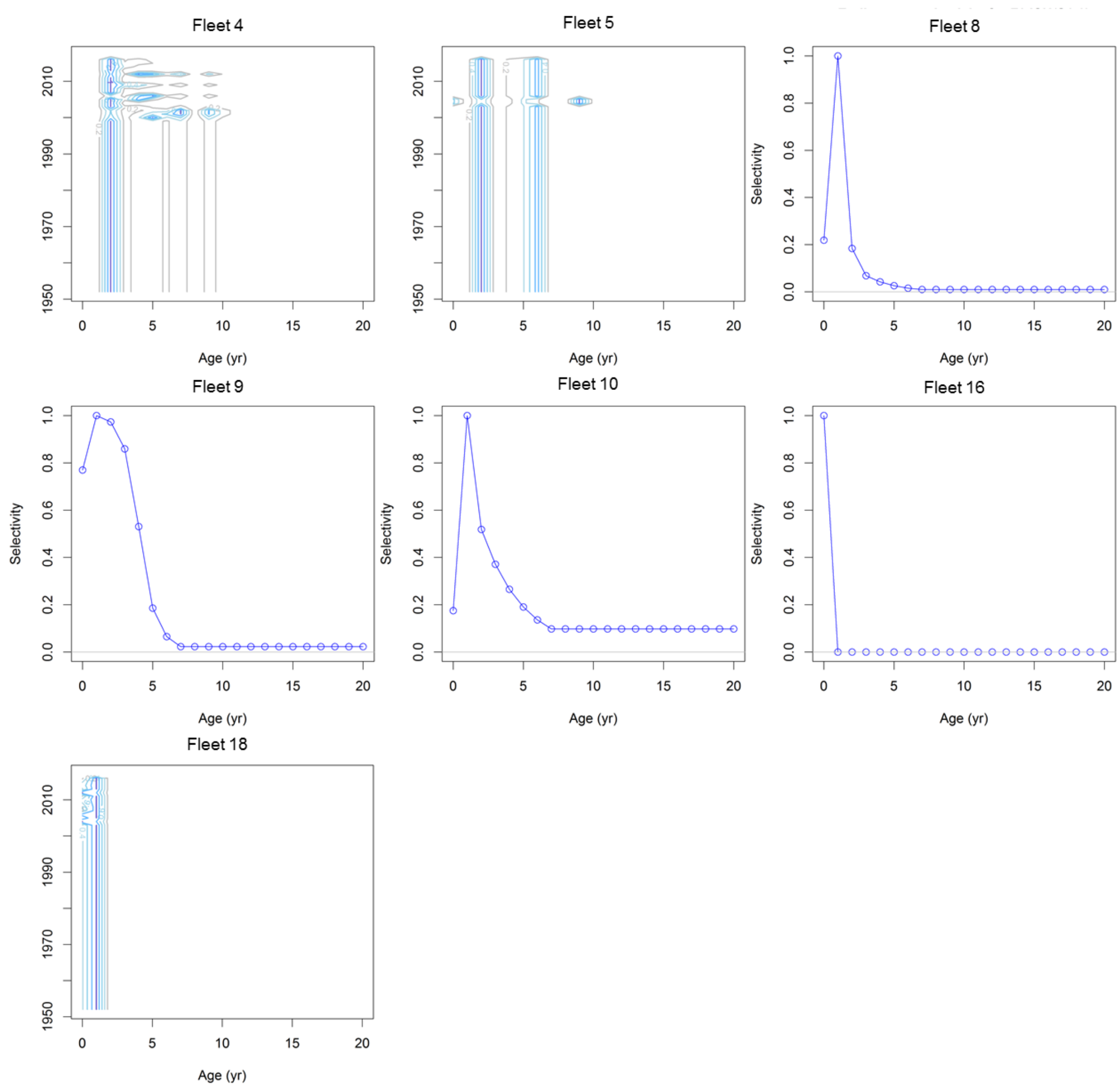


Figure 5-10. Age selectivity for Pacific bluefin tuna (*Thunnus orientalis*) by fishery. Fisheries with time-varying selectivity patterns are displayed in contour plots.

