NORTHERN COMMITTEE
SIXTEENTH REGULAR SESSION

ELECTRONIC MEETING
[To be confirmed]

Stock Assessment of Pacific Bluefin Tuna in the Pacific Ocean in 2020

WCPFC-NC16-2020/IP-04

ISC[1]

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

ANNEX 11

20th Meeting of the
International Scientific Committee for Tuna
and Tuna-Like Species in the North Pacific Ocean
Held Virtually
July 15-20, 2020

STOCK ASSESSMENT OF PACIFIC BLUEFIN TUNA IN THE PACIFIC OCEAN IN 2020

July 2020

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EXECUTIVE SUMMARY

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.

Catch History

While there are few Pacific bluefin tuna (PBF) catch records prior to 1952, PBF landings records are available dating back to 1804 from coastal Japan and to the early 1900s for U.S. fisheries operating in the EPO. Based on these landing records, PBF catch is 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 and estimated annual catches of PBF fluctuated widely from 1952-2018 (Figure S-1). During this period reported catches peaked at 40,383 t in 1956 and reached a low of 8,653 t in 1990. The reported catch in 2017 and 2018 was 14,802 t and 10,168 t, respectively including non-ISC member countries. Management measures were implemented by RFMOs beginning in 2011 (WCPFC in 2011 and IATTC in 2012) and became stricter in 2015. While a suite of fishing gears have been used to catch PBF, the majority of catch is currently made in purse seine fisheries (Figure S-2). Catches during 1952-2018 were predominately composed of juvenile PBF; the catch of age 0 PBF has increased significantly since the early 1990s but shows a decreasing trend as the total catch in weight declined since the mid-2000s (Figures S-1 and S-3).

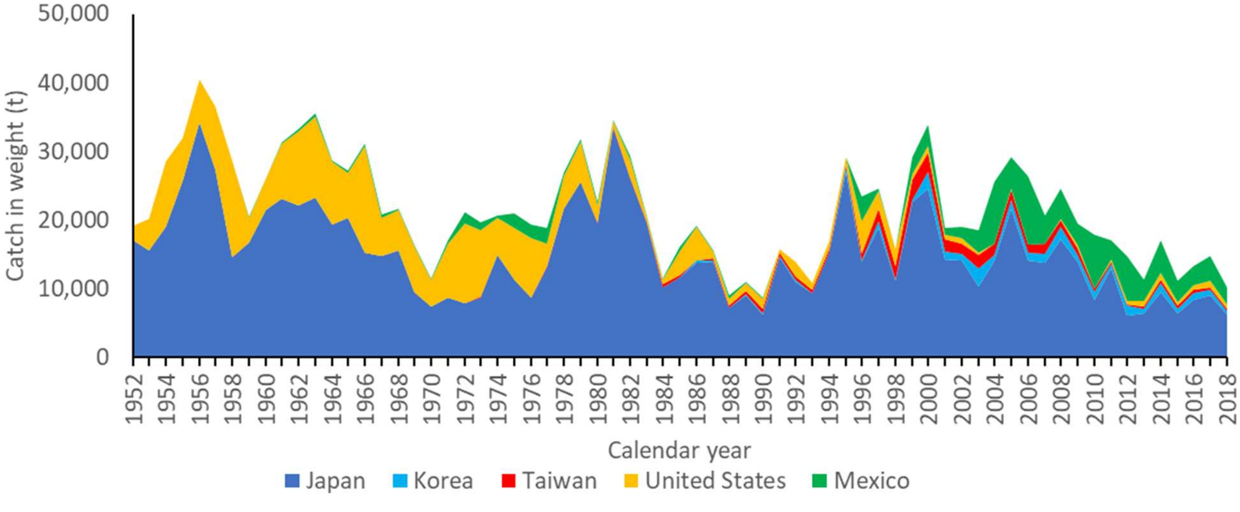

Figure S-1. Annual catch (ton) of Pacific bluefin (*Thunnus orientalis*) tuna by ISC member countries from 1952 through 2018 (calendar year) based on ISC official statistics.

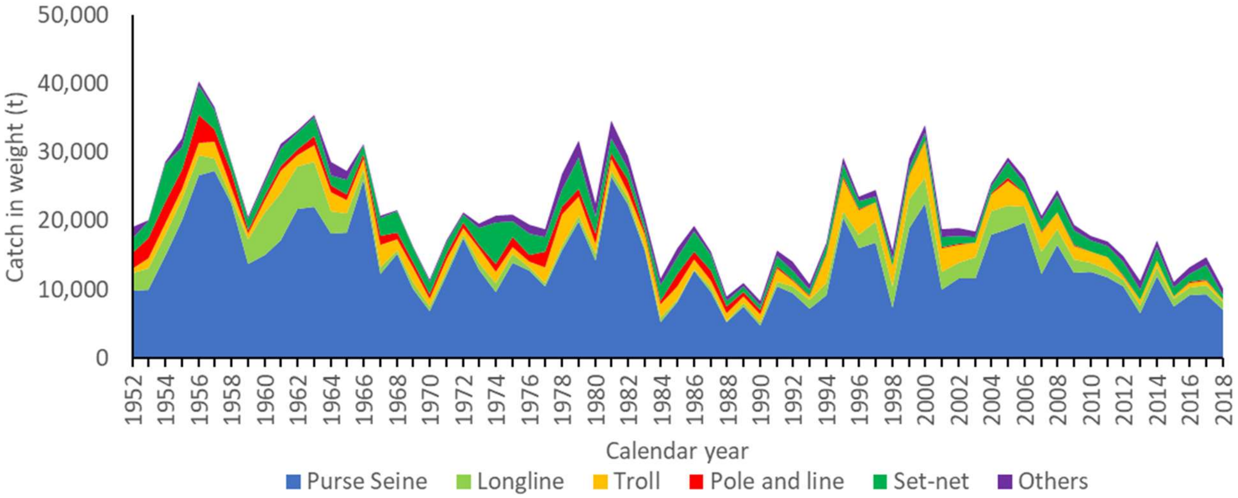

Figure S-2. Annual catch (ton) of Pacific bluefin tuna (*Thunnus orientalis*) by gear type by ISC member countries from 1952 through 2018 (calendar year) based on ISC official statistics.

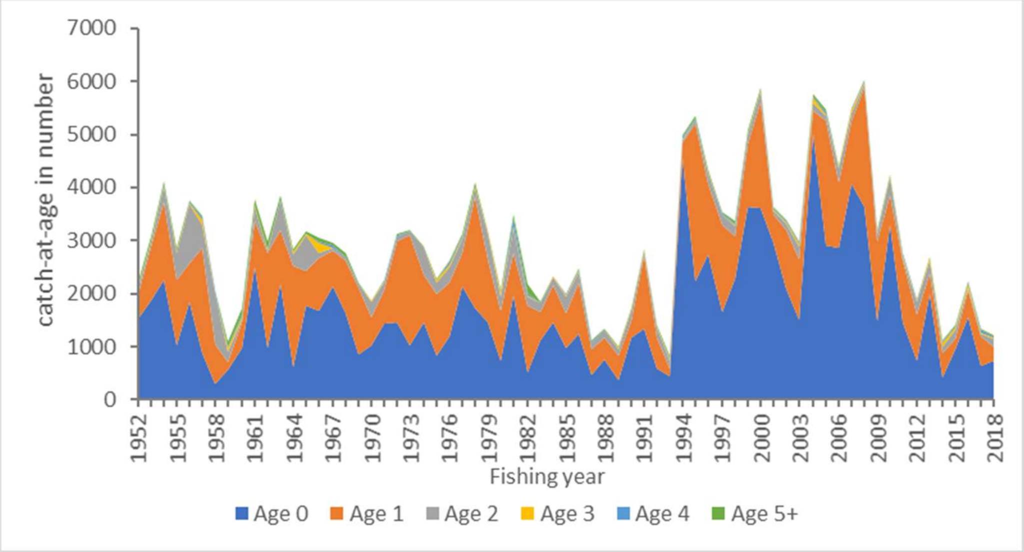

Figure S-3. Estimated annual catch-at-age (number of fish) of Pacific bluefin tuna (*Thunnus orientalis*) by fishing year by the base-case model (1952-2018).

Data and Assessment

Population dynamics were estimated using a fully integrated age-structured model (Stock Synthesis (SS) v3.30) fitted to catch (retained and discarded), size-composition and catch-per-unit of effort (CPUE) based abundance index data from 1952 to 2019, provided by Members of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC), Pacific Bluefin Tuna Working Group (PBFWG) and non-ISC countries obtained through the Secretariat of the Pacific Community (SPC). Life history parameters included a length-at-age relationship from otolith-derived ages and natural mortality estimates from a tag-recapture study and empirical-life history methods.

A total of 25 fleets were defined for use in the stock assessment model based on country/gear/season/region stratification until the end of the fishing year 2018 (June 2019).

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

Since the previous benchmark assessment in 2016, the stock assessment model was thoroughly reviewed and improved. Biological assumptions including growth, length-weight relationship, maturity, natural mortality, and the stock-recruitment relationship were reviewed and the PBFWG concluded that no new information was available that necessitated a change in the existing model settings. Fleet definitions were refined to better capture the difference in the nature of fisheries, increasing from 19 fleets in 2016 to 25 in 2020 including fleets with estimated unaccounted mortality from released PBF. Model parameterization was further fine-tuned to better describe the population dynamics, resulting in 415 estimated parameters. After implementing these improvements and refinements, the PBFWG found that the base case model fits the data well and that the results are internally consistent among most of the data sources. Based on these observations, the PBFWG concluded that the 2020 assessment model reliably represents the population dynamics and is the best available scientific information for the PBF stock.

Stock Status and Conservation Information

The base-case model results show that: (1) spawning stock biomass (SSB) fluctuated throughout the assessment period (fishing years 1952-2018); (2) the SSB steadily declined from 1996 to 2010; (3) the slow increase of the stock biomass continues since 2011; (4) total biomass in 2018 exceeded the historical median with an increase in immature fish; and (5) fishing mortality ($F_{\%SPR}$) declined from a level producing about 1% of SPR[1] in 2004-2009 to a level producing 14% of SPR in 2016-2018 (Table S-1). 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. The SSB in 2018 was estimated to be around 28,000 t (Table S-1 and Figure S-4), which is a 3,000 t increase from 2016 according to the base-case model. An increase of young fish (0-2 years old) is observed in 2016-2018 (Figure S-5), likely resulting from low fishing mortality on those fish (Figure S-6) and is expected to accelerate the recovery of SSB in the future.

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[1] SPR (spawning potential ratio) 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 fishing level to the cumulative spawning biomass that could be produced by an average recruit over its lifetime if the stock was unfished. $F_{\%SPR}$: F that produces % of the spawning potential ratio (i.e., 1-%SPR).

Table S-1. Total biomass, spawning stock biomass, recruitment, spawning potential and depletion ratio of Pacific bluefin tuna (*Thunnus orientalis*) estimated by the base-case model, 1952-2018.

Fishing Year	**Total Biomass (t)**	**Spawning Stock Biomass (t)**	**Recruitment (1,000 fish)**	**Spawning Potential Ratio**	**Depletion Ratio**
1952	134,751	103,502	4,857	11.4%	16.4%
1953	136,428	97,941	20,954	12.7%	15.5%
1954	146,741	87,974	34,813	7.8%	13.9%
1955	156,398	75,360	13,442	11.4%	11.9%
1956	175,824	67,700	33,582	16.1%	10.7%
1957	193,597	76,817	11,690	10.7%	12.1%
1958	201,937	100,683	3,195	19.2%	15.9%
1959	209,300	136,430	7,758	23.2%	21.6%
1960	202,121	144,411	7,731	17.4%	22.8%
1961	193,546	156,302	23,339	3.4%	24.7%
1962	176,618	141,277	10,737	10.8%	22.3%
1963	165,892	120,244	28,112	6.8%	19.0%
1964	154,192	105,870	5,696	6.6%	16.7%
1965	142,548	93,222	10,710	3.0%	14.7%
1966	119,683	89,236	8,680	0.1%	14.1%
1967	105,084	83,208	10,897	1.3%	13.2%
1968	91,408	77,466	14,535	1.2%	12.2%
1969	80,523	64,299	6,484	8.5%	10.2%
1970	74,222	53,961	7,027	3.1%	8.5%
1971	66,114	46,839	12,420	1.0%	7.4%
1972	64,114	40,447	23,552	0.3%	6.4%
1973	63,023	35,273	10,968	5.6%	5.6%
1974	64,885	28,502	13,322	6.3%	4.5%
1975	65,074	26,410	11,252	8.0%	4.2%
1976	64,512	29,274	9,253	2.9%	4.6%
1977	74,670	35,105	25,601	3.7%	5.6%
1978	76,601	32,219	14,037	5.6%	5.1%
1979	73,615	27,093	12,650	7.9%	4.3%
1980	72,809	29,657	6,910	5.2%	4.7%
1981	57,482	27,928	13,340	0.3%	4.4%
1982	40,398	24,240	6,512	0.0%	3.8%
1983	33,210	14,456	10,133	6.1%	2.3%
1984	37,464	12,651	9,184	5.1%	2.0%
1985	39,591	12,817	9,676	2.8%	2.0%
1986	34,349	15,147	8,181	1.1%	2.4%
1987	32,008	13,958	6,026	8.1%	2.2%
1988	38,086	14,931	9,304	11.0%	2.4%
1989	41,849	14,839	4,409	14.4%	2.3%
1990	58,122	18,953	18,096	18.2%	3.0%
1991	69,351	25,294	10,392	9.8%	4.0%
1992	76,228	32,252	3,958	14.8%	5.1%
1993	83,624	43,639	4,450	16.4%	6.9%
1994	97,731	50,277	29,314	13.7%	7.9%
1995	94,279	62,784	16,533	4.8%	9.9%
1996	96,463	61,826	17,787	8.9%	9.8%
1997	90,349	56,393	11,259	5.9%	8.9%
1998	95,977	55,888	16,018	4.0%	8.8%
1999	92,232	51,705	22,842	3.7%	8.2%
2000	76,795	48,936	14,383	1.7%	7.7%
2001	78,052	46,408	17,384	9.7%	7.3%
2002	76,110	44,492	13,761	5.7%	7.0%
2003	68,707	43,806	7,110	2.3%	6.9%
2004	66,433	36,701	27,930	1.4%	5.8%
2005	55,778	30,004	15,256	0.6%	4.7%
2006	43,912	24,089	13,660	1.1%	3.8%
2007	43,765	19,061	23,146	0.4%	3.0%
2008	39,646	14,805	21,265	0.8%	2.3%
2009	35,135	11,422	8,002	1.3%	1.8%
2010	38,053	10,837	18,230	2.4%	1.7%
2011	38,901	12,096	12,574	4.9%	1.9%
2012	41,058	14,578	6,845	7.4%	2.3%
2013	49,383	16,703	12,798	4.7%	2.6%
2014	47,864	18,503	3,783	8.9%	2.9%
2015	52,725	21,014	8,778	10.4%	3.3%
2016	62,069	25,009	16,504	10.5%	4.0%
2017	71,228	25,632	6,663	16.5%	4.1%
2018	82,212	28,228	4,658	15.4%	4.5%
Median (1952-2018)	73,615	35,273	11,259	5.9%	5.6%
Average(1952-2018)	86,908	49,388	13,199	7.1%	7.8%

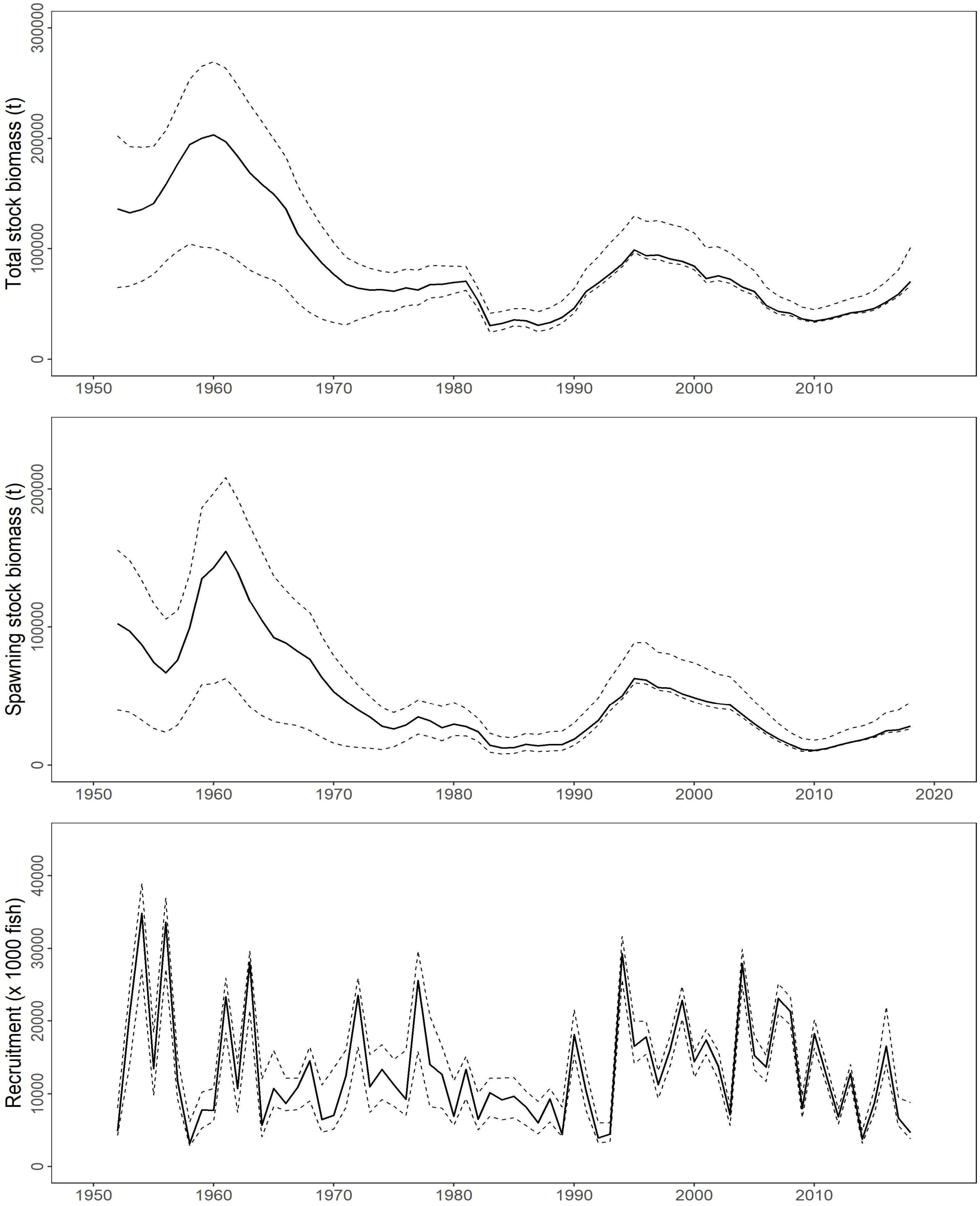


Figure S-4. Total stock biomass (top), spawning stock biomass (middle), and recruitment (bottom) of Pacific bluefin tuna (*Thunnus orientalis*) (1952-2018) estimated from the base-case model. The solid line is the point estimate and dashed lines delineate the 90% confidence interval.

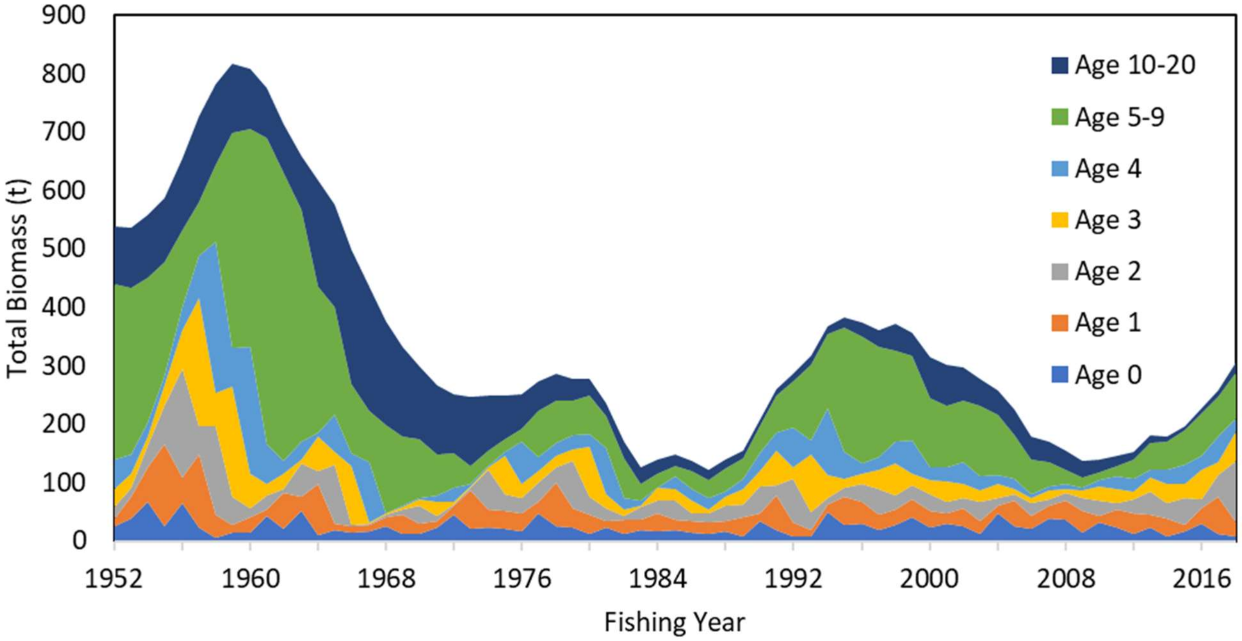


Figure S-5. Total biomass (tonnes) by age of Pacific bluefin tuna (*Thunnus orientalis*) estimated from the base-case model (1952-2018).

Historical recruitment estimates have fluctuated since 1952 without an apparent trend. Relatively low recruitment levels estimated in 2010-2014 were of concern in the 2016 assessment. The 2015 recruitment estimate is lower than the historical average while the 2016 recruitment estimate (about 17 million fish) is higher than the historical average (Table S-1 and Figure S-4). The recruitment estimates for 2017 and 2018, which are based on fewer observations and more uncertain, are below the historical average.

Estimated age-specific fishing mortalities (F) on the stock during the periods of 2011-2013 and 2016-2018 compared with 2002-2004 estimates (the reference period for the WCPFC Conservation and Management Measure) are presented in Figure S-6. A substantial decrease in estimated F is observed in ages 0-2 in 2016-2018 relative to the previous years. Note that stricter management measures in the WCPFC and IATTC have been in place since 2015.

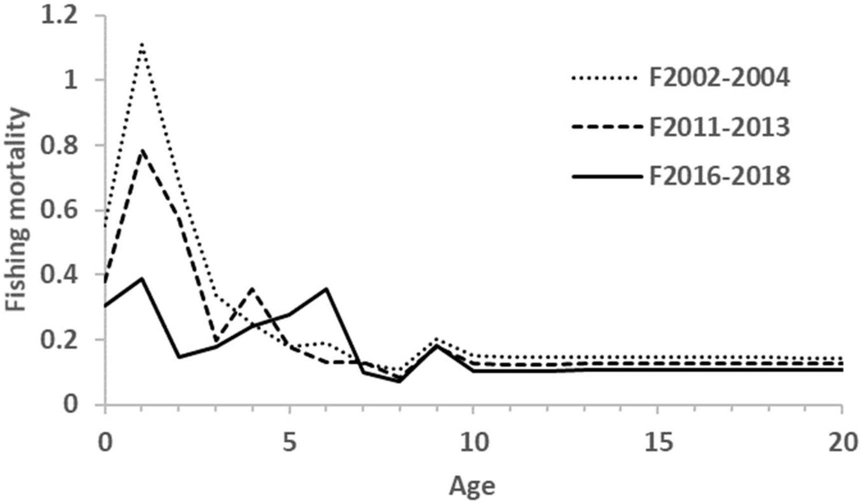


Figure S-6. Geometric means of annual age-specific fishing mortalities (F) of Pacific bluefin tuna (*Thunnus orientalis*) for 2002-2004 (dotted line), 2011-2013 (broken line) and 2016-2018 (solid line).

The WCPFC and IATTC adopted an initial rebuilding biomass target (the median SSB estimated for the period from 1952 through 2014) and a second rebuilding biomass target (20%$SSB_{F=0}$ under average recruitment), without specifying a fishing mortality reference level. The 2020 assessment estimated the initial rebuilding biomass target ($SSB_{MED1952-2014}$) to be 6.4%$SSB_{F=0}$ and the corresponding fishing mortality expressed as SPR of $F_{6.4\%SPR}$ (Table S-2). The Kobe plot shows that the point estimate of the SSB_{2018} was 4.5%$SSB_{F=0}$ and the recent (2016-2018) fishing mortality corresponds to $F_{14\%SPR}$ (Table S-1 and Figure S-7). Although no reference points have been adopted to evaluate the status of PBF, an evaluation of stock status against some common reference points (Table S-2) shows that the stock is overfished relative to biomass-based limit reference points adopted for other species in WCPFC (20%$SSB_{F=0}$) and fishing mortality has declined but not reached the level corresponding to that reference point (20%SPR).

Table S-2. Ratios of the estimated fishing mortalities (Fs and 1-SPRs for 2002-04, 2011-13, 2016-18) relative to potential fishing mortality-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*) from the base-case model**.** F_{max}: Fishing mortality (F) that maximizes equilibrium yield per recruit (Y/R). $F_{0.1}$: F at which the slope of the Y/R curve is 10% of the value at its origin. F_{med}: F corresponding to the inverse of the median of the observed R/SSB ratio. $F_{xx\%SPR}$: F that produces given % of the unfished spawning potential (biomass) under equilibrium condition.

Reference period				**(1-SPR)/(1-SPRxx%)**				**Estimated SSB for terminal year of each period (ton)**	**Depletion rate for terminal year of each period (%)**
	F_{max}	**$F_{0.1}$**	**F_{med}**	**SPR10%**	**SPR20%**	**SPR30%**	**SPR40%**		
2002-2004	1.92	2.84	1.14	1.08	1.21	1.38	1.61	36,701	5.80
2011-2013	1.54	2.26	0.89	1.05	1.18	1.35	1.57	16,703	2.64
2016-2018	1.14	1.65	0.57	0.95	1.07	1.23	1.43	28,228	4.46

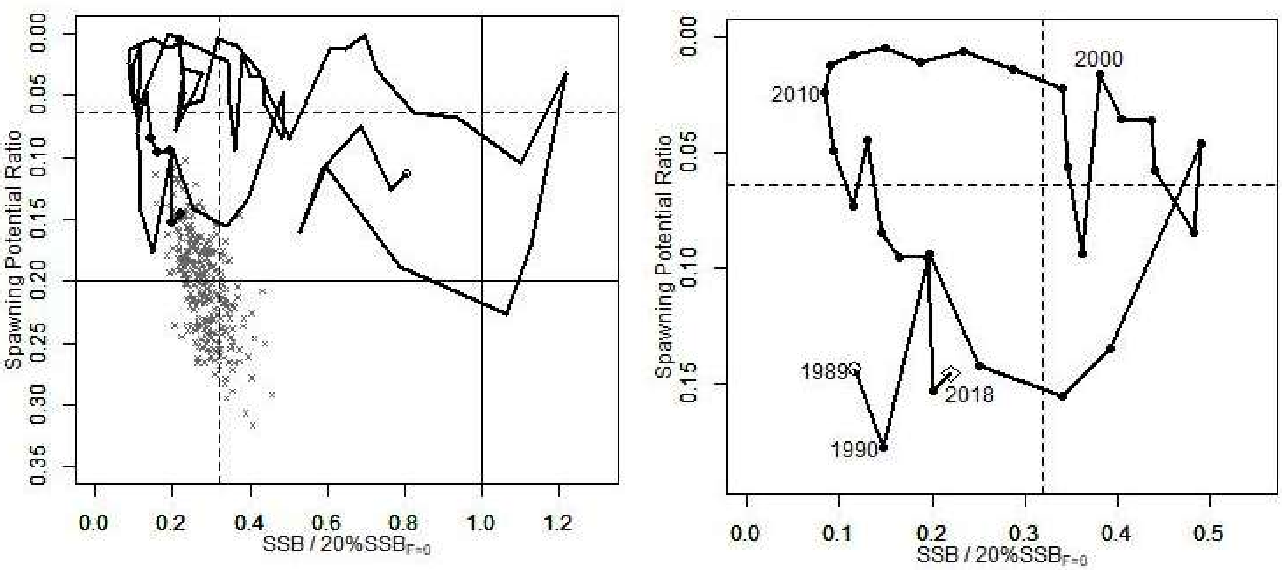


Figure S-7. Kobe plots for Pacific bluefin tuna (*Thunnus orientalis*) estimated from the base-case model. The X-axis shows the annual SSB relative to 20%SSB$_{F=0}$ and the Y-axis shows the spawning potential ratio (SPR) as a measure of fishing mortality. Vertical and horizontal solid lines in the left figure show 20%SSB$_{F=0}$ (which corresponds to the second biomass rebuilding target) and the corresponding fishing mortality that produces SPR, respectively. Vertical and horizontal broken lines in both figures show the initial biomass rebuilding target (SSB$_{MED}$ = 6.4%SSB$_{F=0}$) and the corresponding fishing mortality that produces SPR, 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), solid circles indicate the last five years of the assessment (2014-2018), and grey crosses indicate the uncertainty of the terminal year estimated by bootstrapping. The right figure shows the trajectory of the last 30 years.

Figure S-8 depicts the historical impacts of the fleets on the PBF stock, showing the estimated biomass when fishing mortality from the 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 fishery group targeting small fish (ages 0-1) has had a greater impact and the effect of this group in 2018 was greater than any of the other fishery groups. The impact of the EPO fisheries group was large before the mid-1980s, decreasing significantly thereafter. The WPO longline fisheries group 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. There is greater uncertainty regarding discards than other fishery impacts because the impact of discarding is not based on observed data.

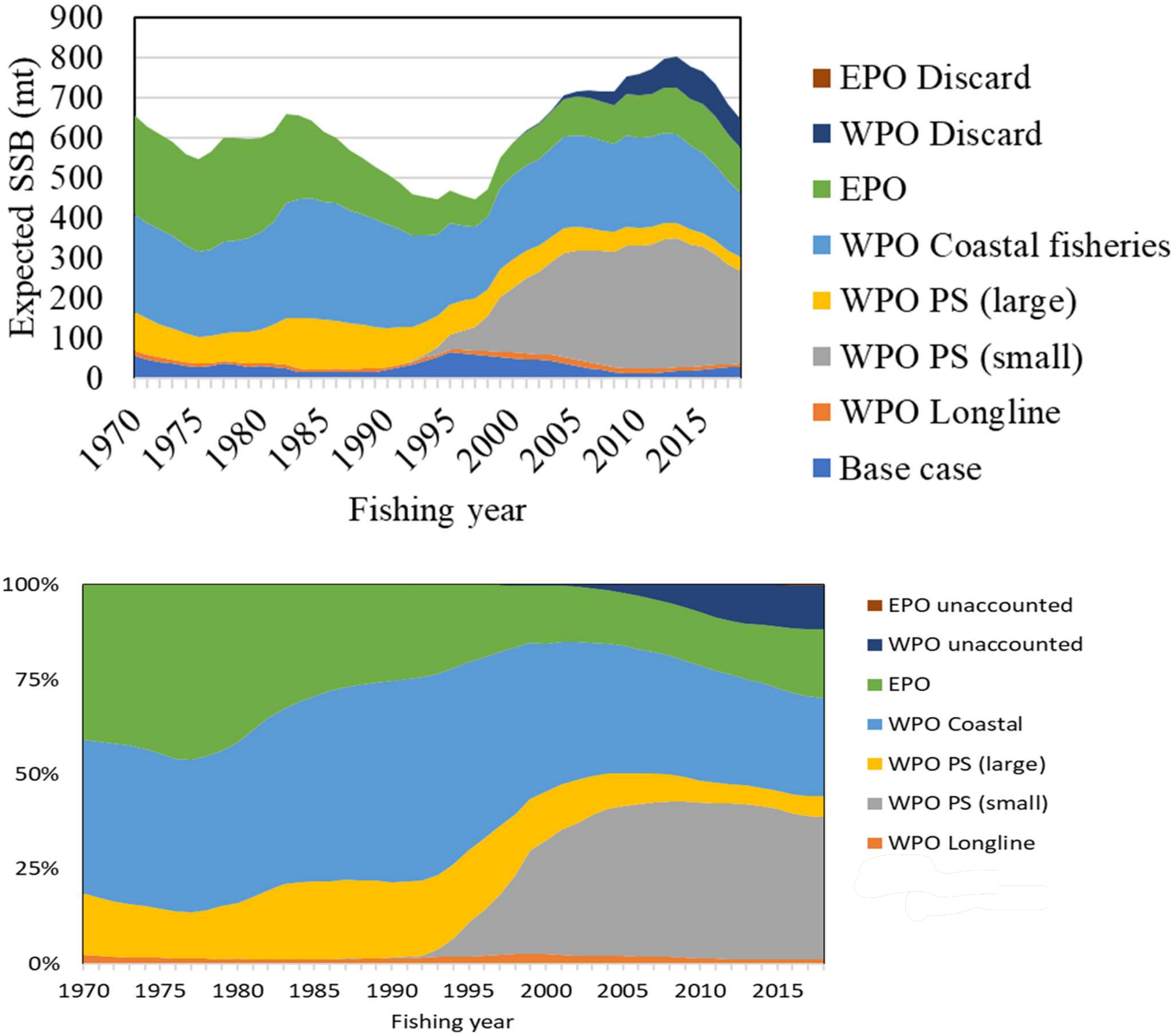


Figure S-8. The trajectory of the spawning stock biomass of a simulated population of Pacific bluefin tuna (*Thunnus orientalis*) when zero fishing mortality is assumed, estimated by the base-case model. (top: absolute SSB, bottom: relative SSB). Fisheries group definition; WPO longline fisheries: F1, F12, F17, 23. WPO purse seine fisheries for small fish: F2, F3, F18, F20. WPO purse seine fisheries for large fish: F4, F5. WPO coastal fisheries: F6-11, F16, F19. EPO fisheries: F13, F14, F15, F24. WPO unaccounted fisheries: F21, 22. EPO unaccounted fisheries: F25. For exact fleet definitions, please see the 2020 PBF stock assessment report on the ISC website.

Stock Status

The PBF spawning stock biomass (SSB) has gradually increased in the last 8 years. Young fish (age 0-2) shows a more rapid increase in recent years. These changes in biomass

coincide with a decline in fishing mortality over the last decade. Based on these findings, the following information on the status of the Pacific bluefin tuna stock is provided:

1. **The latest (2018) SSB is estimated to be 4.5% of $SSB_{F=0}$. No biomass-based limit or target reference points have been adopted for PBF. However, the PBF stock is overfished relative to the potential biomass-based reference points (SSB_{MED} and $20\%SSB_{F=0}$) adopted for other tuna species by the IATTC and WCPFC.**
2. **The recent (2016-2018) $F_{\%SPR}$ is estimated to produce 14%SPR. No fishing mortality-based limit or target reference points have been adopted for PBF by the IATTC and WCPFC, however, recent fishing mortality is above the level producing 20%SPR. However, in the context of a stock subject to rebuilding measures including catch limits, fishing mortality should be interpreted not only against fishing mortality-based reference points but also the projected ability of the stock to meet the rebuilding targets in the defined time period.**

Conservation Advice

After the steady decline in SSB from 1995 to the historically low level in 2010, the PBF stock has started recovering slowly, consistent with the management measures implemented in 2014-2015. The spawning stock biomass in 2018 was below the two biomass rebuilding targets adopted by the WCPFC while the 2016-18 fishing mortality ($F_{\%SPR}$) has reduced to a level producing 14%SPR. The projection results based on the base-case model under several harvest and recruitment scenarios and time schedules requested by the RFMOs are shown in Tables S-3 to S-5 and Figure S-9. Under all examined scenarios the initial goal of WCPFC and IATTC, rebuilding to SSB_{MED} by 2024 with at least 60% probability, is reached and the risk of SSB falling below SSB_{loss} at least once in 10 years is negligible. The projection results show that PBF SSB recovers to the biomass-based rebuilding targets due to reduced fishing mortality by applying catch limits as the stock increases (Figure S-10). In most of the scenarios, the SSB biomass is projected to recover to the initial rebuilding target (SSB_{MED}) in the fishing year 2020 (April of 2021) with a probability above the 60% level prescribed in the WCPFC CMM (Table S-4).

The projection results assume that the CMMs are fully implemented and are based on certain biological and other assumptions. For example, these future projection results do not contain assumptions about discard mortality. Although the impact of discards on SSB is small compared to other fisheries (Figure S-8), discards should be considered in the harvest scenarios. Given the low SSB, the uncertainty in future recruitment, and the influence of recruitment has on stock biomass, monitoring recruitment and SSB should continue so that the recruitment level can be understood in a timely manner.

A Kobe chart and impacts by fleets estimated from future projections under the current management scheme are provided for information, (Figures S-10 and S-11, respectively). Because the projections include catch limits, fishing mortality ($F_{x\%SPR}$) is expected to decline, i.e., SPR will increase, as biomass increases. Further stratification of future impacts is possible if the allocation of increased catch limits among fleets/countries is specified.

Table S-3. Future projection scenarios for Pacific bluefin tuna (*Thunnus orientalis*).

Scenario #	Upper Limit increase in requeste scenarios				Catch limit in the projection			
	WCPO		EPO		WCPO		EPO	
	Small	Large	Small	Large	Small	Large	Small	Large
1	0%				4725	6582	3300	
2	0%				4725	6582	3300	
3	5%				4960	6909	3465	
4	10%				5196	7238	3630	
5	15%				5433	7567	3794	
6	20%				5669	7897	3960	
7	0%	500	500		4725	7081	3800	
8	250	250	500		4973	6830	3800	
9	0	600	400		4725	7180	3700	
10	5%	1300	700		4960	7880	4000	
11	10%	1300	700		5196	7880	4000	
12	5%	1000	500		4960	7580	3800	
13	0	1650	660		4725	8231	3960	
14	125	375	550		4848	6955	3850	
15	0	0	0		0	0	0	

* The numbering of Scenarios is different from those given by the IATTC-WCPFC NC Joint WG meeting.

* Fishing mortality in scenario 15 was kept at zero. Fishing mortality in scenario 1 is maintained at the reference level which is the geometric mean values of quarterly age-specific fishing mortality during 2002-2004. In other scenarios fishing mortality was increased to fully utilize the respective catch limits from the reference level. Fishing mortality for the EPO recreational fishery was assumed to be the F2009-11 average level except for scenario 15.

* The Japanese unilateral measure (transferring 250 mt of catch upper limit from that for small PBF to that for large PBF during 2017-2020) is reflected in the projections.

Table S-4. 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 #	Upper Limit increase				Probability of SSB is below the Initial rebuilding target at 2024 in case the low recruitment continue	The fishing year expected to achieve the initial rebuilding target with >60% probability	The fishing year expected to achieve the 2nd rebuilding target with >60% probability	Probability of achiving the initial rebuilding target at 2024	Probability of achiving the second rebuilding target at 2034	Probability of SSB falling below the historical lowest at any time during the projection period.	Probability of Catch falling below the historical lowest at any time during the projection period.	Median SSB at 2024	Median SSB at 2034
	WCPO		EPO										
	Small	Large	Small	Large									
1	0%				0%	2020	2026	100%	99%	0%	100%	107,098	286,958
2	0%				0%	2020	2026	100%	99%	0%	100%	104,973	287,020
3	5%				0%	2020	2027	100%	98%	0%	100%	99,968	272,814
4	10%				0%	2020	2027	100%	96%	0%	100%	95,096	258,850
5	15%				0%	2020	2028	99%	94%	0%	100%	90,293	244,959
6	20%				0%	2020	2028	99%	91%	0%	100%	85,618	231,003
7	0%	500	500		0%	2020	2027	100%	98%	0%	100%	99,903	277,396
8	250	250	500		0%	2020	2027	100%	97%	0%	100%	98,164	268,473
9	0	600	400		0%	2020	2027	100%	98%	0%	100%	100,035	278,004
10	5%	1300	700		0%	2020	2027	99%	96%	0%	100%	92,504	259,802
11	10%	1300	700		0%	2020	2027	99%	95%	0%	100%	89,951	249,996
12	5%	1000	500		0%	2020	2027	100%	97%	0%	100%	94,952	264,218
13	0	1650	660		0%	2020	2027	99%	97%	0%	100%	93,897	267,976
14	125	375	550		0%	2020	2027	100%	98%	0%	100%	98,729	272,323
15	0	0	0		0%	2019	2022	100%	100%	0%	100%	221,391	560,259

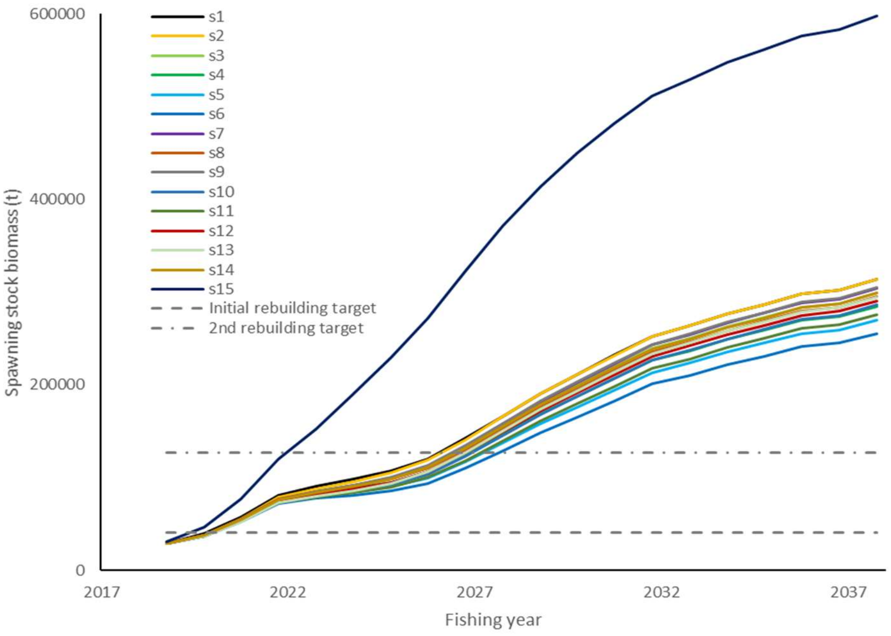
* The numbering of Scenarios is different from those given by the IATTC-WCPFC NC Joint WG meeting and same as Table 3.

* Recruitment is switched from low recruitment during 1980-1989 to average recruitment over the whole assessment period in the following year of achieving the initial rebuilding target.

Table S-5. Expected yield for Pacific bluefin tuna (*Thunnus orientalis*) under various harvesting scenarios based on the base-case model.

scenario #	Upper Limit increase				Median SSB at 2024	Median SSB at 2034	Expected annual yield in 2019, by area and size category (t)				Expected annual yield in 2024, by area and size category (t)				Expected annual yield in 2034, by area and size category (t)			
	WPO		EPO				WPO		EPO		WPO		EPO		WPO		EPO	
	Small	Large	Small	Large			Small	Large	Commercial	Sport	Small	Large	Commercial	Sport	Small	Large	Commercial	Sport
1	0%				107,098	286,958	4,396	5,444	3,310	508	4,583	6,739	3,315	800	4,499	6,871	3,321	1,167
2	0%				104,973	287,020	4,396	6,924	3,541	504	4,580	6,771	3,724	799	4,495	6,851	3,746	1,168
3	5%				99,968	272,814	4,614	7,260	3,468	501	4,809	7,101	3,468	767	4,720	7,187	3,465	1,130
4	10%				95,096	258,850	4,833	7,590	3,633	499	5,038	7,433	3,634	737	4,945	7,523	3,630	1,091
5	15%				90,293	244,959	5,052	7,914	3,797	496	5,267	7,764	3,798	708	5,171	7,859	3,794	1,053
6	20%				85,618	231,003	5,269	8,223	3,964	494	5,493	8,093	3,963	680	5,394	8,195	3,960	1,014
7	0%	500	500		99,903	277,396	4,396	7,411	3,802	500	4,583	7,269	3,803	781	4,497	7,349	3,800	1,150
8	250	250	500		98,164	268,473	4,640	7,172	3,802	499	4,824	7,017	3,802	756	4,734	7,105	3,800	1,118
9	0	600	400		100,035	278,004	4,396	7,506	3,701	501	4,583	7,370	3,703	783	4,496	7,449	3,699	1,152
10	5%	1300	700		92,504	259,802	4,627	8,153	4,003	497	4,814	8,073	4,005	745	4,723	8,156	4,000	1,107
11	10%	1300	700		89,951	249,996	4,858	8,157	4,003	495	5,042	8,074	4,004	721	4,947	8,163	4,000	1,076
12	5%	1000	500		94,952	264,218	4,627	7,881	3,803	498	4,813	7,773	3,805	753	4,722	7,857	3,800	1,115
13	0	1650	660		93,897	267,976	4,396	8,444	3,963	498	4,587	8,426	3,967	769	4,498	8,501	3,960	1,138
14	125	375	550		98,729	272,323	4,517	7,291	3,852	499	4,703	7,142	3,853	767	4,614	7,226	3,850	1,132
15	0%	0%	0		221,391	560,259	0	0	0	0	0	0	0	0	0	0	0	0

* Catch limits for EPO commercial fisheries are applied for the catch of both small and large fish made by the fleets.