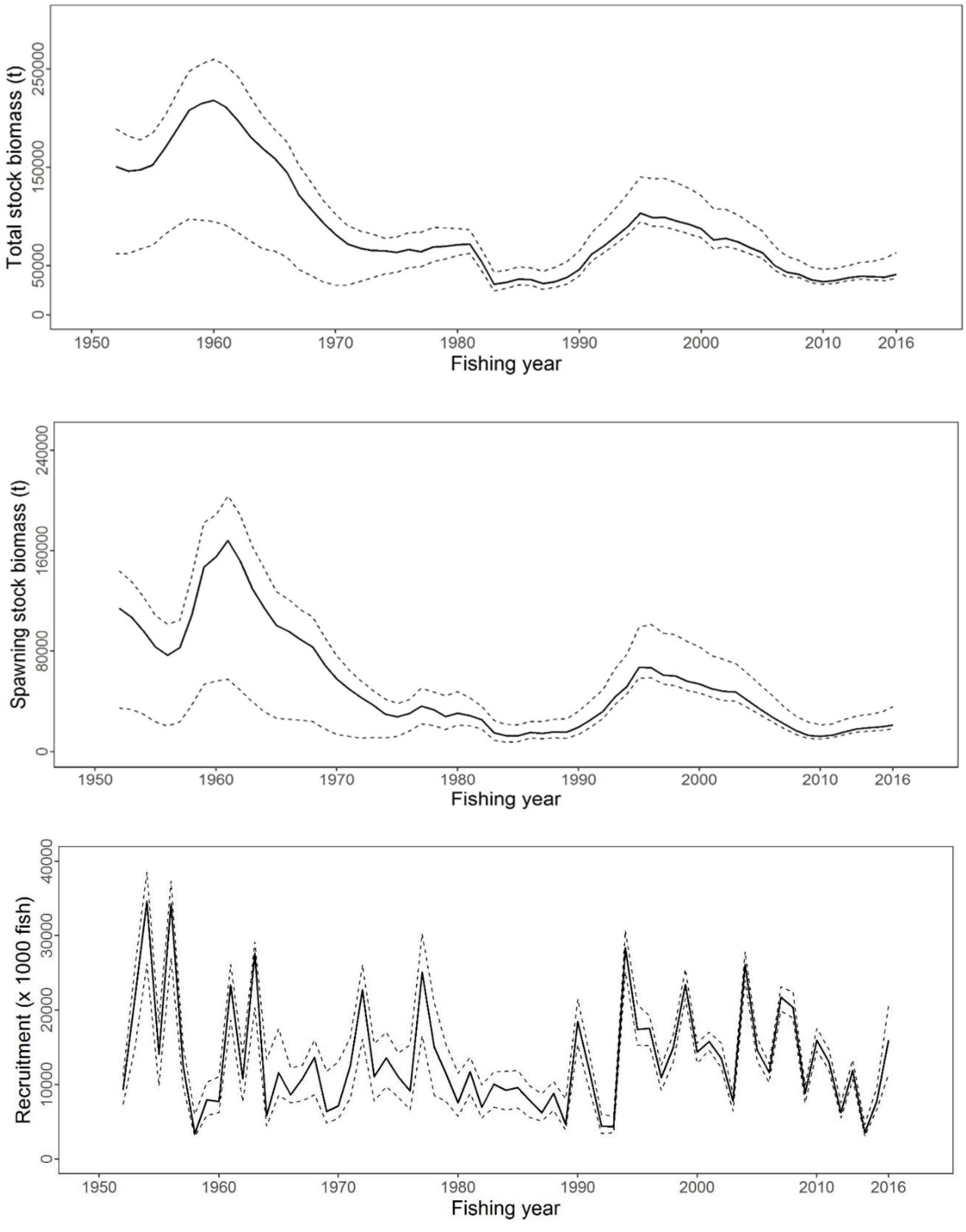


Figure 5-11. Total stock biomass (top), spawning stock biomass (middle) and recruitment (bottom) of Pacific bluefin tuna (*Thunnus orientalis*) from the base-case model. The solid line indicates point estimate and dashed lines indicate the 90% confidence interval.

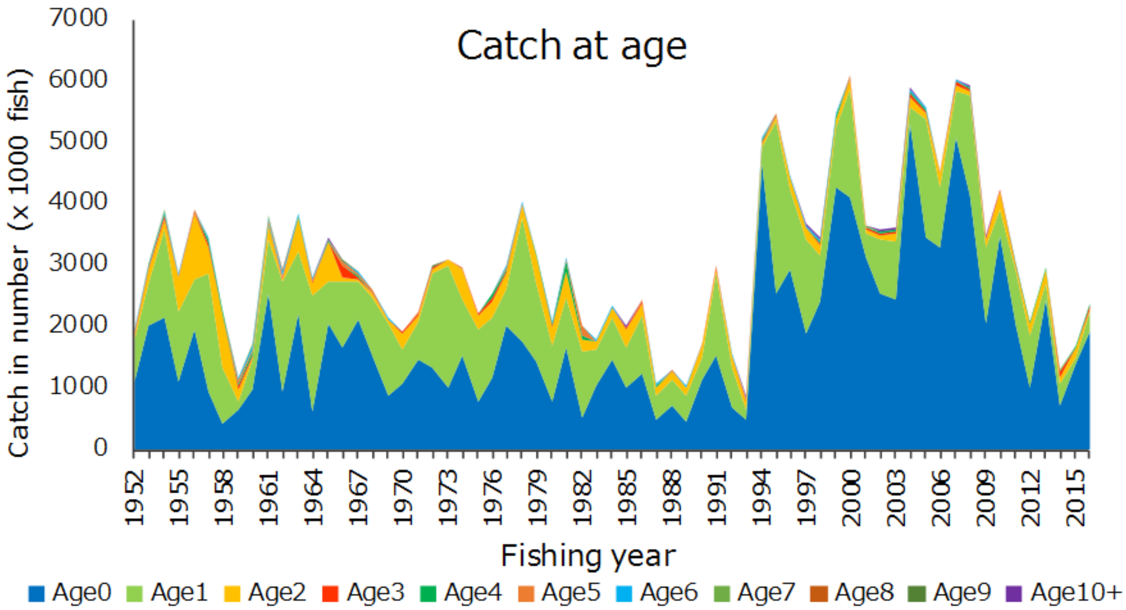


Figure 5-12. Annual catch-at-age (in number) of Pacific bluefin tuna (*Thunnus orientalis*) by fishing year (1952-2016).

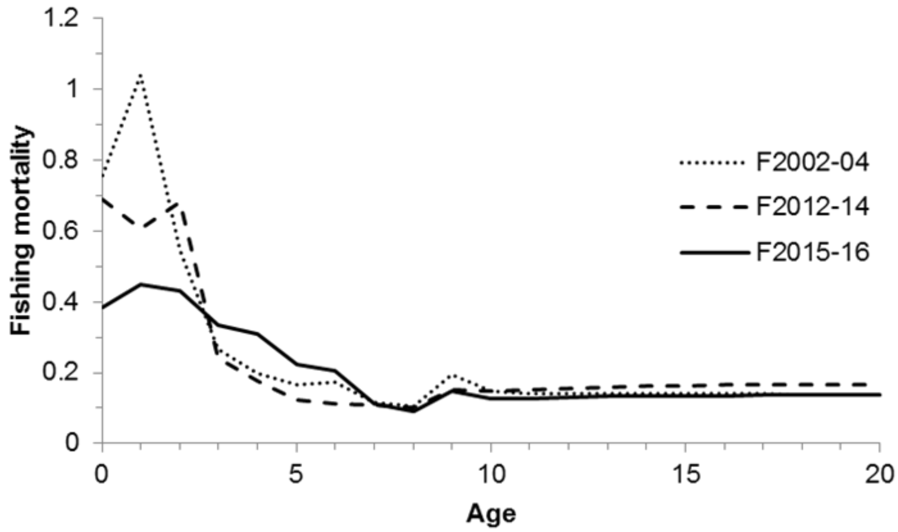


Figure 5-13. Geometric means of annual age-specific fishing mortalities of Pacific bluefin tuna (*Thunnus orientalis*) for 2002-2004 (dotted line), 2012-2014 (dashed line) and, 2015-2016 (solid line).