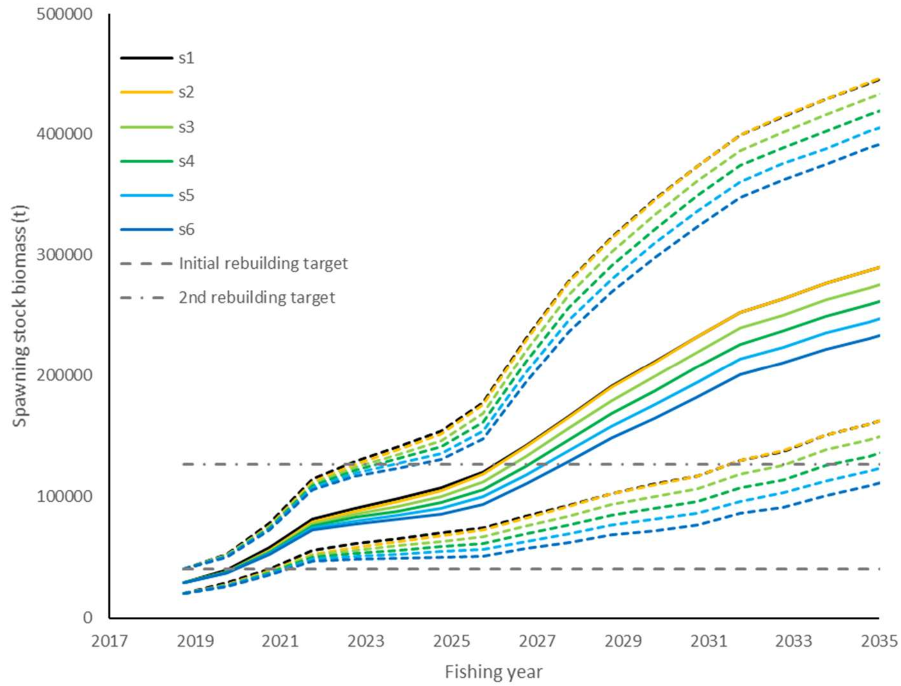


Figure S-9. Comparisons of various projection results for Pacific bluefin tuna (*Thunnus orientalis*) obtained from bias-adjusted bootstrap projection results. (Top) Median of all harvest scenarios examined from Table 3. (Bottom) Median of scenarios 1 to 6 (solid lines) and their 90% confidence intervals (dotted lines). The horizontal dashed lines are the initial (lower) and second rebuilding targets (upper), respectively.

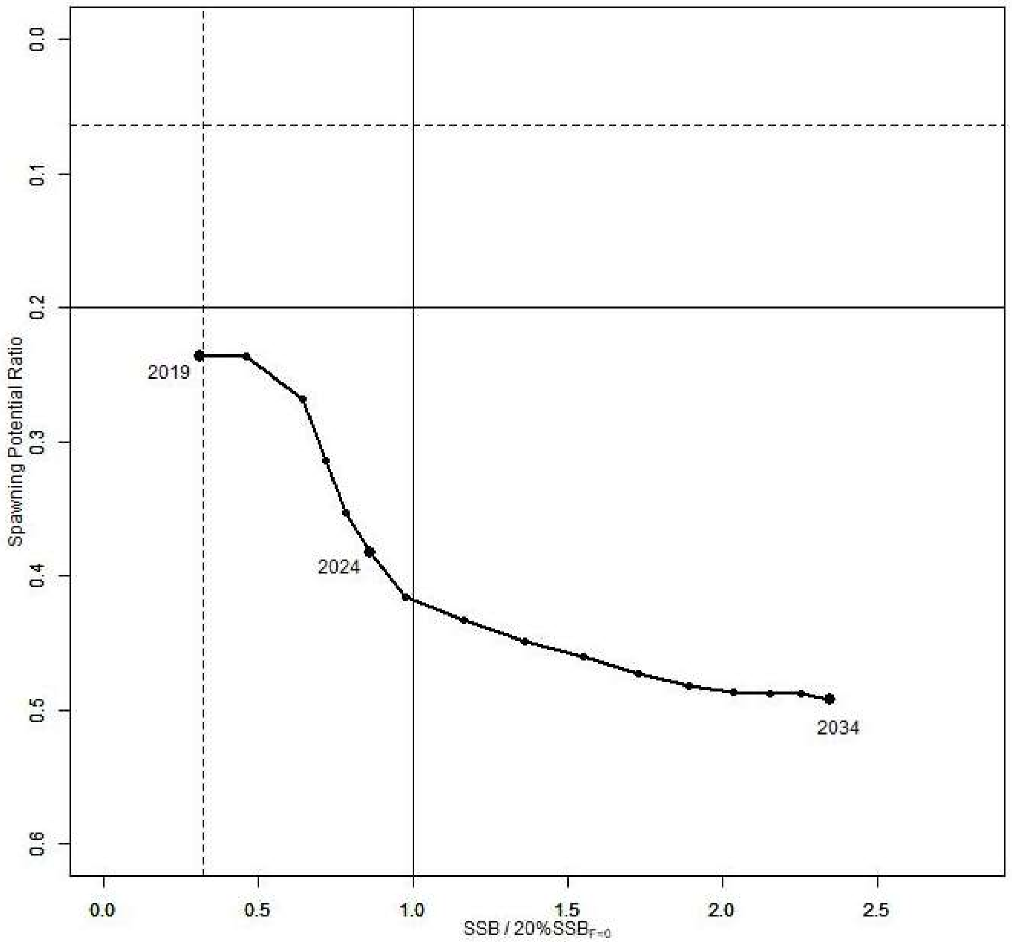


Figure S-10. “Future Kobe Plot” of projection results for Pacific bluefin tuna (*Thunnus orientalis*) from Scenario 1 from Table S-3.

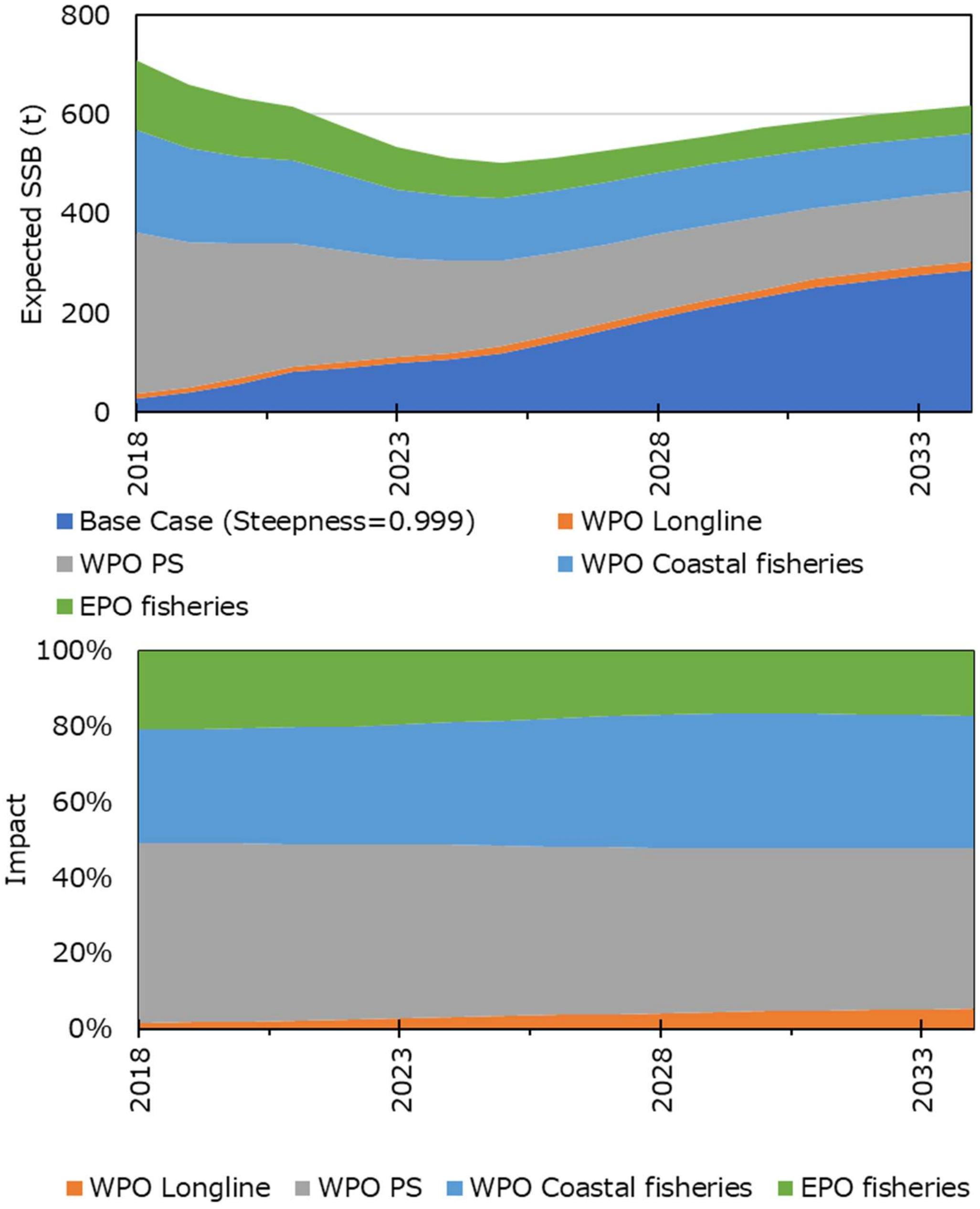


Figure S-11. "Future impact plot" from projection results for Pacific bluefin tuna (*Thunnus orientalis*) from Scenario 1 of Table S-3. The impact is calculated based on the expected increase of SSB in the absence of the respective group of fisheries.

1. 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 information. The results are submitted to Pacific tuna regional fisheries management organizations (RFMOs), in particular, the Western Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC) for review and used as the basis of management actions (the Conservation and Management Measures (CMMs) of WCPFC and IATTC resolutions).

The PBFWG completed the last benchmark stock assessment in 2016 and the updated stock assessment in 2018 using fishery data from 1952 through 2016 (ISC 2018). The 2018 stock assessment concluded that (1) the 2016 stock biomass (3.3%$SSB_{F=0}$) is below the two biomass rebuilding targets adopted by the WCPFC and IATTC while the 2015-16 fishing intensity (spawning potential ratio, SPR) is at a level corresponding to the initial rebuilding target, and (2) the management measures by the WCPFC (CMM 2018-02) and IATTC Resolution (C-18-01) under the low recruitment scenario resulted in an estimated 97% probability of achieving the initial biomass rebuilding target by 2024, and an estimated 96% probability of achieving the second biomass rebuilding target 10 years after the achievement of the initial rebuilding target or by 2034, whichever is earlier.

In the years since the last assessment, there have been advances in knowledge of fishery discards and size data (discards: Lee et al. 2020a, Nakatsuka and Fukuda 2020, Piner et al. 2020; size data: Fukuda 2019, Fukuda and Nakatsuka 2019, Heberer and Lee 2019, Kim et al. 2019, Ohashi and Tsukahara 2019), developing abundance indices using spatio-temporal models (Liu and Chang 2019, Chang et al. 2020, Tsukahara et at. 2020), and modeling selectivity to deal with misfits of the size composition (Lee et al. 2019). These advances were incorporated into the 2020 assessment model.

The 2020 benchmark assessment of Pacific bluefin tuna was conducted during 02-12 March 2020. This report summarizes the assessment results using newly available seasonal fishery data (i.e., catch, discards, size composition data) and annual abundance index through 2019 calendar year in a length-based, age-structured, and forward-simulation population model (i.e., Stock Synthesis).

In this report, "year" denotes the fishing year in the model unless otherwise specified. Relationships among calendar year, fishing year, and year class are shown in Table 1-1. A fishing year starts on the 1st of July and ends on the 30th of June of the following year, and the 1st of July is also assumed to be the date of birth (recruitment) for PBF in the model. For example, the 2018 fishing year corresponds to the 1st of July, 2018 to the 30th of June, 2019.

2. BACKGROUND ON BIOLOGY AND FISHERIES

Biology

Stock Structure

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

The major spawning areas of PBF are found in the western North Pacific Ocean (WPO): one is in waters between the Ryukyu Islands in Japan and the east of Taiwan, another one is in the southern portion of the Sea of Japan (Schaefer 2001), and the other possible one is around Kuroshio-Oyashio transition area in the coastal area of northeastern Japan (Ohshimo et al. 2018, Tanaka et al. 2020) (Figure 2-1). The natal origins of adult PBFs caught either in the waters around the Ryukyu Islands or in the Japan Sea were from both spawning grounds (Uematsu et al. 2018). Age-1 PBFs caught in eastern Pacific Ocean (EPO) were also originated from both spawning grounds using the trace elements in otoliths (Wells et al. 2020). These findings suggest that PBFs comprise a single stock because no significant difference of natal origin between two spawning grounds. Genetics and tagging information (e.g., Bayliff 1994, Tseng and Smith 2012) suggesting a single stock for PBFs. Nakatsuka (2020) reviewed available genetics and reproductive information, otolith and vertebrae data, and fishery data concluded that no information exclusively pointed to the existence of multiple stocks. Therefore, a single stock is used in the PBF assessment within ISC and accepted by the RFMOs (WCPFC and IATTC).

Reproduction

PBFs are iteroparous spawners, i.e., they spawn more than once in their lifetime. Spawning occurs in the limited areas and seasons: from April to July in the waters around the Ryukyu Islands and off eastern Taiwan and from July to August in the Sea of Japan based on histological studies on PBF gonads (Yonemori 1989, Ashida et al. 2015, Okochi et al. 2016) and distribution of PBF larvae (Yabe et al. 1974). The recent histological study showed that 80% of the fish ca. 30 kg (corresponding to the 3 years old about age 2.75 in the assessment model) caught in the Sea of Japan from June to August were mature (Tanaka 2006, Okochi et al. 2016). Almost all the fish caught in the waters of the Ryukyu Islands and eastern Taiwan were above 60 kg (> 150 cm fork length (FL)) (Chen et al. 2006, Ashida et al. 2015). These fish were at least 5 years old (age 4.75 in the model) and were all mature. In addition, active spawning females (Ohshimo et al. 2018) and larvae (Tanaka et al. 2020) were recently found in Kuroshio-Oyashio transition area (Figure 2-1). Consider the velocity of Kuroshio current, the presence of spawning females and these larvae indicates another possible spawning ground from May to August. However, it remains to be verified if these PBF larvae can recruit to the stock.

Although the large PBF were also found in the EPO, in particular recent some years at the Southern California, a recent study which evaluate PBF ovaries of 64 individuals (125-188 cm body length) showed no evidence of active spawning in the EPO (Snodgrass et al., 2019).

Distribution and Movements

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

The movements of PBFs are among the best documented of any highly migratory species despite large inter-annual variations of movement (numbers of migrants, the timing of migration, and migration routes). 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). Ages 0-1 fish hatched in the waters around the Ryukyu Islands and eastern Taiwan migrate north with Kuroshio Current in the summer as they grow, whereas age-0 fish hatched in the Sea of Japan migrates along with the Japanese and Korean coasts (Inagake et al. 2001, Itoh et al. 2003). Depending on ocean conditions, an unknown portion of immature ages 1-3 fish in the WPO makes a seasonal clockwise eastward migration across the North Pacific Ocean (stable isotope in muscle tissues: Tawa et al. 2017, Madigan et al. 2017), spending up to several years as juveniles in the EPO before returning to the WPO (Inagake et al. 2001). The mechanism of eastward trans-Pacific migration is hypothesized due to the limitation of food sources in the WPO and the favorite oceanographic condition (Polovina 1996). While PBFs are 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, PBFs reside in the waters off the southern coast of Baja California, and as the waters warm up in summer, PBFs move northwest into southern California bight. By fall, PBFs are found in the waters off central and northern California. After spending 3-4 years in EPO, PBFs move westward presumably for purposes of spawning as no spawning ground has been observed outside of WPO. This westward migration was observed from December to March as PBFs begin their migration along the coast of California (Boustany et al. 2010). The large interannual and seasonal variation of the trans-Pacific movement made it implausible to quantify the migration rates.

Growth

Age of PBF has been determined using hard tissues such as vertebral ring counts (Aikawa and Kato 1938), scale ring counts (Yukinawa and Yabuta 1967), tag-recapture (Bayliff et al. 1991), and otoliths (daily increments: Foreman 1996; annual rings: Shimose et al. 2008, 2009, Shimose and Takeuchi 2012). A standardized technique for age determination of PBF based on the otolith samples was then developed among the ISC members at the Pacific Bluefin and North Pacific Albacore Tuna Age Determination Workshop in 2014 (Shimose and Ishihara 2015). This was the first large-scale age determination study for PBF. The annuli rings of otolith samples caught by the troll, purse seine, set-net, handline, and longline fisheries landed at Japan and Taiwan between 1992 and 2014 and the daily increments of otolith samples caught by the troll and set-net fisheries in the west coast of Japan between 2011 and 2014 were examined. In addition to analyzing the number of opaque zones in otolith, post-bomb radiocarbon dating was used to validate age estimation, and the estimated ages were consistent between post-bomb radiocarbon dating and otolith thin sections (Ishihara et al. 2017).

Fukuda et al. (2015b), then, estimated growth curves by integrating these annuli data for 1,782 fish (70.5-271 cm in folk length [FL] corresponding to 1-28 years old) and daily increment data for 228 fish (18.6-60.1 cm in FL corresponding to 51-453 days old after hatching). Their analyses indicated that a simple von-Bertalanffy growth function (VBGF; von Bertalanffy 1938) applied to fish aged 0-28 could not fit length at age 0 well due to seasonal patterns in age-0 growth (PBFs grow rapidly from July to December but then hardly grow during winter) (Fukuda et al. 2015a).

These paired age-length data were then used in two ways to estimate growth curves. First, a traditional estimation method treated the paired age-length data obtained from annuli and daily rings data as random at age, and the fitting procedure was optimized outside the integrated assessment model. Second, a length-conditional method used the same age-length data but treated them as random at length (conditional age-at-length (CAAL) data). CAAL data were incorporated into the integrated stock assessment models to simultaneously estimate growth parameters with underlying population dynamics (Piner et al. 2016, Lee et al. 2017). Fukuda et al. (2016) explored several growth patterns using both traditional estimation method (a simple VBGF, a two-stanzas growth model, a two growth patterns model representing different birth date) and length-conditional method (a seasonal growth model) in the earlier integrated model runs and found that the simple VBGF model and the seasonal growth model fit the length compositions better than the other growth models. The seasonal growth model, however, heavily relied on the CAAL data to estimate growth. Since these CAAL data were not representative of the age structure of the population mainly due to the combination of the un-modeled age-based movement and possible sampling bias, including these CAAL data in the integrated model can cause bias and imprecision in estimates of not only growth but also population dynamics (Lee et al. 2019). The PBFWG decided to use a simple VBGF estimated by Fukuda et al. (2015b) and externally calculate the variance of length at age using the length compositions and CAAL data (ISC 2016). Any misfit of length compositions was further addressed by adding modeling processes in the selectivity section 4.3.2.

The variances of length composition data for all fisheries were reviewed during the 2016 stock assessment workshop meeting (ISC 2016). The estimated variance of length composition data generally stabilizes after fish mature suggesting that the coefficient of variation (CV) of length at age decreases from age 0 to 3 and steadies from age 3 and above. The possible causes of the higher variance of length at young ages could be from seasonal growth, different birth dates, different growth patterns among years, etc. and the actual variance could be the result of a mix of many factors. This CV of CAAL data was estimated using the length-conditional method developed in Lee et al. (2017).

The growth curve assumed in this assessment was generally consistent with the previous studies (Shimose et al. 2009, Shimose and Takeuchi 2012, Shimose and Ishihara 2015, Fukuda et al. 2015b); 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.

The length-weight relationship of PBF based on the von Bertalanffy growth curve used in this stock assessment is shown in Table 2-1 and Figure 2-4.

Natural Mortality

Natural mortality coefficients (*M*) is one of the most difficult parameters to be reliably estimated in the stock assessment model based on the simulation studies (Lee et al. 2011, Lee et al. 2012). The ad-hoc approaches based on the tagging analyses, life-history and information from similar species were used. *M* 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. A constant natural mortality coefficient was further derived from the median value obtained across a suite of empirical and life-history based methods to represent age 2 and older 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 released from EPO, where the young fish (1-5 years old) occur. The major criticism to use *M* estimated from Whitlock et al (2012) is that the estimate doesn't represent the whole population due to the incomplete tagging samples (solely in EPO). This stock assessment used the same *M* schedule as the previous stock assessments. See section 4.2.5 for the actual model setting for the *M* values.

Review of Fishery and RFMOs' management

The main fisheries from each fishing nation and the RFMOs' management measures are summarized in this section, whereas the fleet structures and associated data used in the stock assessment are summarized in section 3.3 (fishery definitions).

While there were few PBF catch records prior to 1952, some PBF landings records are available dating back to 1804 from coastal Japan and to the early 1900s for U.S. fisheries operating in the EPO. The 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 ISC member countries fluctuated widely from 1952-2018 (Figure 2-6). Five countries mainly harvest PBF, 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 34,612 t in 1981, reached the low amount at 8,653 t in 1990, increased to 33,946 t in 2000, and then declined after 2005. While a suite of fishing gears catch PBF, most of the catch is from purse seine fisheries (Figure 2-7).

The trend of the total catch is associated with RFMOs' management. In 2011, WCPFC started the conservation and management measure to regulate the catches for small PBF (<30 kg in body weight) in its convention area (WCPFC CMM 2010-04). The catch limit was further reduced for 2014 (WCPFC CMM 2013-09) and 2015 (WCPFC CMM 2014-04). The current measure (WCPFC CMM 2019-02), which has been in force since 2015, is to maintain the catch for small PBF less than 50% of the 2002-2004 average level and the catch for large PBF (>30 kg in body weight) less than the 2002-2004 average level. In 2012, IATTC started the conservation and management measure to regulate the catches for all range in size of PBF in its convention area (IATTC resolution C-12-09). The catch limit was also further reduced for 2015 and 2016 (IATTC resolution C-14-06). The current measure (IATTC resolution C-18-01) limited total commercial catch for 2019 and 2020, combined, less than 6,200 tons.

The major active PBF fisheries in Japan are longlines, purse seines, trolling, and set nets. Other gear types such as pole-and-line, drift net, and hand-line used to take a considerable amount of catches. The fishing grounds for the currently active fisheries are generally in coastal or nearshore waters, ranging from Hokkaido to the Ryukyu Islands. The distant-water longline fisheries also catch PBF, but their catch is small compared to other active fisheries. Overall, 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). More details of Japanese fisheries taking PBF can be referred to Yamada (2007) and section 3 (longline fishery: Section 3.5.3; purse seine fishery: Section 3.5.4, 3.5.7, 3.5.8, 3.6.3, 3.6.4, and 3.6.5).

In the United States of America (U.S.), two major active PBF fisheries (purse seine and recreational fisheries) catch PBF off the west coast of North America. The U.S. purse seine fishery used to catch a large amount of PBF for canning in the waters off Baja California until Mexico established its Exclusive Economic Zone (EEZ) in 1976 and excluded U.S. purse seine vessels. After 1983, the U.S. purse seine fishery only caught PBFs opportunistically (Aires-da-Silva et al. 2007). Currently, the vast majority of PBF catch in the U.S. is from recreational fisheries in U.S. and Mexican waters (Heberer and Lee 2019).

The Mexican purse seine fishery was developed rapidly after Mexico established its EEZ and is the most important large pelagic fishery in Mexico. This fishery is monitored by an at-sea observer program with 100% coverage, captains' logbooks and Vessel Monitoring Systems (VMS), and recently stereoscopic cameras (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; PBFs are caught near Baja California for farming. The Mexican PBF catch history recorded three large annual catches (above 7,000 t) in the years 2004, 2006, and 2010.

In Korea, PBF are mostly caught by the offshore large purse seine fishery (OLPS), but there is some smalls amount of catches reported by the coastal fisheries in recent years. The catch of the OLPS fishery was below 500 t until the mid-1990s, increased with a peak of 2,601 t in 2003, and then has fluctuated from 600 t to 1,900 t. In 2018, the catch of the OLPS fishery was 523 t. The main fishing ground of the OLPS fishery is off Jeju Island, but the vessels occasionally operate in the Yellow Sea and the East Sea (Yoon et al. 2014, Lee et al. 2018).

The amount of PBFs caught by the Taiwanese fisheries (small-scale longline, purse seine, large-scale pelagic driftnet, set net, offshore and coastal gillnet, and bottom longline fisheries) was small (<300 t) between the 1960s and the early 1980s. After 1984, the total landings increased gradually to over 300 t mostly due to the small-scale longline vessels (<100 gross registered tonnage (GRT)) targeting spawners for the sashimi market from April to June. The highest observed catch was 3,000 t in 1999, and then catch declined rapidly to less than 1,000 t in 2008 and to the lowest level of about 200 t in 2012. The catch then slightly increased and in 2018, the preliminary estimate of PBF catch was 454 t.

3. STOCK ASSESSMENT INPUT DATA

Spatial Stratification

PBFs are distributed across the North Pacific Ocean and considered to be a single stock (Nakatsuka 2019). Juvenile PBFs move between the western Pacific Ocean (WPO) and the eastern Pacific Ocean (EPO) (Itoh et al. 2003, Boustany et al. 2010), before returning to the WPO to spawn. Because of the lack of direct information on movement rates, a true spatial model has not been used for assessment purposes. Instead, this and previous assessments have been assumed an instantaneously mixed population and incorporated regional selection patterns to implicitly model space ("areas-as-fleets approach", Waterhouse et al. 2014). The areas-as-fleets approach used by the PBFWG was evaluated in a simulation study, suggesting that although the use of alternative model processes is not as effective as a true spatially explicit model, management quantities can be well estimated when fishery selection is properly set up to account for both availability (spatial patterns) and contact gear selectivity (Lee et al. 2017). A spatially explicit model continues to be an area for future research.

Temporal Stratification

In the stock assessment for PBF, a "fishing year" is defined as July 1st through June 30th of the following calendar year. Thus, the 2018 fishing year corresponds to 1st July 2018 to 30th June 2019. Unless otherwise indicated, the term "year" in this report refers to the fishing year. The time period modeled in the assessment of PBF is 1952-2018, 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 "month 1" (starting from July; see section 4) in the assessment model. Relationships between calendar year, fishing year, and year class are shown in Table 1-1.

Fishery definition

A total of 25 fisheries were defined for the stock assessment of PBF based on stratification of country, gear type, season, area, and size of fish caught (Table 3-1) after PBFWG data preparatory meeting (ISC 2019). Representative fisheries for each Fleet are as follows;

Fleet 1: Japanese longline fisheries (JP LL) for all seasons for 1952-1992, and for season 4 after 1993,
Fleet 2: Japanese small pelagic fish purse seine fishery in the East China Sea (JP SPPS) for seasons 1, 3, and 4,
Fleet 3: Korean offshore large scale purse seine fishery (KR OLPS),
Fleet 4: Japanese tuna purse seine fishery in the Sea of Japan (JP TPSJS),
Fleet 5: Japanese tuna purse seine fishery off the Pacific coast of Japan (JP TPS PO),
Fleet 6: Japanese troll fishery (JP Troll) for seasons 2-4,
Fleet 7: Japanese pole and line fishery (JP PL),
Fleet 8-10: Japanese set-net fisheries (JP SetNet),
Fleet 11: Japanese other fisheries (JP Others), mainly small-scale fisheries in the Tsugaru Strait,

Fleet 12: Taiwanese longline fishery (TW LL) in southern fishing ground,
Fleet 13: EPO commercial purse seine fishery (U.S. dominant) for 1952-2001 (U.S. COMM),
Fleet 14: EPO commercial purse seine fishery (Mexico dominant) after 2002 (MX COMM),
Fleet 15: EPO sports fishery (EPO SP) after 2014,
Fleet 16: Japanese troll fishery for farming (JP Troll for Penning),
Fleet 17: Taiwanese longline fishery (TW LL) in northern fishing ground,
Fleet 18: Japanese small pelagic fish purse seine fishery in the East China Sea (JP SPPS) for season 2,
Fleet 19: Japanese troll fishery (JP Troll) for season 1,
Fleet 20: Japanese small pelagic fish purse seine fishery in the East China Sea (JP SPPS) for farming,
Fleet 21: Unaccounted mortality fisheries (in weight) in WPO,
Fleet 22: Unaccounted mortality fisheries (in number) in WPO,
Fleet 23: Japanese longline fisheries (JP LL) for seasons 1-3 after 1993,
Fleet 24: Eastern Pacific Ocean sports fishery (EPO SP) for 1952-2013,
Fleet 25: Unaccounted mortality fisheries (in number) in EPO.
Some gear/areas fisheries with only a minimal amount of PBF catch were included in the fleet with similar size compositions, fishing ground, and seasons. The decision for which fleet to include the catch was based on expert opinion regarding composition similarity. For example, reported small catch by Korea (by trawl, set-net, and troll fisheries) is included in Fleet 3. Taiwanese purse seine catch was included in Fleet 4, the driftnet catch of 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 Season 1-3 and Season 4 were included in Japanese set-net fleets, Fleet 8 and 9, respectively. The other Japanese catch (by trawl and other small longline other than those from the Tsugaru Strait) were included in Fleet 11. Non ISC members' catch after 2014 (i.e., by New Zealand, Australia, etc.) is included in Fleet 12.

Catch and discard data

Catch data

Although fisheries catching PBF have 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, 1952 is used as the starting year of the stock assessments, because a more consistent catch reporting process was adopted, and the catch-and-effort data from Japanese longline fleet were available from that year onward.

Throughout the assessment period, total annual catch fluctuated widely, with the historical maximum and minimum total catches of any calendar year are 40,383 t in 1956 and 8,653 t in 1990, respectively (Table 3-2, Figure 2-6). Annual catches have averaged about 15,000 t in the last decade (in 2009-2018 calendar years). The majority of PBF have been taken by the purse seine fisheries: Japanese tuna purse seine fishery operating off the Pacific coast of Japan (Fleet 5), U.S. purse seine fishery (Fleet 13) with a large portion of the catch until the 1990s, Japanese small pelagic fish purse seine fishery operating in the East China Sea (Fleet 2 and Fleet 18), Japanese tuna purse seine fishery in the Sea of Japan (Fleet 4), and Mexican purses seine fisheries (Fleet 14) (Figure 3-2 (a)).

For the assessment model, catches were compiled for each fleet quarterly (Table 3-3). For some fisheries, quarterly catches for the early period were estimated using recent quarterly catch proportions applied to annual catch data. Examples include Fleets 8 and 9 before 1994 (Kai 2007a), Fleet 5 before 1971 (Takeuchi 2007), etc.. For most fleets, recent quarterly catches were directly derived from logbook or landing statistics. Other fleets primarily operate in only one season such as Fleet 11 which includes small-scaled Japanese fisheries (e.g., trawl, small longline, etc.), and their annual total catch was placed in Season 2. The catches by Fleet 10 were aggregated and placed in Season 2. Catch data for stock assessment were expressed in tones for all fleets except for Fleet 15, 16, 20, 22, and 25 where quarterly catches were expressed in thousands of fish (Figure 3-2 (b)). All the quarterly catch data were updated up to Season 4 of 2018 (2019 calendar year Quarter 2). Here we note that catch for Fleet 2 decreased in some years from previous stock assessment as the catch for farming was separated into a separate Fleet 20. In the previous assessment, catch for Fleet 16 was double the reported catch in order to accommodate unknown unaccounted mortality. In this assessment, catch for Fleet 16 was halved and the other half was included in Fleet 22 which is the unaccounted mortality fleet.

Unaccounted mortality

It is recognized that impactful management measures may have altered fishery practices in the most recent years. The PBFWG agreed that the base-case of this assessment should include "unaccounted mortality" (ISC 2019). In this document, we define "unaccounted mortality" as fishery caused kills that do not show up in landings data. This can include predation of sportfishing catches in addition to discard mortalities. Japan (Nakatsuka and Fukuda 2020), Korea (Lee et al. 2020a), and the U.S. (Piner et al. 2020) provided discard information in response to PBFWG recommendation. Mexico suggested there is no discard or post-release mortality reported from the IATTC/AIDCP onboard observers with a 100% coverage rate. Taiwan also suggested there is no sign of releasing PBF from their fishery while there is a sufficient margin in their fishing quota.

Fleet 21 (unaccounted mortality fisheries from WPO, 2017-2018) includes estimated dead discards from Japan fisheries (setnet, purse seine, longline, and troll, etc.) and Korea purse seine fisheries in the unit of weight, whereas Fleet 22 (Unaccounted mortality fisheries in WPO, 1998-2018) and Fleet 25 (Unaccounted mortality fisheries in EPO, 1999-2018) include estimated dead discards from Japan fisheries for penning (troll and small pelagic purse seine) and from U.S. sport fisheries, respectively, in the unit of number.

Japanese discard mortality was estimated as 5% of reported catch for all Japanese fisheries for 2017 and 2018 when the release of PBF considered having become significant (Nakatsuka and Fukuda 2020). Korean discard amount was estimated in the same manner (Lee et al. 2020a). For the U.S. recreational fishery, catches, releases (discards), and predation events of hooked fish are recorded in California Commercial Passenger Fishing Vessels logbooks. An estimate of release mortality and subsequent discard mortality numbers were developed for this fleet. A random-effect inverse variance meta-analysis estimated the mortality rate (6%) (Piner et al. 2020). To reflect the uncertainty of these removals, the CV for these unaccounted mortality fleets were given at the high value (0.3) (ISC 2020).

Abundance Indices

Overview

CPUE-based abundance indices which were discussed in ISC PBFWG are listed in Table 3-4. These series were derived from fishery-specific catch and effort data which were standardized with appropriate statistical methods (Figure 3-3 and Table 3-5). In the previous assessment, the PBFWG used four longline CPUE series as the adult abundance indices (S1, S2, S3, and S5), and a Japanese troll index (S4) as the recruitment index for the base-case model (ISC 2018). The S1, S2, and S3 indices (Japanese coastal, offshore, and distant-water longlines, respectively) temporally covered the recent period (1993-2018), early period (1952-1973), and middle period (1974-1992), respectively. S5 index (Taiwanese longline fishery) is also an adult abundance index for the recent period (2002-2018). In this assessment, abundance indices from the same fisheries as the previous assessment were included in the negative loglikelihood function of the stock assessment model. The input coefficients of variation (CV) of abundance indices were set at 0.2 for all indices, years, and seasons, when the CV statistically estimated by the standardization model was less than 0.2. If the CV estimated by the standardization model was more than 0.2, the actual CV value was used to represent the sampling variability for the observation. This is the same approach used in the previous assessment (ISC 2018).

Japanese Longline CPUE indices (S1, S2, & S3)

Japanese longline CPUE indices are derived from logbook data. A total of 3 indices are developed from this longline information; one for the coastal (before 1993) and two for the offshore and distant water fisheries (after 1993). The offshore and distant-water longline CPUE indices have to be split up into two time-series; 1952-1973 (S2; Fujioka et al. 2012b) and 1974-1992 (S3; Yokawa 2008), because of the change in operational pattern and available dataset (i.e., hooks-per-basket).

For this assessment, the abundance index from the Japanese coastal longline (S1: 1993-2018) used a new spatio-temporal standardization model (Tsukahara et al. 2020). The time series developed was very similar to the previous GLMM analysis, but the PBFWG considered it an improved technical representation of the relative abundance.

Japanese Troll CPUE index (S4)

Catch-and-effort data for the coastal troll fisheries targeting age-0 PBF in Nagasaki prefectures have been collected from five fishing ports. The troll fishery in Nagasaki prefecture dominates Japanese troll catch, and the fishery can fish age-0 PBF from both spawning grounds (Ryukyu Islands and the Sea of Japan) because of the geographical location of the fishing ground (Ichinokawa et al. 2012). The units of effort in the catch-and-effort data are the cumulative daily number of unloading troll vessels, nearly equivalent to the total number of trolling trips because most troll vessels make one-day trips. The effort data only recorded information that at least one PBF was caught: zero-catch data was unavailable. Therefore, a log-normal model was applied for the standardization of the CPUE (S5).

In the previous PBF assessment, catch and size composition data of Japanese troll fisheries were separated into two fleets by season (Fleets 6 and 19) (ISC 2018). However, in the previous assessment, the troll abundance index (S4) had developed using the data from all seasons, while its selectivity was assumed the same with Fleet 6. For this assessment, the S4 index was developed using only seasons 2-4 data to maintain consistency with the composition data of Fleet 6 (Nishikawa et al. 2019). In addition, the PBFWG agreed to exclude the 2017 data point for the S4 abundance index due to the lack of spatial and temporal coverage compared with the other years (Nishikawa et al. 2020).

Taiwanese Longline CPUE indices for southern area (S5-S9)

An adult index of relative abundance was developed from Taiwanese fishing operations. The fishing ground of the Taiwanese longline fleet can be separated into southern and northern areas. The southern area has been considered as the main fishing ground for this fleet. The CPUE used in this assessment was based on the operations in the southern area and standardized by GLMM (Chang et al. 2020) (S5: 2002-2018) and was developed using the following process; (1) Estimating PBF catch in the number of fish from landing weight for 2003 based on an MCMC simulation, (2) Deriving fishing days for 2007-2009 from vessel monitoring system (VMS) data and voyage data recorder (VDR), (3) Deriving fishing days for 2003-2006 from vessels trip information based on linear relationships between fishing days and at-sea days for a trip, by vessel size and fishing port, during 2007-2018, and (4) Estimating and standardizing the CPUE (catch number per fishing days) for 2003-2018 (Chang and Liu 2018, Chang et al. 2020). In this assessment, the years 2001-2002 were removed from the standardization of the S5 time series because of much reduced data coverage.

In addition to this index, four indices were also developed but not included in the likelihood function. These alternative indices include an index for the north area from the non-spatial model for 2002-2018 (S9) and three indices for the north, south, or combined areas from the spatio-temporal model for 2006-2018 data (S6-S8). These indices are being evaluated for potential use in future stock assessments.

Size composition data

Overview

Quarterly size composition data (length or weight) for PBF from 1952 to 2018 were compiled for the stock assessment. All length data (fork length (FL)) were measured to the nearest centimeter (cm), whereas weight data were measured to the nearest kilogram (kg). In the assessment model, the length data bins of 2, 4, and 6 cm width were used for 16-58, 58-110, and 110-290 cm FL fish, respectively. Composition data in weight were binned in a range of bin sizes (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). This bin strategy attempted to create two bins for each age between 0 and 15 (Fujioka et al. 2012a). The lower boundary of each length or weight bin was used to define the bin.

For this assessment, the size composition data for Fleets 7, 13, and 24 were not updated from the previous assessment (ISC 2018). Length composition data were updated and estimated for Fleets 1-6, 8, 9, 12, 14, 15, 17-20, and 23, while weight composition data were updated for Fleets 10 and 11. Of these, the size compositions for Fleets 10-11 were combined to simplify the assessment model (Table 3-6). Fleet 16 was assumed to catch only age-0 fish, thus their size composition was not required. Figure 3-5 shows the quarterly size compositions of each fleet.

The sources of input sample sizes for the size composition data were summarized in Table 3-6. Depending on the corresponding fisheries and available data, the sample size was based on four different criteria; "Number of fish measured", "Number of landing wells sampled", "Number of the total month of wells sampled by port", and "Number of haul wells sampled".

Japanese Longline (Fleets 1 and 23)

Length-composition data for PBF from the Japanese longline fishery (Fleet 1) are available for the periods of 1952-1968 and 1994-2018 (Figure 3-5). Until the 1960s, the data were collected mainly from the Tsukiji market. Since the 1990s, sampling and market data have been collected at the major PBF unloading ports (e.g., Okinawa, Miyazaki, and Wakayama prefectures). Length measurements were relatively sparse from 1969 to 1993 and there are concerns about their representativeness and so those data are not included in the assessment.

Length compositions for 1952-1968 were estimated based on the aggregated catch and length measurement data by year, month, and area (5x5 degree cells). Using this stratification, length composition was raised by catch in the number of fish (Mizuno et al. 2012). Since 1993, the length compositions were estimated based on the quarterly landing amount and length measurement in each prefecture. Using quarter and prefecture strata, length composition was raised by landing weight (Ohashi and Tsukahara 2019).

Size composition data from the Japanese longline for season 3 after 1993 are retrieved in this assessment (Ohashi and Tsukahara 2019), and they indicated smaller fish were taken relative to season 4. Therefore, the fishery was separated into two fleets after 1993 in seasons 1-3 (Fleet 23) and in season 4 (Fleet 1) (ISC 2019).

In this assessment, the 2017-18 compositions of Fleet 1 were not included in the base-case model. Those data indicated a shift to smaller size fish, which could be due to the changes in fishery practices caused by a closure during a part of the main fishing season. More work will be needed to understand the potential effects of recent management measures on the stability of the model process linking to this and other data.

Japanese small pelagic fish purse seines in the East China Sea (Fleets 2, 18, and 20)

Length composition data for PBF from the Japanese small pelagic fish purse seine in the East China Sea are derived from length measurements taken at the major landing ports (Fukuoka and Matsuura). Size sampling has been conducted for each market brand and raised by the amounts of landings for each market brand (Kumegai et al. 2015).

The composition data are separated into two fleets by season (Fleet 2 and 18). Fleet 2 (Seasons 1, 3, and 4) has composition data available for 2002-2018, whereas Fleet 18 (Season 2) has data for 2003-2012, 2014, and 2016. In the assessment, the data in Seasons 3-4 of 2014 for Fleet 2 were not used because there seems to be large uncertainty when measuring the data due to the changes in the landing procedures in the ports.

For this assessment, a new fleet (Fleet 20) was created from the Japanese purse seines operating in the East China Sea for farming. The size composition data for this new fleet were obtained using a stereo-scopic camera at farm caging (Fukuda and Nakatsuka 2019).

Korean purse seine (Fleet 3)

Length-composition data from the Korean purse seine (Fleet 3) are available since 2010 (Lee et al. 2020b). In the previous assessment, the size composition from both the Japanese small pelagic purse seine (Fleet 2) and the Korean purse seine (Fleet 3) has been combined into a single fleet (Fleet 2) for 2010-2014 (ISC 2016b). The size compositions of both fleets were similar. However, since 2013, larger sized fish (> around 70 cm) have begun to occur in season 3 for Fleet 3. Thus, the two fleets were disaggregated for this assessment (ISC 2019). Size sampling for Fleet 3 composition data was conducted by fish sampling at port and measurement at the laboratory by scientists.

Japanese purse seines in the Sea of Japan (Fleet 4)

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

Japanese purse seines 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 Tukiji 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 the length measurements from this fishery had been taken since the 1980s, an appropriate method to create the size composition representing the catch has not yet been established for the entire period. Therefore, the length composition for this fleet included in the past assessments had been limited to 1995-2006 (Figure 3-5). The size composition data for those years were highly variable (from 50 cm to very large), and it was recognized the need for further research especially focusing on the smaller fish.