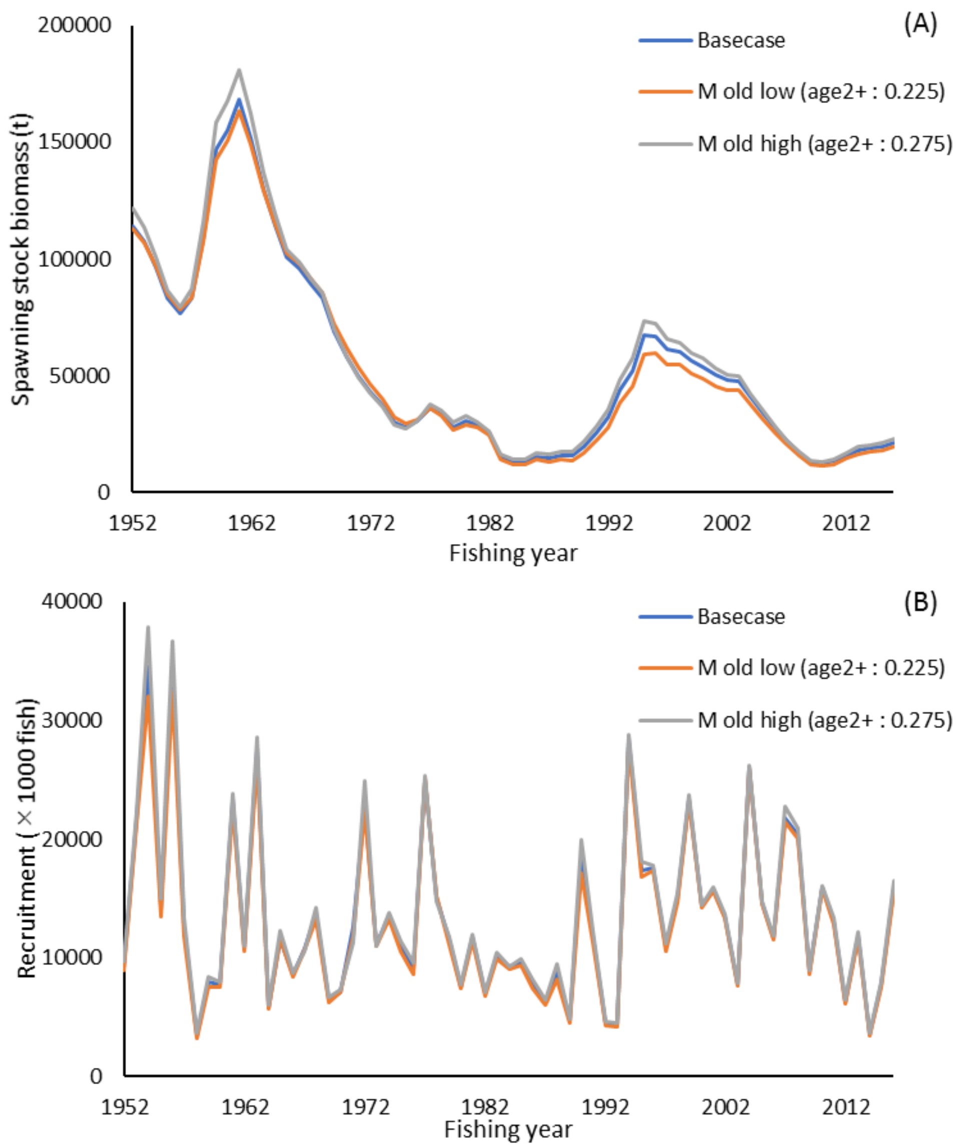


Figure 5-14. Estimated (A) spawning stock biomass and (B) recruitment of Pacific bluefin tuna (*Thunnus orientalis*) for the base-case model and sensitivity analyses using alternative high and low natural mortality schedules.

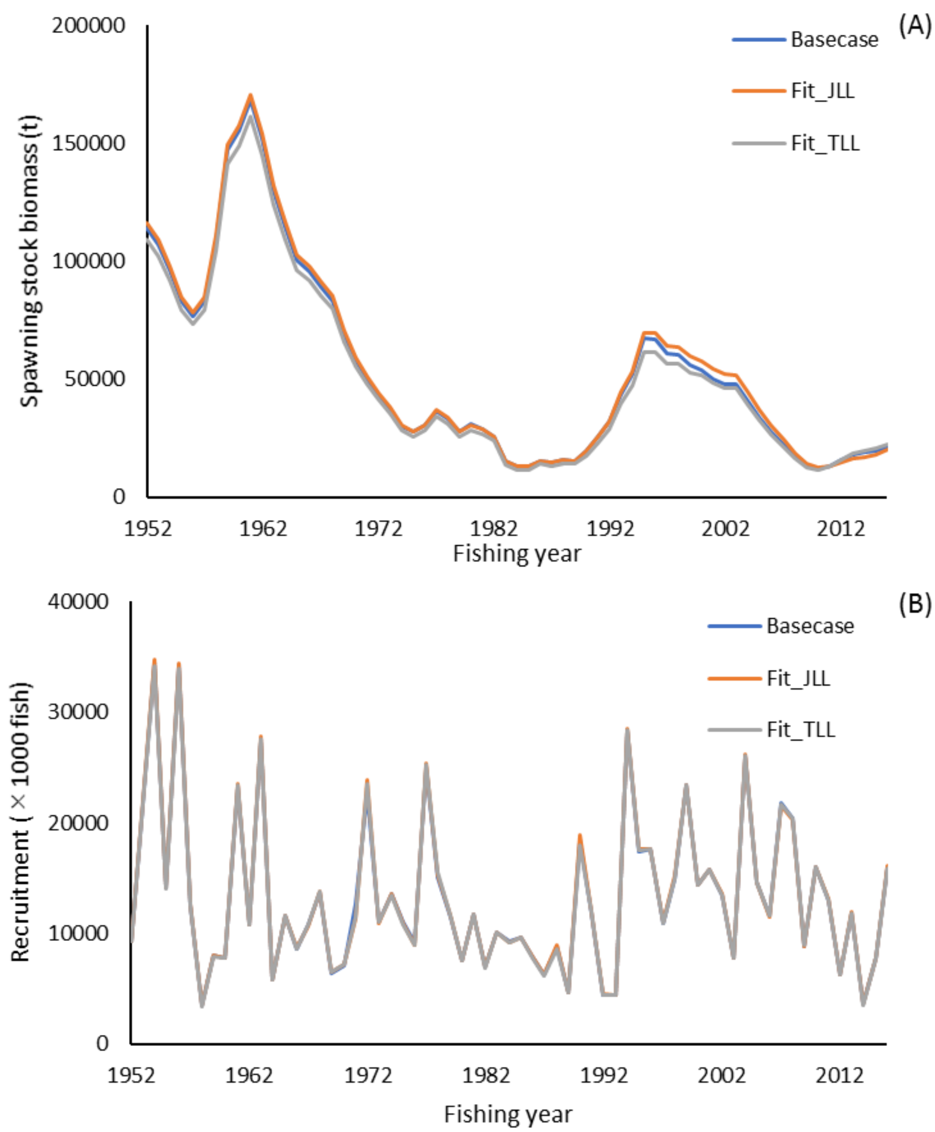


Figure 5-15. Estimated (A) spawning stock biomass and (B) recruitment of Pacific bluefin tuna (*Thunnus orientalis*) for the base-case model and sensitivity analysis using alternative assumption if the model is fitted more closely to either of Japanese or Taiwanese longline CPUE based abundance index.