In this assessment, new size compositions were created for 2014-2018 based on the port sampling program, which has been strengthened since 2015 (calendar year). This fleet has had low catches for 2011-2014 (calendar years), and no size composition data was available for this period (Fukuda 2019).

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

Length-composition data for the Japanese troll fisheries (Fleet 6 and 19) were estimated as follows: 1) Fish length was measured at the main unloading ports, 2) The measurement data was aggregated by “area” and “month” as the minimum spatial and temporal strata, and 3) These aggregated data were raised by catch in the number of fish in the corresponding strata (Fukuda et al. 2015). Based on this procedure, the estimated quarterly length-composition data were fit in the assessment model unless more than 20% of catch did not have corresponding size data. According to this criterion, the length composition data for seasons 1, 3, and 4 in 2017 and season 4 in 2018 were not included in updated data for this assessment.

The Fleets 6 and 7 tend to operate in the same area and catch similar-sized fish (primarily age-0 fish). Thus, the size selectivity information of Fleet 6 has been shared by Fleet 7 in the assessment model because of the relatively poor size sampling of Fleet 7 (Figure 3-5).

Japanese set-net and other fisheries (Fleets 8 to 11)

Size measurement data for PBF from Japanese set-net fisheries 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 introducing broad size category stratum (i.e., Small/Medium/Large) and limiting over-strata calculation (Hiraoka et al. 2018). Due to the complexity of the dataset, the set-net fishery was divided into 3 fleets: Fleet 8 is ine the Seasons 1, 2, and 3 in all prefectures except for Hokkaido and Aomori, Fleet 9 is in Season 4 from the same areas, and Fleet 10 is all-season fishery in Hokkaido and Aomori (ISC 2015b). For Fleets 8 and 9, length-composition data are available. The data showed that the catch-at-size data were highly variable from year to year, and quarter and quarter, probably because of the influence of the environmental conditions and migration (Kai 2007a). Size compositions for PBF from the set-net fishery in Hokkaido and Aomori prefectures (Fleet 10) are the weight measurements (Sakai et al. 2015). Fleet 11 also has weight composition data, which includes hand line and small-scaled longline fisheries in the Tsugaru Strait and its adjacent waters (Nishikawa et al. 2015). The weight composition data for Fleet 11 were combined to Fleet 10.

Taiwanese longline (Fleet 12 and 17)

Length-composition data for PBF from the Taiwanese longline fishery (Fleets 12 and 17) were based on the market landing information and port sampling. Since 2010, additional information has been available from the catch documentation scheme (CDS) program, which can provide more size samples with better quality (Chang et al. 2015). The Taiwanese longline fishery was separated into two fleets by fishing area; Fleet 12 for the southern area and Fleet 17 for the northern area. For this 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: 1992-2018, Fleet 17: 2009-2018).

EPO commercial purse seine fisheries (U.S. dominant) for 1952-2001 (Fleet 13) and (Mexico dominant) after 2002 (Fleet 14)

Length-composition data for PBF from EPO purse seine fishery are collected by port samplers from IATTC and national/municipal at-sea observers and sampling programs (Bayliff 1993, Aires-da-Silva and Dreyfus 2012). Fleet 13 is the U.S. dominant EPO purse seine fishery for 1952-2001, and its length composition data from 1952 to 1982 are used to estimate the selectivity pattern for the stock assessment (ISC 2015b). Fleet 14 is the Mexico dominant EPO purse seine fishery (2001 onwards), and its length composition data from 2005 to 2018 are used to estimate the selectivity pattern. Since 2013, size composition data are measured by stereoscopic cameras from the largest farming company (Dreyfus and Aires-da-Silva 2015). For this assessment, the length composition data for 2017-2018 were updated (Dreyfus 2020).

U.S. recreational fisheries (Fleets 15 and 24)

Size composition data for PBF from the U.S. recreational fishery had been collected by IATTC staff from 1993 to 2011 (Hoyle 2006). Since 2014, NOAA took over the sampling program (Heberer and Lee 2019), and size composition data are measured by port samplers. In this assessment, the U.S. recreational fishery was separated into two fleets: Fleet 24 in 1952-2013 when the IATTC conducted the sampling and Fleet 15 in 2014-2018 when the NOAA conducted the sampling. There was no information about how the size sampling program operated prior to 2012, thus the PBFWG agreed that the size composition data before 2012 are not used. Selectivity for Fleet 24 was assumed to be similar to that for Fleet 15.

Japanese troll fishery for farming (Fleet 16)

For the stock assessment, the troll fishery for farming is assumed to target only age-0 fish (ISC 2015a) since there are no size compositions available.

Unobserved mortality fleets (Fleets 21, 22, and 25)

Unobserved mortality related to the possible post-release mortality of discards were included as removals. The unobserved mortality was separated into three separate fleets. This is new information and included in the assessment because recent management measures coupled with the beginning of increasing abundance are thought to increase potential discarding. Because there is no available data to represent the size distribution of unobserved fish, the size selectivity for these fleets was assumed to be similar to the associated fisheries (Section 4.3.2).

4. MODEL DESCRIPTION

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 3.30.14 (Methot and Wetzel 2013). SS is a stock assessment model that estimates the population dynamics of a stock using a variety of fishery-dependent, fishery-independent, and biological information. Although it was initially developed for coastal pelagic fishes (sardine and anchovy), it has become a standard tool for tunas and other highly migratory species in the Atlantic, Indian, and 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 algorithm. This assessment uses the maximum likelihood estimation to estimate parameters and normal approximation or bootstrapping to estimate parameter uncertainty.

SS is comprised of three subcomponents: (1) a systems dynamics subcomponent that recreates estimates of the numbers/biomass at age using estimates or pre-specified values of movement, natural mortality, growth, fecundity, and spawner-recruitment relationship, etc., (2) an observational subcomponent that relates observed (measured) quantities such as CPUE or proportion at length/age to the population dynamics through estimates of catchability and selectivity, and (3) a statistical subcomponent that uses likelihoods to quantify the fits of the observations to the recreated population.

Biological and Demographic Assumptions

Sex Specificity

This assessment assumes that there is no difference in sexual dimorphism. Studies have found that the sex ratio between females and males is not statistically different from 1:1 (Chen et al. 2006, Shimose and Takeuchi 2012). Males are generally larger than females after they reach sexually mature (Maguire and Hurlbut 1984, Shimose et al. 2009, Shimose and Takeuchi 2012). Shimose and Takeuchi (2012) and Takeuchi (2012) further estimated sex-specific growth for PBF, however, samples of paired age-length data by sex are often skewed. Given the lack of records of sex in the fishery data, a single-sex was assumed for this assessment.

Growth

A sex-combined length-at-age relationship was externally estimated from paired age-length otolith samples (annual rings: Shimose et al. 2009, Shimose and Takeuchi 2012, Shimose and Ishihara 2015; annual and daily rings: Fukuda et al. 2015b) described in the section 2.1.4. This relationship was then re-parameterized to the von Bertalanffy growth equation used in SS **(**Figure 2-3**)** and adjusted for the birth date (1st of 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 length (in cm) associated with ages (in year) near the first (A_1) and second (A_2) ages, L_∞ is the asymptotic average length-at-age (Francis 1988), and K is the growth coefficient (y^{-1}). The growth parameters K, L_1, and L_2 were fixed in the SS model, with K at 0.188 y^{-1} and L_1 and L_2 at 19.05 cm and 118.57 cm for age 0 and age 3, respectively based on the length-at-age relationship by Fukuda et al. 2015b. L_∞ can be re-parameterized as:

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

L_∞ is then calculated as 249.917 cm. The process errors modeled as the coefficients of variation (CVs) were the function of the mean length at age, $CV = f(\text{length-at-age})$. Based on the estimated variances from the length composition data and the conditional age-at-length data, the CV was then fixed at 0.259 and 0.044 for age 0 and 3, respectively. Linear interpolation between 0-3 was used to generate the process error for intervening ages, and ages 3 and older were assumed the same as age 3. The parametrization above results in the traditional von Bertalanffy parameters as follows:

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

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 birthday, the first day in the fishing year) = theoretical age where length is equal to zero.

Ages Modeled

Ages from age 0 to the maximum age of 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 the age where the number of fish is minimized. Given the M schedule, approximately 0.15% of an unfished cohort remains by age 20.

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 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).

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 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.

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 (fishing month 10). 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 fishing month 1.

A standard Beverton and Holt stock-recruitment relationship (SR) was used in this assessment. The expected recruitment for year y (R_y) is a function of spawning biomass (SSB_y), an estimated unfished equilibrium spawning biomass (SSB_0), a specified steepness parameter (h), and an estimated unfished recruitment (R_0).

$$R_y = \frac{4hR_0SSB_y}{SSB_0(1-h)+SSB_y(5h-1)}e^{-0.5b_y\sigma_R^2+\tilde{R}_y}$$

$$\tilde{R}_y \sim N(0,\sigma_R^2)$$

Annual recruitment deviations from the SR relationship ($\tilde{R}_y$) were estimated from 1953 to 2018 and assumed to follow a normal distribution with a specified standard deviation σ_R in natural log space (Methot and Taylor 2011, Methot and Wetzel 2013). This σ_R penalizes recruitment deviated from the spawner-recruitment curve. The central tendency that penalizes the log (recruitment) deviations for deviating from zero was assumed to sum to zero over the estimated period. Estimation of σ_R is known to be difficult in the penalized likelihood estimation (Maunder and Deriso 2003), so an iteratively tuning σ_R approach was used to match the standard deviation of the estimated recruitment deviations. A couple of repeated model runs were conducted to numerically estimate a value of σ_R in SS based on Methot and Taylor 2011, resulting that σ_R was set to be 0.6 in the assessment model and was about the variability of deviates estimated by the model. Relatively large σ_R allows the model to be less sensitive to our assumptions about the steepness.

A log-bias adjustment pattern fraction (b) was applied during the data-poor period (1953-2018) to assure unbiased estimation of mean recruitment. Because the b was calculated in SS, a two-steps procedure was used to apply the estimation of b based on Methot and Taylor 2011. The first model run was to estimate recruitment deviations and variability around these values without adjusting any bias. The b was also calculated in the first model run based on the estimated recruitment deviations and σ_R, which was 0.9. The assessment model was to apply this estimated b obtained from the first run. The closer to the max value of 1 for b means that data are more informative about recruitment deviations and vice versa because the b is in log space.

The steepness of the stock-recruitment relationship (h) 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 could be estimable 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 of h was around 0.999, close to the asymptotic value of 1.0. Therefore, steepness was specified 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.

Stock Structure

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

Movement

PBF is a highly migratory species, with juveniles known to move widely between the EPO and WPO (Section 2.1.3). In this assessment, PBF stock was assumed to occur in a single, well-mixed area, and 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 was based, were fishery specific (i.e., country-gear type) and therefore contained spatial inferences (fleet-as-area approach). This approach estimated fishery-specific time-varying length- and age-based selectivity patterns separately and was shown to be able to approximate the changes in cohorts due to movement and gear selectivity (see Section 4.3.2).

Model Structure

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. These assumptions can make a population in the initial year that is either at an unfished equilibrium, is in equilibrium with an estimated mortality rate influenced by data on historical equilibrium catch, or has estimable age-specific deviations from equilibrium. 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 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 backward 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 prior to 1952, this assessment used the second method (estimate) to develop non-equilibrium initial conditions that estimating 1) R1 offset, 2) initial fishing mortality rates, and 3) early recruitment deviations. The R1 offset was estimated to reflect the initial equilibrium recruitment relative to R0. This R1 has been estimated in the previous assessments. The equilibrium fishing mortality rates (Fs) were estimated because the initial equilibrium involved not only natural mortality but also fishing mortality. The estimation of the equilibrium Fs can be based on the equilibrium catch, which is the catch taken from a stock for which removals and natural mortality are balanced by stable recruitment and growth. Although this assessment did not fit equilibrium catch (no influence on the total likelihood function for deviating from assumed equilibrium catch), equilibrium Fs were freely estimated. Equilibrium Fs were estimated for the Japanese longline fleets (Fleet 1) and Japanese set-net fleets for seasons 1-3 (Fleet 8) because they represented fleets that took large and small fish, respectively. Ten-years recruitment deviations prior to the start of the dynamic period were estimated to adjust the equilibrium initial age composition before starting the dynamic to be a non- equilibrium initial age composition. The model first applied the R1 offset and initial equilibrium Fs level to an equilibrium age composition to obtain a preliminary number-at-age. Then it applied the recruitment deviations for the specified number of younger ages (information came from the size compositions for early years in the assessment) in this number-at-age. Since the number of estimated ages in the initial age composition is less than the maximum age, the older ages retained their equilibrium levels. Because the older ages in the initial age compositions will have less information, the bias adjustment was set to be zero.

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 the gear catches a fish of a given size/age, 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 migratory juveniles. Therefore, in addition to estimating length-based gear selectivity, time-varying age-based selectivity was estimated to approximate the time-varying age-based movement rate. The use of time-varying selection results in better fits to the composition data compared to the time-invariant selection model, which had adverse consequences on fits to other prioritized data (ISC 2014, ISC 2016a).

We also used a combination of model processes (time-varying length- and age-based selectivity) and data weightings to ensure goodness of fits to size composition for the fleets that caught high numbers of fish since 1990 when data were abundant (Table 4-1). In general, fleets with large catches of migratory ages, good quality of size composition data, and no CPUE index were modeled with time-varying selection (Lee et al. 2015). Fleets taking mostly age-0 fish or adults were treated as time-invariant unless 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. Details are given below.

Fishery-specific selectivity was estimated by fitting length composition data for each fleet except Fleets 7, 11, 20, 21, 22, 24, and 25, whose selectivity patterns were borrowed from other fleets based on the similarity of the size of fish caught (Table 4-1). The size composition data for Fleet 11 were combined to Fleet 10, whereas the size composition data for Fleets 7, 16, and 24 were not used to estimate its selectivity due to poor quality of sampling, limited observations, or/and unclear sampling scheme. The size composition data for the discard fleets (Fleets 21, 22, and 25) were not available but it was assumed that their selectivity pattern was similar to that from the retained catch. The selectivity for Fleet 16 was assumed to be 100% selected at only age 0.

Fleets with CPUE index (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 (non-migratory ages caught by these fleets (either age-0 fish or spawners) resulting in a single well-behaved mode), 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 pattern 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 an asymptotic selection was used (Piner 2012). This assumption along with the observed sizes and life history parameters set an upper bound to population size. This asymptotic assumption was later removed in the sensitivity analysis (see Section 5.5.5). 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, 19, and 23) and fleets taking fish of migratory ages (ages 1-5 for Fleets 3, 4, 5, 8, 9, 10, 13, 14, 15, and 18). Selectivity for non-CPUE fleets taking fish of non-migratory ages was 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 estimated. As for non-CPUE fleets taking fish of migratory ages, both length- and age-based selectivity patterns were estimated (Lee et al. 2015). Selection is then a product of the age- and length-based selection patterns. The pattern for the length-based selection was time-invariant asymptotic or dome-shaped, while the age-based selection estimated separate parameters for each age and was time-varying for migratory ages. However, the three EPO fleets (Fleets 13, 14, and 15) were modeled with time-varying length-based selection due to the possible difference in growth between EPO and WPO. Because of the large number of parameters involved, fleets without a significant catch (Fleets 8, and 9) did not include the time-varying age-based component.

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.

Likelihood Components

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.

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.

Model Diagnostics

Age Structured Production Model

Following the proposal by Maunder and Piner (2015), the Age Structured Production Model (ASPM) diagnostics were performed to evaluate if the catch and indices data included in the base-case model can provide the information about the population scale under the model processes and selectivity specified in the base-case model. For this diagnostic, the base-case model was modified by fixing the selectivities of all fleets to those estimated in the base-case model and not fitting to the size composition data. The annual recruitment deviates were not estimated in the ASPM so that recruitment follows the stock recruitment curve. The ASPM only estimates the global scaling parameters such as the log of unfished recruitment (LogR_0) and equilibrium fishing mortality rate (Initial F) and is fitting to the observed catch and the abundance indices. If scale (unfished spawning stock biomass) and the model fits to the adult indices (Japanese and Taiwanese longline indices; S1 to S3, and S5) are similar between the base-case model and ASPM, catch and indices can inform the population scale and the effect of fishery to the long-term trend of adult biomass.

An ASPM with annual recruitment deviations specified at those estimated in the base-case model (ASPM-R), were also performed to evaluate if the addition of information about the recruitment, which were strongly implied by the recruitment index (Japanese troll CPUE index; S4), can improve the fits to the adult indices. If the fixed recruitments improve fits to the adult indices, this is evidence that the recruitment index is consistent with the other data sources in the model and provide good information on recruitment variability.

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.

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.

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.

Sensitivity analysis

The effect of model assumptions that could not be incorporated with the base-case model 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:

- Natural Mortality
- Maturity
- Steepness
- Fit to the 2017 and 2018 size composition of Jpn Longline (F1)
- No asymptotic parameter in the model
- High and low discard catch
- Data-weighting of size composition data
- Variation of recruitment (Sigma R)

Projections and Biological Reference Points

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 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.
Since the median estimators of the SSB after 1990 from bootstrap replicates distributed above the point estimates of SSB from the base-case model, an ad-hoc correction of bias in the SSB at the terminal year of the assessment as well as in projection was carried out (Fukuda et al. 2020). In the projections reported in this report, 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 and adjusted for the bias between bootstrap and point estimate.

Future recruitment is randomly resampled from the recruitment estimates by each base-case model replicates. For the sake of precautionarily 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).

Several alternative harvest scenarios of 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 CMM19-02) and IATTC convention area (IATTC Resolution C18-01). For the EPO commercial fishery, since the IATTC Resolution apply only a catch limit, constant catch limit of 3,300 tons with high F level 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. Scenario 2 was examined to investigate the effects of the alternative management method of which the stock was managed only by the catch control in the WCPFC convention area.

The Harvest Strategy proposed at the Joint WCPFC NC-IATTC WG meeting (JWG) 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 JWG also requested ISC to test several harvesting scenarios which have different fraction or amount of catch limits increment by small and large PBF.

Accordingly, scenarios from 3 to 6 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 7-14 were examined to assess the effects of different fraction or amount of catch limits increment 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 (2016-2018) 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 3-14) was increased to levels so as to exhaust the catch limit (Fukuda et al. 2020). In addition to the above mentioned scenarios, a future population dynamics with zero removals (no fishery) was also examined (scenario 15).

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 historical lowest at any time of projection period, and expected future catch at certain year.

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%SSBF=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. STOCK ASSESSMENT MODELLING RESULTS

Model Convergence

All estimated parameters in the base-case model were within the boundaries, and the final gradient of the model was 0.00094. The model hessian was positive-definite and the variance-covariance matrix could be estimated. Based on the results from the 180 model runs with the random perturbations of initial values and phasing, there was some evidence for local minimums around the best fitting model. Most runs that stopped prior to reaching the best observed negative log-likelihood were similar in results as the base case model. The best-fitting model was chosen as the base-case model, and the PBFWG considered it to have likely converged to a global minimum as there was no evidence of further improvements on the total likelihood (Figure 5-1).

Model Diagnostics

Age structured production model (ASPM) diagnostics

The ASPM model generally fits well the abundance indices for the adult PBF such as S1, S3 (Japanese longline late and middle periods), and S5 (Taiwanese longline south), without invoking process variation in recruitment (Figure 5-2). This result indicated that the model processes contributing to productivity (growth, natural mortality, and recruitment) and selectivity (fleet-specific time-varying selectivity) and the catch time series reasonably explain the effects of fishing that lead to changes in adult fish indices. This production model effect alone can provide information of the population scale (unfished stock size). Because the base-case model prioritized the indices, the ASPM and base-case models estimated similar levels of the population scale, although there are a difference in the estimated biomass during the assessment period (Figure 5-3). This result confirms that composition data are not the primary drivers of the estimated scale in dynamics.

Although the simple ASPM could not get the adequate fit the recruitment index (S4; Japanese troll), an ASPM with recruitment deviations specified at levels that exactly matched the recruitment index (ASPM-R) improved the model fits the all indices (Figure 5-2). The estimated scale and trends of the population by the ASPM-R were also closer to the full model than those of ASPM (Figure 5-3). Those results indicate that the information provided by the recruitment index (S4) are consistent with those of the other data sources and likely provide good information on recruitment variability.

Likelihood Profiles on fixed log-scale Unfished Recruitment (log R0)

Results of the profile of total and component likelihoods over a range of fixed log(R0) for the base-case model are shown in Figure 5-4. 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 the data component was the most consistent with that fixed population scale. All likelihood components showed best fits at very similar values of log(R0). Recruitment (penalty of the deviations) fit best at 9.625, all combined CPUEs 9.51, and all combined size composition at 9.45. The estimate of log (R0) for the base-case model was 9.51 (Figure 5-4 (A)).

Both size compositions and CPUE components showed informative gradients in relative likelihood away from their minimum. Catch data is treated as a likelihood component in this model, however, the gradient for the catch component was not informative about log(R0). The recruitment component showed a strong influence on the low side of log(R0), which is reasonable as greater recruitment variability is expected as the mean level of recruitments is specified lower. We note that the likelihood comes from contributions of time series of recruitment deviations and not the penalty applied to the difference between the log of recruitment in initial equilibrium regime and log of R0. It is worth noting that the observed variability of recruitment deviations is slightly lower than assumed recruitment variability (fixed σR = 0.6). However, sensitivity runs with the alternative assumptions of σR do not show significant difference from those of the base-case model (see section 5.3.1 and 5.5.8).

Composition data from the fleets with abundance indices (Japanese longline (Fleet 1), Japanese Troll (Fleet 6), and Taiwanese longline in the south fishing ground (Fleet 12)) had the largest impact on the log(R0) profile (Figure 5-4 (b)). The composition data from the rest of the fleets were of less importance to the log(R0) estimation. This is expected as fleets without indices were fit using time-varying selectivity, which reduced their direct influence on the global scale.

Most of the abundance indices showed a gradual slope of relative likelihoods around a value of 9.5 indicating consistent estimates of population scale. However, the abundance index for S5 (Taiwanese longline south fishing ground) indicated a gradual improvement in relative likelihood as log(R0) decreased (Figure 5-4 (C)).

Given the complexity of the biology and fleet structure, the PBFWG considers the base-case model to have a desirable property of being internally consistent regarding population scale. Furthermore, the unwanted influence of composition data on the population scale has been reasonably well handled as demonstrated by relative likelihood values for composition component < 2 units base model estimate of log(R0).

Goodness-of-fit to Abundance Indices

Predicted and observed abundance indices (section 3.5.2) by fishery for the base-case model are shown in Figure 5-5. The fits were generally within 95% CI for all the abundance indices. In particular, the base-case model fits very well to the S2, S3 (Japanese longline for the early and middle periods), and S4 (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 fits well to the S1 and S9 indices (Japanese longline for the late period and Taiwanese longline CPUEs with 0.30 and 0.24 of RMSEs, respectively). Therefore, the PBFWG considered the data and model structure to provide a good prediction of recent changes in population abundance.

Goodness-of-fit to Size compositions

The base-case model fits the size modes in data (aggregated by fishery and season well (Figure 5-6 and Table 5-1). The average effective sample sizes (effNs, an estimate of the models expected precision) are generally larger than the average input sample sizes, indicating more precision in the assessment model for those data than were assumed.

Annual residuals in Fleets 2, 6, and 10 were substantially decreased from the previous assessment by estimating the selectivity of the last bin of the double normal function or adding a model process (e.g., time block) (Figure 5-7). Although the aggregated fits were generally good, the annual residual plots for some fleets (e.g., Fleet 1) indicate some degree of misfits. It should be noted that fleets with CPUE assumed a time-invariant selection pattern, which exacerbated the annual misfit to composition data from those fleets. The PBFWG noted this as a subject for future research (see section 7).

In general, the current base-case model, which incorporated detailed gear-specific selectivity and spatial and temporal (seasonal) variation of availability, could replicate the observed size composition data.

Retrospective Analysis

The retrospective analysis showed a small but persistent over- or underestimation of terminal SSB. The pattern coincided with short-term trends in abundance (Figure 5-8a). This pattern is likely the result of the retrospective period covering a period with an inflection point (2010) in abundance. The retrospective analysis did not indicate a substantial pattern of over- or under- estimating recruitment for the recent 10 terminal years except the 2017 data point when the reliable age-0 index was not available (Figure 5-8b). 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 is consistent regarding the relative strength of the recruitment. The PBFWG concluded that the retrospective did not show evidence of significant model misspecification.

Model Parameter Estimates

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 5-9. The estimated recruitment deviations were relatively precise after 1990 indicating that these periods were well informed by data. The recent two years (2017-2018) of the recruitment deviations have larger uncertainty because of reduced information on those two-year classes. The variability of recruitment deviations (σR) in the base case ([1953-2018] $\sigma R = 0.55$) is close but slightly lower than assumed recruitment variability ($\sigma R = 0.6$). As these values are close, the estimated population scale and recruitment would not be substantially affected by the recruitment penalty.

Selectivity

The estimated selectivity curves by each fleet for the base-case model are shown in Figures 5-10 and 5-11. In the model, a combination of estimating length-based and age-based selections were applied for Fleets 2, 3, 4, 5, 6, 8, 9, 10, 15, 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 3, 4, 5, 10, and 18. For the rest of the fleets with estimated length-based selectivity (Fleets 1, 13, 14, 17, and 19), dome-shaped patterns were estimated except for Fleet 12 with the asymptotic pattern. Among these fisheries, temporal variations were captured for Fleets 1, 13, 14, and 15. A combination of age and length selection is used to approximate the gear-specific contact selectivity as well as the spatial and temporal (seasonal) variation in availability. This modeling approach is largely responsible for the increased number of parameters estimated since the 2018 assessment. In total, 333 selectivity parameters were estimated in the base-case model.

In general, the length- or age- based selectivity of all fleets allowing time-varying selection indicated gradual/distinct change of selection pattern from for catching small (young) fish to large (old) fish (Figure 5-10 and 5-11). In particular, the larger (older) fish have been more available in recent years for Fleet 3, 5, 10, 14, and 15.

Stock Assessment Results

Total and Spawning Stock Biomass

The base-case model produced estimated dynamics that were very consistent with those from the previous assessment over the years both covered. The primary differences are in estimates of SSB around the peaks in the 1960s and 1990s. Point estimates of total stock biomass from the base-case model showed long-term fluctuation (Table 5-2 and Figure 5-12) ranging from a low of about 33,000 t in 1983 to a high of about 209,000 t in 1959. Estimated total stock biomass showed a gradual increase since 2009, and particularly for the recent 3 years, there is an increase of young fish (0-2 years old) (Figure 5-13).

Spawning stock biomass (SSB) estimates also exhibited long-term fluctuation, which is consistent with that of total stock biomass (Figure 5-12). Estimates of SSB at the beginning of quarter 4 (April-June) in the first five years (1952-1956) of the assessment period averaged approximately 86,000 t (Table 5-2). The highest SSB of about 156,000 t occurred in 1961, while the lowest SSB of about 11,000 t occurred in 2010. In the 1990s, SSB reached its second highest level of about 63,000 t in 1995 and declined until 2010. Since 2011, SSB continued to show a tendency of slow increase, and the SSB of the terminal year was estimated to be about 28,000 t.

The quadratic approximation to the likelihood function at the global minimum, using the hessian matrix, indicated that the CVs of SSB estimates was about 17% on average for 1980-2018, and 16% for 2018. The average for the period 1952-1979 was about 38%, an increase in uncertainty due to a reduction in data in the first half of the model.

The unfished SSB (SSB_0) was estimated by extrapolating the estimated stock recruit relationship under the equilibrium assumptions to be about 633,000 t (R_0 = 13.5 million fish). The depletion ratios (SSB/SSB_0) of the assessment period ranged from 1.7% to 24.7%. The second peak (1995), a trough in the most recent year (2010) and terminal year (2018) of SSB corresponded 9.9%, 1.7%, and 4.5% of the SSB_0, respectively.

Recruitment

Recruitment (age-0 fish on July 1st) estimates fluctuated widely without an apparent trend and were almost identical with the 2018 assessment. Recent strong cohorts occurred in 2004 (27.9 million fish), 2007 (23.1 million), and 2008 (21.3 million), and moderately good cohorts occurred in 2005 (15.3 million), 2010 (18.2 million), and 2016 (16.5 million) (Table 5-2 and Figure 5-12). The average estimated recruitment was approximately 13.2 million fish for the entire stock assessment period (1952-2018). The 2014 and 2018 recruitments were estimated to be relatively low (3.8 and 4.7 million fish, respectively) and the average recruitment level for the last 10 years

(9.9 million fish) has been below the historical average level. The most recent two years (2017 and 2018) were lower (6.7 and 4.7 million fish, respectively) than average.

It should be noted that the 2017 and 2018 recruitment estimates have higher uncertainty compared to other more recent recruitment estimates. The CVs estimated for the 2017 and 2018 year-classes were 17% and 28%, respectively. The high uncertainty is due to those recruitments being informed by limited data. Importantly, there is no recruitment index available for 2017 year-class. Recruitment estimates were also less precise at the start of assessment period until the 1970's (average CV = 25%, maximum CV = 44%) and became moderately precise from 1980 to 1993 (average CV = 21%, maximum CV = 34%) when CPUE-based recruitment index from the Japanese troll fishery became available. After 1994, recruitment estimates had further improved in their precision (average CV = 9%) due to the comprehensive size data collection for Japanese fisheries that began in 1994.

Catch at Age

The catch number of PBF at each age was estimated internally in the stock assessment model based on the growth assumption, observed catch, and selectivity by fitting to the size composition data. Because there was a big difference in the amount of composition information available before and after 1994 (Figure 3-1), there is greater uncertainty in the estimated catch number at age before the early 1990s.

PBF catches were predominately composed of juveniles (ages 0-2) (Figure 5-14). Historically, the estimated number of fish caught showed a fluctuation ranging from a low of one million fish in 1959 to a high of about 4 million fish in 1978 during 1950's to early 1990's (Figure 5-15). However, from the early 1990s to the 2000s, 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.

After the management measures by the RFMOs started (WCPFC in 2011 and IATTC in 2012), catch in the number of fish decreased to less than 2 million fish on average. The current management measures (WCPFC CMM 2019-02, IATTC Resolution C-18-01), which were strengthened since the 2015 calendar year, have maintained the catch in the number of fish at about 1.5 million fish on average.

Fishing Mortality at Age

Throughout the stock assessment period (1952-2018), fishing mortality rates (F) for ages 0-2 were higher than those for age 3 and older fish (Table 5-3). The average F at age 1 during 1995-2014 was 1.11, while F at ages 0, 2, and 3 were 0.49, 0.61, and 0.21, respectively. The average F at age 4 and older during the same period was 0.15. When the management measures by the RFMOs introduced in 2011, fishing mortality for ages 0-2 decreased (Figure 5-15). When the management measures were strengthened in 2015, a further substantial decrease of F is observed in ages 0-2.

Fishery Impact

The cumulative impact of the different fishery groups on the SSB can be evaluated by simulating the population dynamics while removing each fishery using the base-case model (Wang et al. 2009). Figure 5-16 showed (a) historical fishery impact on the SSB of PBF and (b) ratio of fishery impact within each fishery group.

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 fishery group targeting small fish (ages 0-1) has had a greater impact and the effect of this group in 2018 was greater than any of the other fishery groups. The impact of the EPO fisheries group was large before the mid-1980s, decreasing significantly thereafter. The WPO longline fisheries group 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. The impact of discards is more uncertain than other impacts as it is not based on observed data.

Biological Reference Points

The base case results show that the point estimate of the $SSB_{2018}/SSB_{F=0}$ was 4.5%. As shown in the Kobe plot (Figure 5-17), there has been a gradual recovery in SSB to a level just below the initial (6.4%SSB_0) rebuilding target. The fishing mortality declined in the most recent years (2016-2018) to $F_{14\%SPR}$ which is still a higher rate than most commonly used F-based reference points except F_{Med} and $F_{10\%SPR}$ (Table 5-3).

Currently, a rebuilding measure for this species, which includes two recovery targets and a pre-agreed HCR with certain catch limit, are in force (WCPFC HS 2017-02), and the conservation advice based on the stock status for this species has been considered relative not only to the biological reference point estimations for given past years but also to some indicators associated with the future stock status such as the probability of achieving the rebuilding target at given year (ISC 2018; IATTC SAC09-15 rev2, 2018).

Note that a comparison against fishing mortality-based reference points may be confusing when the stock is subject to rebuilding measures including catch limits; appropriate levels of fishing mortality should be interpreted in the context of the projected ability to meet the rebuilding targets in the defined time period.

Sensitivity Analysis

Natural Mortality

Although the age-specific M used in the assessment is based on empirical evidence, there is still uncertainty in the M value for older fish. Sensitivity runs that assumed either higher or lower (by 10%) for age 2 and older were run. These runs showed a difference in the first and second peaks of SSB (Figure 5-18), but the terminal SSB was not affected substantially by the mortality scenarios. The PBFWG concluded that the base-case model behaved as expected with different assumptions for natural mortality.

Maturity

The age-specific maturation rates assumed in the model are based on empirical evidence, but uncertainty exists. Two alternative sensitivity runs were conducted which assumed either full maturation at age 4 (earlier maturation) or full maturation at age 10 (later maturation). Changes in the maturity schedule did not affect model fit to the data (e.g., negative log-likelihood) or estimated dynamics (e.g., total biomass, recruitment, fishing mortality) given the current specification of the model (Figure 5-19). However, since a fraction of the matured biomass of the population (i.e., SSB) is affected by the change in maturity schedule, some of the reference points such as depletion level were affected by those changes. Because the age structure of PBF in the assessment terminal year was slightly inclined to younger age compared with the equilibrium age structure, a later maturity schedule resulted in a lower depletion ratio and vice versa (Table 5-4). This behavior was expected as there is no strong spawner-recruit relationship and therefore changes in the maturation schedule primarily affect how SSB is summarized.

Steepness

In the past several assessments, the base-case model convergence was sensitive to changes in the assumed level of steepness. Small changes in the specified steepness level resulted in a non-positive definite hessian. A series of sensitivity models were run assuming various levels of steepness. Although the issue of steepness sensitivity remains, the current assessment model does allow for model convergence at lower levels of assumed steepness than in prior assessments (Figures 5-20 and 5-21). The PBFWG does not consider this sensitivity to steepness an indication of a model structure issue. The group also does not consider this result a validation of the current assumption of steepness value. Instead, the population is observed at a very low relative stock size, and the model is fine-tuned to explain data under the current assumption.

Fit to the 2017 and 2018 Size composition of Jpn Longline (F1)

The compositions of Fleet 1 in 2017-18 contain samples of relatively smaller fish. At the time of the assessment, it was unknown why these unusual observations occurred. One possible cause was a change in fishery practices due to an unexpected closure. Pending a better understanding of the effects of the recent management measures, those data were not included in the base case model. A sensitivity run was conducted that included those composition data. Inclusion of those data minimally impacted the fit to the longline CPUE but did not affect the estimated dynamics (Figure 5-22). The base-case model is not sensitive to the inclusion/exclusion of those data.

No asymptotic parameter in the model

Taiwanese longline operating in the south fishing ground (Fleet 12) is the only fleet assumed having an asymptotic length-based selectivity in the base-case model. This fleet does catch the largest fish, but forcing an asymptotic selectivity is a strong model assumption. A sensitivity run was conducted allowing for a dome-shape length-based selectivity for the Fleet 12. This sensitivity model estimated a selection pattern that was nearly asymptotic, with similar population dynamics to the base case (Figures 5-23 and 5-24). The model was also able to converge without this strong structural assumption. The PBFWG considered that the base-case model is not sensitive to and does not require an asymptotic selection pattern, likely because of the strong production function effects in the model.

High and Low Discard catch

Recent management measures may have created discard issues for some fleets. Although data on discard is limited, the base-case model assumed discard levels for some fleets. These assumed levels are not well known thus sensitivity runs were conducted assuming discard was either double the assumed value or 0. Model results were nearly identical to the base case with the model able to predict the catches in the discard fleet (Figure 5-25). This result was expected because discarding issues are only in the recent years. The PBFWG concluded that uncertainty in the discard level is not important for this assessment but could become influential in future assessments.

Data-weighting of Size composition data

Because of the large number of fleets with composition data, data weighting is an important issue. A sensitivity run using alternative weighting which down weighting the size composition data of Fleet 13 (EPO commercial fishery in the early period) was conducted. This fleet was chosen because it had a lower harmonic mean value of the estimated effective sample size than the inputted sample size. This change did not substantially affect the estimated spawning biomass or recruitment (Figure 5-26). Although the fits to the abundance indices might be slightly better in the down weighting model than the base-case model, the difference was minimal (1 unit of negative log-likelihood by aggregated for all indices) and there was no sign of improvement in the fit to the size composition data. The PBFWG concluded that the base-case results were not sensitive to the alternative assumption of relative data weighting and thus used the same method with the 2018 assessment. However, continued research into data weighting should be conducted.

Variation of recruitment (Sigma R)

The value of the penalty on recruitment (σR) has implications for many aspects of the estimated dynamics. Although this parameter is not estimated, there is an iterative approach to specifying it close to the observed level. Sensitivity runs were conducted assuming higher and lower σR (between 0.4 and 1.0). These alternative assumptions did not affect substantially the estimated recruitment (Figure 5-27). Assumptions of the higher σR than the base-case ($\sigma R = 0.6$) showed higher negative log-likelihoods for the recruitment penalty (Table x). Assumptions of the lower σR showed lower negative log-likelihoods for recruitment penalty than the base case but resulted in increases in the negative log-likelihoods in other components (i.e., size composition), and thus, the lowest total negative log-likelihood was confirmed at the similar σR value to the base case (Table 5-4 and Figure 5-27). The PBFWG concluded that the current method of specifying this parameter near the observed level is still the best procedure.

6. FUTURE PROJECTION

The WCPFC and IATTC defined the median SSB from point estimates between 1952 and 2014 as the initial rebuilding target[2] and 20% of $SSB_{F=0}$ as the second rebuilding target[3]. The PBFWG evaluates rebuilding to these targets from the terminal year of the assessment model using simulation-based projections. In the most recent projections, annual bias in the bootstrap median of SSB relative to the base-case point estimate was noted. Although the actual cause of the bias between base-case point estimate and the median of the projections is not known, the bias in the SSB at the terminal year of assessment as well as in projections (i.e., the difference between point estimates projected from the base-case model and the bootstrap medians) were corrected as described by Fukuda et al. (2020). To calculate the probability of rebuilding to the targets within specific time periods, the projected SSB estimates are the medians of the 6,000 individual SSB

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[2] The calculation of the initial rebuilding target from the base case model includes point estimates of SSB during 1950s-1970s, which are more uncertain due to the paucity of data prior to 1990 (Figure 3-1).

[3] The second rebuilding target defined as “20%$SSB_{F=0}$ under average recruitment” by the WCPFC Harvest Strategy is conceptually different from the R0 based (expected recruitment at unfished biomass) which has been done by the PBFWG, although two estimates were close.

calculated for each 300 bootstrap replicates followed by 20 stochastic simulations based on the different future recruitment time series (after adjusting for the bias between bootstrap and point estimates as described by Fukuda et al. 2020).

Tables 6-1 and 6-2 summarize the results for the future projections for each harvesting and recruitment scenario and provide the probability of recovery and future expected yields, respectively. Scenario 1 approximates the current management measure which has the highest prospect of recovery among all the examined scenarios except for the zero removals scenario (scenario 15). The projection from scenario 1 showed gradual increase of SSB and a decline in fishing mortality (expressed as $F_{\%SPR}$) to a SSB higher than 40%SSB_0 by 2034 (Figure 6-1). The probabilities of achieving the initial and second rebuilding targets (Table 6-1, Figure 6-1) are above the levels prescribed in the WCPFC Harvest Strategy (75% and 60% in 2024 and 10 years after achieving initial rebuilding target). Figure 6-2 displays the expected fishery impact to the projected SSB under the continuation of current management measures. Impact for all fishery groups is expected to decrease as the stock recovers. The percentage of total fishery impact within each fishery group was generally constant through the projected period, although there were some small changes in each group. Different management measures could have different effects of future impact, particularly when the distribution of catch between small and large PBF is changed. The fishery impact plots for different harvesting scenarios beyond scenario 1 can be found in Appendix 1.

For all the examined scenarios, the probability and the year expected to achieve the initial rebuilding target were more optimistic than the projections resulting from the 2018 assessment. This is due to larger numbers of immature PBF at the terminal year in the base case contributing to a more rapid growth of population by 2022. After 2022, growth of the population is expected to moderate due to the low recruitments assumed for 2019-2020. After 2025, the population would grow again due to projections assuming a return to a longer-term average recruitment after 2021.

All scenarios satisfy the probability of rebuilding required 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 20% increase in thee catch limit (Scenario 6) would lower probability of reaching the second target by 8% and rebuild to a lower biomass by 2034 (Table 6-1and Figure 6-3). It is worth noting that all the scenarios examined under the recruitment assumption as given by the WCPFC harvest strategy produced expected SSB by 2034 higher than 30% of $SSB_{F=0}$.

The results of scenarios 7 to 14, which have different fraction or amount of catch limits on small and large PBF, confirm that measures restricting the catch of small fish is more effective than those on large fish in rebuilding the stock (Table 6-1).

Under the average recruitment condition with zero removals (scenario 15), SSB trajectories achieved the second rebuilding target by 2022 fishing year (2023 calendar year) (Table 6-1 and Figure 6-4). This scenario points to the potential productivity of the current population. In summary, in all the scenarios explored, the probability of achieving the initial rebuilding target were estimated to be above the level prescribed in the WCPFC Harvest guidelines prepared by the RFMOs joint working group. The prospect of rebuilding to the 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.

7. MAJOR UNRESOLVED OR FUTURE ISSUES

This section highlights a selection of the major issues that the PBFWG was either unable to adequately resolve or anticipate in this assessment and these issues could become problems for future assessments. This list is not meant to be an all-inclusive list.

The proliferation of fleets, parameters and model convergence

The number of countries and fisheries fishing for PBF combined with the spatial disaggregation of the population age-groups has resulted in a proliferation of fleets modeled since the 2016 assessment. This increase in fleets is reinforced by a desire of member countries and managers to evaluate individual fishery impacts. Matching the length composition data in the assessment model requires a combination of estimating length-based and age-based selection. This combination selection pattern is used because in a single-area model both gear and availability components of selection apply. This has greatly increased the number of parameters estimated and this trend is expected to continue as more years are included. Although the working group does not consider that the model is over parameterized, it does see the potential for convergence issues to arise in the future. In preparation for this potentiality, some considerations should be given to ways to simplify the model that maintains the working group's desire to understand each fishery's impact while limits issues associated with composition misfit.

Fisheries with a strong modal distribution of length

Several fisheries with observed length compositions indicated a steep increase in selection on the first few sizes taken. Given the parametric selectivity currently used, parameters associated with describing the ascending limb of selectivity have little information on their values because selectivity is changing rapidly within a single size bin. The working group should explore alternative model structure or the data preparation (e.g., smaller size bin) to resolve this issue. This issue is somewhat related to issue 7.1 as these poorly informed parameters can cause convergence issues.

CPUE and size composition data for key longline indices

The current assessment relies on two longline fleets' abundance indices to represent annual changes in abundance of large mature PBF. To limit impacts of migratory patterns which potentially change the availability of different size/age groups taken, data analysis has proceeded on seasonal and area subsets of those fleets (see section 3.6.2.). Recent composition data suggested that even with these data analysis considerations, the fleets used to create CPUE data are seeing an influx of new migrants in the observed size compositions and CPUE standardization. The influx of new migrants are smaller in size and may represent newly recruited spawners to this fleet as the population rebuilds or seasonal migrants that the above-mentioned data preparation was attempted to remove. Further work needs to be conducted to ensure that data sub-setting and resulting analysis are able to maintain that the observed CPUE is a reliable indicator of changes in abundance with a consistent selectivity pattern. Exploration of spatial-temporal modeling is already being conducted and may represent one option to deal with the issue.

Unseen mortality or discards

Management measures enacted over the last 5 years has resulted in the increasing abundance of juvenile age classes. More restrictive management coupled with the potential for rapid increases in local abundance may be resulting in increased bycatches and following releasing of unwanted sized PBF. The working group attempted to deal with this potential problem with the addition of unseen mortalities, but its magnitude is poorly understood. Depending on the relative magnitude of this unseen fishery mortality, this issue, unless properly understood, may potentially weaken the strong relationship between observed catches, production function, and the model's ability to predict changes in abundance of fishes taken in the longline fleets. This 'fishing effect' is the backbone of the current assessment and has allowed for strong model stability and improved its predictions. Measures to either account for this unseen mortality or eliminate it should be explored.

Bootstrapping bias

Stock assessment replicates were simulated using the parametric bootstrapping in SS and then used in the future projections in order to account for the uncertainty in the assessment terminal year and recruitment estimates. The distribution of the bootstrapped SSBs showed a positive bias compared to the point estimates from the base-case model since the 1980s. Although the source of the bias was not identified, this bias was corrected using the ad-hoc method by adjusting the differences in the median future SSB between the base-case model and bootstrap replicates. The appropriateness of the ad-hoc bias correction method and potential impacts on the calculated probabilities of achieving the rebuilding targets is not completely understood. The working group should continue to investigate the source of the bias.

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9. TABLES AND FIGURES

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

Fishing year	2016				2017				2018				2019	
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 2016				SSB in 2017				SSB in 2018		
Day of birth in SS	Birthday of 2016 yr class				Birthday of 2017 yr class				Birthday of 2018 yr class				Birthday of 2019 yr class	
Recruitment	Recruitment in 2016				Recruitment in 2017				Recruitment in 2018				Recruitment in 2019	
Year class	2016 yr class				2017 yr class				2018 yr class				2019 yr class	
Calender year	2016		2017				2018				2019			
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 (1952-1992)	JP Longline (1993-2018, Season 4)			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	S10
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)				S4, S11
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			S5, S6, 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 (2014-)				
Fleet 16	JPTroll4Pen	Number	JP Troll for Farming				
Fleet 17	TWLL (North)	Weight	TW Longline (North area)				S7, S8
Fleet 18	JPSPPS (Seas2)	Weight	JP SPPS (Season 2)				
Fleet 19	JPTroll (Seas1)	Weight	JP Troll (Season 1)				S12
Fleet 20	JSPPS Pen	Weight	JSPPS for Farming				
Fleet 21	Unaccounted mortality	Weight	Discard amount for JPN and KOR fisheries				
Fleet 22	Unaccounted mortality	Number	Discard amount for JPN				
Fleet 23	JPLL (Seas1-3)	Weight	JP Longline(1993-)				
Fleet 24	EPOSP_early	Number	US Recreational Fisheries (-2013)				
Fleet 25	Unaccounted mortality in EPO	Number	Discard amount for US Recreational Fisheries				

*1 Catch for KRean Trawl, KRean Setnet and KRean Troll are **included** in the input data until the 2020 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 Season 1 in the input data.

Note: Seasons follow the fishing year.

Table 3-2. Pacific bluefin tuna (*Thunnus orientalis*) catches (in metric tons) by fisheries, for calendar year 1952-2018.

Calendar Year	Japan (JP)[1]									Sub Total
	Purse Seine		Dist. & Off. Longline		Coastal Longline	Troll[2]	Pole and Line	Set Net	Others	
	Tuna PS	Small PS	NP	SP						
1952	7,680		2,694	9		667	2,198	2,145	1,700	17,094
1953	5,570		3,040	8		1,472	3,052	2,335	160	15,636
1954	5,366		3,088	28		1,656	3,044	5,579	266	19,027
1955	14,016		2,951	17		1,507	2,841	3,256	1,151	25,739
1956	20,979		2,672	238		1,763	4,060	4,170	385	34,268
1957	18,147		1,685	48		2,392	1,795	2,822	414	27,302
1958	8,586		818	25		1,497	2,337	1,187	215	14,666
1959	9,996		3,136	565		736	586	1,575	167	16,760
1960	10,541		5,910	193		1,885	600	2,032	369	21,531
1961	9,124		6,364	427		3,193	662	2,710	599	23,078
1962	10,657		5,769	413		1,683	747	2,545	293	22,107
1963	9,786		6,077	449		2,542	1,256	2,797	294	23,201
1964	8,973		3,140	114		2,784	1,037	1,475	1,884	19,406
1965	11,496		2,569	194		1,963	831	2,121	1,106	20,280
1966	10,082		1,370	174		1,614	613	1,261	129	15,243
1967	6,462		878	44		3,273	1,210	2,603	302	14,772
1968	9,268		500	7		1,568	983	3,058	217	15,601
1969	3,236		313	20	565	2,219	721	2,187	195	9,456
1970	2,907		181	11	426	1,198	723	1,779	224	7,448
1971	3,721		280	51	417	1,492	938	1,555	317	8,772
1972	4,212		107	27	405	842	944	1,107	197	7,840
1973	2,266		110	63	728	2,108	526	2,351	636	8,788
1974	4,106		108	43	1,069	1,656	1,192	6,019	754	14,948
1975	4,491		215	41	846	1,031	1,401	2,433	808	11,266
1976	2,148		87	83	233	830	1,082	2,996	1,237	8,697
1977	5,110		155	23	183	2,166	2,256	2,257	1,052	13,202
1978	10,427		444	7	204	4,517	1,154	2,546	2,276	21,577
1979	13,881		220	35	509	2,655	1,250	4,558	2,429	25,537
1980	11,327		140	40	671	1,531	1,392	2,521	1,953	19,574
1981	25,422		313	29	277	1,777	754	2,129	2,653	33,353
1982	19,234		206	20	512	864	1,777	1,667	1,709	25,988
1983	14,774		87	8	130	2,028	356	972	1,117	19,471
1984	4,433		57	22	85	1,874	587	2,234	868	10,161
1985	4,154		38	9	67	1,850	1,817	2,562	1,175	11,673
1986	7,412		30	14	72	1,467	1,086	2,914	719	13,714
1987	8,653		30	33	181	880	1,565	2,198	445	13,985
1988	3,583	22	51	30	106	1,124	907	843	498	7,163
1989	6,077	113	37	32	172	903	754	748	283	9,118
1990	2,834	155	42	27	267	1,250	536	716	455	6,282
1991	4,336	5,472	48	20	170	2,069	286	1,485	650	14,536
1992	4,255	2,907	85	16	428	915	166	1,208	1,081	11,063
1993	5,156	1,444	145	10	667	546	129	848	365	9,310
1994	7,345	786	238	20	968	4,111	162	1,158	398	15,186
1995	5,334	13,575	107	10	571	4,778	270	1,859	586	27,090
1996	5,540	2,104	123	9	778	3,640	94	1,149	570	14,008
1997	6,137	7,015	142	12	1,158	2,740	34	803	811	18,852
1998	2,715	2,676	169	10	1,086	2,876	85	874	700	11,191
1999	11,619	4,554	127	17	1,030	3,440	35	1,097	709	22,628
2000	8,193	8,293	121	7	832	5,217	102	1,125	689	24,577
2001	3,139	4,481	63	6	728	3,466	180	1,366	782	14,212
2002	3,922	4,981	47	5	794	2,607	99	1,100	631	14,186
2003	956	4,812	85	12	1,152	2,060	44	839	446	10,407
2004	4,934	3,323	231	9	1,616	2,445	132	896	514	14,099
2005	4,034	8,783	107	14	1,818	3,633	549	2,182	548	21,668
2006	3,644	5,236	63	11	1,058	1,860	108	1,421	777	14,178
2007	2,965	3,875	83	8	1,679	2,823	236	1,503	657	13,829
2008	3,029	7,192	19	8	1,371	2,377	64	2,358	770	17,189
2009	2,127	5,950	8	7	1,072	2,003	50	2,236	575	14,029
2010	1,122	2,620	5	6	885	1,583	83	1,603	495	8,401
2011	2,227	6,113	9	11	828	1,820	63	1,651	283	13,004
2012	1,043	1,419	6	8	667	570	113	1,932	343	6,101
2013	2,008	763	7	7	777	904	8	1,415	529	6,418
2014	2,250	3,206	11	4	672	1,023	5	1,907	499	9,577
2015	2,759	886	12	4	607	413	8	1,242	432	6,361
2016	3,267	1,828	13	4	644	778	44	1,227	508	8,314
2017	3,341	1,199	21	0	880	603	86	2,255	665	9,049
2018[3]	3,225	825	19	0	679	372	8	645	431	6,204

0

1 Part of Japanese catch is estimated by the WG from best available source for the stock assessment use.

2 Japanese troll catch since 1998 includes catch for farming.

3 Catch of most recent year is provisional.

Table 3-2. Cont.

Calendar Year	Korea (KR)[4]					Taiwan (TW)				
	Purse Seine	Setnet	Troll	Trawl	Sub Total	Longline	Purse Seine	Distant Driftnet	Others	Sub Total
1952										
1953										
1954										
1955										
1956										
1957										
1958										
1959										
1960										
1961										
1962										
1963										
1964										
1965						54				54
1966										0
1967						53				53
1968						33				33
1969						23				23
1970										0
1971						1				1
1972						14				14
1973						33				33
1974						47			15	62
1975						61			5	66
1976						17			2	19
1977						131			2	133
1978						66			2	68
1979						58				58
1980						114			5	119
1981						179				179
1982	31				31	207		2		209
1983	13				13	175	9	2		186
1984	4				4	477	5		8	490
1985	1				1	210	80	11		301
1986	344				344	70	16	13		99
1987	89				89	365	21	14		400
1988	32				32	108	197	37	25	367
1989	71				71	205	259	51	3	518
1990	132				132	189	149	299	16	653
1991	265				265	342		107	12	461
1992	288				288	464	73	3	5	545
1993	40				40	471	1		3	475
1994	50				50	559				559
1995	821				821	335			2	337
1996	102				102	956				956
1997	1,054				1,054	1,814				1,814
1998	188				188	1,910				1,910
1999	256				256	3,089				3,089
2000	2,401			0	2,401	2,780			2	2,782
2001	1,176			10	1,186	1,839			4	1,843
2002	932			1	933	1,523			4	1,527
2003	2,601			0	2,601	1,863			21	1,884
2004	773			0	773	1,714			3	1,717
2005	1,318			9	1,327	1,368			2	1,370
2006	1,012			3	1,015	1,149			1	1,150
2007	1,281			4	1,285	1,401			10	1,411
2008	1,866			10	1,876	979			2	981
2009	936			4	940	877			11	888
2010	1,196			16	1,212	373			29	402
2011	670		0	14	684	292			16	308
2012	1,421		1	2	1,424	210			2	212
2013	604	1	0	0	605	331			2	333
2014	1,305	6	0	0	1,311	483			38	521
2015	676	1	0	0	677	552			25	577
2016	1,024	3	0	2	1,029	454			0	454
2017	734	3	0	6	743	415			0	415
2018	523	7	0	5	535	381			0	381

[4] Catch statistics of Korea derived from Japanese Import statistics for 1982-1999.

Table 3-2. Cont.

Calendar Year	United States (US)[5]			Sub Total	Mexico (MX)		Sub Total	Sub total	Out of ISC members		Grand Total
	Purse Seine	Others	Sport		Purse Seine	Others			New Zealand (NZ)[6]	Australia (AU)[7]	
1952	2,076		2	2,078				2,078			19,172
1953	4,433		48	4,481				4,481			20,117
1954	9,537		11	9,548				9,548			28,575
1955	6,173		93	6,266				6,266			32,005
1956	5,727		388	6,115				6,115			40,383
1957	9,215		73	9,288				9,288			36,590
1958	13,934		10	13,944				13,944			28,610
1959	3,506	56	13	3,575	171	32	203	3,779			20,539
1960	4,547	0	1	4,548				4,548			26,079
1961	7,989	16	23	8,028	130		130	8,158			31,236
1962	10,769	0	25	10,794	294		294	11,088			33,195
1963	11,832	28	7	11,867	412		412	12,280			35,481
1964	9,047	39	7	9,093	131		131	9,224			28,631
1965	6,523	77	1	6,601	289		289	6,890			27,224
1966	15,450	12	20	15,482	435		435	15,918			31,161
1967	5,517	0	32	5,549	371		371	5,920			20,745
1968	5,773	8	12	5,794	195		195	5,989			21,623
1969	6,657	9	15	6,681	260		260	6,940			16,419
1970	3,873	0	19	3,892	92		92	3,983			11,432
1971	7,804	0	8	7,812	555		555	8,367			17,140
1972	11,656	45	15	11,716	1,646		1,646	13,362			21,216
1973	9,639	21	54	9,714	1,084		1,084	10,798			19,619
1974	5,243	30	58	5,331	344		344	5,675			20,685
1975	7,353	84	34	7,471	2,145		2,145	9,616			20,948
1976	8,652	25	21	8,698	1,968		1,968	10,666			19,381
1977	3,259	13	19	3,291	2,186		2,186	5,477			18,811
1978	4,663	6	5	4,674	545		545	5,218			26,863
1979	5,889	6	11	5,906	213		213	6,119			31,715
1980	2,327	24	7	2,358	582		582	2,940			22,634
1981	867	14	9	891	218		218	1,109			34,641
1982	2,639	2	11	2,652	506		506	3,159			29,387
1983	629	11	33	673	214		214	887			20,557
1984	673	29	49	751	166		166	917			11,573
1985	3,320	28	89	3,437	676		676	4,113			16,089
1986	4,851	57	12	4,920	189		189	5,109			19,266
1987	861	20	34	915	119		119	1,033			15,507
1988	923	50	6	979	447	1	448	1,427			8,989
1989	1,046	21	112	1,180	57		57	1,236			10,943
1990	1,380	92	65	1,537	50		50	1,587			8,653
1991	410	6	92	508	9		9	517	2		15,781
1992	1,928	61	110	2,099	0		0	2,099	0		13,995
1993	580	103	283	966				966	6	0	10,797
1994	906	59	56	1,021	63	2	65	1,086	2	1	16,884
1995	657	49	245	951	11		11	962	2	1	29,213
1996	4,639	70	40	4,749	3,700		3,700	8,449	4		23,519
1997	2,240	133	131	2,504	367		367	2,872	14	1	24,607
1998	1,771	281	422	2,474	1	0	1	2,475	20	3	15,787
1999	184	184	408	776	2,369	35	2,404	3,180	21	5	29,178
2000	693	61	319	1,073	3,019	99	3,118	4,192	21	8	33,980
2001	292	48	344	684	863		863	1,548	50	7	18,846
2002	50	12	613	675	1,708	2	1,710	2,385	55	6	19,093
2003	22	18	355	395	3,211	43	3,254	3,649	41	12	18,593
2004		11	50	61	8,880	14	8,894	8,955	67	10	25,621
2005	201	7	73	281	4,542		4,542	4,823	20	13	29,222
2006		2	94	96	9,927		9,927	10,023	21	5	26,392
2007	42	2	12	56	4,147		4,147	4,203	13	4	20,745
2008		1	63	64	4,392	15	4,407	4,471	14	3	24,533
2009	410	6	156	572	3,019		3,019	3,591	16	3	19,467
2010		1	88	89	7,746		7,746	7,835	10	0	17,860
2011		118	225	343	2,730	1	2,731	3,074	28	1	17,099
2012		43	400	443	6,668	1	6,669	7,112	13	1	14,863
2013		11	809	820	3,154		3,154	3,974	24	0	11,354
2014	401	7	420	828	4,862		4,862	5,690	12	0	17,112
2015	86	12	399	498	3,082		3,082	3,580	16	0	11,211
2016	316	41	368	724	2,709		2,709	3,433	18	0	13,248
2017	466	21	450	937	3,643		3,643	4,580	14	0	14,802
2018	12	50	484	546	2,482		2,482	3,028	20	0	10,168

[5] US in 1952-1958 contains catch from other countries - primarily Mexico. Other includes catches from gillnet, troll, pole-and-line, and longline.

[6] Catches by New Zealand from 1991 to 2006 are derived from the Ministry of Fisheries, Science Group (Compilers) 2006: Report from the Fishery Assessment Plenary,

[7] Catches by Australia are provided by SPC.

Table 3-3. Quarterly catch of Pacific bluefin tuna (*Thunnus orientalis*) by fleet and fishing year for 1952-2018.

Fishing year	Season	Weight (mt)																		Number (1000 fish)				Number (individual)
		Fleet1 and Fleet 23	Fleet2	Fleet3	Fleet4	Fleet5	Fleet6	Fleet7	Fleet8	Fleet9	Fleet10	Fleet11	Fleet12	Fleet13	Fleet14	Fleet17	Fleet18	Fleet19	Fleet 21	Fleet15 and Fleet 24	Fleet16	Fleet20	Fleet22	Fleet 25
1952	1	1073	0	0	0	4936	0	713	736	0	236	0	0	1951	0	0	0	23	0	0	0	0	0	0
1952	2	132	0	0	0	0	498	505	537	0	170	172	0	24	0	0	0	0	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	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	0	0	0	0
1953	1	764	0	0	0	3580	0	650	371	0	255	0	0	3843	0	0	0	51	0	3	0	0	0	0
1953	2	241	0	0	0	0	1098	706	458	0	186	131	0	590	0	0	0	0	0	1	0	0	0	0
1953	3	263	0	0	0	0	318	609	430	0	2	0	0	0	0	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	0	0	0	0
1954	1	1096	0	0	0	3448	0	744	1109	0	861	0	0	6845	0	0	0	58	0	1	0	0	0	0
1954	2	178	0	0	0	0	1236	923	1032	0	613	219	0	403	0	0	0	0	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	0	0	0	0
1954	4	1310	0	0	0	5008	40	761	0	1334	43	0	0	3131	0	0	0	0	0	1	0	0	0	0
1955	1	1172	0	0	0	9008	0	665	788	0	364	0	0	2467	0	0	0	53	0	4	0	0	0	0
1955	2	311	0	0	0	0	1125	862	889	0	260	101	0	93	0	0	0	0	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	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	0	0	0	0
1956	1	1521	0	0	0	13483	0	953	636	0	262	0	0	4753	0	0	0	62	0	30	0	0	0	0
1956	2	161	0	0	0	0	1316	1232	1134	0	185	192	0	974	0	0	0	0	0	2	0	0	0	0
1956	3	163	0	0	0	0	459	359	506	0	3	0	0	0	0	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	0	0	0	0
1957	1	566	0	0	0	12111	0	425	558	0	74	0	0	8779	0	0	0	84	0	6	0	0	0	0
1957	2	98	0	0	0	0	1785	545	830	0	25	194	0	296	0	0	0	0	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	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	0	0	0	0
1958	1	113	0	0	0	4650	0	541	189	0	10	0	0	11188	0	0	0	52	0	1	0	0	0	0
1958	2	211	0	0	0	0	1117	709	316	0	4	183	0	112	0	0	0	0	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	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	0	0	0	0
1959	1	841	0	0	0	5565	0	135	227	0	29	0	0	2487	0	0	0	26	0	1	0	0	0	0
1959	2	916	0	0	0	0	550	178	408	0	10	153	0	0	0	0	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	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	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	0	0	0	0
1960	2	729	0	0	0	0	1407	182	504	0	80	302	0	40	0	0	0	0	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	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	0	0	0	0
1961	1	1472	0	0	0	5768	0	170	430	0	12	0	0	6755	0	0	0	112	0	2	0	0	0	0
1961	2	597	0	0	0	0	2383	201	701	0	4	580	0	217	0	0	0	0	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	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	0	0	0	0
1962	1	593	0	0	0	6677	0	176	744	0	71	0	0	8578	0	0	0	59	0	2	0	0	0	0
1962	2	459	0	0	0	0	1256	227	527	0	43	288	0	1	0	0	0	0	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	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	0	0	0	0
1963	1	600	0	0	0	6301	0	305	406	0	240	0	0	9718	0	0	0	89	0	0	0	0	0	0
1963	2	255	0	0	0	0	1897	381	689	0	158	276	0	53	0	0	0	0	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	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	0	0	0	0
1964	1	360	0	0	0	5798	0	246	562	0	49	0	0	7420	0	0	0	97	0	1	0	0	0	0
1964	2	260	0	0	0	0	2078	315	726	0	27	366	0	13	0	0	0	0	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	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	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	0	0	0	0
1965	2	336	0	0	0	0	1465	200	690	0	18	313	0	918	0	0	0	0	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	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	0	0	0	0
1966	1	285	0	0	0	7025	0	188	161	0	57	0	0	11021	0	0	0	56	0	2	0	0	0	0
1966	2	275	0	0	0	0	1204	133	291	0	29	81	0	2	0	0	0	0	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	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	0	0	0	0
1967	1	246	0	0	0	4085	0	330	273	0	84	0	0	2768	0	0	0	114	0	3	0	0	0	0
1967	2	73	0	0	0	0	2443	261	728	0	44	259	0	40	0	0	0	0	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	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	0	0	0	0
1968	1	135	0	0	0	5527	0	255	456	0	177	0	0	4812	0	0	0	55	0	1	0	0	0	0
1968	2	54	0	0	0	0	1171	206	755	0	93	206	0	325	0	0	0	0	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	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	0	0	0	0
1969	1	109	0	0	0	2061	0	184	294	0	319	0	0	5258	0	0	0	78	0	1	0	0	0	0
1969	2	54	0	0	0	0	1656	213	426	0	196	160	0	49	0	0	0	0	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	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	0	0	0	0
1970	1	23	0	0	0	1633	0	210	282	0	190	0	0	2534	0	0	0	42	0	1	0	0	0	0
1970	2	35	0	0	0	0	894	194	398	0	99	161	0	2	0	0	0	0	0	1	0	0	0	0
1970	3	181	0	0	0	0	286	234	163	0	4	0	0	31	0	0	0	0	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	0	0	0	0

Table 3-3. Cont.

Fishing year	Season	Weight (mt)																		Number (1000 fish)				Number (individual)
		Fleet1 and Fleet 23	Fleet2	Fleet3	Fleet4	Fleet5	Fleet6	Fleet7	Fleet8	Fleet9	Fleet10	Fleet11	Fleet12	Fleet13	Fleet14	Fleet17	Fleet18	Fleet19	Fleet 21	Fleet15 and Fleet 24	Fleet16	Fleet20	Fleet22	Fleet 25
1971	1	19	0	0	0	887	0	230	200	0	340	0	0	3349	0	0	0	52	0	1	0	0	0	0
1971	2	43	0	0	0	0	1114	240	261	0	202	212	0	939	0	0	0	0	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	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	0	0	0	0
1972	1	15	0	0	0	2163	0	449	127	0	164	0	0	8861	0	0	0	29	0	1	0	0	0	0
1972	2	31	0	0	0	0	629	159	233	0	89	124	0	1603	0	0	0	0	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	0	0	0	0
1972	4	799	0	0	0	464	56	160	0	501	70	0	33	2043	0	0	0	0	0	2	0	0	0	0
1973	1	21	0	0	0	1803	0	419	359	0	277	0	0	8690	0	0	0	74	0	4	0	0	0	0
1973	2	25	0	0	0	0	1573	183	514	0	186	286	0	0	0	0	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	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	0	0	0	0
1974	1	105	0	0	0	3690	0	483	865	0	546	0	0	4238	0	0	0	58	0	6	0	0	0	0
1974	2	48	0	0	0	0	1236	363	1424	0	362	368	0	151	0	0	0	0	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	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	0	0	0	0
1975	1	121	0	0	0	1077	0	1096	309	0	605	0	0	5748	0	0	0	36	0	3	0	0	0	0
1975	2	61	0	0	0	0	769	50	378	0	431	132	0	769	0	0	0	0	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	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	0	0	0	0
1976	1	54	0	0	0	1026	0	1300	301	0	818	0	0	7250	0	0	0	29	0	2	0	0	0	0
1976	2	15	0	0	0	0	619	518	431	0	540	152	0	497	0	0	0	0	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	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	0	0	0	0
1977	1	37	0	0	0	1047	0	1258	222	0	485	0	0	3094	0	0	0	76	0	2	0	0	0	0
1977	2	12	0	0	0	0	1617	377	378	0	331	168	0	348	0	0	0	0	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	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	0	0	0	0
1978	1	340	0	0	3	78	0	2329	282	0	441	0	0	4403	0	0	0	158	0	0	0	0	0	0
1978	2	16	0	0	0	0	3372	380	512	0	298	246	0	21	0	0	0	0	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	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	0	0	0	0
1979	1	104	0	0	0	2736	0	1720	527	0	768	0	0	3539	0	0	0	93	0	1	0	0	0	0
1979	2	24	0	0	0	0	1982	406	861	0	541	888	0	227	0	0	0	0	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	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	0	0	0	0
1980	1	20	0	0	0	5159	0	1641	322	0	574	0	0	1439	0	0	0	54	0	1	0	0	0	0
1980	2	41	0	0	0	0	1143	468	353	0	387	474	0	59	0	0	0	0	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	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	0	0	0	0
1981	1	56	0	0	1297	17781	0	2382	271	0	352	0	0	742	0	0	0	68	0	0	0	0	0	0
1981	2	41	0	0	0	0	1426	302	393	0	248	523	0	1	0	0	0	0	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	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	0	0	0	0
1982	1	73	0	6	1615	12209	0	1905	198	0	300	0	0	2682	0	0	0	5	0	1	0	0	0	0
1982	2	20	0	5	0	0	370	444	277	0	204	132	0	406	0	0	0	0	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	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	0	0	0	0
1983	1	8	0	3	570	2262	0	897	143	0	113	0	0	631	0	0	0	21	0	1	0	0	0	0
1983	2	15	0	2	0	0	1925	131	210	0	74	310	0	125	0	0	0	0	0	1	0	0	0	0
1983	3	41	0	1	0	0	287	33	380	0	3	0	0	72	0	0	0	0	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	0	0	0	0
1984	1	20	0	1	807	1184	0	588	311	0	343	0	0	563	0	0	0	28	0	3	0	0	0	0
1984	2	9	0	1	0	0	1558	391	413	0	215	336	0	90	0	0	0	0	0	1	0	0	0	0
1984	3	24	0	0	0	0	538	1011	265	0	3	0	0	62	0	0	0	0	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	0	0	0	0
1985	1	8	0	0	448	889	0	961	229	0	714	0	0	1264	0	0	0	12	0	5	0	0	0	0
1985	2	8	0	0	0	0	1165	120	352	0	488	447	0	1126	0	0	0	0	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	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	0	0	0	0
1986	1	8	0	70	16	1072	0	668	375	0	564	0	0	3759	0	0	0	5	0	1	0	0	0	0
1986	2	5	0	60	0	0	1238	212	553	0	387	403	0	801	0	0	0	0	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	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	0	0	0	0
1987	1	20	0	18	250	3550	0	519	193	0	612	0	0	813	0	0	0	6	0	1	0	0	0	0
1987	2	9	0	15	0	0	505	98	297	0	432	187	0	63	0	0	0	0	0	1	0	0	0	0
1987	3	19	0	8	0	0	89	146	94	0	1	0	0	0	0	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	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	0	0	0	0
1988	2	10	0	6	0	0	1020	42	118	0	157	127	0	227	0	0	6	0	0	0	0	0	0	0
1988	3	27	3	17	0	0	259	68	86	0	0	0	0	7	0	0	0	0	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	0	0	0	0
1989	1	20	88	15	580	3623	0	411	81	0	186	0	0	988	0	0	0	88	0	5	0	0	0	0
1989	2	4	0	12	0	0	529	146	114	0	132	110	0	130	0	0	20	0	0	1	0	0	0	0
1989	3	21	0	32	0	0	166	17	165	0	1	0	0	16	0	0	0	0	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	0	0	0	0

Table 3-3. Cont.

Fishing year	Season	Weight (mt)																		Number (1000 fish)				Number (individual)
		Fleet1 and Fleet 23	Fleet2	Fleet3	Fleet4	Fleet5	Fleet6	Fleet7	Fleet8	Fleet9	Fleet10	Fleet11	Fleet12	Fleet13	Fleet14	Fleet17	Fleet18	Fleet19	Fleet 21	Fleet15 and Fleet 24	Fleet16	Fleet20	Fleet22	Fleet 25
1990	1	24	32	27	149	2474	0	830	64	0	90	0	0	1311	0	0	0	3	0	4	0	0	0	0
1990	2	10	0	23	0	0	990	47	179	0	60	199	0	194	0	0	118	0	0	0	0	0	0	0
1990	3	16	99	65	0	0	636	30	421	0	1	0	0	0	0	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	0	0	0	0
1991	1	14	182	54	224	3466	0	429	123	0	146	0	2	334	0	0	0	82	0	5	0	0	0	0
1991	2	14	0	46	0	0	1191	103	363	0	95	414	0	5	0	0	5165	0	0	0	0	0	0	0
1991	3	36	394	71	0	0	274	18	183	0	2	0	0	0	0	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	0	0	0	0
1992	1	10	255	59	469	2183	0	944	173	0	116	0	0	1650	0	0	0	0	0	8	0	0	0	0
1992	2	20	0	50	0	0	642	65	269	0	66	193	0	328	0	0	198	0	0	0	0	0	0	0
1992	3	15	582	10	0	0	145	12	102	0	1	0	0	0	0	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	0	0	0	0
1993	1	62	99	8	83	3831	0	204	161	0	32	0	6	525	0	0	0	48	0	10	0	0	0	0
1993	2	37	0	7	0	0	320	36	230	0	16	207	0	113	0	0	12	0	0	0	0	0	0	0
1993	3	42	25	12	0	0	67	0	70	0	1	0	0	2	0	0	0	0	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	0	0	0	0
1994	1	77	14	10	694	3973	0	206	168	0	36	0	3	967	0	0	0	458	0	2	0	0	0	0
1994	2	22	0	9	0	0	3570	65	356	0	31	272	0	58	0	0	185	0	0	0	0	0	0	0
1994	3	11	406	202	0	0	2475	9	132	0	0	0	0	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	0	0	0	0
1995	1	35	4055	168	496	2798	0	143	243	0	213	0	2	716	0	0	0	440	0	16	0	0	0	0
1995	2	25	0	142	0	0	1130	94	788	0	205	476	0	0	0	0	8860	0	0	0	0	0	0	0
1995	3	31	1355	25	0	0	136	5	84	0	0	0	0	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	0	2	0	0	0	0
1996	1	25	451	21	450	1967	0	90	129	0	142	0	4	7652	0	0	0	256	0	1	0	0	0	0
1996	2	26	0	18	0	0	3191	66	416	0	110	503	0	0	0	0	158	0	0	0	0	0	0	0
1996	3	27	594	259	0	0	846	1	114	0	0	0	0	1	0	0	0	0	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	0	3	0	0	0	0
1997	1	27	3000	215	708	4027	0	113	165	0	20	0	15	2638	0	0	0	224	0	5	0	0	0	0
1997	2	44	0	183	0	0	1120	25	246	0	53	702	0	41	0	0	2309	0	0	0	0	0	0	0
1997	3	18	559	46	0	0	605	2	158	0	1	0	0	4	0	0	0	0	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	0	1	0	0	0	0
1998	1	53	549	38	326	2376	0	108	114	0	29	0	23	2017	0	0	0	131	0	21	23	0	23	0
1998	2	46	0	33	0	0	1613	64	359	0	68	609	0	24	0	0	1049	0	0	1	0	0	0	0
1998	3	33	686	63	0	0	798	10	317	0	1	0	0	0	0	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	0	1	0	0	0	0
1999	1	25	2228	52	579	5448	0	65	133	0	16	0	26	442	0	0	0	129	0	35	107	0	107	0
1999	2	41	0	44	0	0	2101	17	391	0	46	482	0	49	0	0	653	0	0	1	0	0	0	0
1999	3	39	651	747	0	0	1456	1	168	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
1999	4	893	2380	1597	0	3403	770	83	0	164	5	0	2780	669	0	0	0	0	0	8	0	0	0	9
2000	1	15	3214	30	747	4042	0	66	154	0	87	0	29	3204	0	0	0	117	0	13	191	0	191	2
2000	2	12	0	27	0	0	2780	6	475	0	72	638	0	0	0	0	2048	0	0	0	0	0	0	0
2000	3	8	898	963	0	0	934	0	358	0	1	0	0	0	0	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	0	1	0	0	0	14
2001	1	13	409	9	239	1918	0	167	73	0	174	0	57	821	0	0	0	83	0	21	275	0	275	37
2001	2	26	0	37	0	0	1847	113	293	0	232	683	0	0	0	0	261	0	0	1	0	0	0	1
2001	3	76	62	160	0	0	988	17	113	0	0	0	0	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	0	1	0	0	0	2
2002	1	45	959	509	599	2767	0	224	157	0	235	0	61	0	1497	0	0	37	0	31	358	0	358	35
2002	2	56	0	88	0	0	706	24	231	0	251	409	0	0	0	0	1835	0	0	2	0	0	0	3
2002	3	95	99	238	0	0	520	11	84	0	0	0	0	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	0	1	0	0	0	1
2003	1	78	783	88	571	200	0	58	96	0	291	0	84	0	2704	0	0	80	0	21	442	0	442	46
2003	2	85	0	1881	0	0	416	6	156	0	71	403	0	0	0	0	2159	0	0	1	0	0	0	0
2003	3	116	38	53	0	0	182	5	109	0	3	0	1	0	0	0	0	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	0	1	0	0	0	0
2004	1	154	10	59	2100	2225	0	114	136	0	81	0	93	0	5285	0	0	78	0	3	526	0	526	49
2004	2	205	0	105	0	0	1868	94	186	0	68	421	0	0	0	0	2131	0	0	0	0	0	0	1
2004	3	122	586	720	0	0	1173	164	379	0	15	0	0	0	0	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	0	0	0	0
2005	1	106	3280	222	3694	77	0	171	414	0	137	0	71	0	2764	0	0	293	0	5	454	0	454	4
2005	2	108	0	121	0	0	1034	30	346	0	102	413	0	0	0	0	3029	0	0	0	0	0	0	0
2005	3	81	59	220	0	0	513	68	284	0	7	0	0	0	640	0	0	0	0	0	0	0	0	3
2005	4	873	2412	339	0	940	85	23	0	356	135	0	1078	0	4714	49	0	0	0	5	0	0	0	0
2006	1	115	252	354	2012	692	0	315	148	0	328	0	48	0	4573	0	0	251	0	2	633	0	633	3
2006	2	62	0	102	0	0	695	17	229	0	69	331	0	0	1	0	2513	0	0	0	0	0	0	0
2006	3	61	485	376	0	0	228	32	253	0	10	0	0	0	0	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	0	0	0	0
2007	1	66	363	121	2123	364	0	238	150	0	381	0	58	0	2723	4	0	101	0	1	876	0	876	3
2007	2	71	0	776	0	0	1985	105	314	0	52	1013	0	0	44	0	1968	0	0	0	0	0	0	0
2007	3	99	214	581	0	0	619	12	268	0	2	0	0	0	0	0	0	0	0	0	0	0	0	2
2007	4	802	1610	1003	0	1	220	30	0	844	239	0	784	0	1794	175	0	0	0	1	0	0	0	58
2008	1	33	3007	62	3028	0	0	287	389	0	186	0	35	0	2613	2	0	72	0	10	607	0	607	54
2008	2	40	0	230	0	0	1163	14	455	0	95	797	0	0	1	0	2361	0	0	0	0	0	0	2
2008	3	39	702	518	0	0	868	1	449	0	1	0	0	0	0	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	0	1	0	0	0	0

Table 3-3. Cont.

Fishing year	Season	Weight (mt)																		Number (1000 fish)				Number (individual)
		Fleet1 and Fleet 23	Fleet2	Fleet3	Fleet4	Fleet5	Fleet6	Fleet7	Fleet8	Fleet9	Fleet10	Fleet11	Fleet12	Fleet13	Fleet14	Fleet17	Fleet18	Fleet19	Fleet 21	Fleet15 and Fleet 24	Fleet16	Fleet20	Fleet22	Fleet 25
2009	1	26	2891	97	1299	828	0	108	180	0	181	0	82	0	2221	3	0	62	0	12	256	0	256	8
2009	2	23	0	112	0	0	703	43	143	0	106	677	0	0	3	0	181	0	0	0	0	0	0	0
2009	3	35	718	617	0	0	264	0	342	0	1	0	0	0	0	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	0	3	0	0	0	12
2010	1	27	123	26	1052	35	0	179	190	0	79	0	45	0	5300	0	0	20	0	4	563	0	563	34
2010	2	10	0	145	0	0	979	44	237	0	9	693	0	0	1	0	388	0	0	1	0	0	0	0
2010	3	25	67	191	0	0	492	29	374	0	4	0	0	0	0	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	0	2	0	0	0	0
2011	1	49	611	21	1906	320	0	38	158	0	148	0	48	0	2379	0	0	39	0	29	375	0	375	15
2011	2	32	0	43	0	0	789	22	217	0	36	567	0	0	19	0	2377	0	0	1	0	0	0	0
2011	3	20	9	163	0	0	242	70	360	0	5	0	0	0	1	0	0	0	0	0	0	0	0	0
2011	4	189	530	674	0	3	7	45	0	500	151	0	148	0	1286	50	0	0	0	4	0	0	0	0
2012	1	24	261	559	841	199	0	103	205	0	514	0	26	0	5421	0	0	2	0	35	180	0	180	31
2012	2	13	0	28	0	0	233	0	176	0	54	644	0	0	3	0	620	0	0	1	0	0	0	16
2012	3	28	9	76	0	0	256	2	273	0	4	0	0	0	0	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	0	3	0	0	0	0
2013	1	28	10	1	1729	268	0	81	132	0	204	0	40	0	1788	0	0	22	0	57	264	0	264	56
2013	2	15	0	35	0	0	477	3	217	0	82	895	0	0	8	0	2	0	0	5	0	0	0	1
2013	3	9	79	516	0	0	789	0	306	0	2	0	0	0	2	0	0	0	0	0	0	0	0	9
2013	4	311	2459	783	0	0	60	43	0	818	285	0	257	0	4036	216	0	0	0	1	0	0	0	3
2014	1	21	654	6	2203	47	0	125	92	0	231	0	21	0	1228	1	0	40	0	25	61	0	61	111
2014	2	26	0	6	0	0	97	1	107	0	110	679	0	0	2	0	14	0	0	2	0	0	0	117
2014	3	39	246	607	0	0	60	7	76	0	1	0	0	0	1	0	0	0	0	1	0	0	0	13
2014	4	191	86	5	0	939	18	12	0	388	261	0	308	0	3133	237	0	0	0	2	0	121	0	41
2015	1	25	27	0	1864	0	0	11	88	0	210	0	26	0	43	0	0	19	0	25	243	27	243	294
2015	2	47	0	65	0	0	233	6	77	0	167	808	0	0	3	0	7	0	0	0	0	0	0	5
2015	3	72	1	981	0	0	153	5	116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2015	4	217	97	33	0	1287	82	5	0	199	283	0	237	0	2716	215	0	0	0	2	0	267	0	58
2016	1	83	463	6	1772	0	0	8	135	0	183	0	23	0	329	0	0	224	0	8	261	1	261	245
2016	2	20	0	9	0	0	213	52	254	0	62	769	0	0	16	0	805	0	0	2	0	0	0	18
2016	3	50	83	738	0	0	178	31	479	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
2016	4	358	131	0	0	1620	6	64	0	368	175	0	232	0	3650	172	0	0	0	2	0	219	0	3
2017	1	37	111	3	1691	0	0	32	259	0	518	0	30	0	479	1	0	82	0	10	164	0	164	316
2017	2	35	0	2	0	0	299	1	109	0	316	1038	0	0	0	0	375	0	219	5	0	0	0	118
2017	3	59	11	530	0	0	81	30	148	0	1	0	0	0	418	0	0	0	0	1	0	0	0	3
2017	4	354	81	0	0	1571	15	25	0	209	36	0	257	0	2429	115	0	0	171	2	0	245	12	0
2018	1	11	124	0	1536	0	0	5	98	0	37	0	38	0	40	0	0	42	0	6	218	1	218	374
2018	2	37	0	5	0	0	196	8	110	0	7	529	0	0	18	0	95	0	183	4	0	0	0	74
2018	3	194	8	542	0	0	296	35	233	0	1	0	0	0	2007	0	0	0	80	0	0	0	0	0
2018	4	423	152	16	0	1567	51	9	0	233	52	0	247	0	7	169	0	0	0	5	0	232	12	42

Table 3-4 (a). Abundance indices (CPUE) used in the base-case stock assessment model for Pacific bluefin tuna (*Thunnus orientalis*).

CPUE #	Abundance index	Available period (fishing year)	Corresponding fisheries	Corresponding fleet for the selectivity setting	Data quality	Document for reference	Update
S1	Japanese coastal longline CPUE for spawning season.	**1993-2018**	JP Longline	Fleet 1 : JPLL	Standardized by spatio-temporal GLMM	ISC/20/PBFWG-1/02	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	
S4	Japanese troll CPUE in Nagasaki prefecture (Sea of Japan and East China sea)	**1980-2016, 2018**	JP Troll	Fleet 6 : JP Troll (Seas 2-4)	Standardized by lognormal model	ISC/20/PBFWG-1/04	X
S5	Taiwanese longline CPUE (South area)	**2002-2018**	TW Longline	Fleet 12 : TWLL (South)	Standardized by GLMM	ISC/20/PBFWG-1/03	X

Table 3-4 (b). Abundance indices (CPUE) **NOT** used in the base-case stock assessment model for Pacific bluefin tuna (*Thunnus orientalis*).

CPUE #	Abundance index	Available period (fishing year)	Corresponding fisheries	Corresponding fleet for the selectivity setting	Data quality	Document for reference	Update
S6	Taiwanese longline geo-stat CPUE (South area)	**2006-2018**	TW Longline	Fleet 12 : TWLL (South)	Standardized by spatio-temporal GLMM	ISC/20/PBFWG-1/03	X
S7	Taiwanese longline geo-stat CPUE (North area)	**2006-2018**	TW Longline	Fleet 17 : TWLL (North)	Standardized by spatio-temporal GLMM	ISC/20/PBFWG-1/03	X
S8	Taiwanese longline geo-stat CPUE (Whole area)	**2006-2018**	TW Longline	Fleet 12 : TWLL (South)	Standardized by spatio-temporal GLMM	ISC/20/PBFWG-1/03	X
S9	Taiwanese longline GLMM CPUE (North area)	**2003-2018**	TW Longline	Fleet 17 : TWLL (North)	Standardized by GLMM	ISC/20/PBFWG-1/03	X
S10	Korean Offshore Large scale Purse Seine CPUE	**2004-2017**	KR Purse Seine	Fleet 3: KROLPS	Standardized by GLM	ISC/19/PBFWG-2/13	X
S11	Japanese Recruitment monitoring in the East China Sea	**2011-2018**	JP Troll	Fleet 6 : JP Troll (Seas 2-4)	Standardized by GLMM	ISC/19/PBFWG-2/12	X
S12	Japanese Recruitment monitoring in the Pacific Ocean	**2011-2018**	JP Troll	Fleet 19: JP Troll (Seas 1)	Standardized by GLMM	ISC/19/PBFWG-2/12	X

Table 3-5 (a). Available abundance indices (CPUE) of Pacific bluefin tuna (*Thunnus orientalis*). S1, S2, S3, S4, and S5 were fitted to the base-case model (numbers in bold). Numbers in grey indicate that data points were removed. S1-9 ,11,12 were annual indices.