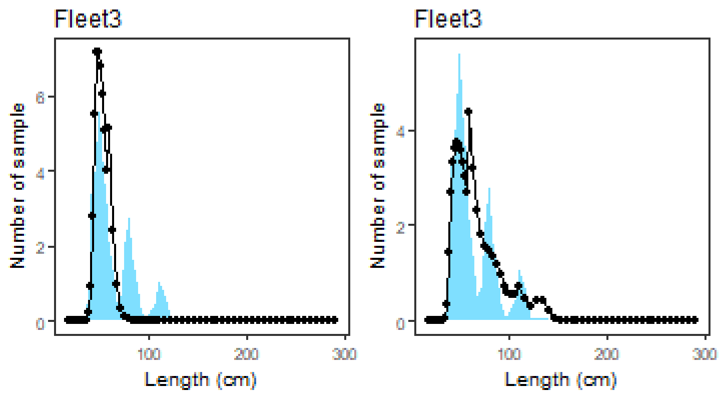
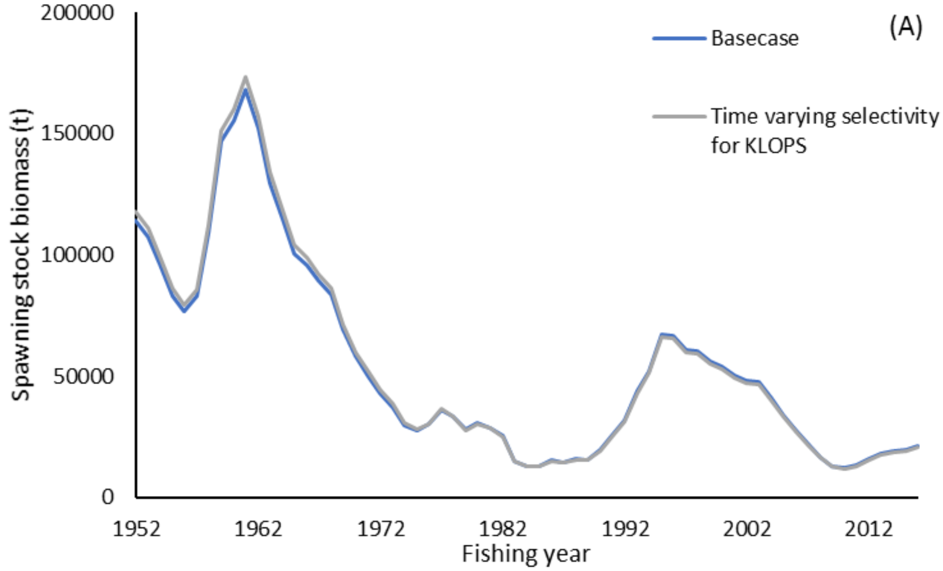


Figure 5-16. Model fits (black lines with dots) and the observation (blue areas) of the size composition of fleet 3 in the base-case model (left) and a sensitivity run (right) using alternative assumption if the model is fitted more closely to that data by assuming time-varying selectivity.



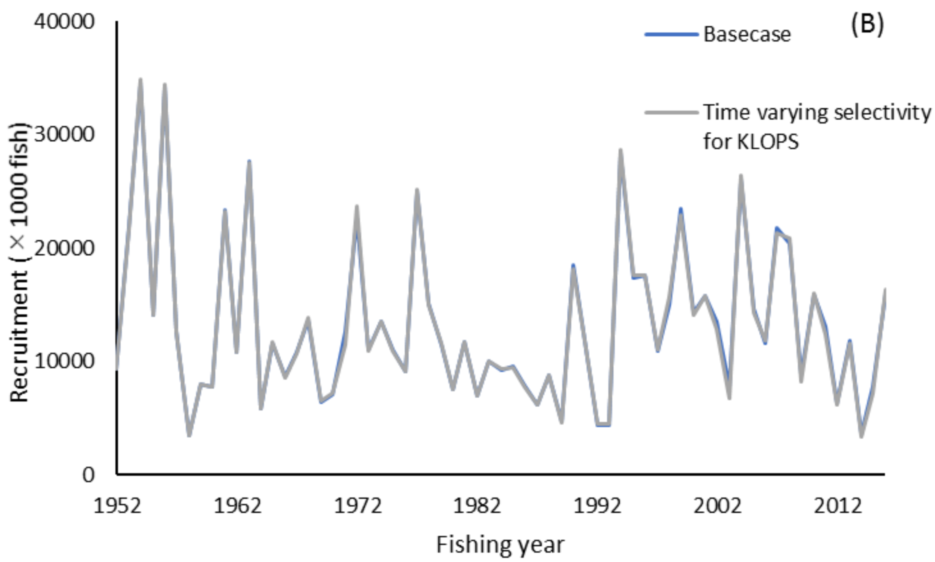


Figure 5-17. Estimated (A) spawning stock biomass and (B) recruitment of Pacific bluefin tuna (*Thunnus orientalis*) for the base-case model and sensitivity analyses which assumed time-varying selectivity for Korean offshore large purse seine.