Fishing	JP LL			JP Troll	TW LL					JP Troll Monitoring	
year	S1	S2	S3	S4	S5	S6	S7	S8	S9	S11	S12
1952		0.01									
1953		0.01									
1954		0.01									
1955		0.01									
1956		0.01									
1957		0.01									
1958		0.02									
1959		0.03									
1960		0.02									
1961		0.02									
1962		0.02									
1963		0.01									
1964		0.01									
1965		0.01									
1966		0.01									
1967		0.01									
1968		0.01									
1969		0.01									
1970		0.00									
1971		0.00									
1972		0.00									
1973		0.00									
1974		0.01	0.00								
1975			0.00								
1976			0.00								
1977			0.00								
1978			0.00								
1979			0.00								
1980			0.00	0.68							
1981			0.00	1.20							
1982			0.00	0.63							
1983			0.00	0.93							
1984			0.00	0.95							
1985			0.00	0.89							
1986			0.00	1.00							
1987			0.00	0.73							
1988			0.00	0.84							
1989			0.00	0.66							
1990			0.00	1.30							
1991			0.00	1.35							
1992			0.00	0.59							
1993	2.28		0.01	0.49							
1994	1.69		0.00	2.05							
1995	2.05		0.01	1.12							
1996	2.13		0.01	1.64							
1997	1.94		0.01	0.96							
1998	1.49		0.00	0.84							
1999	1.06		0.00	1.54							
2000	0.77		0.00	1.17							
2001	0.92		0.00	1.17							
2002	1.39			0.76	2.14						
2003	1.41			0.66	2.22						
2004	1.55			1.32	1.56				0.92		
2005	0.90			1.45	1.68				1.18		
2006	0.99			0.75	1.19	127.46	8.73	2.37	0.73		
2007	0.61			1.45	1.02	68.34	12.54	1.47	1.03		
2008	0.36			1.48	0.94	41.07	14.50	1.01	1.11		
2009	0.22			1.17	0.49	29.90	6.10	0.64	0.65		
2010	0.20			1.14	0.43	21.67	9.00	0.56	0.77		
2011	0.15			0.99	0.37	18.00	6.51	0.44	0.63	0.69	1.40
2012	0.31			0.50	0.39	20.73	9.10	0.55	0.76	0.68	0.68
2013	0.31			0.91	0.63	28.83	14.92	0.80	1.25	1.19	1.12
2014	0.38			0.43	0.73	30.08	18.10	0.85	1.14	0.34	0.40
2015	0.42			0.51	0.71	36.61	19.05	1.01	1.48	0.61	0.67
2016	0.65			1.11	0.85	37.47	15.28	0.97	1.21	1.42	0.99
2017	0.69				0.81	54.78	8.64	1.09	0.73	2.06	1.75
2018	1.10			0.64	0.85	53.14	14.95	1.24	1.41	1.17	1.45

Table 3-5 (b). Available abundance indices (CPUE) of Pacific bluefin tuna (*Thunnus orientalis*). S10 was quarterly index

Fishing Year	Season	S10	CV
2003	1		
2003	2		
2003	3		
2003	4	1.513	0.02
2004	1	0.753	0.02
2004	2	1.078	0.02
2004	3	2.142	0.02
2004	4	1.076	0.02
2005	1	0.698	0.02
2005	2	0.768	0.02
2005	3	0.634	0.02
2005	4	0.752	0.02
2006	1	0.560	0.02
2006	2	0.646	0.02
2006	3	0.677	0.02
2006	4	0.508	0.02
2007	1	0.584	0.02
2007	2	1.114	0.02
2007	3	1.131	0.02
2007	4	1.683	0.02
2008	1	0.453	0.02
2008	2	0.913	0.02
2008	3	1.555	0.02
2008	4	1.241	0.02
2009	1	0.724	0.02
2009	2	0.707	0.02
2009	3	0.748	0.02
2009	4	0.857	0.02
2010	1	0.446	0.02
2010	2	0.582	0.02
2010	3	0.801	0.02
2010	4	1.473	0.02
2011	1	0.344	0.02
2011	2	0.557	0.02
2011	3	0.845	0.02
2011	4	2.336	0.02
2012	1	1.812	0.02
2012	2	0.432	0.02
2012	3	0.560	0.02
2012	4	3.650	0.02
2013	1	0.327	0.02
2013	2	0.653	0.02
2013	3	1.256	0.02
2013	4	1.151	0.02
2014	1		
2014	2		
2014	3	1.075	0.02
2014	4	0.574	0.02
2015	1		
2015	2	0.621	0.02
2015	3	0.940	0.02
2015	4	0.699	0.02
2016	1	0.387	0.02
2016	2	0.340	0.02
2016	3	1.614	0.02
2016	4		
2017	1		
2017	2		
2017	3	3.011	0.02
2017	4		
2018	1		
2018	2		
2018	3		
2018	4		

Table 3-6. 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 (Season 4)		1952-1968, 1993-2018	Scaled Number of fish measured	X
Fleet2[*1]	JPSPPS (Seas1, 3, 4)	Length bin	JPSPPS (Season 1, 3, 4)		2002-2018	Number of landing well measured	X
Fleet3[*1]	KROLPS	Length bin	KROLPS		2010-2018	Number of trip or set well measured /2	X
Fleet4	TPSJS	Length bin	JP TPSJS		1987-1989, 1991-2018	same velue with the last assessment	X
Fleet5	TPSPO	Length bin	JP TPSPO		1995-2006 and 2014-2018	Number of trip or set well measured /2	X
Fleet6	JP Troll (Seas2-4)	Length bin	JP Troll (Season 2-4)		1994-2018	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)		1993-2018	Total month of well sampled port	X
Fleet9	SetNet (Seas4)	Length bin	JP Setnet (Season 4)		1993-2018	Total month of well sampled port	X
Fleet10[*3]	SetNet_HK_AM	Weight bin	JP Setnet in Hokkaido and Aomori	JP Handline & Tsugaru Longline	1994-2018	Total month of well sampled port	X
Fleet11[*3]	JP Others	Weight bin	JP Handline & Tsugaru Longline		1994-2018	Total month of well sampled port	X
Fleet12	TWLL (South)	Length bin	TWLL (South area)		1992-2018	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, 2008-2018	Number of haul well measured	X
Fleet15[*4]	EPOSP	Length bin	US Recreational Fisheries		2014-2018	Number of trip or set well measured /2	X
Fleet16[*5]	Troll4Pen	Age (age-0 only)	JPTroll for farming				
Fleet17	TWLL (North)	Length bin	TWLL (North area)		2009-2018	Scaled Number of fish measured	X
Fleet18	JPSPPS (Seas2)	Length bin	JPSPPS (Season 2)		2012-2018	Number of landing well measured	X
Fleet19	JP Troll (Seas1)	Length bin	JP Troll (Season 1)		1994-2004, 2006-2008, 2011,2012, 2016, 2018	Total month of well sampled port	X
Fleet20	JSSPS for Pen	Length bin	JSSPS for farming		2016-2018	Number of set well measured /4	X
Fleet21	Unaccounted mortality in WPO (weight)	Length bin	Discard amount for JPN and KOR fisheries				
Fleet22	Unaccounted mortality in WPO (number)	Length bin	Discard amount for JPN				
Fleet23	JPLL (1993- ,S3)	Length bin	JPLL (Season 3)		1993-2018	Scaled Number of fish measured	X
Fleet24	EPOSP_early	Length bin	US Recreational Fisheries		1993-2003, 2005-06, 2008-11		
Fleet25	Unaccounted mortality in EPO (number)	Length bin	Discard amount for US recreational fishery				

[*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	Main 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	Time-varying Option
Fleet 1	JPLL (Seas 4)	Spawners in WPO	High*	Length	Good	Yes	Low	Dome-shaped (double normal)	-	Constant on length-based	-
Fleet 2	JSPPS (Seas1, 3, 4) for consumption	Age 0 fish in WPO	Medium*	Length	Good	-	High	Dome-shaped (double normal)	Full selection at ages 0-1	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	Asymptotic (logistic)	Age-specific (ages 1-4)	Constant on length-based; time-varying on ages 1-2 for 2007-2018	Deviation
Fleet 4	JPTPSJS	Migratory ages (ages 1-5)	High*	Length	Very Good	-	High	Asymptotic (logistic)	Age-specific (ages 3-9)	Constant on length-based; time-varying on ages 3-7 for 2000-2014	Deviation
Fleet 5	JPTPSPO	Migratory ages (ages 1-7)	Medium*	Length	Fair to Good (improvement after 2014 by systematic sampling)	-	High	Asymptotic (logistic)	Age-specific (ages 1-10)	Constant on length-based; time-varying on ages 1, 4-7 for 2004-2005, 2011-2014, 2015-2018	Block
Fleet 6	JPTroll (Season2-4)	Age 0 fish in WPO	High*	Length	Good	Yes	High	Dome-shaped (double normal)	Full selection at ages 0-2	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 1-6)	Medium*	Weight	Good	-	Low	Asymptotic (logistic)	Age-specific (ages 1-6)	Constant on length-based; Time varying on ages1, 4-5 for 2004-2005, 2011-2014, 2015-2018)	Block
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)	-	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)	-	Time–varying on length-based for 1954-1981	Block
Fleet 14	MEXCOMM (2002-)	Migratory ages (ages 1-5)	High*	Length	Fair to Good (improvement after 2013 due to the stereo-camera)	-	High	Dome-shaped (double normal)	-	Time–varying on length-based for 2006-2018	Block
Fleet 15	EPO Sports (2014-)	Migratory ages (ages 1-5)	Low	Length	Fair (Good samples are available after 2014)	-	Low	Dome-shaped (double normal)	Full selection at ages 0-7	Time–varying on length-based for 2014-2018	Block
Fleet 16	JPTroll for farming	Age 0 fish in WPO	Low	-	Catch in # of Age-0 fish are available	-	Med	None	Full selection 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 2004-2018	Deviation
Fleet 19	JPTroll (Season1)	Age 0 fish in WPO	Medium*	Length	Good	-	High	Dome-shaped (double normal)	-	Constant on length-based	-
Fleet 20	JPSPPS for farming	Age 0-1 in WPO	Medium*	Length	Good (improvement after 2016 due to the stereo-camera); Catch in # of fish are available	-	Med	Share to Fleet 2			
Fleet 21	Discard in WPO (mt)	Not Available				-	NA	Mirror to Fleet 8			
Fleet 22	Discard in WPO (Num)	Not Available				-	NA	Mirror to Fleet 8			
Fleet 23	JPLL (Seas 1-3)	Migratory ages (ages 1-7)	Medium*	Length	Good	-	Low	Dome-shaped (double normal)	-	Constant on length-based	-
Fleet 24	EPO Sports (-2013)	Migratory ages (ages 1-5)	Low	Length	Fair	-	Low	Mirror to Fleet 14			
Fleet 25	EPO Discard in Num	Migratory ages (ages 1-5)	NA			-	Low	Mirror to Fleet 14			

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

Scenario #	Upper Limit increase in requeste scenarios				Catch limit in the projection			
	WCPO		EPO		WCPO		EPO	
	Small	Large	Small	Large	Small	Large	Small	Large
1	0%				4725	6582	3300	
2	0%				4725	6582	3300	
3	5%				4960	6909	3465	
4	10%				5196	7238	3630	
5	15%				5433	7567	3794	
6	20%				5669	7897	3960	
7	0%	500	500		4725	7081	3800	
8	250	250	500		4973	6830	3800	
9	0	600	400		4725	7180	3700	
10	5%	1300	700		4960	7880	4000	
11	10%	1300	700		5196	7880	4000	
12	5%	1000	500		4960	7580	3800	
13	0	1650	660		4725	8231	3960	
14	125	375	550		4848	6955	3850	
15	0	0	0		0	0	0	

* The numbering of Scenarios is different from those given by the IATTC-WCPFC NC Joint WG meeting.

* Fishing mortality in scenario 15 was kept at zero. Fishing mortality in scenario 1 is maintained at the reference level which is the geometric mean values of quarterly age-specific fishing mortality during 2002-2004. In other scenarios fishing mortality was increased to fully utilize the respective catch limits from the reference level. Fishing mortality for the EPO recreational fishery was assumed to be the F2009-11 average level except for scenario 15.

* The Japanese unilateral measure (transferring 250 mt of catch upper limit from that for small PBF to that for large PBF during 2017-2020) is reflected in the projections.

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*
Fleet 1	73	8.2	54.5	26.8
Fleet 2	41	10.5	37.0	15.4
Fleet 3	16	15.2	60.8	32.1
Fleet 4	31	10.6	30.0	14.8
Fleet 5	16	10.4	46.9	38.0
Fleet 6	53	8.7	37.5	16.4
Fleet 7	32	1.0	9.7	6.0
Fleet 8	76	6.5	18.7	12.1
Fleet 9	26	7.0	19.9	13.2
Fleet 10	25	8.6	38.4	15.7
Fleet 11	25	6.7	7.4	6.2
Fleet 12	27	11.0	99.3	36.9
Fleet 13	50	14.5	20.2	6.3
Fleet 14	16	10.1	26.1	17.8
Fleet 15	12	12.2	20.9	12.3
Fleet 16	1	7.2	32.6	32.6
Fleet 17	10	2.8	93.5	67.6
Fleet 18	14	10.6	19.7	10.8
Fleet 19	18	6.4	25.7	10.6
Fleet 20	3	12.6	23.1	13.5
Fleet 23	26	3.4	27.7	20.2
Fleet 24	25	12.0	11.2	5.3

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

Fishing Year	Total Biomass (t)	Spawning Stock Biomass (t)	Recruitment (1,000 fish)	Spawning Potential Ratio	Depletion Ratio
1952	134,751	103,502	4,857	11.4%	16.4%
1953	136,428	97,941	20,954	12.7%	15.5%
1954	146,741	87,974	34,813	7.8%	13.9%
1955	156,398	75,360	13,442	11.4%	11.9%
1956	175,824	67,700	33,582	16.1%	10.7%
1957	193,597	76,817	11,690	10.7%	12.1%
1958	201,937	100,683	3,195	19.2%	15.9%
1959	209,300	136,430	7,758	23.2%	21.6%
1960	202,121	144,411	7,731	17.4%	22.8%
1961	193,546	156,302	23,339	3.4%	24.7%
1962	176,618	141,277	10,737	10.8%	22.3%
1963	165,892	120,244	28,112	6.8%	19.0%
1964	154,192	105,870	5,696	6.6%	16.7%
1965	142,548	93,222	10,710	3.0%	14.7%
1966	119,683	89,236	8,680	0.1%	14.1%
1967	105,084	83,208	10,897	1.3%	13.2%
1968	91,408	77,466	14,535	1.2%	12.2%
1969	80,523	64,299	6,484	8.5%	10.2%
1970	74,222	53,961	7,027	3.1%	8.5%
1971	66,114	46,839	12,420	1.0%	7.4%
1972	64,114	40,447	23,552	0.3%	6.4%
1973	63,023	35,273	10,968	5.6%	5.6%
1974	64,885	28,502	13,322	6.3%	4.5%
1975	65,074	26,410	11,252	8.0%	4.2%
1976	64,512	29,274	9,253	2.9%	4.6%
1977	74,670	35,105	25,601	3.7%	5.6%
1978	76,601	32,219	14,037	5.6%	5.1%
1979	73,615	27,093	12,650	7.9%	4.3%
1980	72,809	29,657	6,910	5.2%	4.7%
1981	57,482	27,928	13,340	0.3%	4.4%
1982	40,398	24,240	6,512	0.0%	3.8%
1983	33,210	14,456	10,133	6.1%	2.3%
1984	37,464	12,651	9,184	5.1%	2.0%
1985	39,591	12,817	9,676	2.8%	2.0%
1986	34,349	15,147	8,181	1.1%	2.4%
1987	32,008	13,958	6,026	8.1%	2.2%
1988	38,086	14,931	9,304	11.0%	2.4%
1989	41,849	14,839	4,409	14.4%	2.3%
1990	58,122	18,953	18,096	18.2%	3.0%
1991	69,351	25,294	10,392	9.8%	4.0%
1992	76,228	32,252	3,958	14.8%	5.1%
1993	83,624	43,639	4,450	16.4%	6.9%
1994	97,731	50,277	29,314	13.7%	7.9%
1995	94,279	62,784	16,533	4.8%	9.9%
1996	96,463	61,826	17,787	8.9%	9.8%
1997	90,349	56,393	11,259	5.9%	8.9%
1998	95,977	55,888	16,018	4.0%	8.8%
1999	92,232	51,705	22,842	3.7%	8.2%
2000	76,795	48,936	14,383	1.7%	7.7%
2001	78,052	46,408	17,384	9.7%	7.3%
2002	76,110	44,492	13,761	5.7%	7.0%
2003	68,707	43,806	7,110	2.3%	6.9%
2004	66,433	36,701	27,930	1.4%	5.8%
2005	55,778	30,004	15,256	0.6%	4.7%
2006	43,912	24,089	13,660	1.1%	3.8%
2007	43,765	19,061	23,146	0.4%	3.0%
2008	39,646	14,805	21,265	0.8%	2.3%
2009	35,135	11,422	8,002	1.3%	1.8%
2010	38,053	10,837	18,230	2.4%	1.7%
2011	38,901	12,096	12,574	4.9%	1.9%
2012	41,058	14,578	6,845	7.4%	2.3%
2013	49,383	16,703	12,798	4.7%	2.6%
2014	47,864	18,503	3,783	8.9%	2.9%
2015	52,725	21,014	8,778	10.4%	3.3%
2016	62,069	25,009	16,504	10.5%	4.0%
2017	71,228	25,632	6,663	16.5%	4.1%
2018	82,212	28,228	4,658	15.4%	4.5%
Median (1952-2018)	73,615	35,273	11,259	5.9%	5.6%
Average(1952-2018)	86,908	49,388	13,199	7.1%	7.8%

Table 5-3. Ratios of the estimated fishing mortalities (Fs and 1-SPRs for 2002-04, 2011-13, 2016-18) relative to potential fishing mortality-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*) from the base-case model**.** F_{max}: Fishing mortality (F) that maximizes equilibrium yield per recruit (Y/R). $F_{0.1}$: F at which the slope of the Y/R curve is 10% of the value at its origin. F_{med}: F corresponding to the inverse of the median of the observed R/SSB ratio. $F_{xx\%SPR}$: F that produces given % of the unfished spawning potential (biomass) under equilibrium condition.

Reference period	$\mathbf{F_{max}}$	$\mathbf{F_{0.1}}$	$\mathbf{F_{med}}$	**(1-SPR)/(1-SPRxx%)**				**Estimated SSB for terminal year of each period (ton)**	**Depletion rate for terminal year of each period (%)**
				SPR10%	**SPR20%**	**SPR30%**	**SPR40%**		
2002-2004	1.92	2.84	1.14	1.08	1.21	1.38	1.61	36,701	5.80
2011-2013	1.54	2.26	0.89	1.05	1.18	1.35	1.57	16,703	2.64
2016-2018	1.14	1.65	0.57	0.95	1.07	1.23	1.43	28,228	4.46

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 #	Upper Limit increase				Probability of SSB is below the Initial rebuilding target at 2024 in case the low recruitment continue	The fishing year expected to achieve the initial rebuilding target with >60% probability	The fishing year expected to achieve the 2nd rebuilding target with >60% probability	Probability of achiving the initial rebuilding target at 2024	Probability of achiving the second rebuilding target at 2034	Probability of SSB falling below the historical lowest at any time during the projection period.	Probability of Catch falling below the historical lowest at any time during the projection period.	Median SSB at 2024	Median SSB at 2034
	WCPO		EPO										
	Small	Large	Small	Large									
1	0%				0%	2020	2026	100%	99%	0%	100%	107,098	286,958
2	0%				0%	2020	2026	100%	99%	0%	100%	104,973	287,020
3	5%				0%	2020	2027	100%	98%	0%	100%	99,968	272,814
4	10%				0%	2020	2027	100%	96%	0%	100%	95,096	258,850
5	15%				0%	2020	2028	99%	94%	0%	100%	90,293	244,959
6	20%				0%	2020	2028	99%	91%	0%	100%	85,618	231,003
7	0%	500	500		0%	2020	2027	100%	98%	0%	100%	99,903	277,396
8	250	250	500		0%	2020	2027	100%	97%	0%	100%	98,164	268,473
9	0	600	400		0%	2020	2027	100%	98%	0%	100%	100,035	278,004
10	5%	1300	700		0%	2020	2027	99%	96%	0%	100%	92,504	259,802
11	10%	1300	700		0%	2020	2027	99%	95%	0%	100%	89,951	249,996
12	5%	1000	500		0%	2020	2027	100%	97%	0%	100%	94,952	264,218
13	0	1650	660		0%	2020	2027	99%	97%	0%	100%	93,897	267,976
14	125	375	550		0%	2020	2027	100%	98%	0%	100%	98,729	272,323
15	0	0	0		0%	2019	2022	100%	100%	0%	100%	221,391	560,259

* The numbering of Scenarios is different from those given by the IATTC-WCPFC NC Joint WG meeting.

* Fishing mortality in scenario 15 was kept at zero. Fishing mortality in scenario 1 is maintained at the reference level which is the geometric mean values of quarterly age-specific fishing mortality during 2002-2004. In other scenarios fishing mortality was increased to fully utilize the respective catch limits from the reference level. Fishing mortality for the EPO recreational fishery was assumed to be the F2009-11 average level except for scenario 15. Fishing mortality for Korean purse seine fishery was assumed to be the F2014-16 average level except for scenario 15.

* The Japanese unilateral measure (transferring 250 mt of catch upper limit from that for small PBF to that for large PBF during 2017-2020) is reflected in the projections.

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

scenario #	Upper Limit increase				Median SSB at 2024	Median SSB at 2034	Expected annual yield in 2019, by area and size category (t)				Expected annual yield in 2024, by area and size category (t)				Expected annual yield in 2034, by area and size category (t)			
	WPO		EPO				WPO		EPO		WPO		EPO		WPO		EPO	
	Small	Large	Small	Large			Small	Large	Commercial	Sport	Small	Large	Commercial	Sport	Small	Large	Commercial	Sport
1	0%				107,098	286,958	4,396	5,444	3,310	508	4,583	6,739	3,315	800	4,499	6,871	3,321	1,167
2	0%				104,973	287,020	4,396	6,924	3,541	504	4,580	6,771	3,724	799	4,495	6,851	3,746	1,168
3	5%				99,968	272,814	4,614	7,260	3,468	501	4,809	7,101	3,468	767	4,720	7,187	3,465	1,130
4	10%				95,096	258,850	4,833	7,590	3,633	499	5,038	7,433	3,634	737	4,945	7,523	3,630	1,091
5	15%				90,293	244,959	5,052	7,914	3,797	496	5,267	7,764	3,798	708	5,171	7,859	3,794	1,053
6	20%				85,618	231,003	5,269	8,223	3,964	494	5,493	8,093	3,963	680	5,394	8,195	3,960	1,014
7	0%	500	500		99,903	277,396	4,396	7,411	3,802	500	4,583	7,269	3,803	781	4,497	7,349	3,800	1,150
8	250	250	500		98,164	268,473	4,640	7,172	3,802	499	4,824	7,017	3,802	756	4,734	7,105	3,800	1,118
9	0	600	400		100,035	278,004	4,396	7,506	3,701	501	4,583	7,370	3,703	783	4,496	7,449	3,699	1,152
10	5%	1300	700		92,504	259,802	4,627	8,153	4,003	497	4,814	8,073	4,005	745	4,723	8,156	4,000	1,107
11	10%	1300	700		89,951	249,996	4,858	8,157	4,003	495	5,042	8,074	4,004	721	4,947	8,163	4,000	1,076
12	5%	1000	500		94,952	264,218	4,627	7,881	3,803	498	4,813	7,773	3,805	753	4,722	7,857	3,800	1,115
13	0	1650	660		93,897	267,976	4,396	8,444	3,963	498	4,587	8,426	3,967	769	4,498	8,501	3,960	1,138
14	125	375	550		98,729	272,323	4,517	7,291	3,852	499	4,703	7,142	3,853	767	4,614	7,226	3,850	1,132
15	0%	0%	0		221,391	560,259	0	0	0	0	0	0	0	0	0	0	0	0

* Catch limits for EPO commercial fisheries are applied for the catch of both small and large fish made by the fleets.

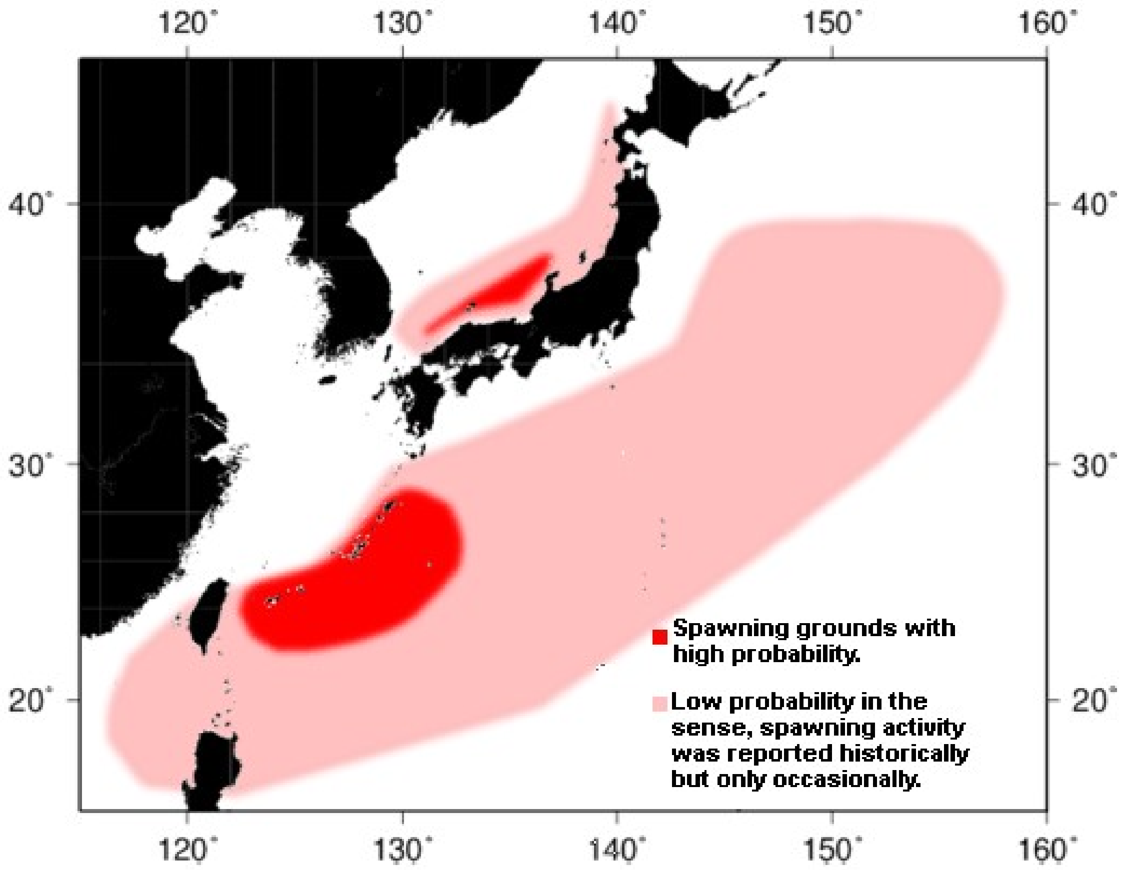


Figure 2-1. Generalized spawning grounds for Pacific bluefin tuna (*Thunnus orientalis*). Red areas represent higher probability of spawning.

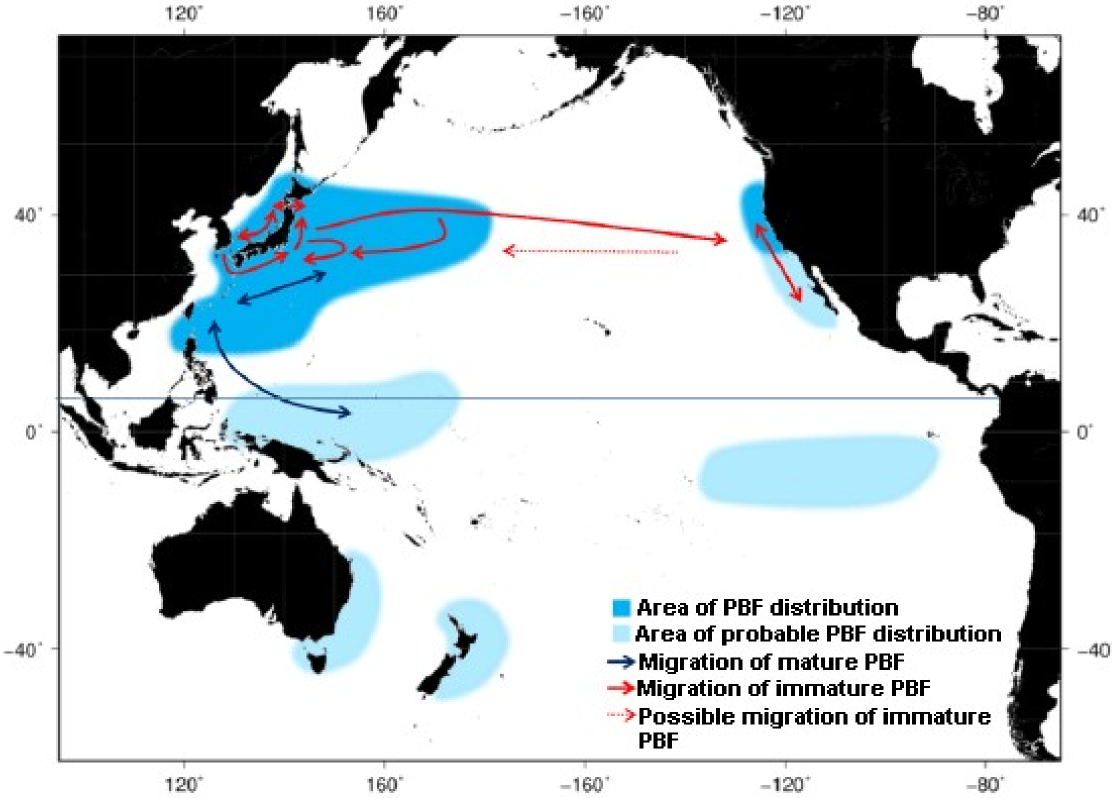


Figure 2-2. Generalized distribution of Pacific bluefin tuna (*Thunnus orientalis*). Darker areas indicate the core habitat.

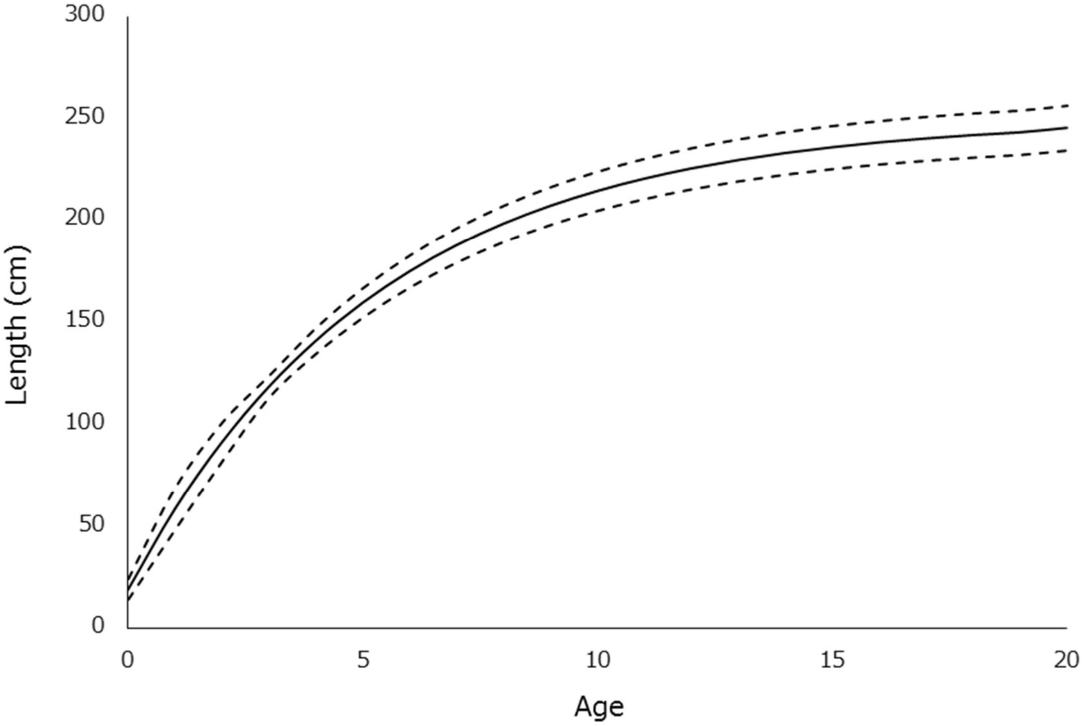


Figure 2-3. The von Bertalanffy growth curve for Pacific bluefin tuna (*Thunnus orientalis*) used in this stock assessment. Integer age (0,1,2,3,…) corresponds to the middle of first quarter 1 of each fishing year (i.e., August 15 in the calendar year).

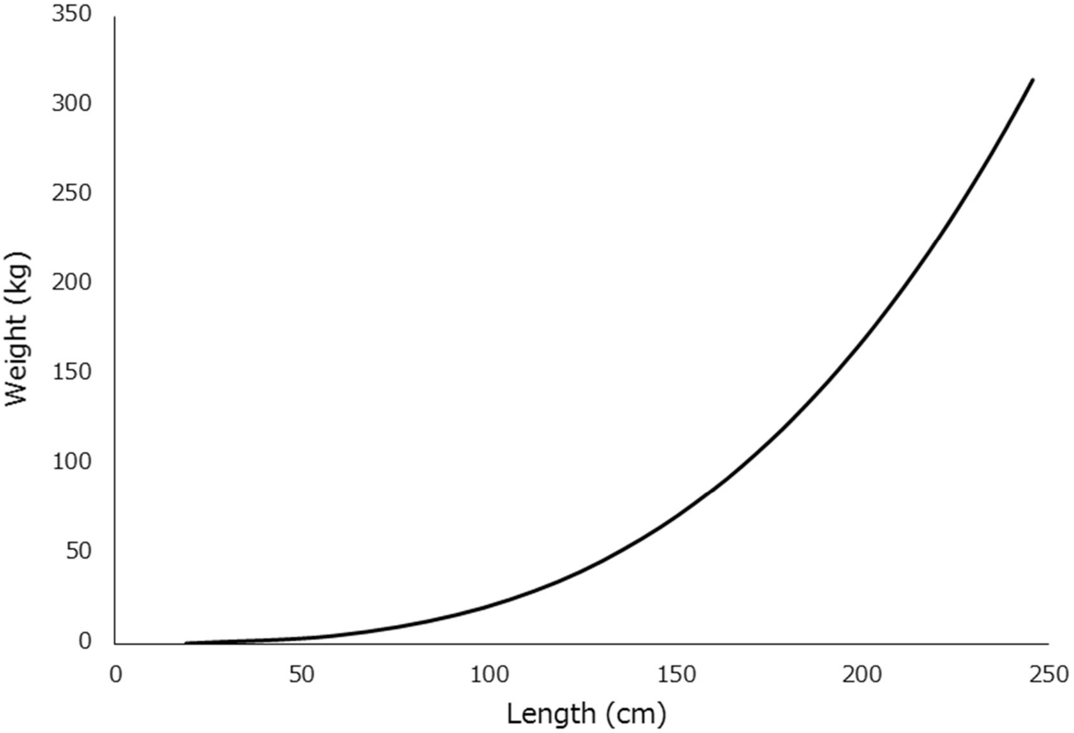


Figure 2-4. Length-weight relationship for Pacific bluefin tuna (*Thunnus orientalis*) used in this stock assessment.

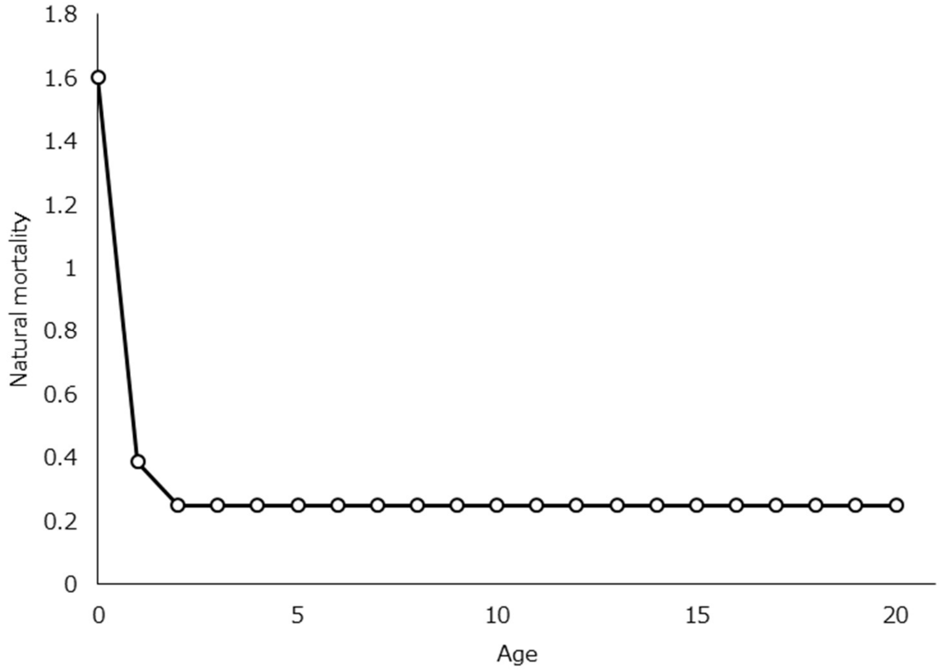


Figure 2-5. Assumed natural mortality (*M*) at age of Pacific bluefin tuna (*Thunnus orientalis*) used in this stock assessment.

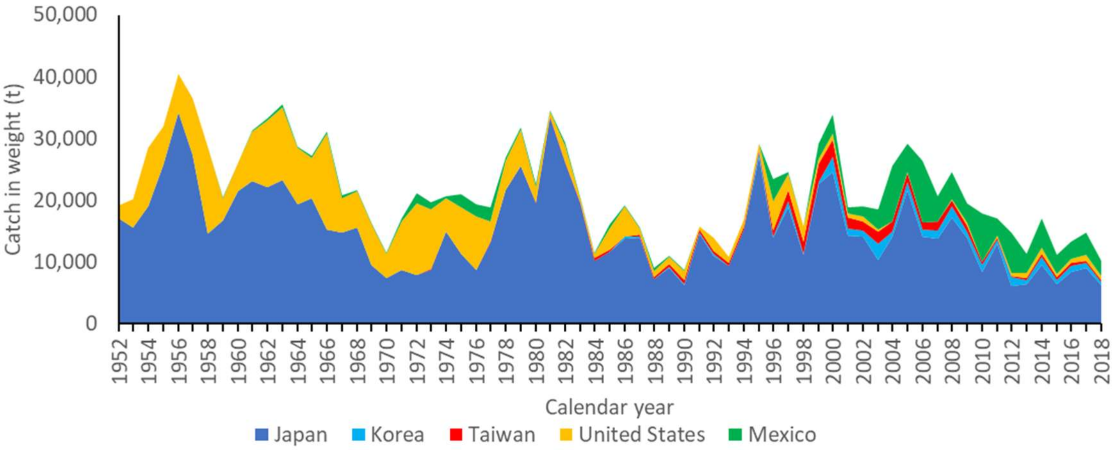


Figure 2-6 Annual catch (ton) of Pacific bluefin (*Thunnus orientalis*) tuna by ISC member countries from 1952 through 2018 (calendar year) based on ISC official statistics.

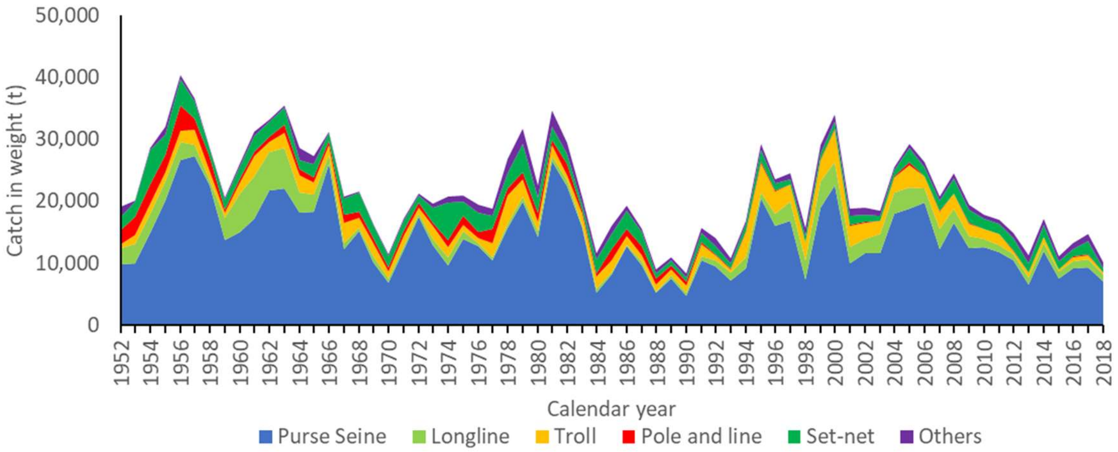


Figure 2-7. Annual catch (ton) of Pacific bluefin tuna (*Thunnus orientalis*) by gear type by ISC member countries from 1952 through 2018 (calendar year) based on ISC official statistics.

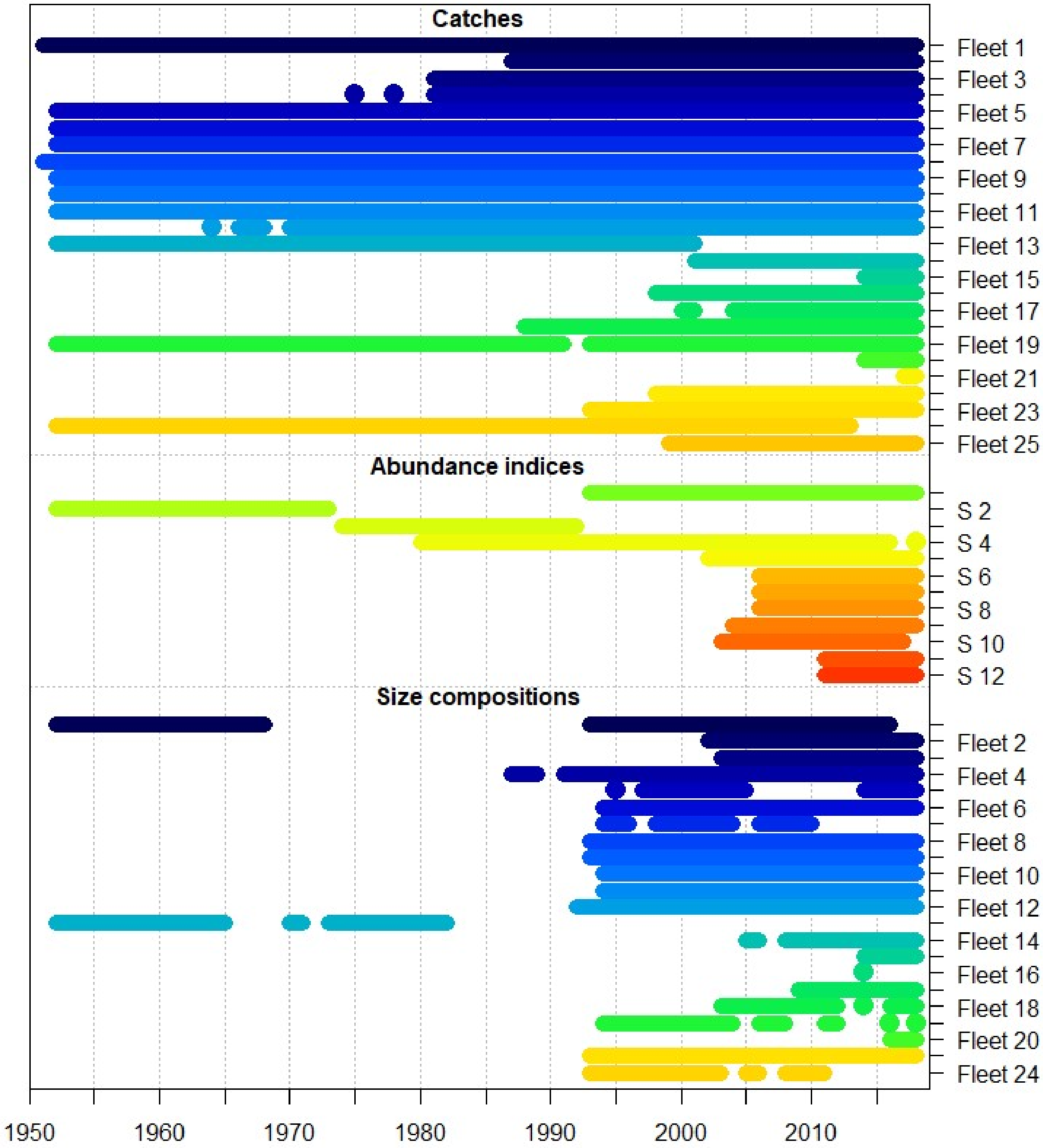


Figure 3-1. Data sources and temporal coverage of catch, abundance indices, and size composition data used in the stock assessment of Pacific bluefin tuna (*Thunnus orientalis*).

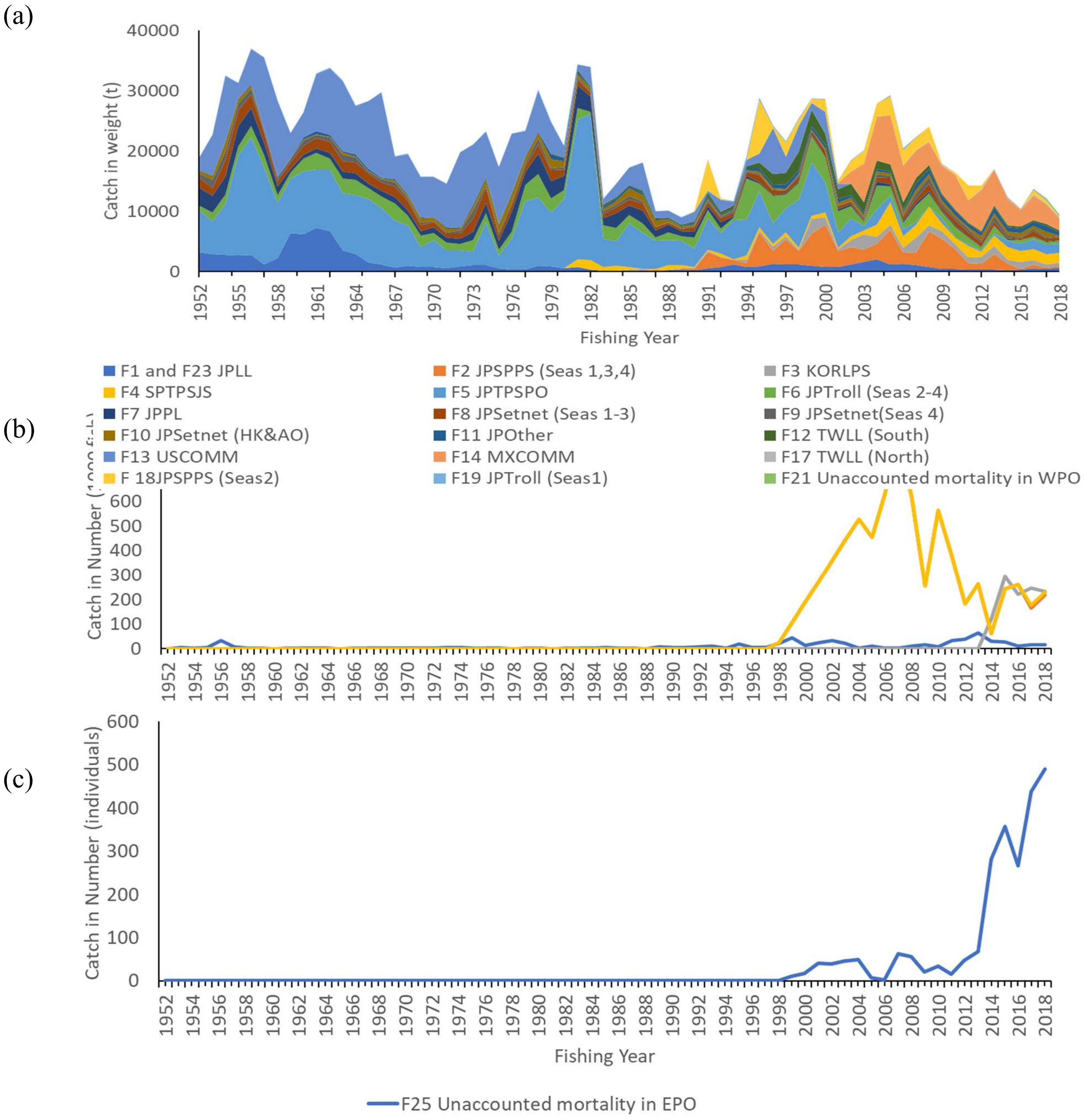


Figure 3-2. Historical annual catch of Pacific bluefin tuna (*Thunnus orientalis*) by Fleets 1-14,17-19,21, and 23 (a: upper panel) , by Fleets 15, 16, 20, 22 and 24 (b: middle panel) , and by Fleet 25 (c: lower panel) for fishing year 1952-2018.

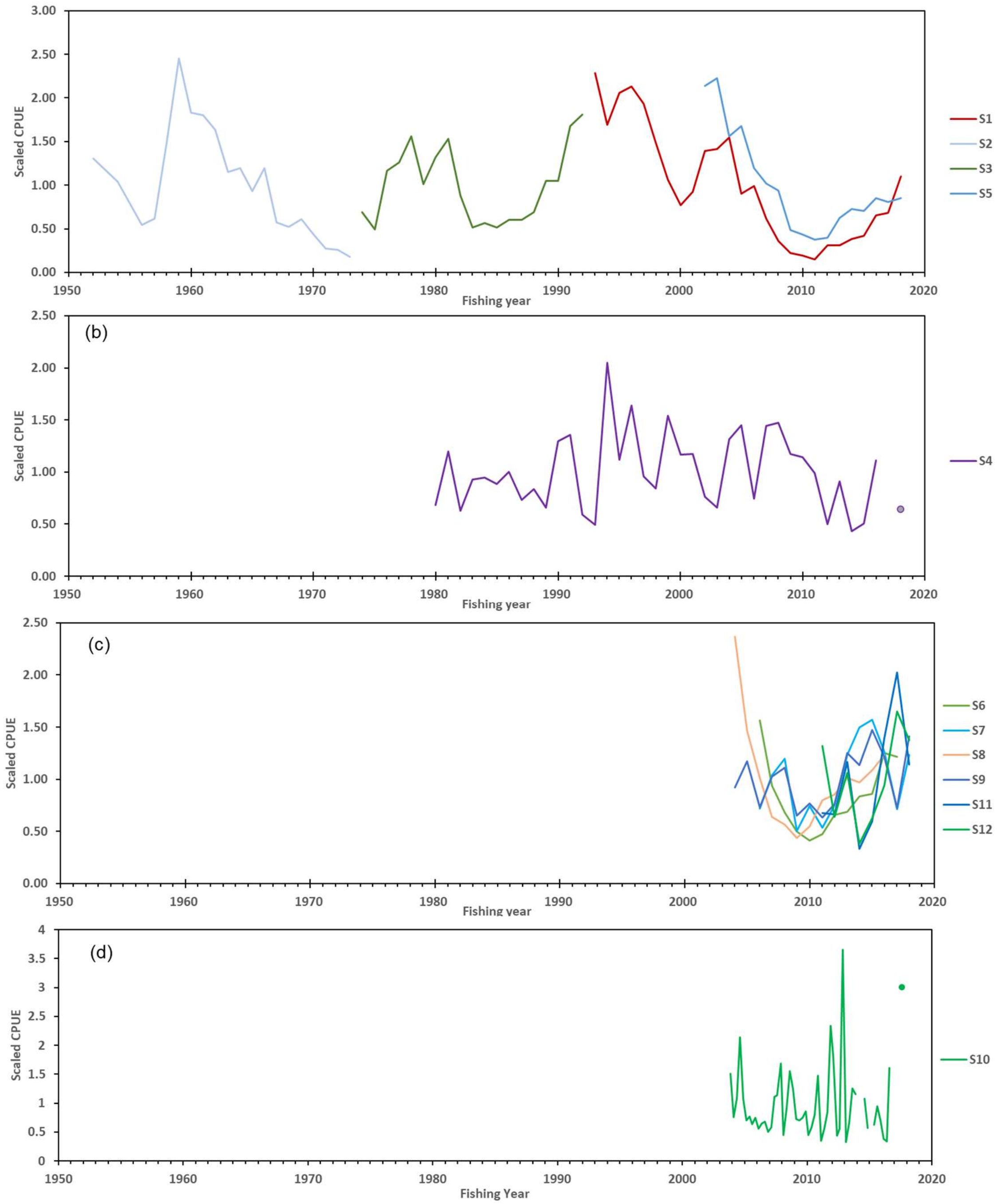


Figure 3-3. Abundance indices of Pacific bluefin tuna (*Thunnus orientalis*) submitted to ISC PBFWG. The longline indices of Japanese fisheries (S1, S2, and S3) and Taiwanese fishery in southern area (S5) were used to represent adult abundance (Fig.-(a)), and the index of Japanese troll fishery (S4) will be used as recruitment index (Fig.-(b)). The other indices were not fitted to the assessment model (Fig.-(c) and (d)); e.g. the indices of Taiwanese longline fishery (S6-9), and Japanese troll monitoring (S11, S12) Korean purse seine (S10).

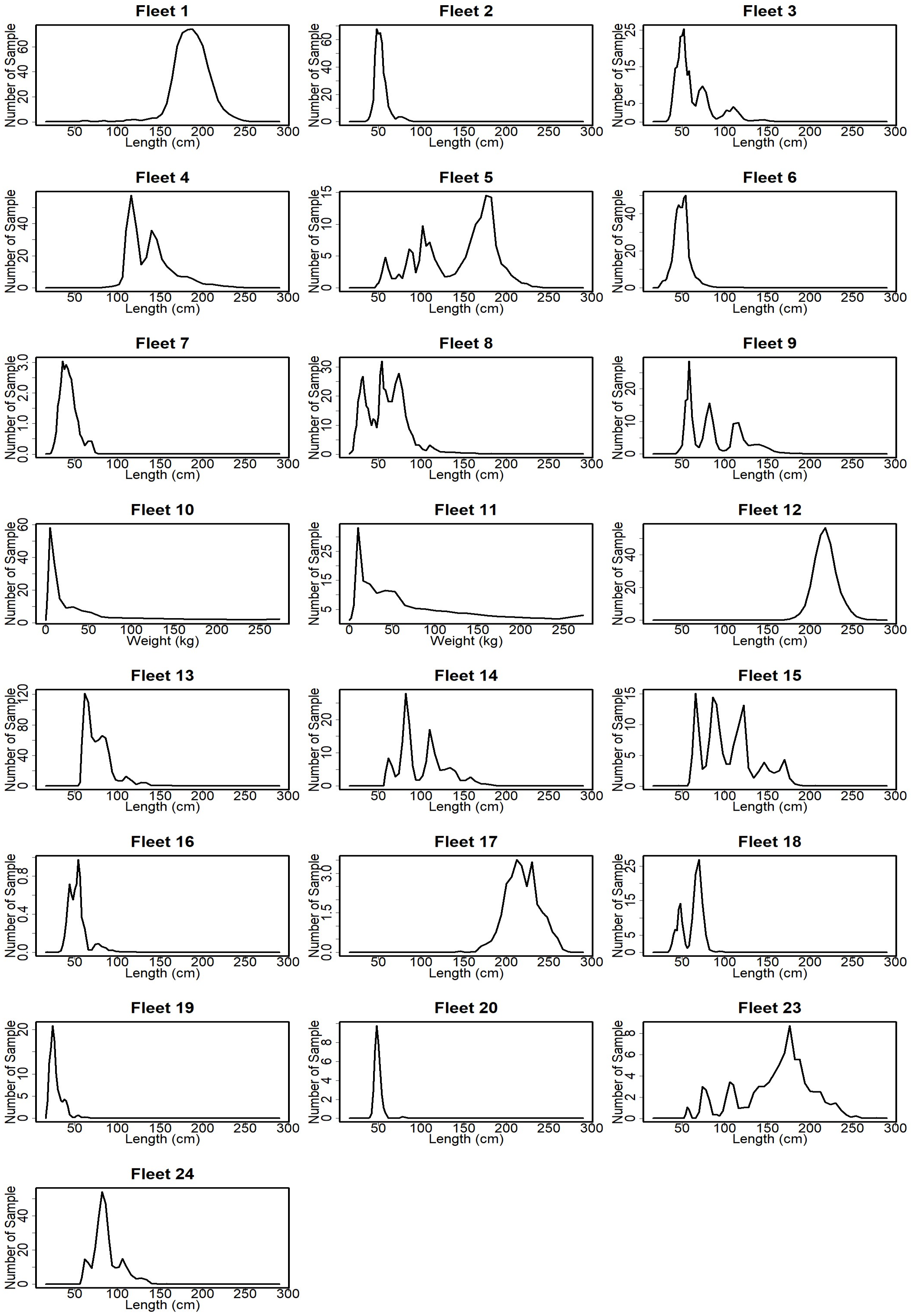


Figure 3-4. Aggregated size compositions of Pacific bluefin tuna (*Thunnus orientalis*) for each fleet used in the stock assessment. The data were aggregated across seasons and years after being scaled by fleet size. The x-axis is in fork length (cm) for all fleets except for Fleet 10-11 in weight (kg).

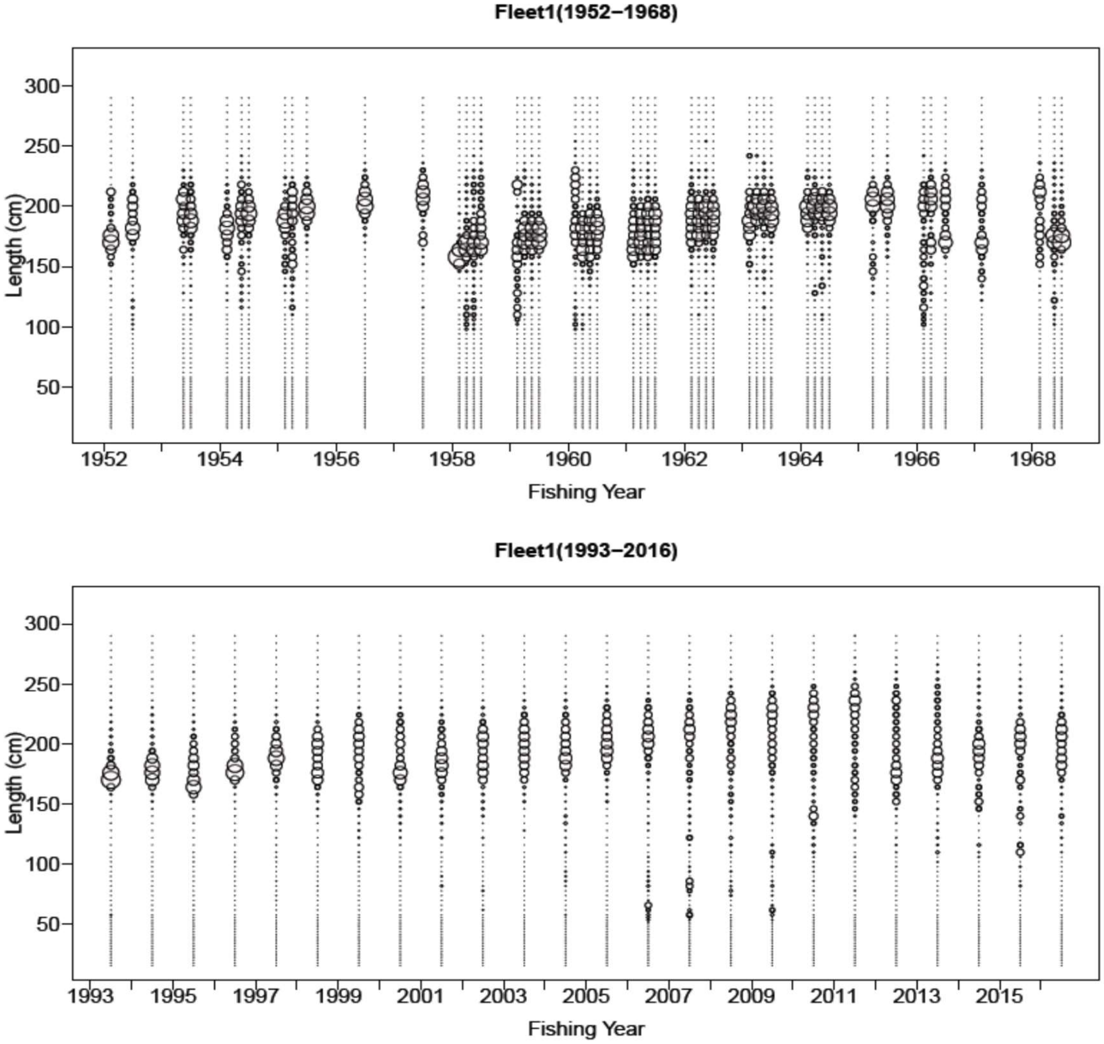
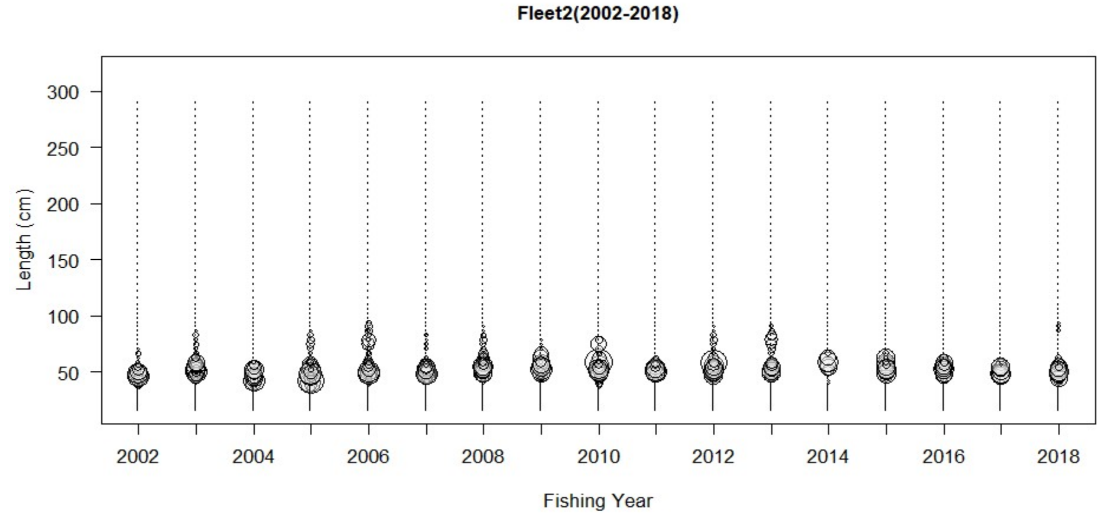
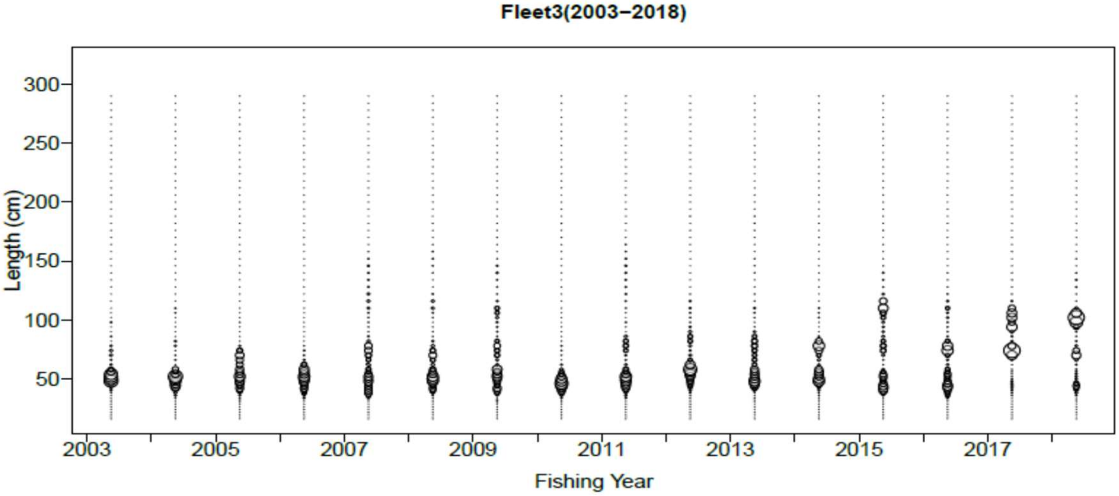
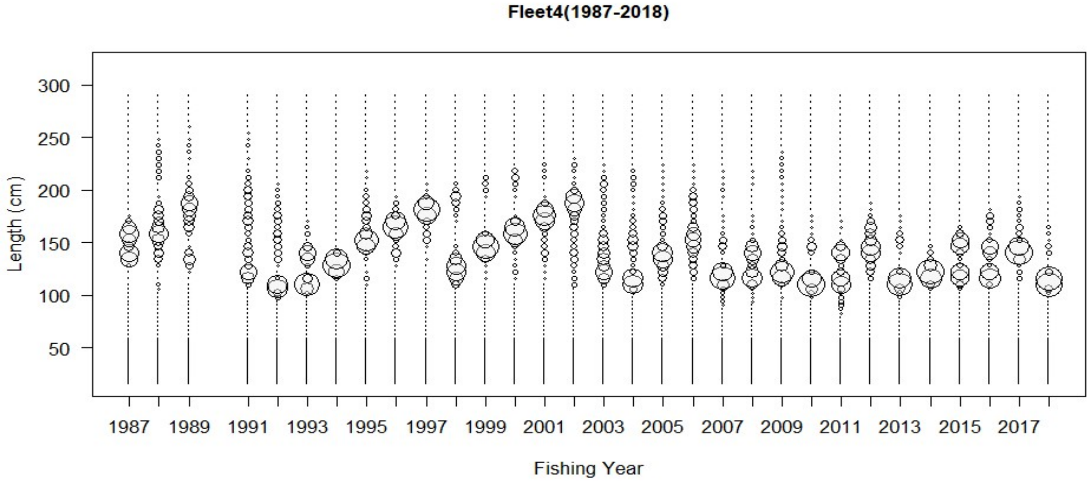


Figure 3-5. Size composition data by fleet and season used in the stock assessment model for Pacific bluefin tuna (*Thunnus orientalis*). Larger circles indicate higher proportions of fish.







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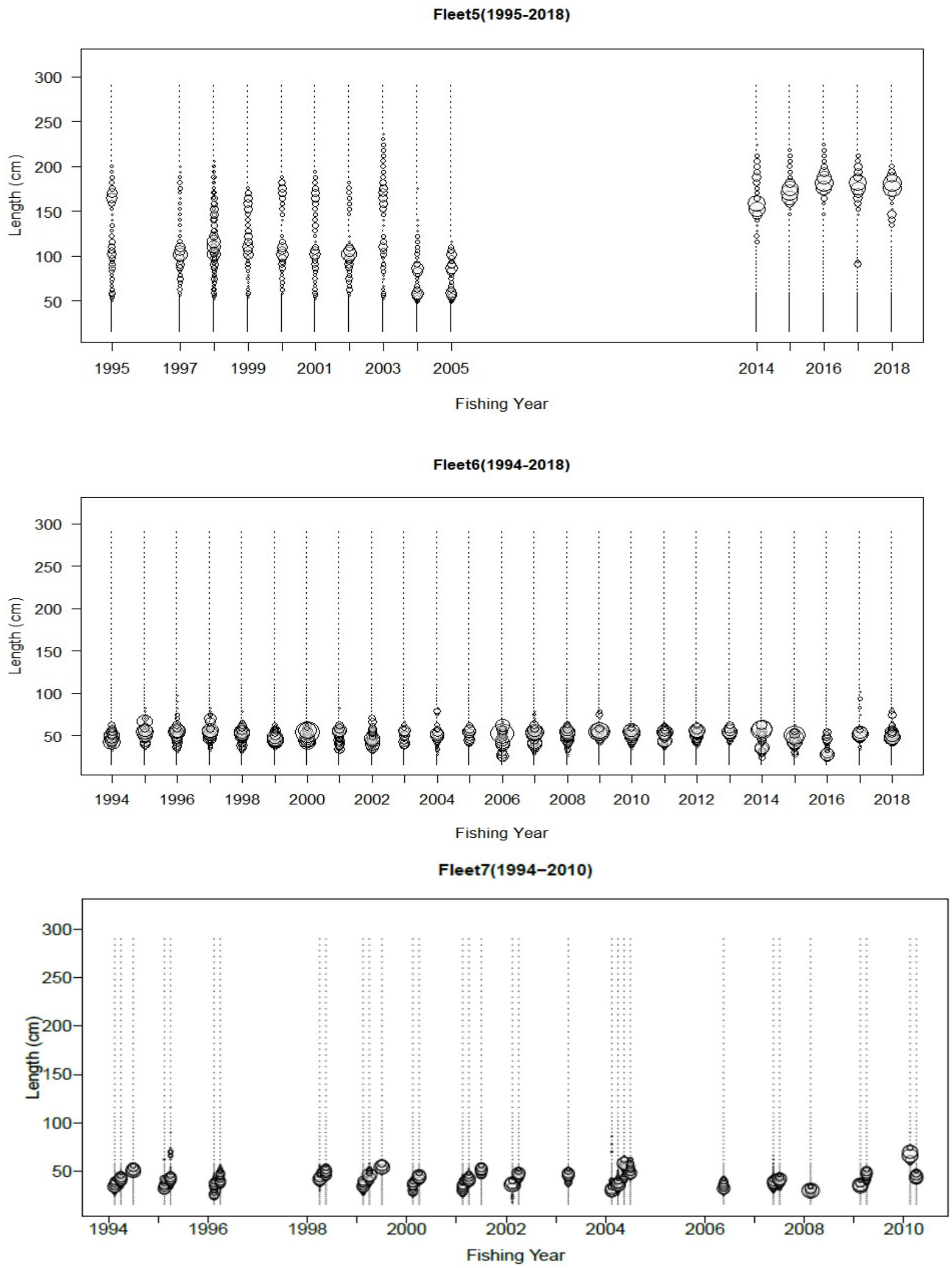

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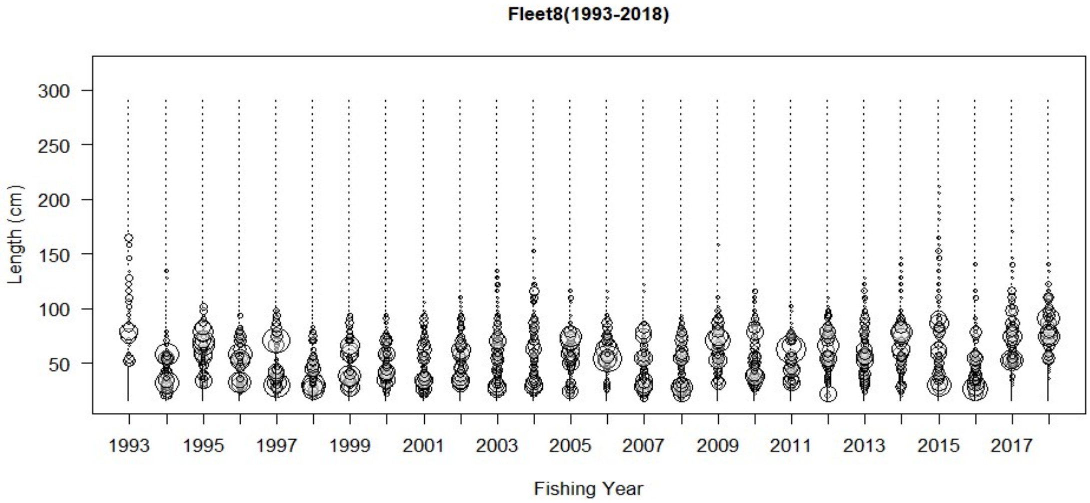

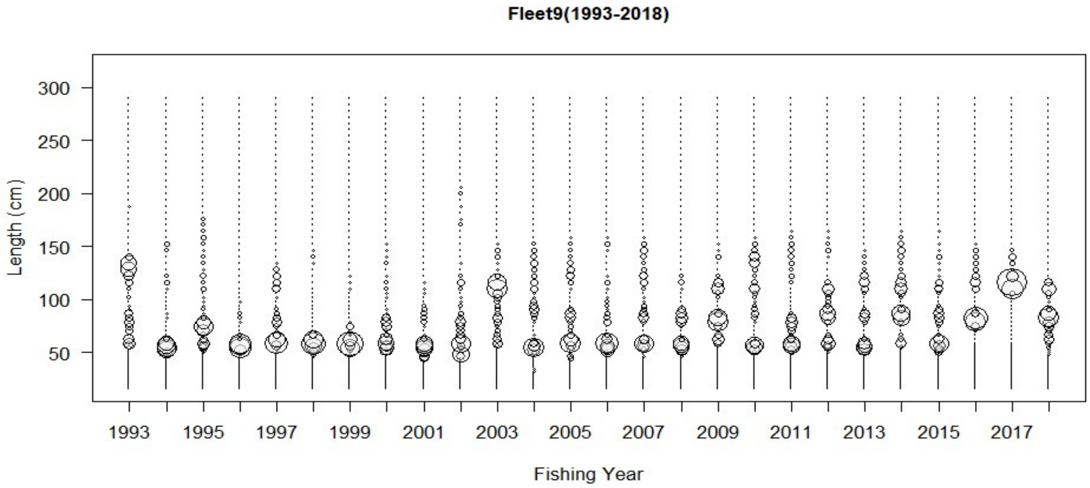

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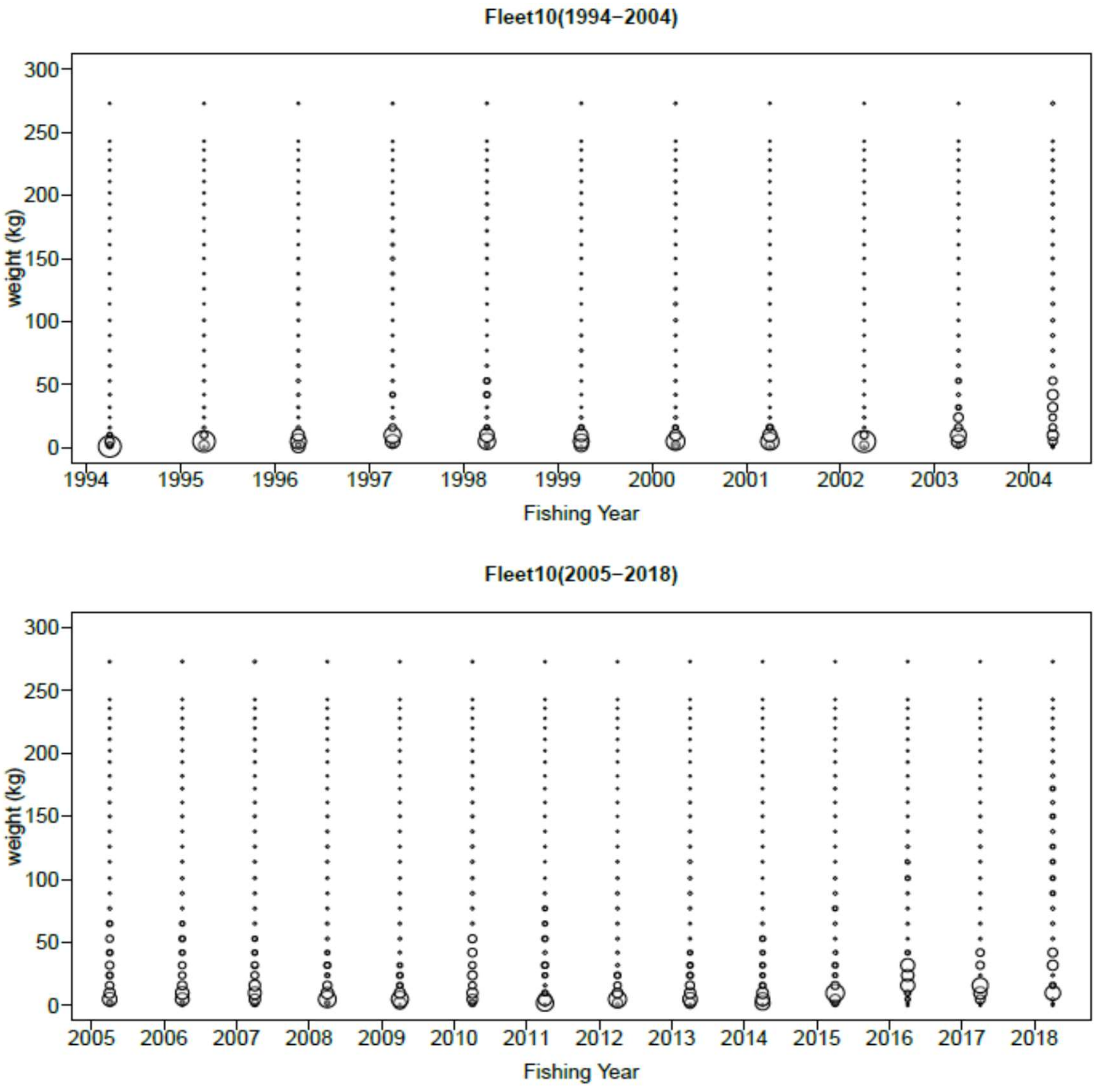

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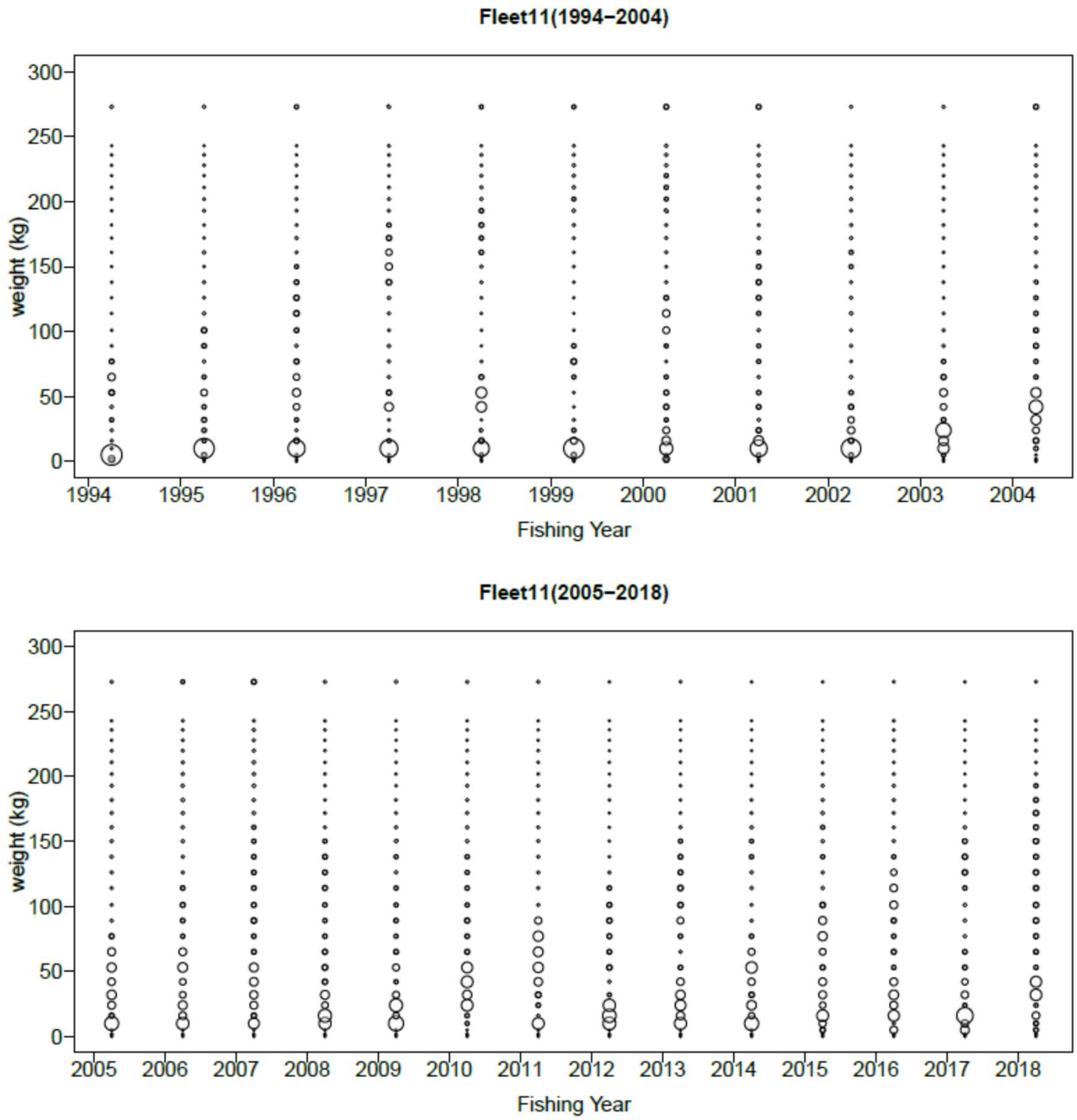

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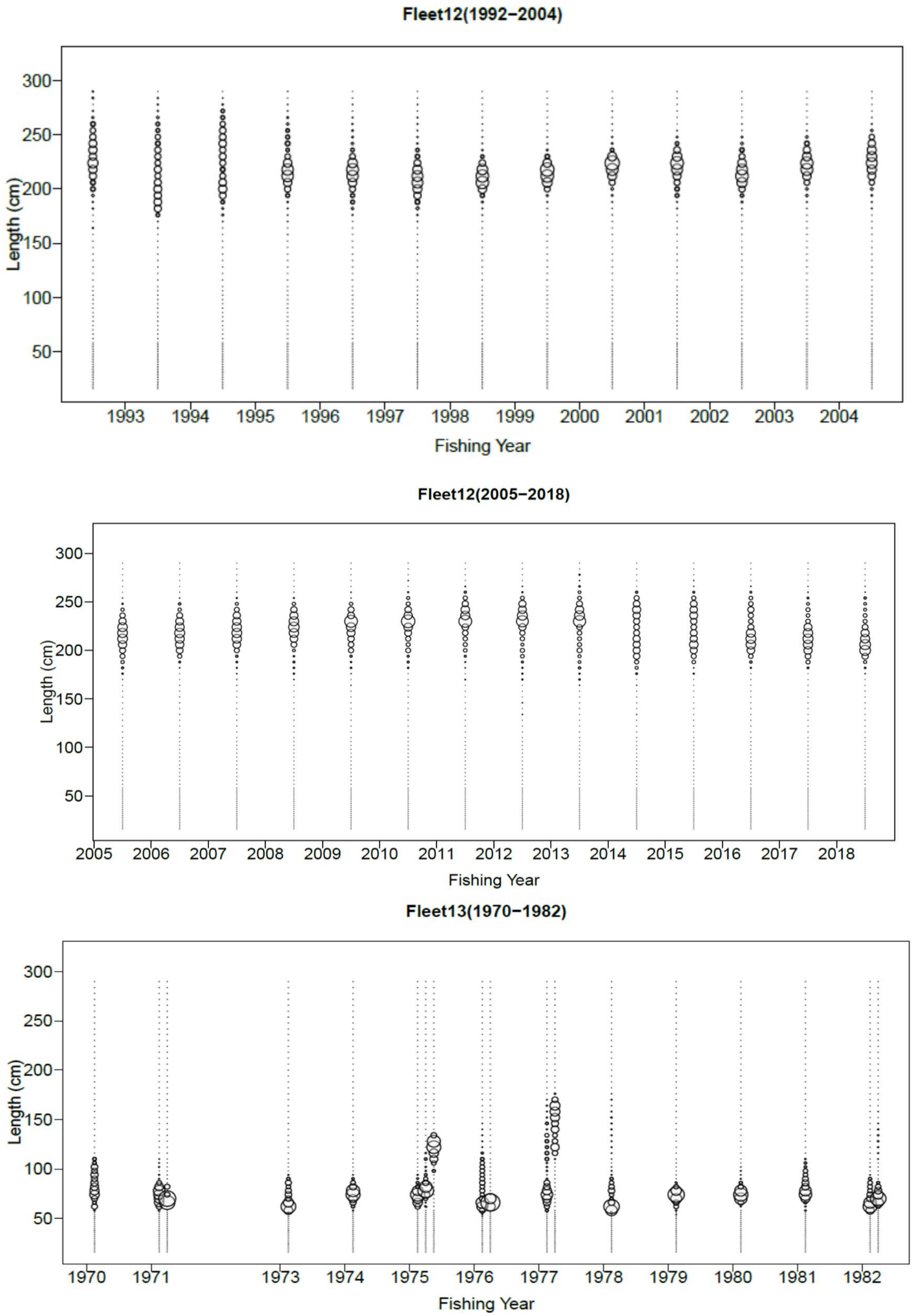

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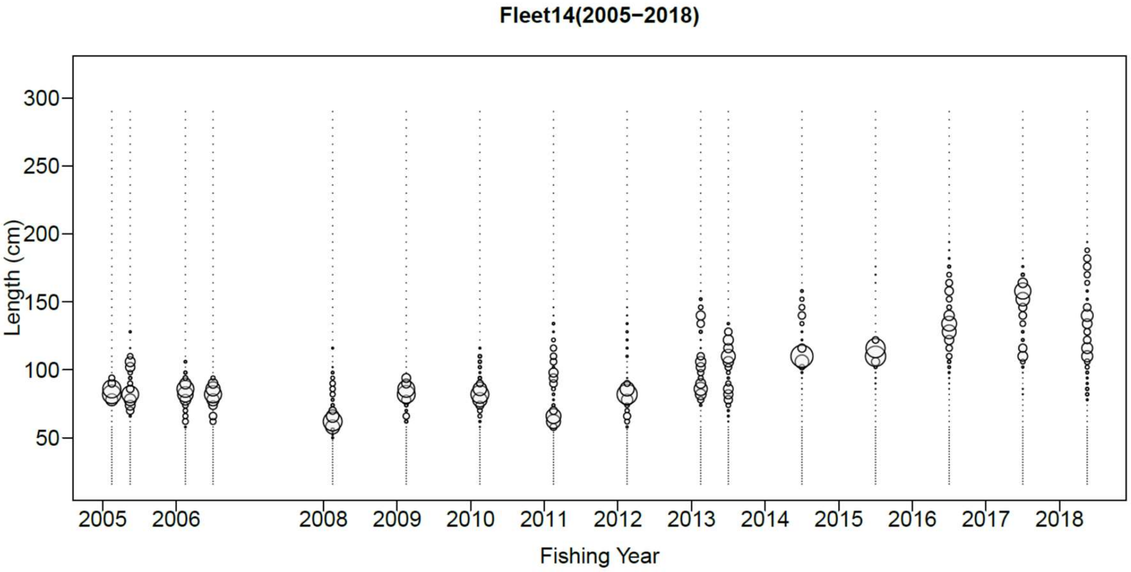