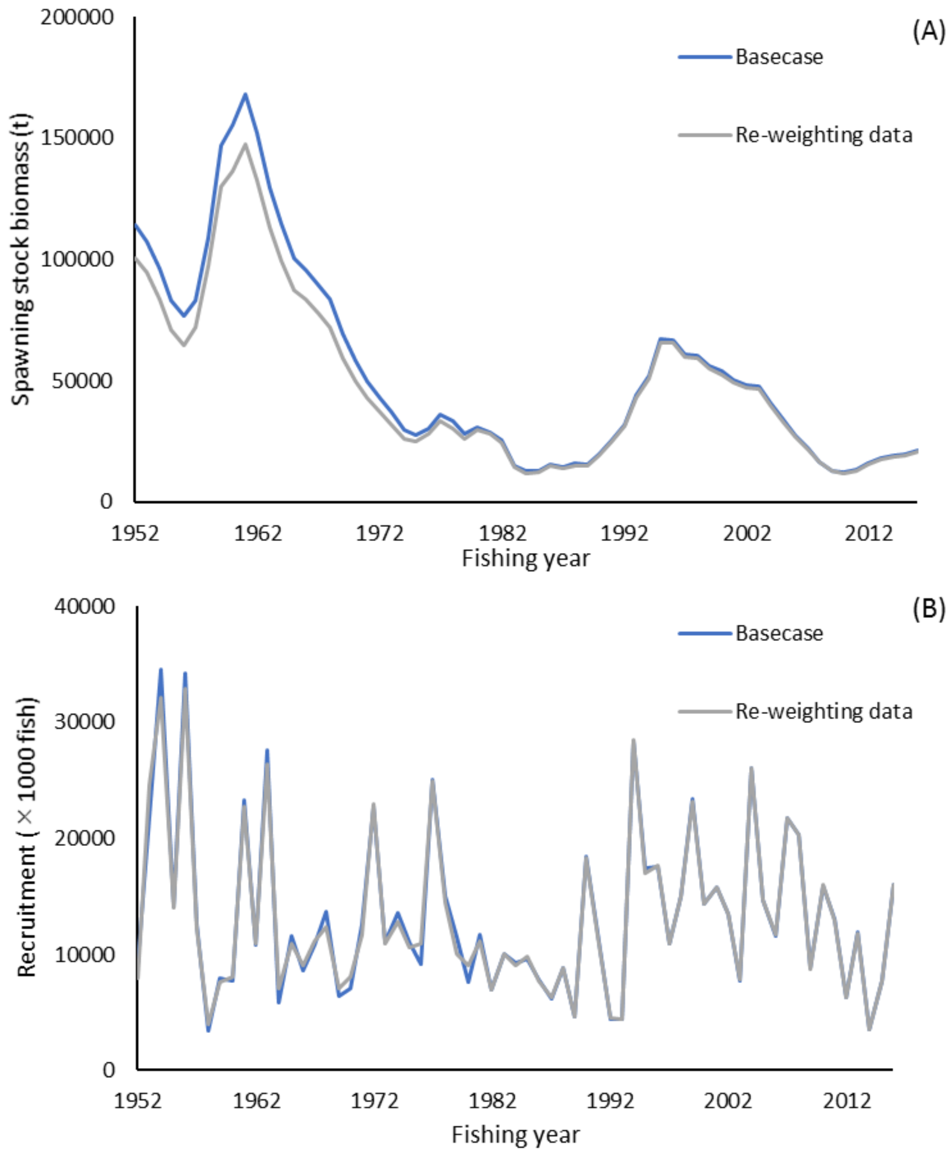


Figure 5-18. Estimated (A) spawning stock biomass and (B) recruitment of Pacific bluefin tuna (*Thunnus orientalis*) for the base-case model and sensitivity analysis using harmonic mean (Table 5-1) as an alternative right-weighting approach on size composition data.

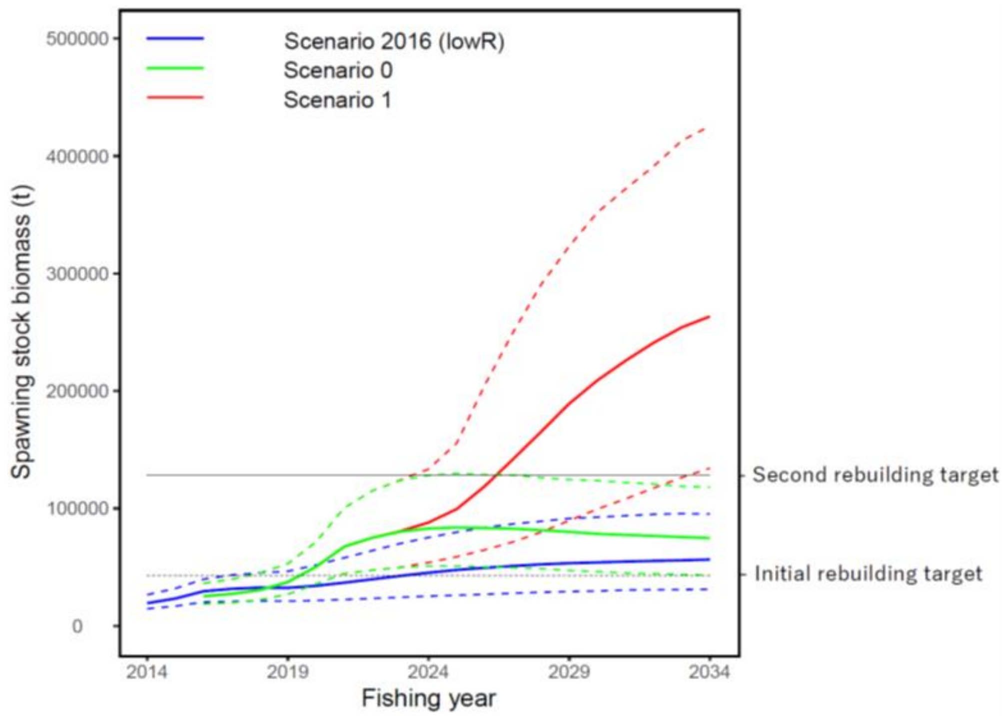


Figure 6-1. Comparisons of various projection results for Pacific bluefin tuna (*Thunnus orientalis*). Comparison of projections under the current measures. Blue: from 2016 assessment under low recruitement, green: from the current assessment under low recruitment (scenario 0), red: from the current assessment with recruitment switch from low to average after achieving initial rebuilding target (scenario 1).

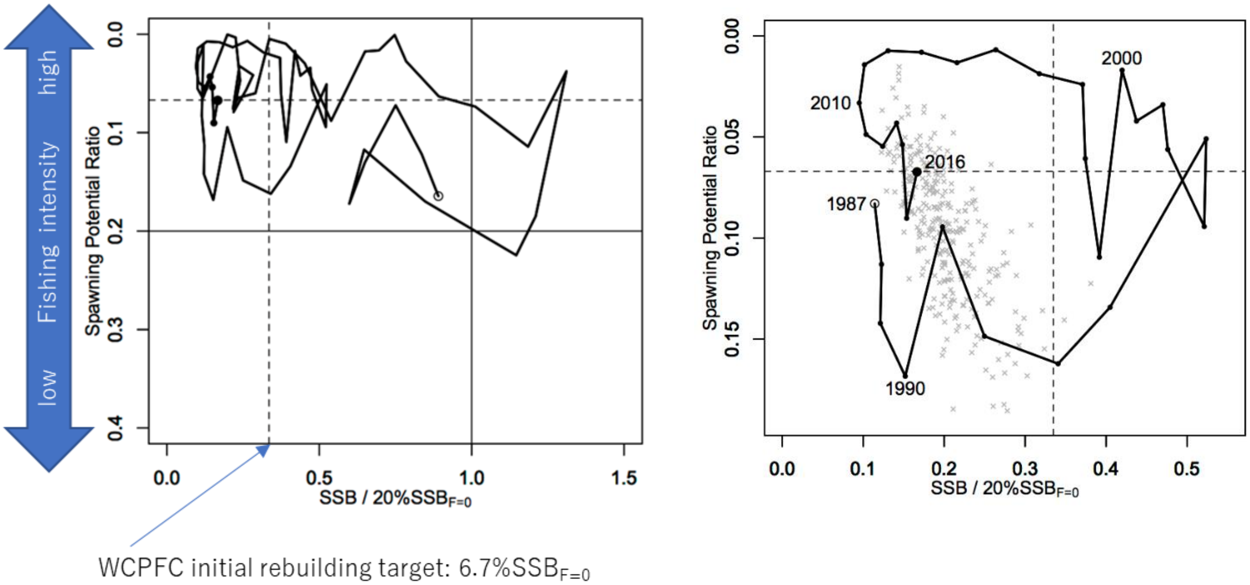


Figure 7-1. Kobe plots for Pacific bluefin tuna (*Thunnus orientalis*). X axis shows the relative SSB value to 20%$SSB_{F=0}$ (second rebuilding target) and Y axis shows spawning potential ratio as a measure of fishing intensity. Vertical and horizontal solid lines indicate the second rebuilding target (20%$SSB_{F=0}$) and corresponding fishing intensity, respectively, while vertical and horizontal dashed lines indicate the initial rebuilding target (SSB_{MED} = 6.7%$SSB_{F=0}$) and corresponding fishing intensity, respectively. SSB_{MED} is calculated as the median of estimated SSB over 1952-2014. The left figure shows the historical trajectory, where the open circle indicates the first year of the assessment (1952) while solid circles indicate the last five years of the assessment (2012-2016). The right figure shows the trajectory only of the last 30 years, where grey crosses indicate the uncertainty of the terminal year.