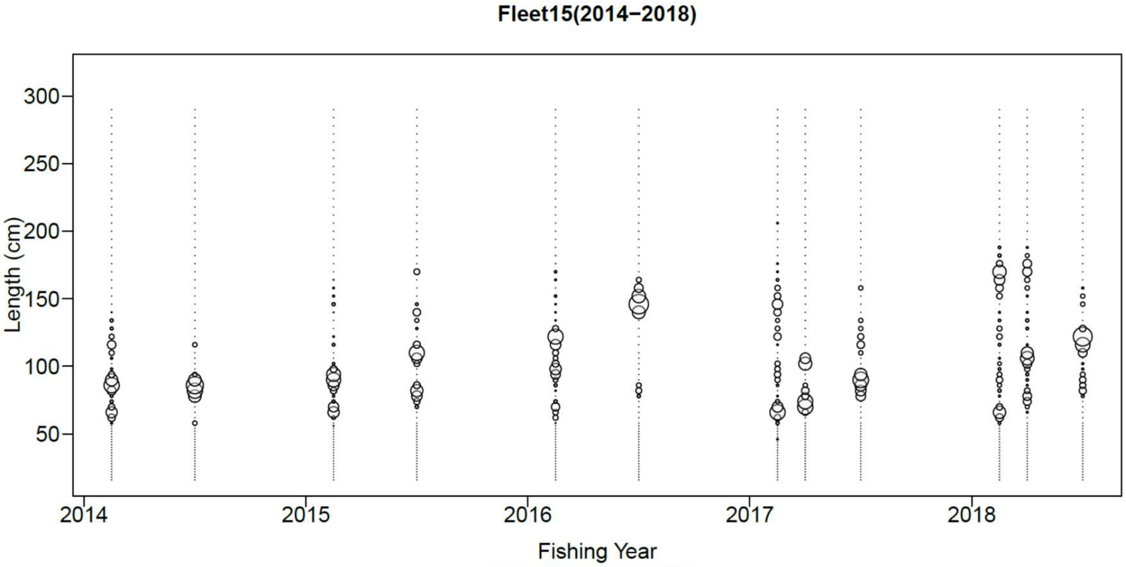

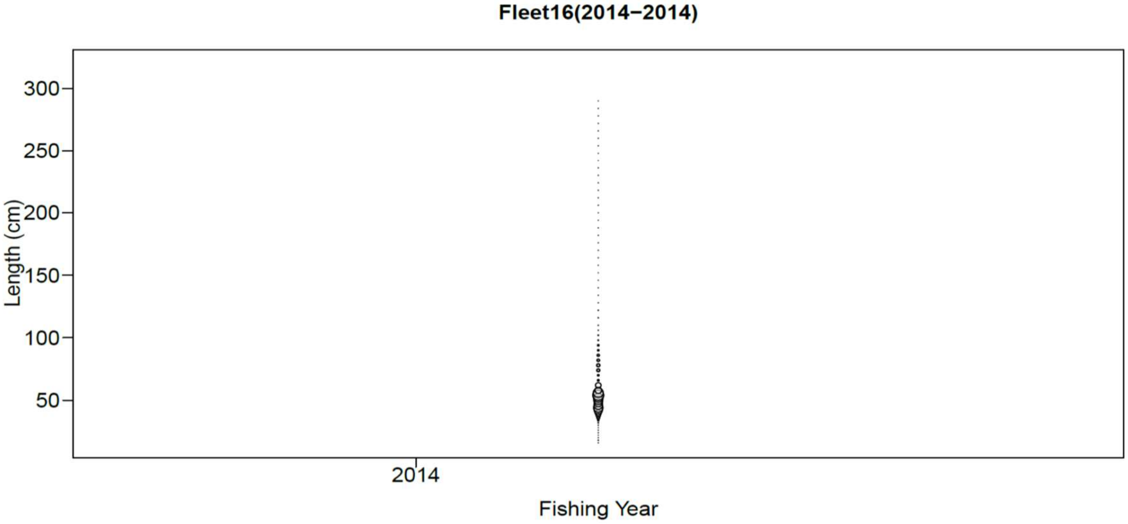

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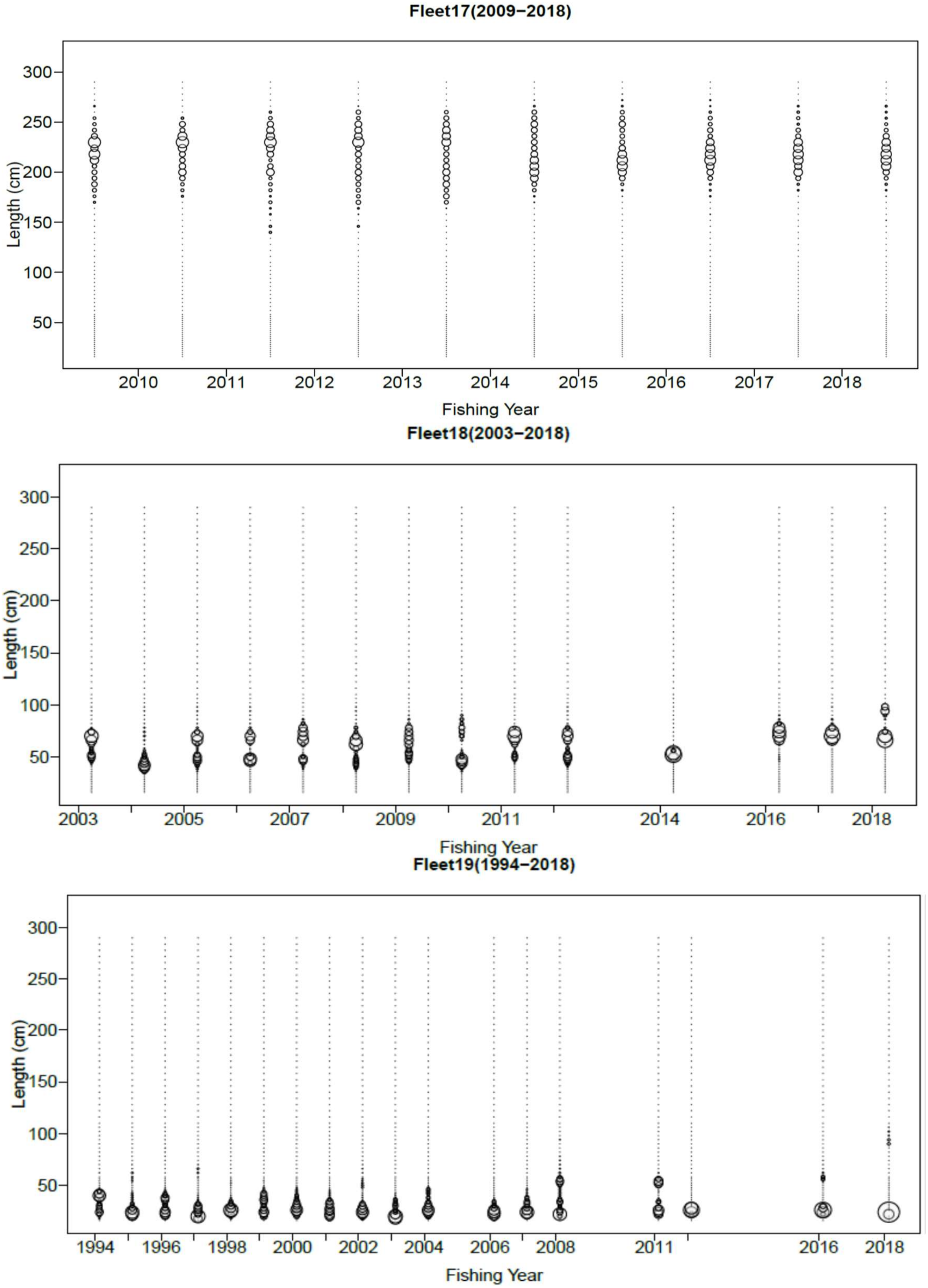

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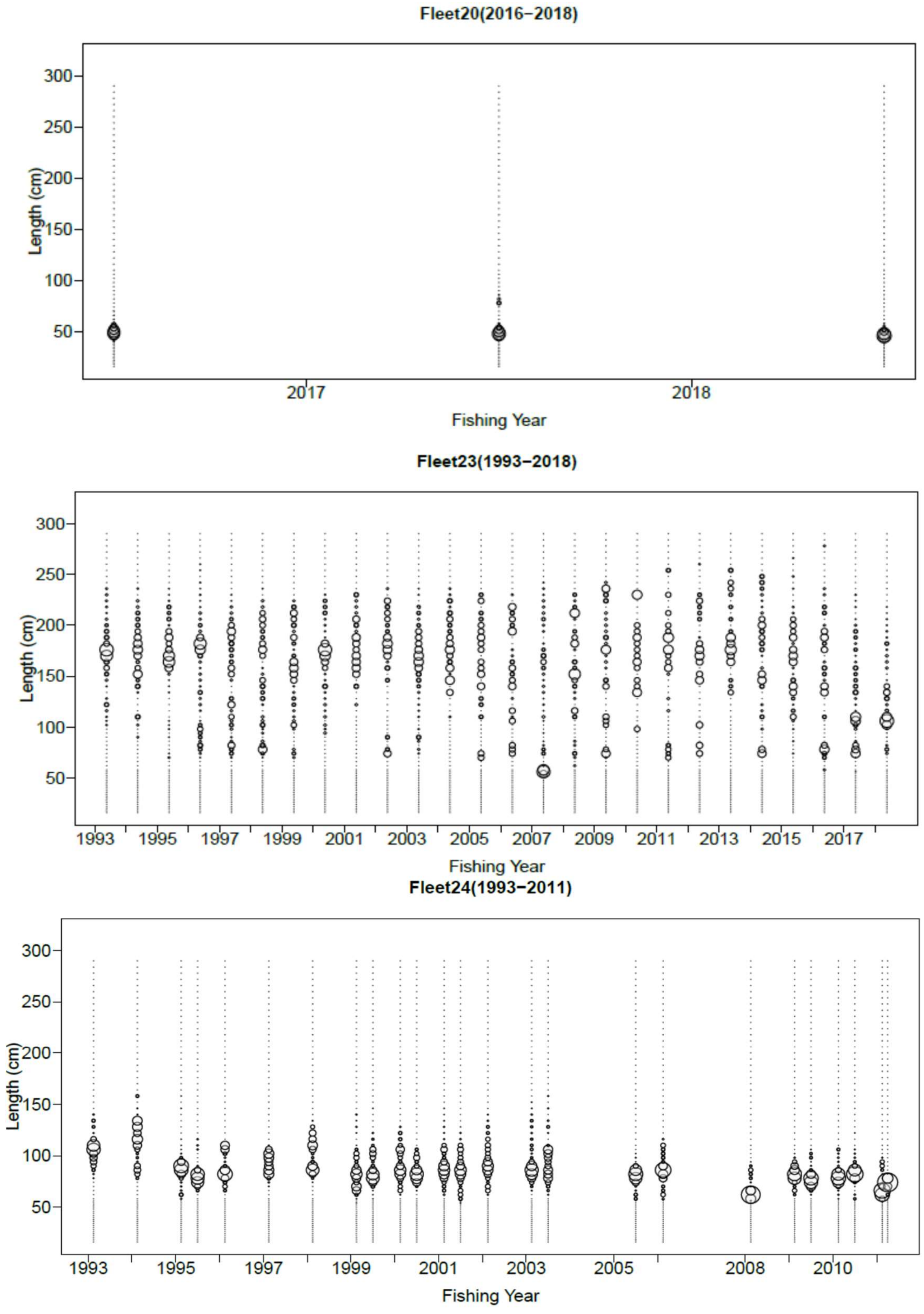

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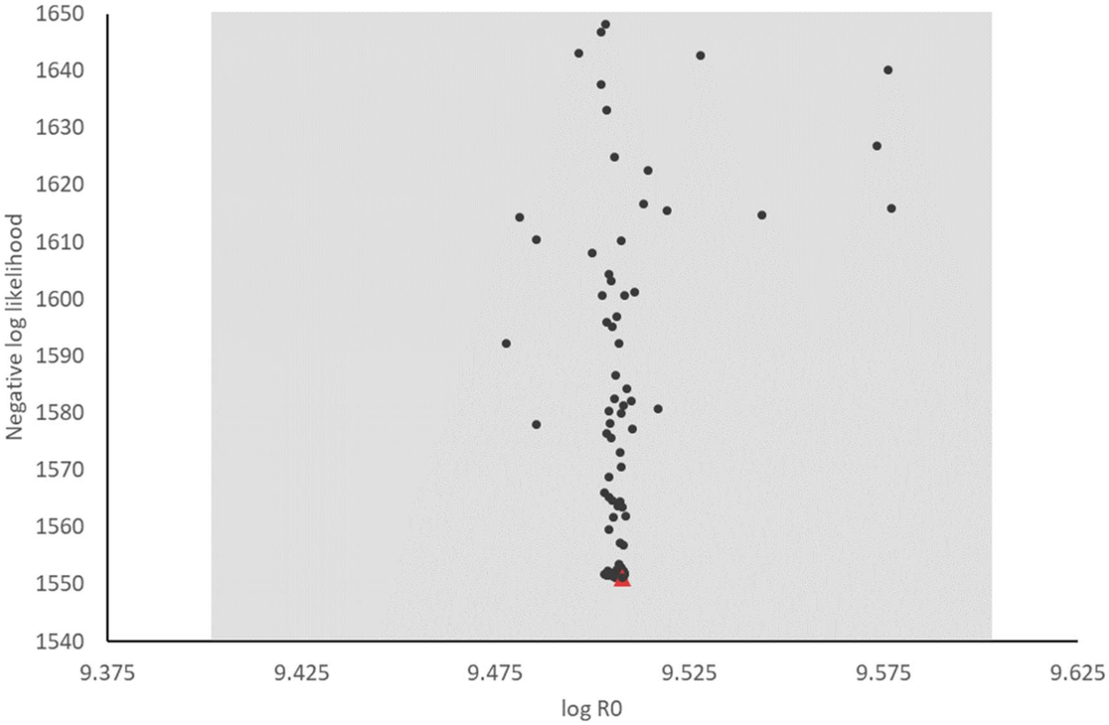


Figure 5-1. Effects of random perturbations of initial values and phasing on log(R_0) and total likelihood by the base-case model for Pacific bluefin tuna (*Thunnus orientalis*). Red triangle represents the value of the base-case model. Gray shaded area shows a range of R0 in which the model explorations for the starting value of R0 were conducted.

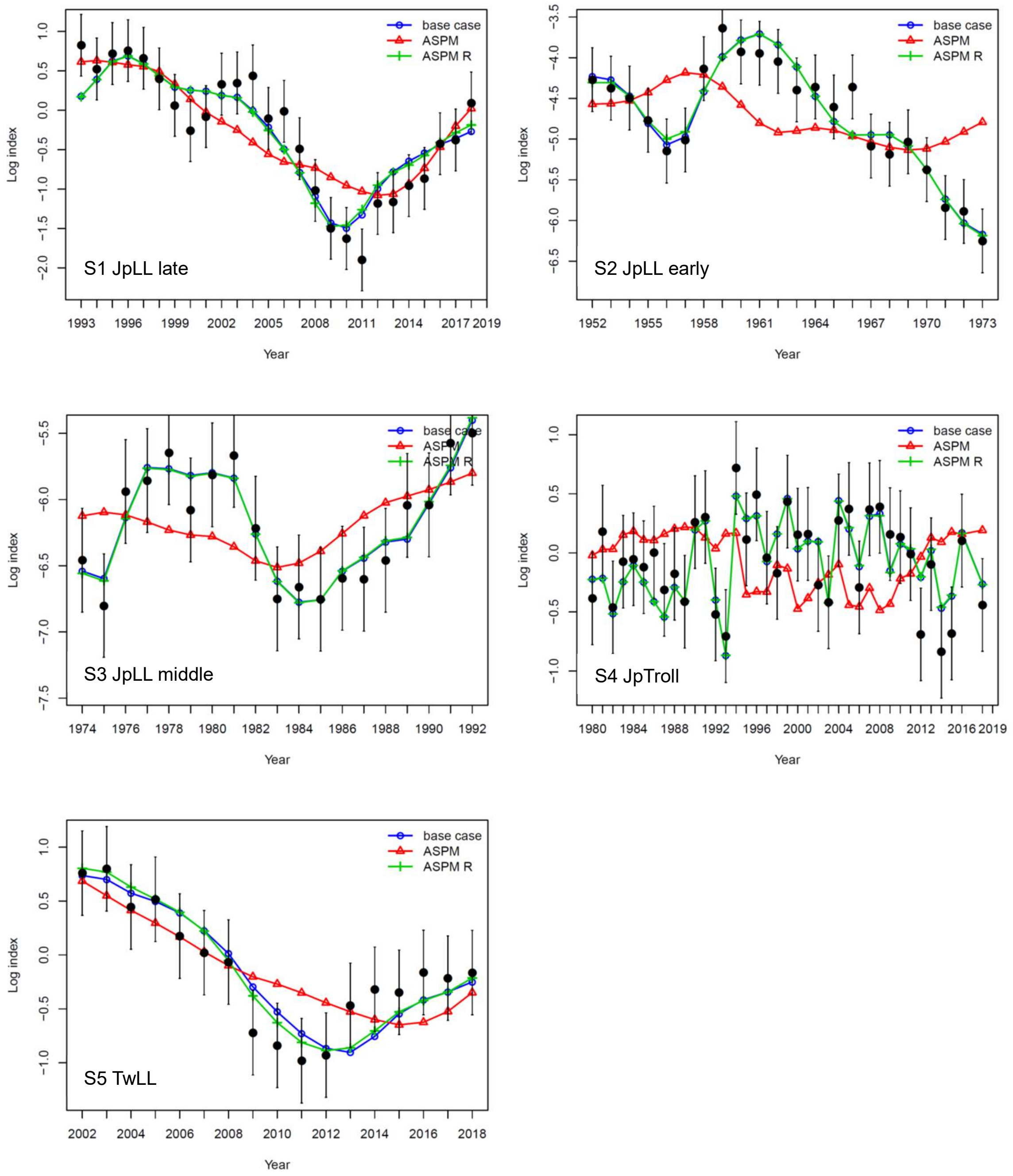


Figure 5-2. Comparisons of the predicted abundance indices for the base-case model (blue lines), age structured production model (ASPM; red lines), and age structured production model with the recruitment deviations (ASPM-R; green lines) of Pacific bluefin tuna (*Thunnus orientalis*), where black closed circles with vertical lines represent the observed abundance indices with 95% CI.

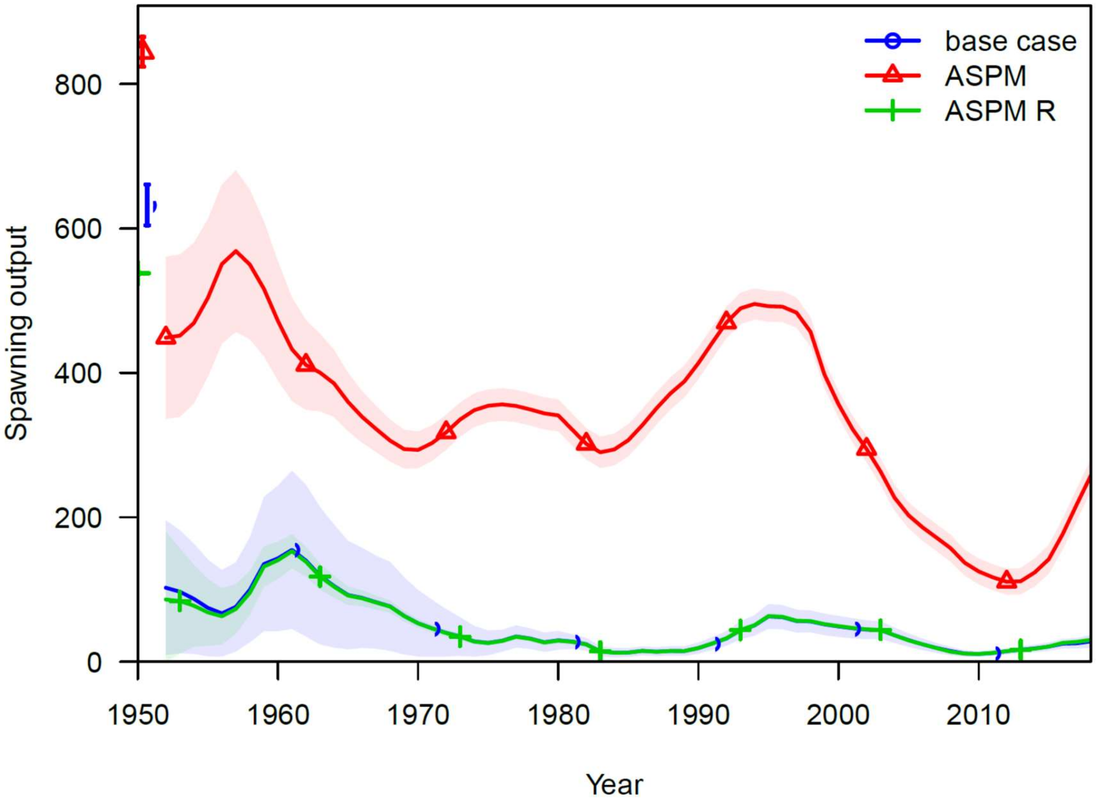


Figure 5-3. Unfished spawning stock biomass (open plots with vertical bars) and spawning stock biomass of Pacific bluefin tuna (*Thunnus orientalis*) for the base-case model (blue), age structured production model (ASPM; red) and age structured production model with recruitment deviations (ASPM-R; green).

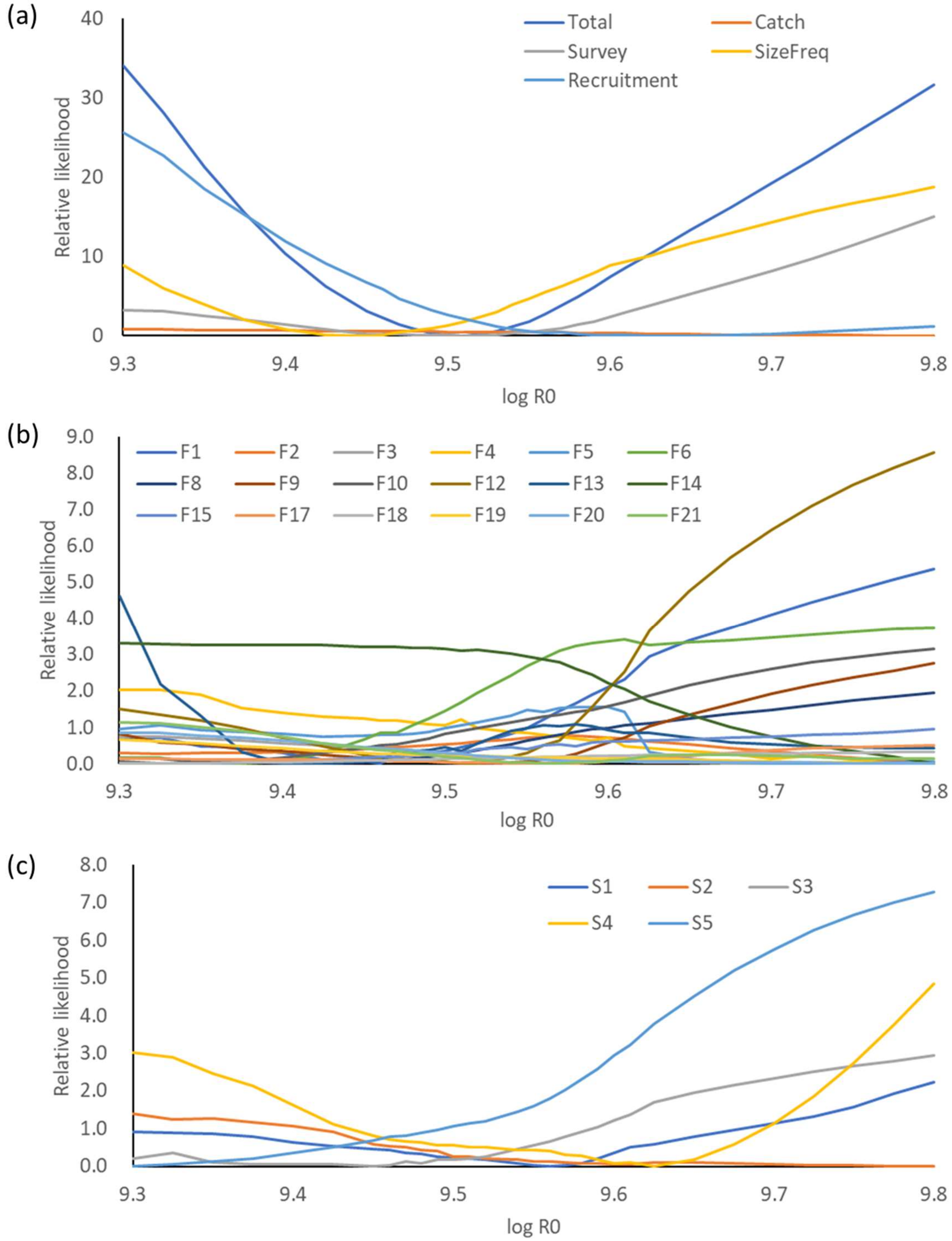


Figure 5-4. Profiles of (a) total and component likelihoods (b) likelihood for each size composition component and (c) likelihood for each index component over fixed log(R_0) for the base-case model of Pacific bluefin tuna (*Thunnus orientalis*).

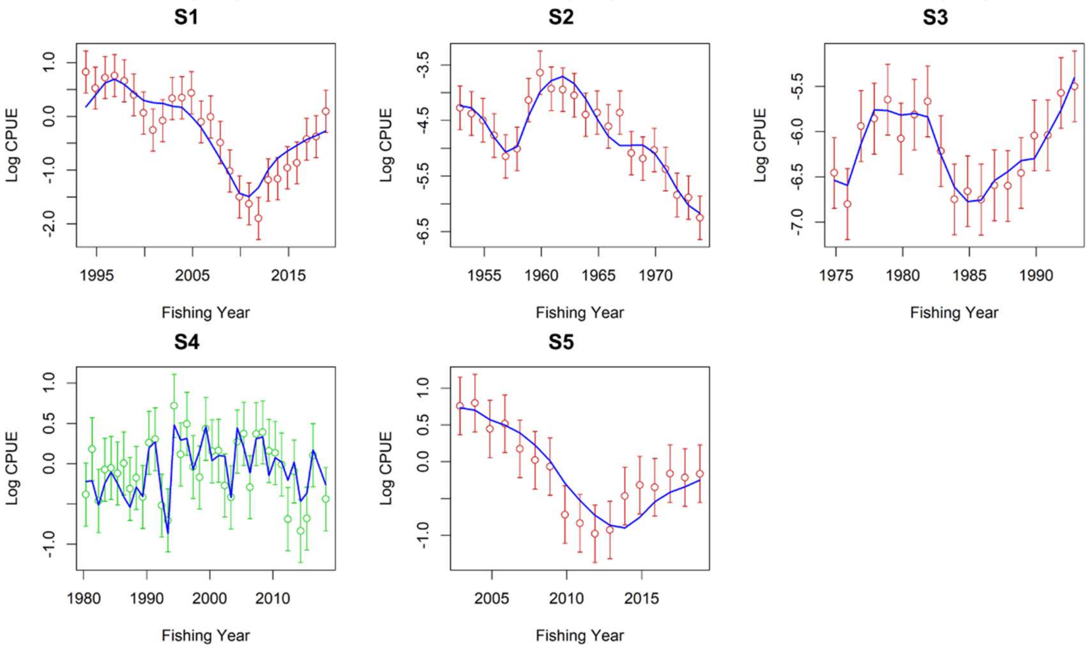


Figure 5-5. Predicted (blue lines) and observed (open dots) abundance indices for the base-case model of Pacific bluefin tuna (*Thunnus orientalis*), where vertical lines represent the 95% CI of observations.

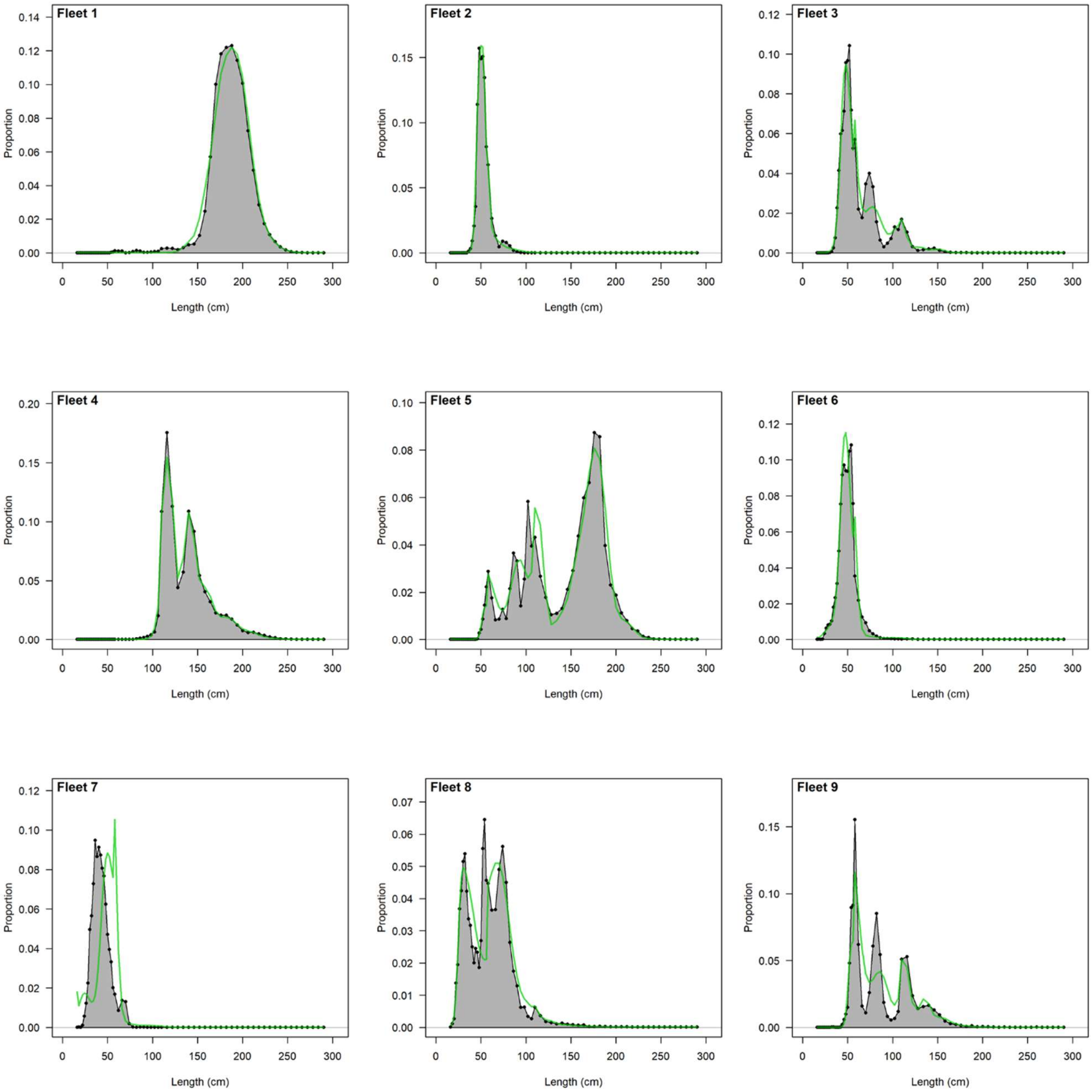
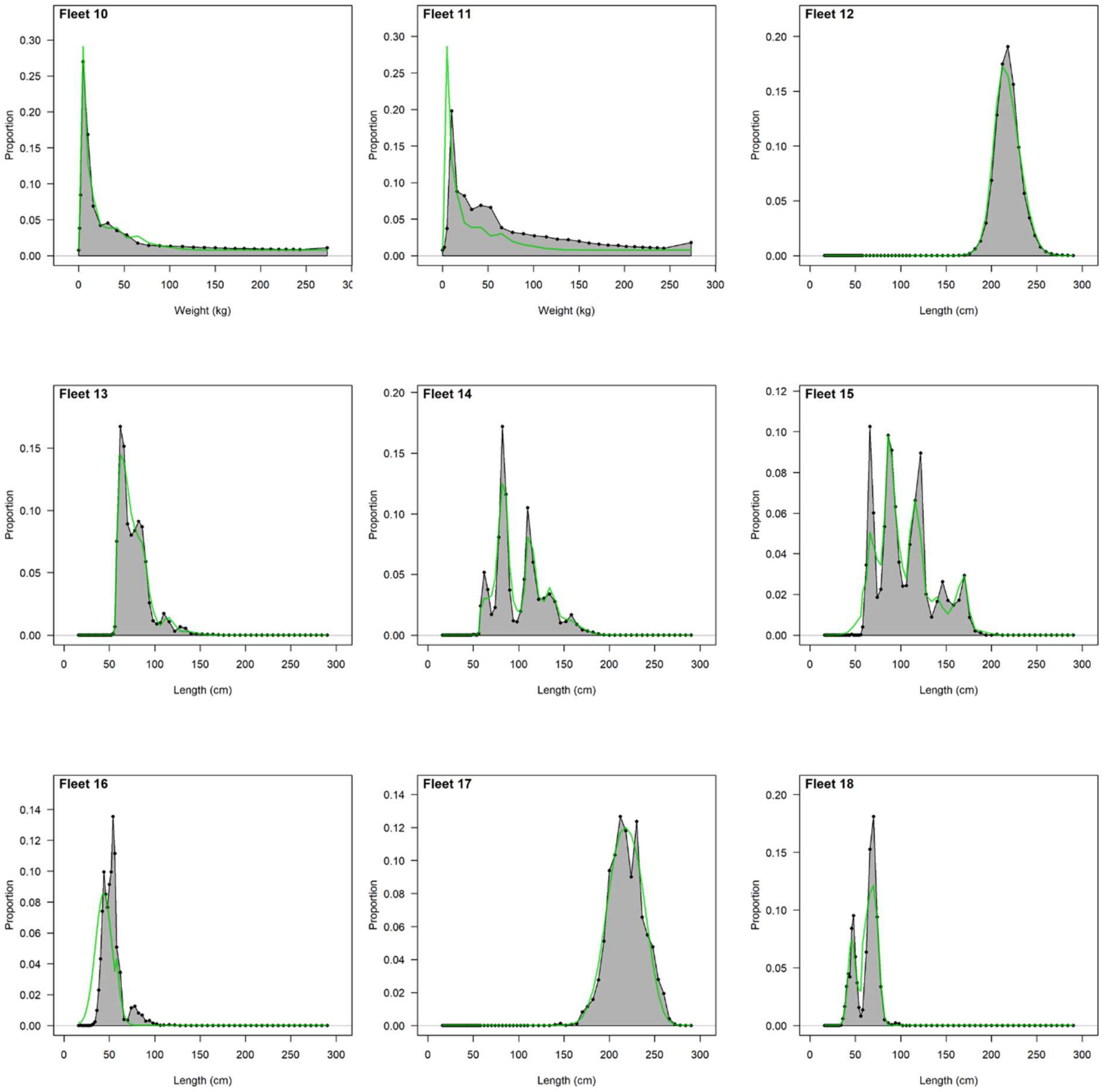


Figure 5-6. Overall fits (green line) to the size compositions by fleet across seasons in the base-case model for Pacific bluefin tuna (*Thunnus orientalis*), where grey areas indicate the observations.



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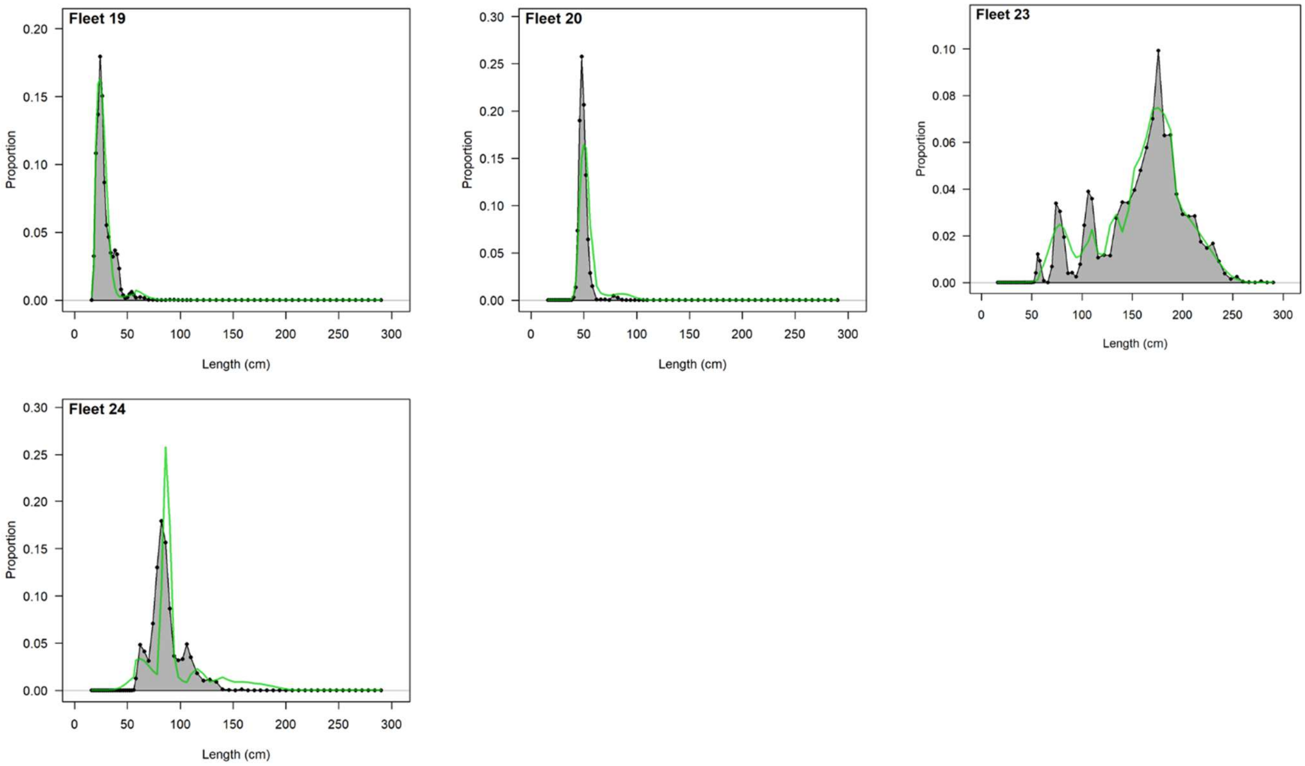

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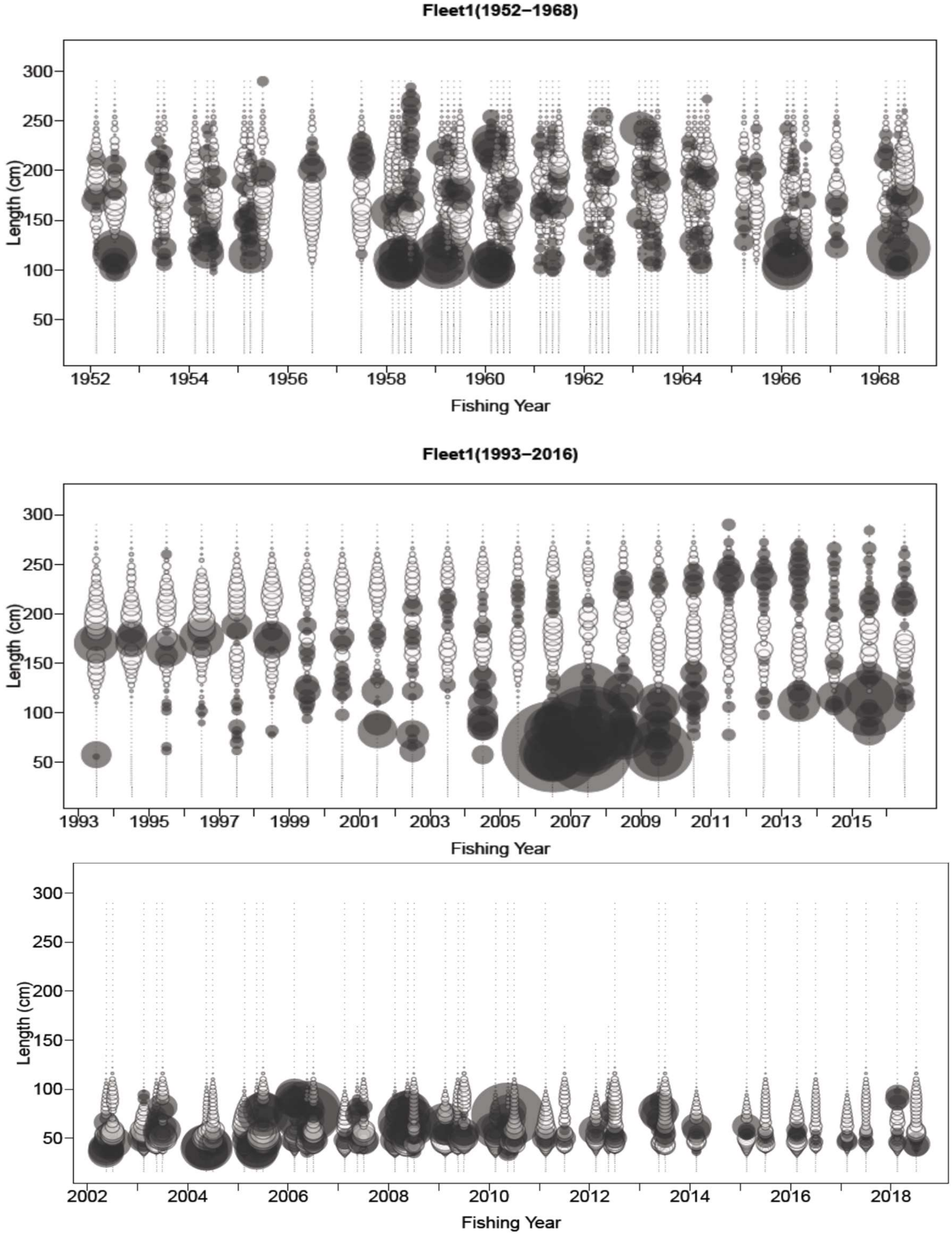
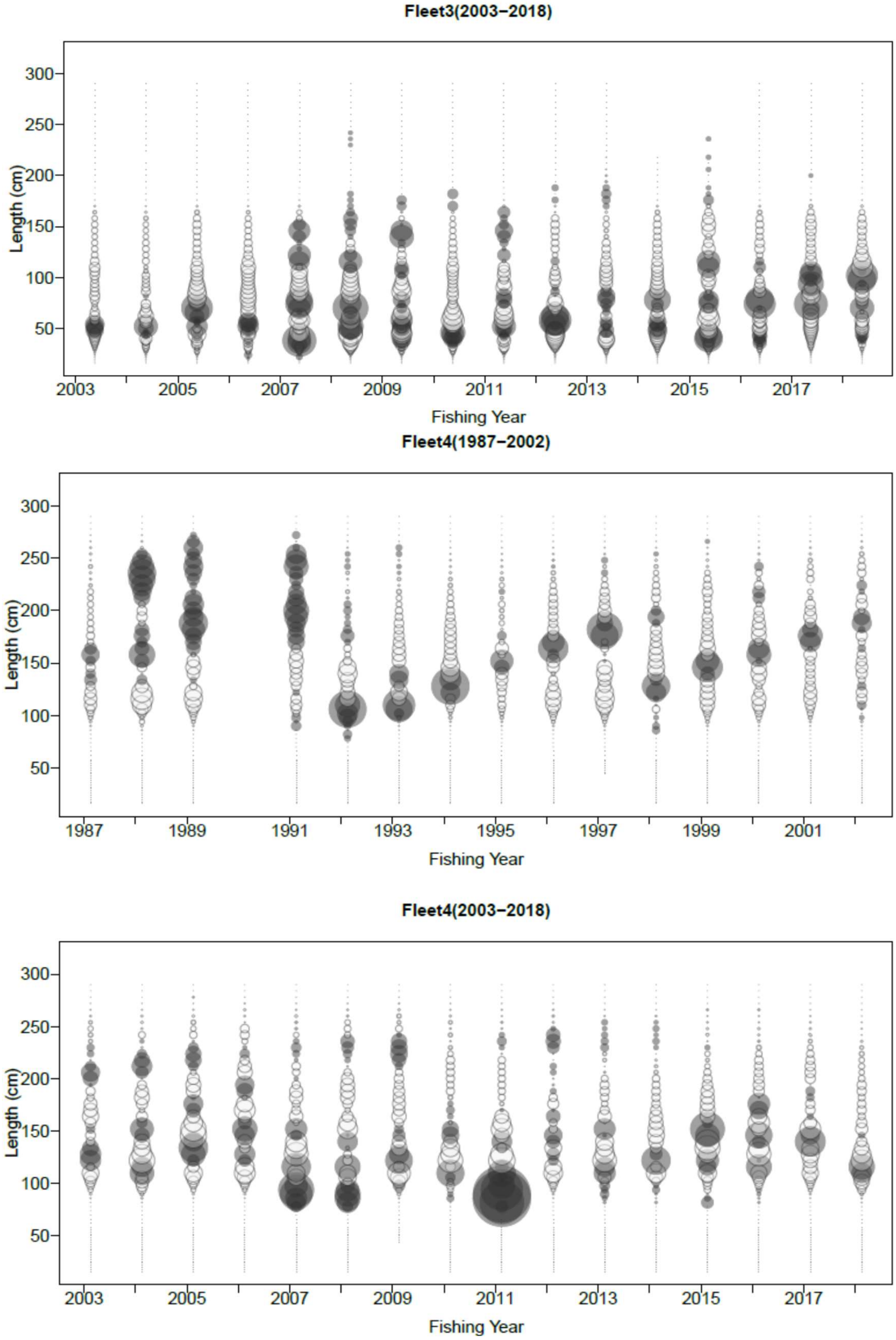


Figure 5-7. Pearson residual plots of model fits to the size composition data of Pacific bluefin tuna (*Thunnus orientalis*) by fishery. The hollow and filled circles represent observations that are higher and lower than the model predictions, respectively. The areas of the circles are proportional to the absolute values of the residuals.