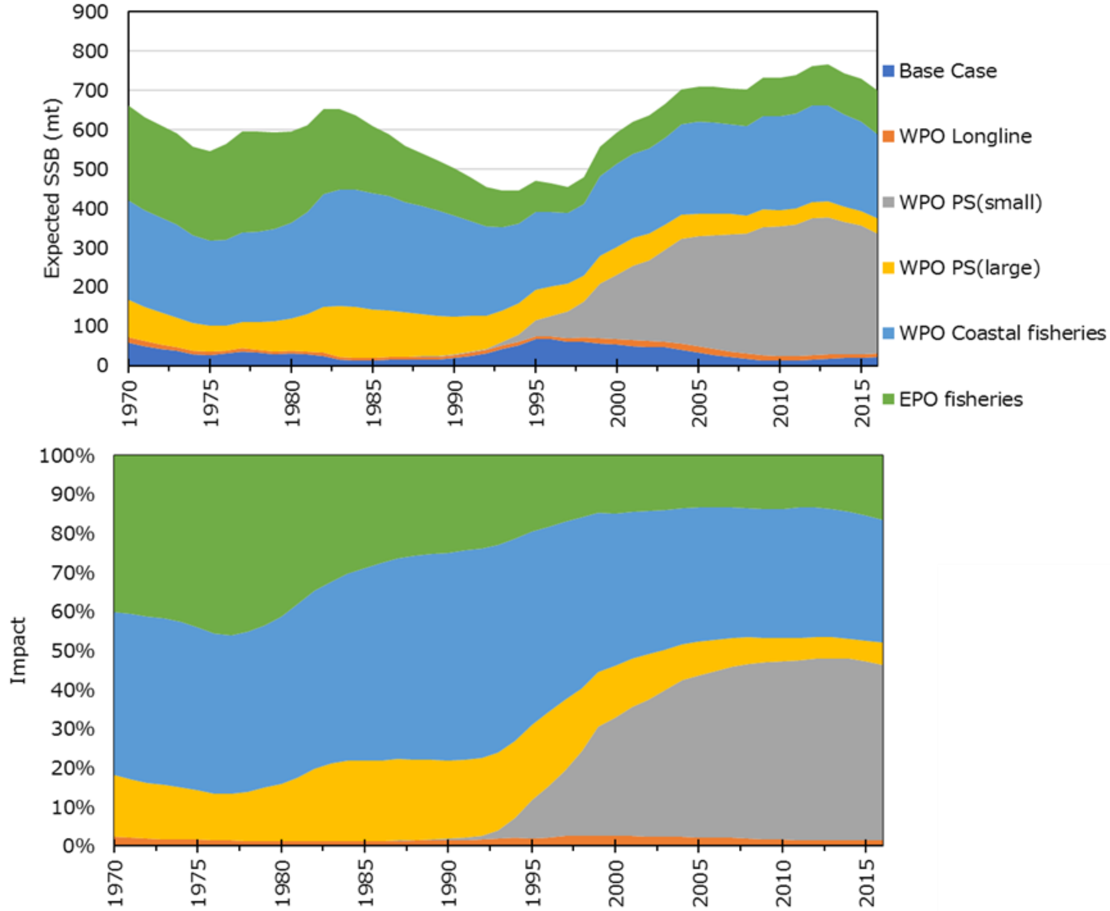


Figure 7-2. Trajectory of the spawning stock biomass of a simulated population of Pacific bluefin tuna (*Thunnus orientalis*) when zero fishing mortality is assumed, estimated by the base-case model. (top: absolute impact, bottom: relative impact). Fleet definition; WPO longline: F1, F12, F17. WPO purse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

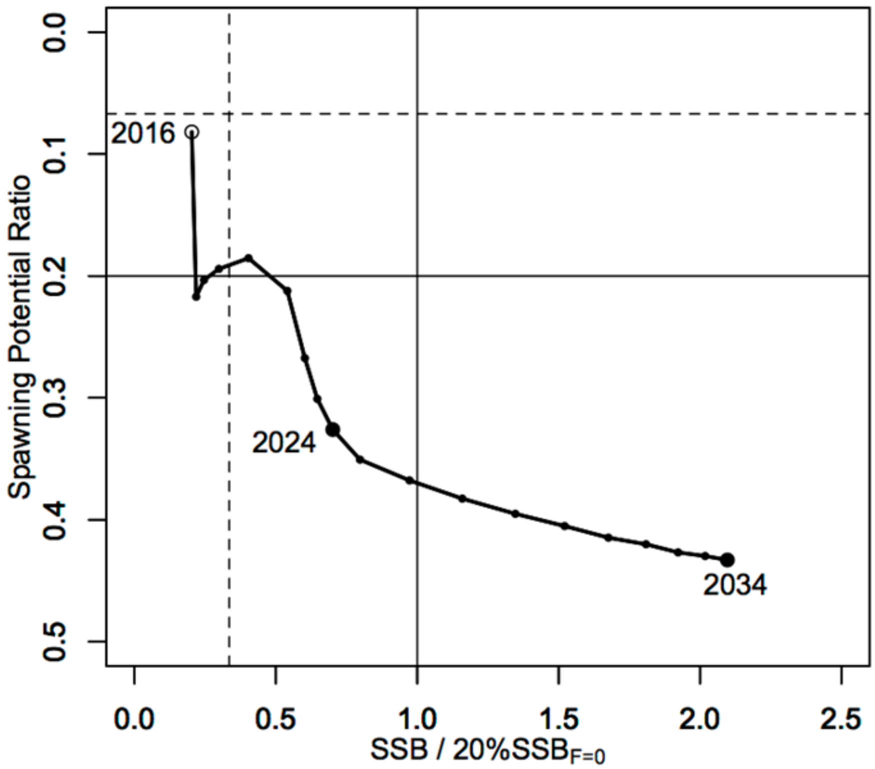


Figure 7-3. A projection result (scenario 1 from Table 4) for Pacific bluefin tuna (*Thunnus orientalis*) in a form of Kobe plot. X axis shows the relative SSB value to 20%$SSB_{F=0}$ (second rebuilding target) and Y axis shows the spawning potential ratio as a measure of fishing intensity. Vertical and horizontal solid lines indicate the second rebuilding target (20%$SSB_{F=0}$) and the corresponding fishing intensity, respectively, while vertical and horizontal dashed lines indicate the initial rebuilding target (SSB_{MED}=6.7%$SSB_{F=0}$) and the corresponding fishing intensity, respectively.

Appendix 1

Additional projections conducted by PBFWG in response to the WCPFC Harvest Strategy 2017-02

The Harvest Strategy proposed at the Joint WCPFC NC-IATTC WG meeting and adopted by WCPFC (Harvest Strategy 2017-02) guided projections conducted by ISC to provide catch reduction options if the projection results indicate that the initial rebuilding target will not be achieved or to provide relevant information for potential increase in catch if the probability of achieving the initial rebuilding target exceeds 75%. The projection results showed that the probability of achieving the initial rebuilding target was above the level (75% or above in 2024) prescribed in the WCPFC Harvest Strategy (scenario 0 of **Table 2**). Accordingly, the PBFWG examined some optional scenarios (**Table 1**) which have higher catch limit.

Scenarios 3, 4, and 5 in **Table 1** were examined to investigate the effects of the less conservative management measures which depict possible increases in catch limit in equivalent fractions from the currently specified limit. Scenarios 6-17 were examined to assess the effects of different fraction of catch limits increment by those for PBF of less than 30 kg of its body weight (hereafter small PBF), and those for PBF of 30 kg and larger (hereafter large PBF). For this analysis, possible catch upper limits for small and large PBF were approximated for the area and country in case they have a possibility to catch both size classes of PBF, given the most recent fishing condition. The catch limits and selectivity for those fisheries were calculated based on the catch at age and fishing mortality at age of the most recent years (2014-2016), which were estimated by the base case assessment model and a sensitivity analysis (sensitivity-4) to reflect the condition of those fisheries closely as possible. Also, in order to be precautionary, fishing mortality in those scenarios with higher catch limits (scenarios 3-17), was increased to levels so as to exhaust the catch limit. In addition to the above mentioned scenarios, a future population dynamics with zero removals (no fishery) was also examined (scenario 18).

Note, though, that current technical limitations do not allow the PBFWG to “tune” projections to search for a measure with a particular probability such as “measures to achieve 70% probability”.

As the performance measures of each harvesting scenarios, PBFWG provided the expected year to achieve each rebuilding target with 60% of probability, the probability achieving each rebuilding target at its time limit prescribed in the management measures of WCPFC and IATTC, the probability of SSB being below the initial rebuilding target in case low recruitment continue, and expected future catch at certain year.

Tables 2 and 3 summarizes the results for the future projections in each harvesting and recruitment scenario with respect to the prospect of recovery and future yields, respectively. Scenario 1, which approximated current management measures, had the highest prospect of recovery among all of the examined scenarios except the zero removals scenario (scenario 18). Naturally, the prospect of recovery is highly dependent on the recruitment scenario. The scenario 0 also has a high probability of achieving the initial rebuilding target by 2024 (98%) even though this scenario is assumed with the low recruitment for the entire projection period. These projection results are more optimistic than those of the 2016 assessment, mainly due to the inclusion of the relatively good recruitment in 2016.

For all of the examined scenarios, the probability of achieving the initial rebuilding target would still satisfy the required level by the Harvest Strategy (i.e., more than 70% for the initial rebuilding target and more than 60% for the second rebuilding target). The projection results indicate that an additional 15% increase in catch limit (Scenario 5) would provide 25 points lower probability of reaching the initial target, a lower biomass by 2034, and 1 or 2 years slower recovery than scenario 1 (**Table 2**). At the same time, it is worth to note that the all of the scenarios examined under a recruitment assumption guided by the WCPFC harvest strategy indicated that the expected SSB by 2034 would correspond to be higher than 30% of $SSB_{F=0}$, while SSB by 2034 under low recruitment and existing management measures would correspond to 11.5% of $SSB_{F=0}$ (scenario 0).

The results of scenarios 6-17, which have different fraction of catch limits increment by small and large PBF, confirm the previous recommendations from the PBFWG that measures to restrict the catch of small fish is more effective than those on large fish.

Given a recruitment condition with zero removals (no fishing), SSB trajectories achieved the second rebuilding target by 2021 and the initial rebuilding target within 3 years. This scenario points to the potential productivity of the current population (scenario 18).

In all scenarios explored, the probability of achieving the initial rebuilding target were estimated to be above the level prescribed in the WCPFC Harvest strategy prepared by the RFMOs joint working group. The prospect of rebuilding to the initial and second rebuilding target and biomass levels in the future will be faster and higher (in terms of probability as well as biomass level) with stricter catch management measures.

Table 1. Harvest scenarios used in the projection for Pacific bluefin tuna (*Thunnus orientalis*).

Scenario #	Fishing mortality*1	WPO Catch limit Japan*2 Small	Large	Korea Small	Large	Taiwan Large	EPO*3 Catch limit Commercial Small	Large	Sports	Catch limit Increase WPO Small	Large	EPO Small	Large
0	F	4,007	4,882	718		1,700	3,300		-	0%		0%	
1	F	4,007	4,882	718		1,700	3,300		-	0%		0%	
2	F x 2.0	4,007	4,882	718		1,700	3,300		-	0%		0%	
3	F x 2.0	4,207	5,126	754		1,785	3,465		-	5%		5%	
4	F x 2.0	4,408	5,370	790		1,870	3,630		-	10%		10%	
5	F x 2.0	4,608	5,614	826		1,955	3,795		-	15%		15%	
6	F x 2.0	4,207	5,858	528	258	2,040	1,733	1,980	-	5%	20%	5%	20%
7	F x 2.0	4,207	5,858	528	258	2,040	1,815	1,815	-	5%	20%	10%	10%
8	F x 2.0	4,408	5,370	553	237	1,870	1,733	1,980	-	10%	10%	5%	20%
9	F x 2.0	4,207	6,591	528	291	2,295	1,733	2,228	-	5%	35%	5%	35%
10	F x 2.0	4,207	6,591	528	291	2,295	1,898	1,898	-	5%	35%	15%	15%
11	F x 2.0	4,608	5,614	578	248	1,955	1,733	2,228	-	15%	15%	5%	35%
12	F x 2.0	4,408	5,858	553	258	2,040	1,815	1,980	-	10%	20%	10%	20%
13	F x 2.0	4,408	5,858	553	258	2,040	1,898	1,898	-	10%	20%	15%	15%
14	F x 2.0	4,608	5,614	578	248	1,955	1,815	1,980	-	15%	15%	10%	20%
15	F x 2.0	4,408	6,347	553	280	2,210	1,815	2,145	-	10%	30%	10%	30%
16	F x 2.0	4,408	6,347	553	280	2,210	1,898	1,898	-	10%	30%	15%	15%
17	F x 2.0	4,608	5,614	578	248	1,955	1,815	2,145	-	15%	15%	10%	30%
18	F x 0	0	0	0	0	0	0	0	0	-	-	-	-

*1 F indicated the geometric mean values of quartaly age-specific fishing mortality during 2002-2004.
*2 The Japanese unilateral measure (transfering 250 mt of catch upper limit from that for small PBF to that for large PBF during 2017-2020) would be reflected.
*3 Fishing mortality for the EPO commercial fishery was asssumed to be enough high to fullfill its catch upper limit (F multiplied by two). For the same reason, fishing mortality for the Korean fleets assumed as F2014-16 multiplied by two for scenarios 2-17. The fishing mortality for the EPO recreational fishery was assumed to be F2009-11 average level.
*4 In scenario 0, the future recrutment were assumed to be the low recruitment (1980-1989 level) forever. In other scenarios, recruitment was switched from low recruitemnt to average recruitment from the next year of achieving the initial rebuilding target.

Table 2. Future projection scenarios for Pacific bluefin tuna (*Thunnus orientalis*) and their probability of achieving various target levels by various time schedules based on the base-case model.

Scenario #	Catch limit Increase				Initial rebuilding target			Second rebuilding target		Median SSB (mt) at 2034
	WPO		EPO		The year expected to achieve the target with >60% probability	Probability of achiving the target at 2024	Probability of SSB is below the target at 2024 under the low recruitment	The year expected to achieve the target with >60% probability	Probability of achiving the target at 2034	
	Small	Large	Small	Large						
0*1	0%		0%		2020	98%	2%	N/A	3%	74,789
1	0%		0%		2020	99%	2%	2028	96%	263,465
2	0%		0%		2021	96%	4%	2028	96%	264,118
3	5%		5%		2021	91%	8%	2029	93%	248,295
4	10%		10%		2021	83%	15%	2029	90%	231,466
5	15%		15%		2021	74%	24%	2030	85%	255,085
6	5%	20%	5%	20%	2021	94%	6%	2028	95%	255,672
7	5%	20%	10%	10%	2021	94%	6%	2028	95%	248,911
8	10%	10%	5%	20%	2021	92%	9%	2029	94%	214,278
9	5%	35%	5%	35%	2021	93%	9%	2029	94%	246,153
10	5%	35%	15%	15%	2021	93%	9%	2029	94%	247,409
11	15%	15%	5%	35%	2021	84%	16%	2029	91%	233,055
12	10%	20%	10%	20%	2021	89%	11%	2029	93%	243,491
13	10%	20%	15%	15%	2021	89%	11%	2029	93%	243,223
14	15%	15%	10%	20%	2021	85%	16%	2029	91%	234,203
15	10%	30%	10%	30%	2021	87%	14%	2029	92%	237,742
16	10%	30%	15%	15%	2021	88%	13%	2029	92%	238,957
17	15%	15%	10%	30%	2021	84%	17%	2029	90%	232,769
18	-	-	-	-	2019	100%	0%	2021	100%	578,051

*1 In scenario 0, the future recrutment were assumed to be the low recruitment (1980-1989 level) forever. In other scenarios, recruitment was switched from low recruitemnt to average recruitment from the next year of achieving the initial rebuilding target.

Table 3. Expected annual yield for Pacific bluefin tuna (*Thunnus orientalis*) under various harvesting scenarios based on the base-case model.

Scenario #	Expected annual yield in 2019, by area and size category (mt)								Expected annual yield in 2024, by area and size category (mt)								Expected annual yield in 2034, by area and size category (mt)							
	WPO					EPO			WPO					EPO			WPO					EPO		
	Japan		Korea		Taiwan	Commercial		Sports	Japan		Korea		Taiwan	Commercial		Sports	Japan		Korea		Taiwan	Commercial		Sports
	Small	Large	Small	Large	Large	Small	Large		Small	Large	Small	Large	Large	Small	Large		Small	Large	Small	Large	Large	Small	Large	
0	3,757	3,803	719	0	581	2,924	448	158	3,984	4,751	719	0	1,382	2,400	933	124	3,985	4,569	719	0	1,642	2,473	856	122
1	3,757	3,803	719	0	581	2,924	448	158	4,025	4,819	720	0	1,383	2,757	627	281	4,026	4,919	720	0	1,721	2,386	1,013	304
2	3,796	5,066	725	0	934	2,941	427	159	4,049	4,946	722	0	1,640	2,600	757	269	4,054	4,944	724	0	1,738	2,363	1,014	309
3	3,976	5,217	759	0	925	3,067	459	152	4,249	5,154	757	0	1,660	2,733	784	256	4,256	5,191	759	0	1,822	2,486	1,060	300
4	4,157	5,341	794	0	917	3,188	495	144	4,447	5,323	793	0	1,651	2,864	811	242	4,456	5,437	795	0	1,898	2,608	1,104	290
5	4,339	5,439	829	0	910	3,306	534	136	4,645	5,417	829	0	1,616	2,987	834	226	4,656	5,676	831	0	1,962	2,730	1,147	281
6	3,985	5,492	530	259	898	1,797	2,003	175	4,264	5,877	529	259	1,680	1,792	1,958	282	4,278	5,908	530	261	2,097	1,805	1,988	320
7	3,985	5,511	530	259	899	1,882	1,835	175	4,263	5,876	529	259	1,693	1,876	1,798	282	4,278	5,908	530	261	2,097	1,890	1,825	320
8	4,167	5,228	555	237	908	1,794	2,001	168	4,461	5,380	553	237	1,620	1,789	1,952	271	4,476	5,414	555	238	1,922	1,803	1,986	313
9	3,985	5,671	530	291	889	1,797	2,255	175	4,264	6,571	529	291	1,639	1,792	2,193	282	4,278	6,648	530	293	2,348	1,805	2,231	320
10	3,984	5,715	530	291	891	1,965	1,920	174	4,263	6,572	529	291	1,670	1,959	1,876	281	4,278	6,647	530	293	2,349	1,974	1,905	320
11	4,349	5,276	580	248	901	1,792	2,250	162	4,660	5,564	576	247	1,564	1,785	2,169	259	4,675	5,660	579	249	1,995	1,802	2,227	305
12	4,166	5,446	555	259	898	1,878	2,002	168	4,461	5,843	553	259	1,632	1,873	1,950	271	4,476	5,907	555	260	2,090	1,888	1,986	313
13	4,166	5,450	555	259	899	1,961	1,918	168	4,461	5,842	553	258	1,635	1,955	1,870	270	4,476	5,907	555	260	2,090	1,972	1,904	312
14	4,348	5,306	580	248	902	1,875	2,001	162	4,660	5,569	576	247	1,586	1,869	1,939	259	4,675	5,659	579	249	1,996	1,887	1,984	305
15	4,166	5,572	555	280	891	1,878	2,171	168	4,461	6,293	553	279	1,603	1,873	2,105	271	4,476	6,400	555	281	2,255	1,888	2,148	312
16	4,166	5,612	555	280	893	1,961	1,919	168	4,461	6,297	553	279	1,629	1,955	1,869	270	4,476	6,400	555	281	2,257	1,972	1,903	312
17	4,348	5,279	580	248	901	1,875	2,167	162	4,660	5,562	576	247	1,567	1,869	2,092	259	4,675	5,659	579	249	1,995	1,887	2,146	305
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0