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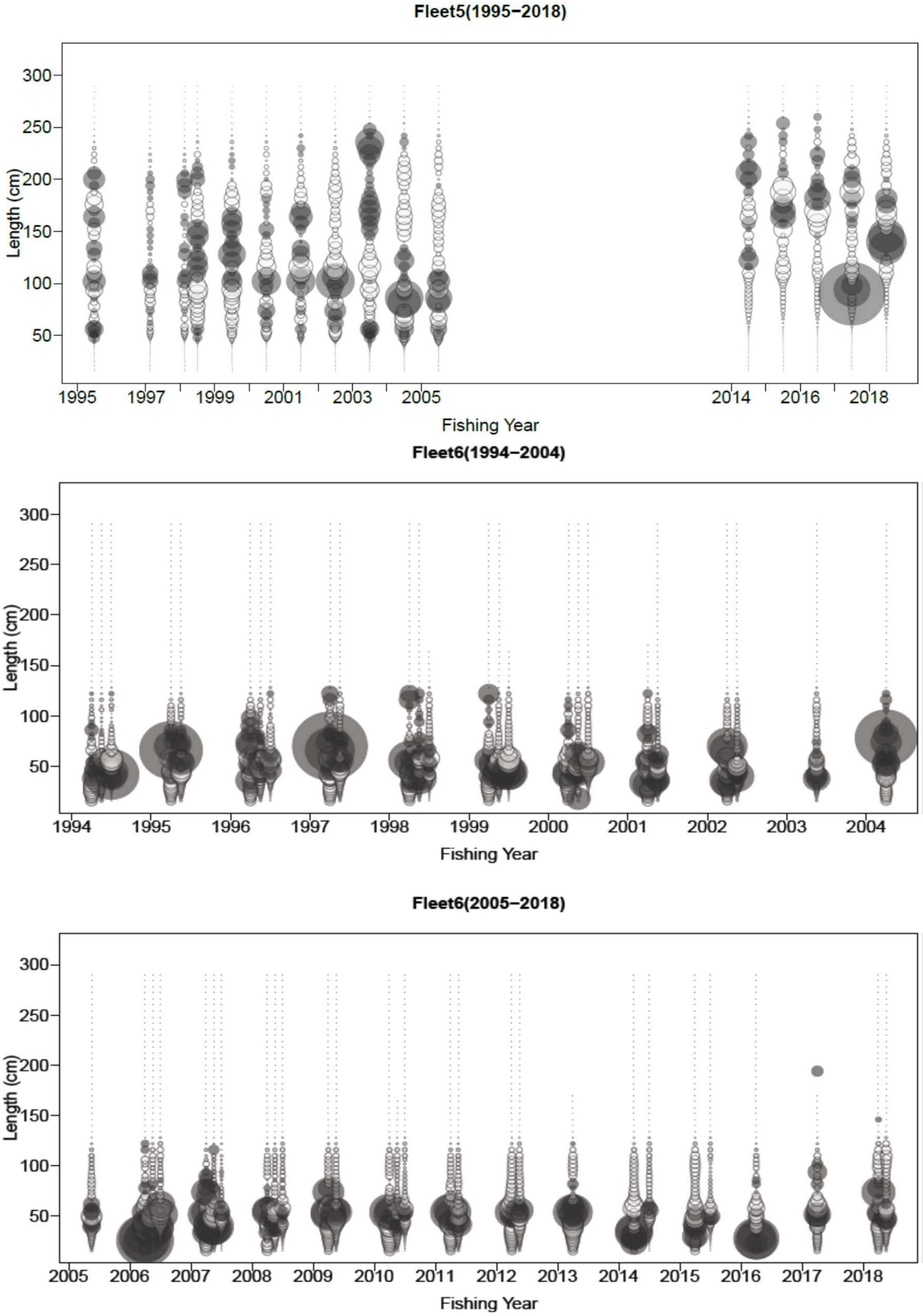

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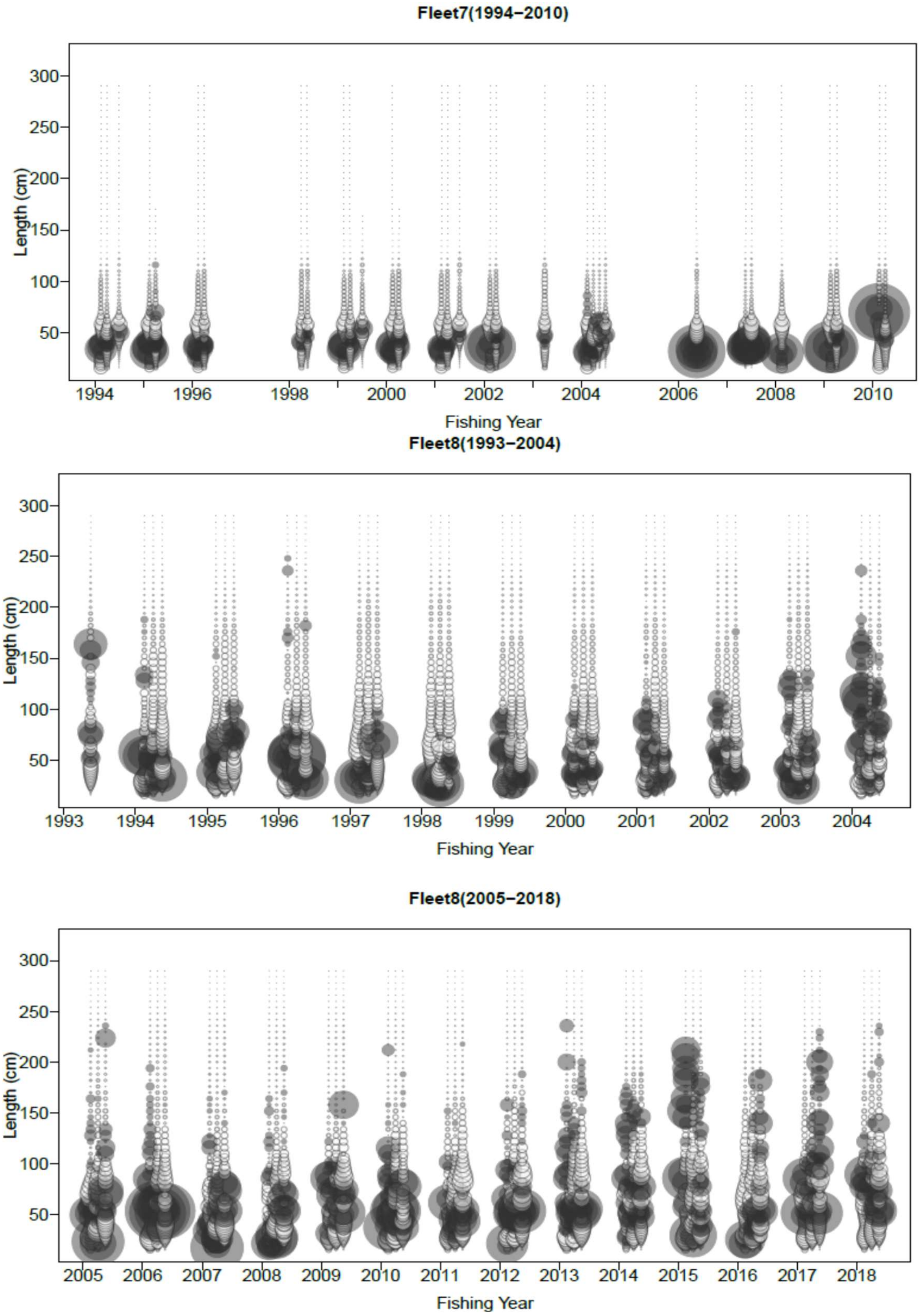

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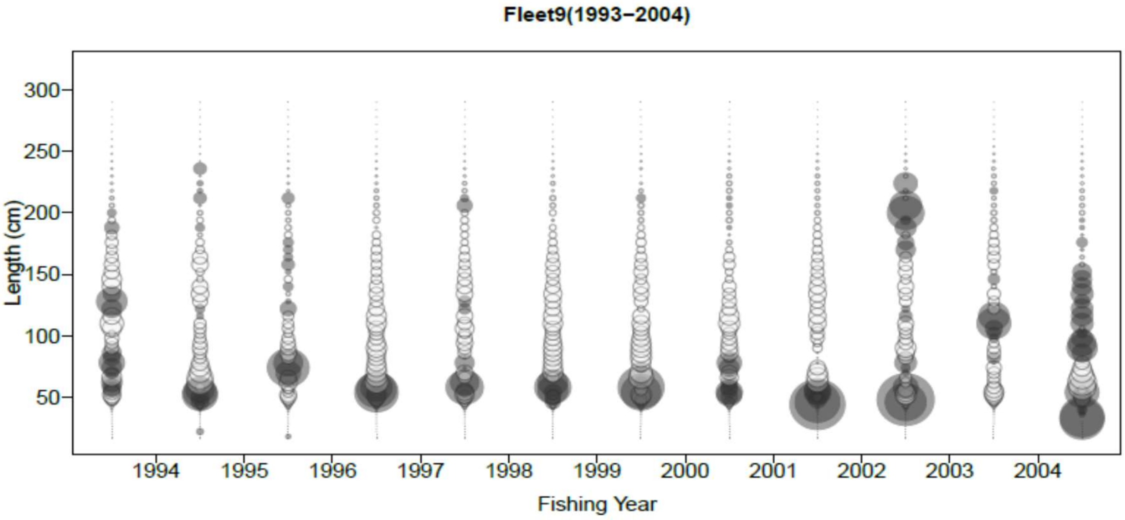

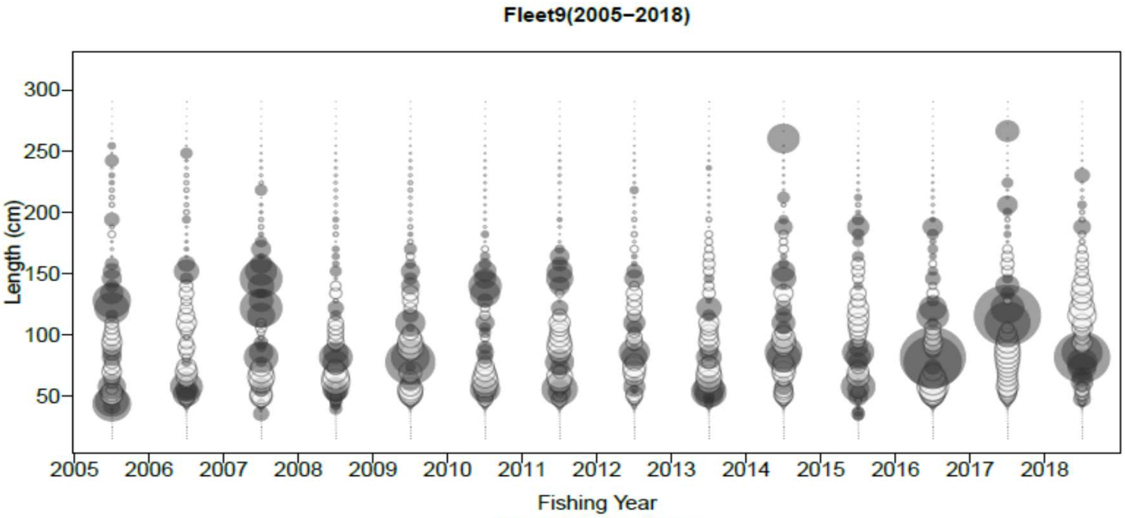

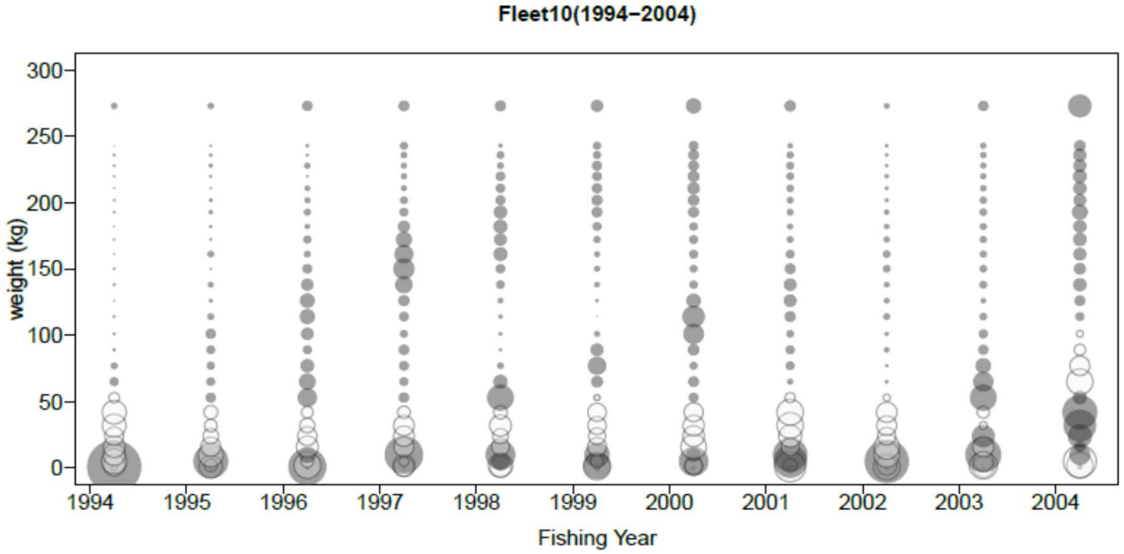

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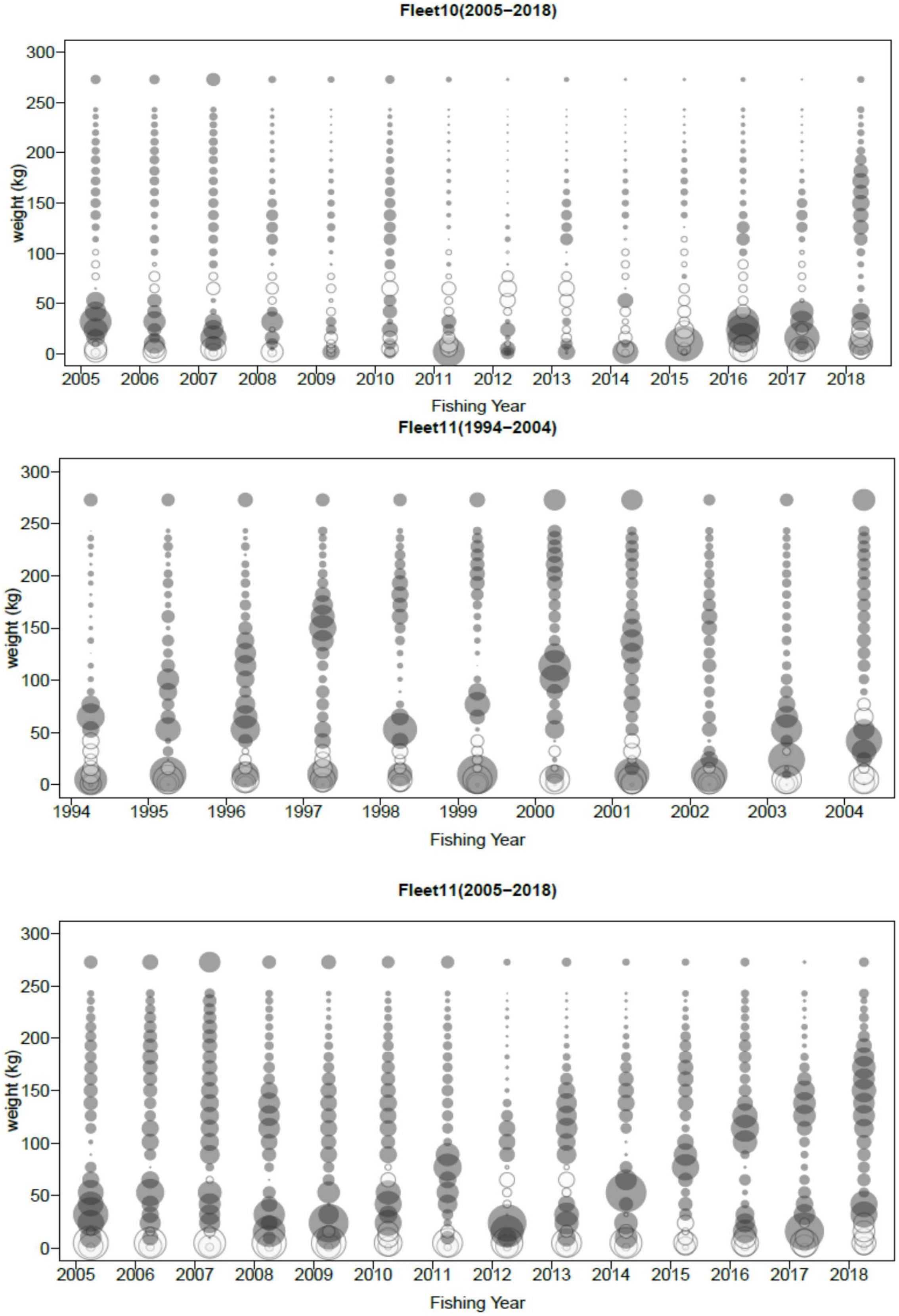

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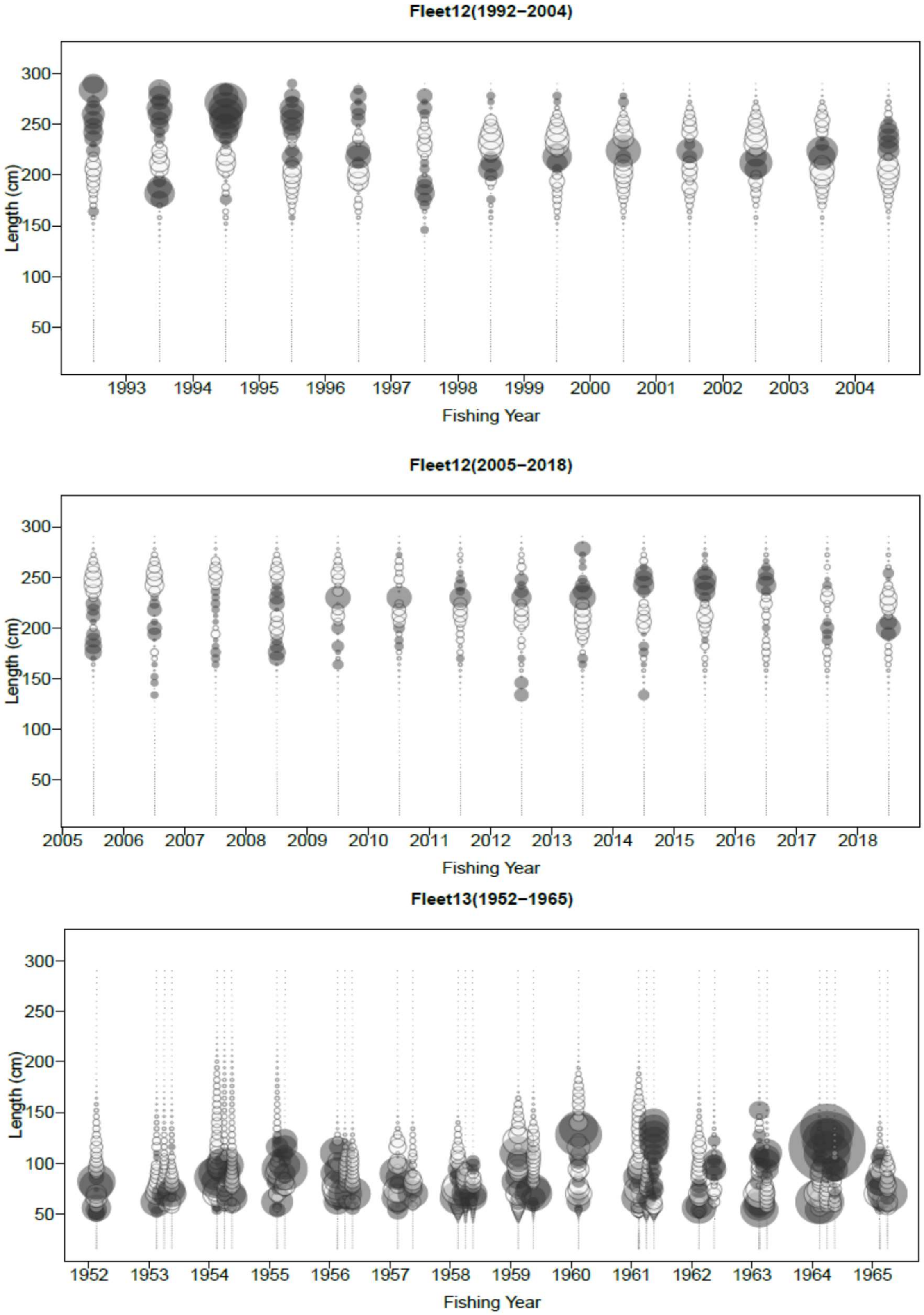

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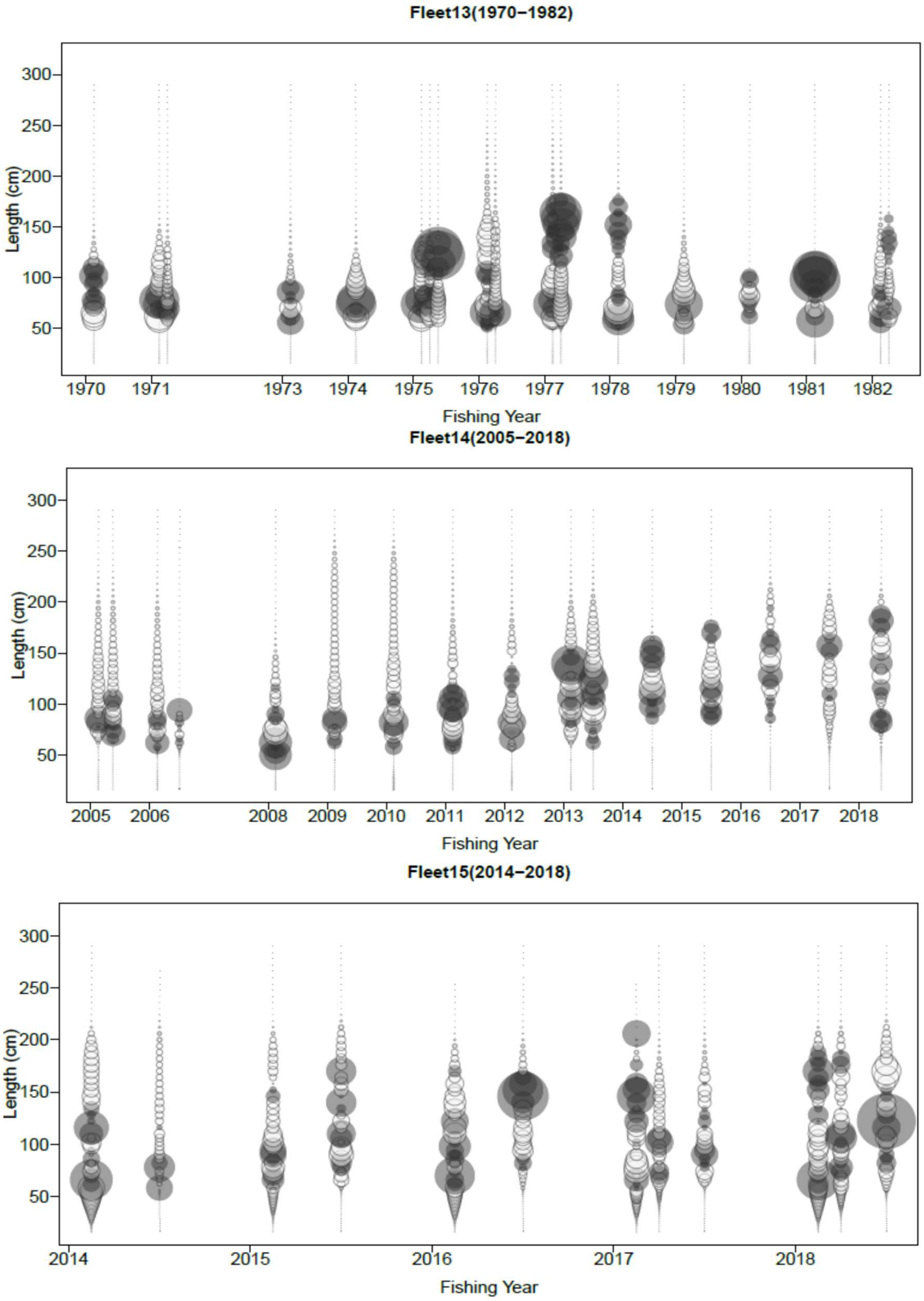

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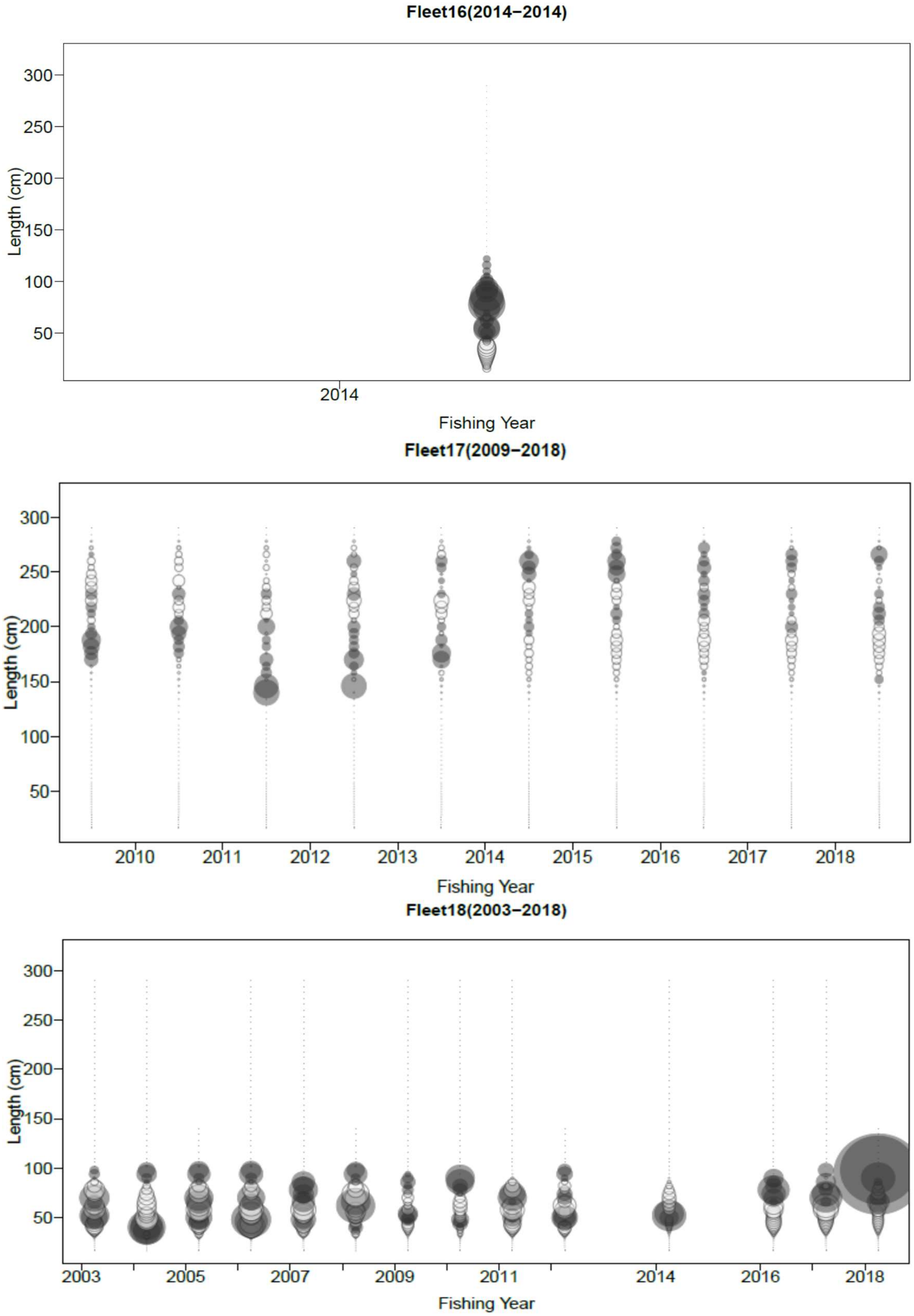

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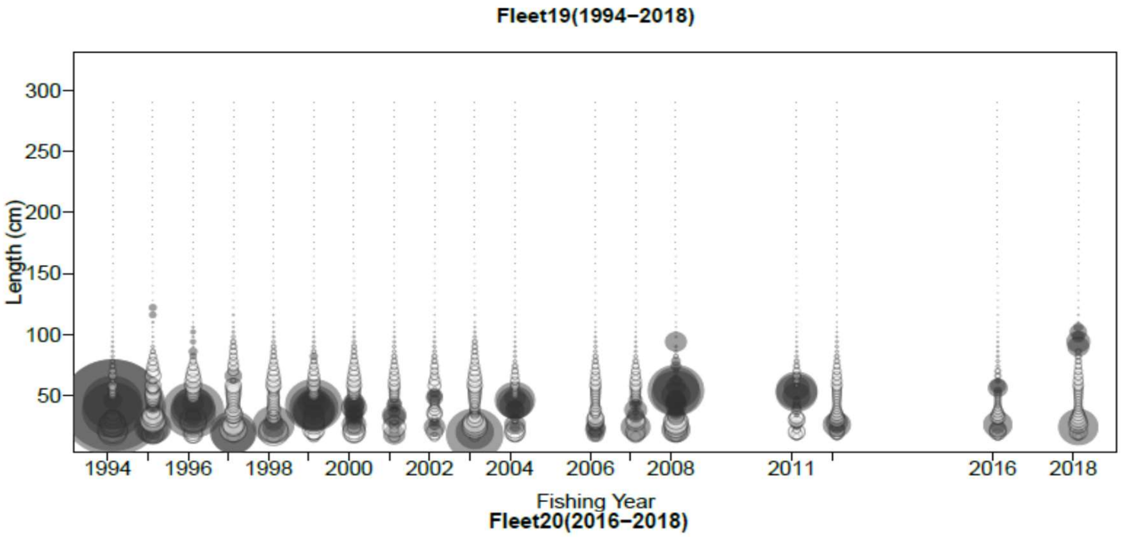

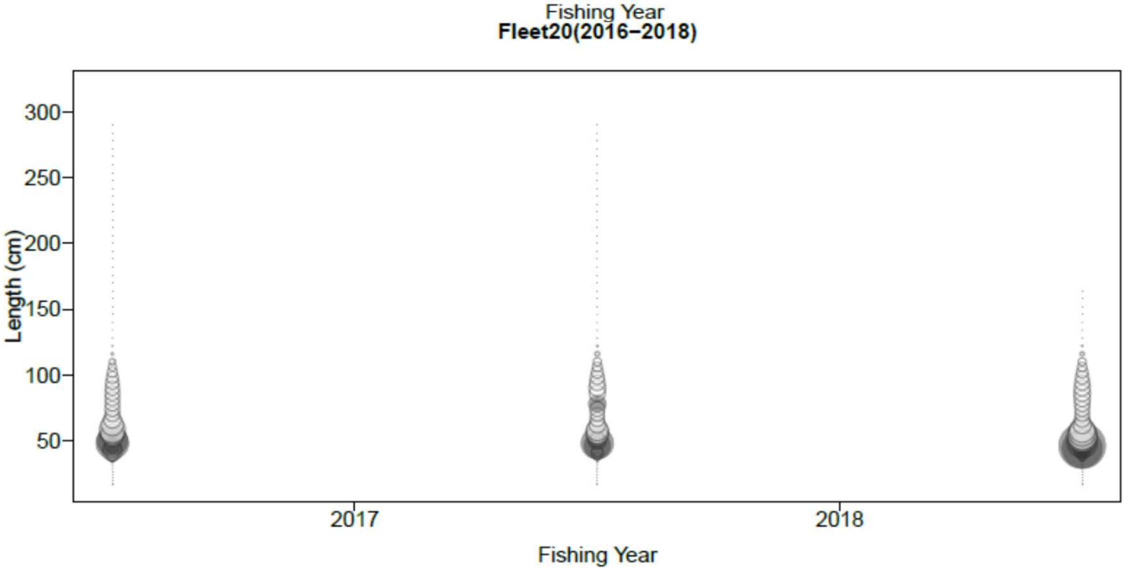

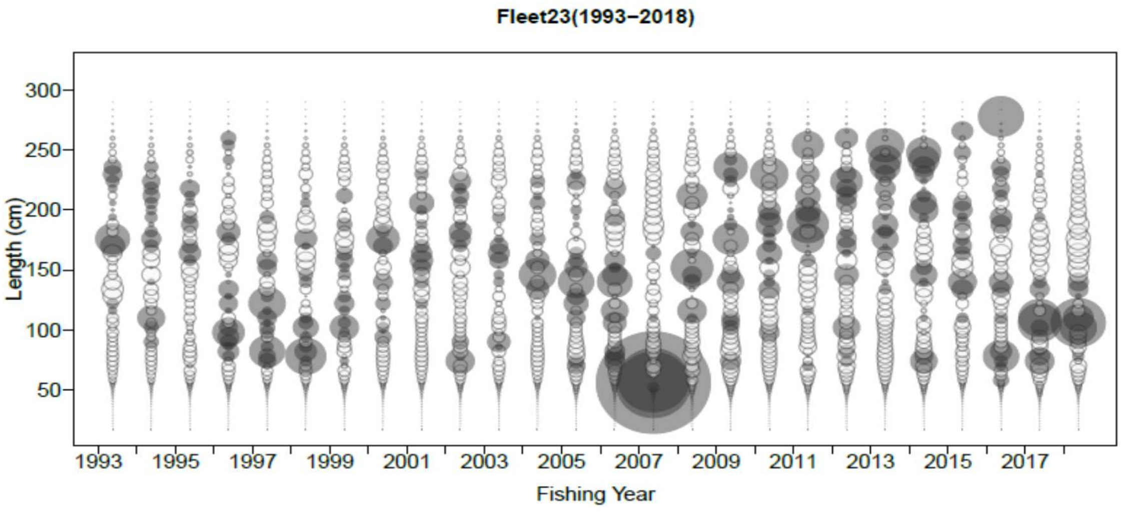

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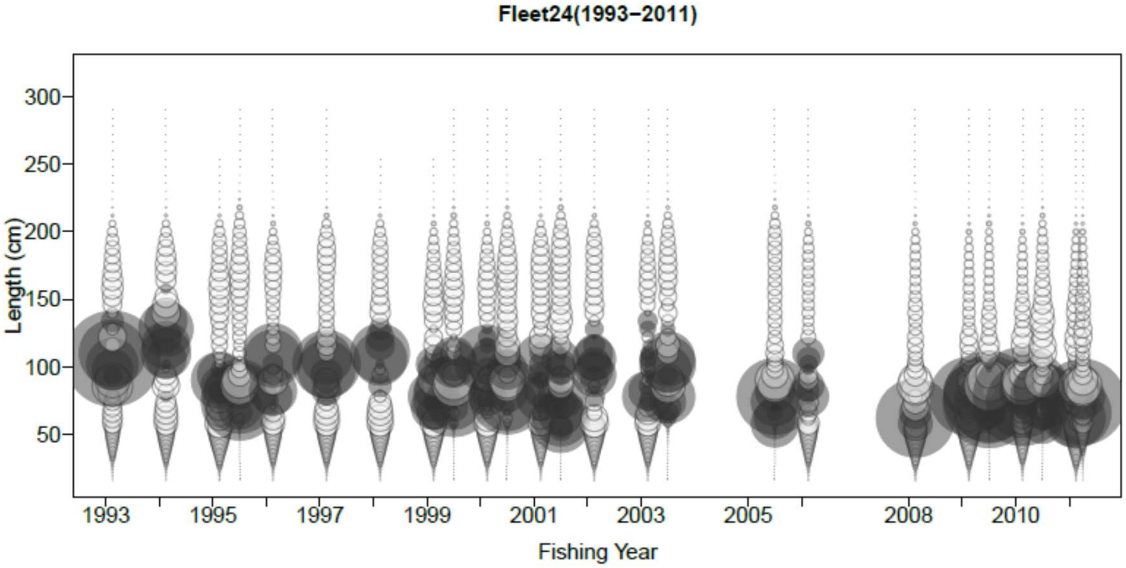

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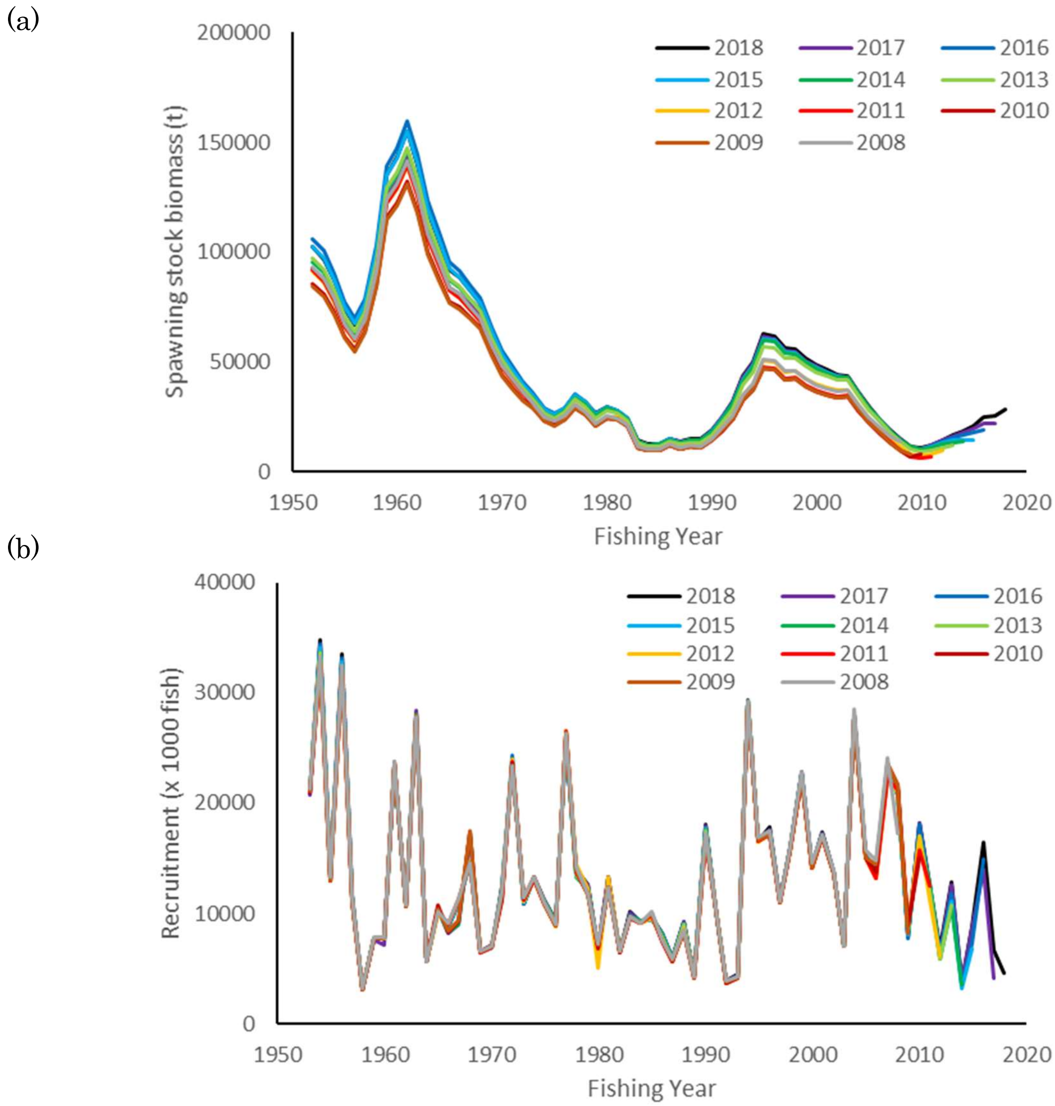


Figure 5-8. Nine-year retrospective analysis of the (a) spawning stock biomass and (b) Recruitment of Pacific bluefin tuna (*Thunnus orientalis*) from the base-case.

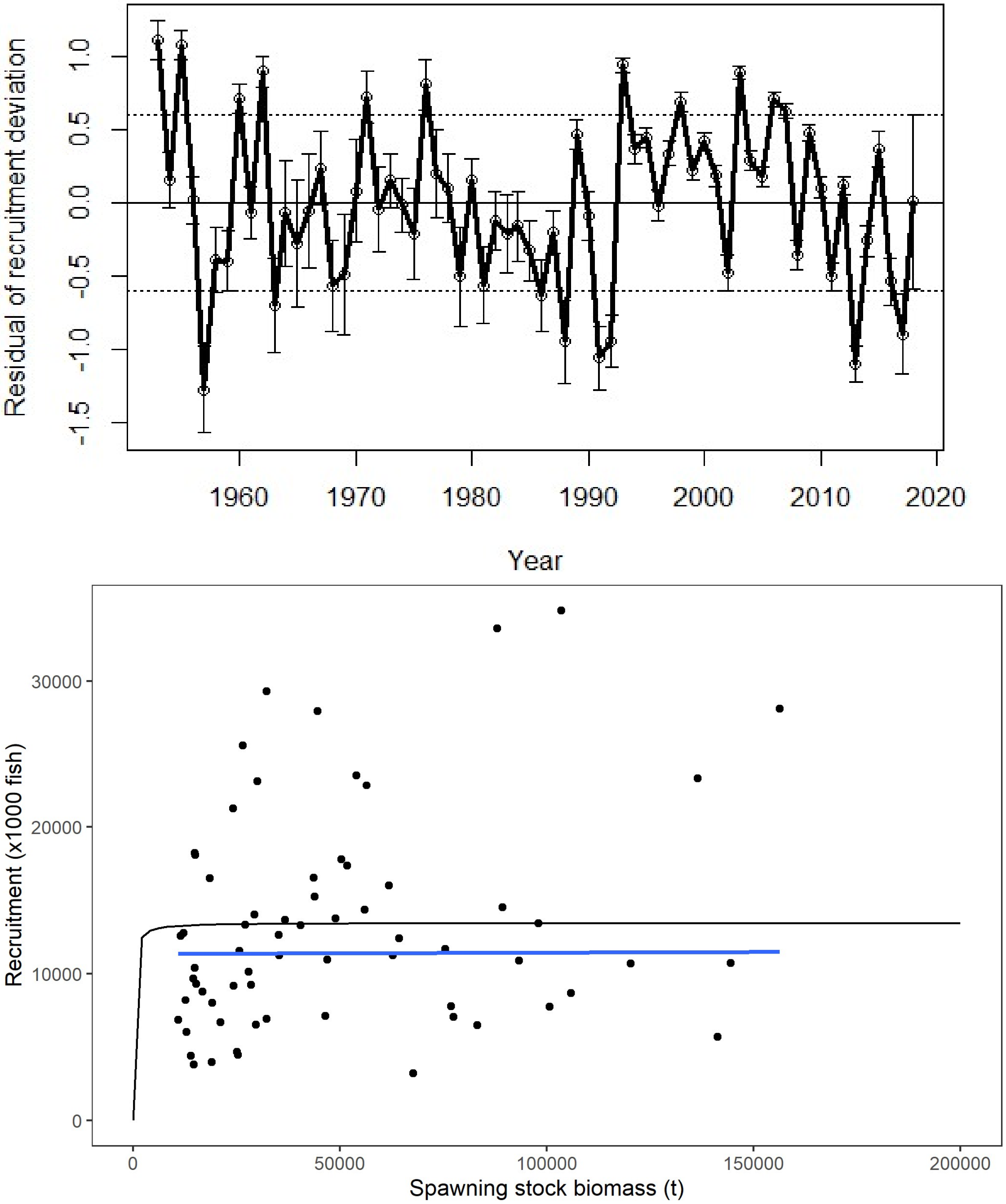
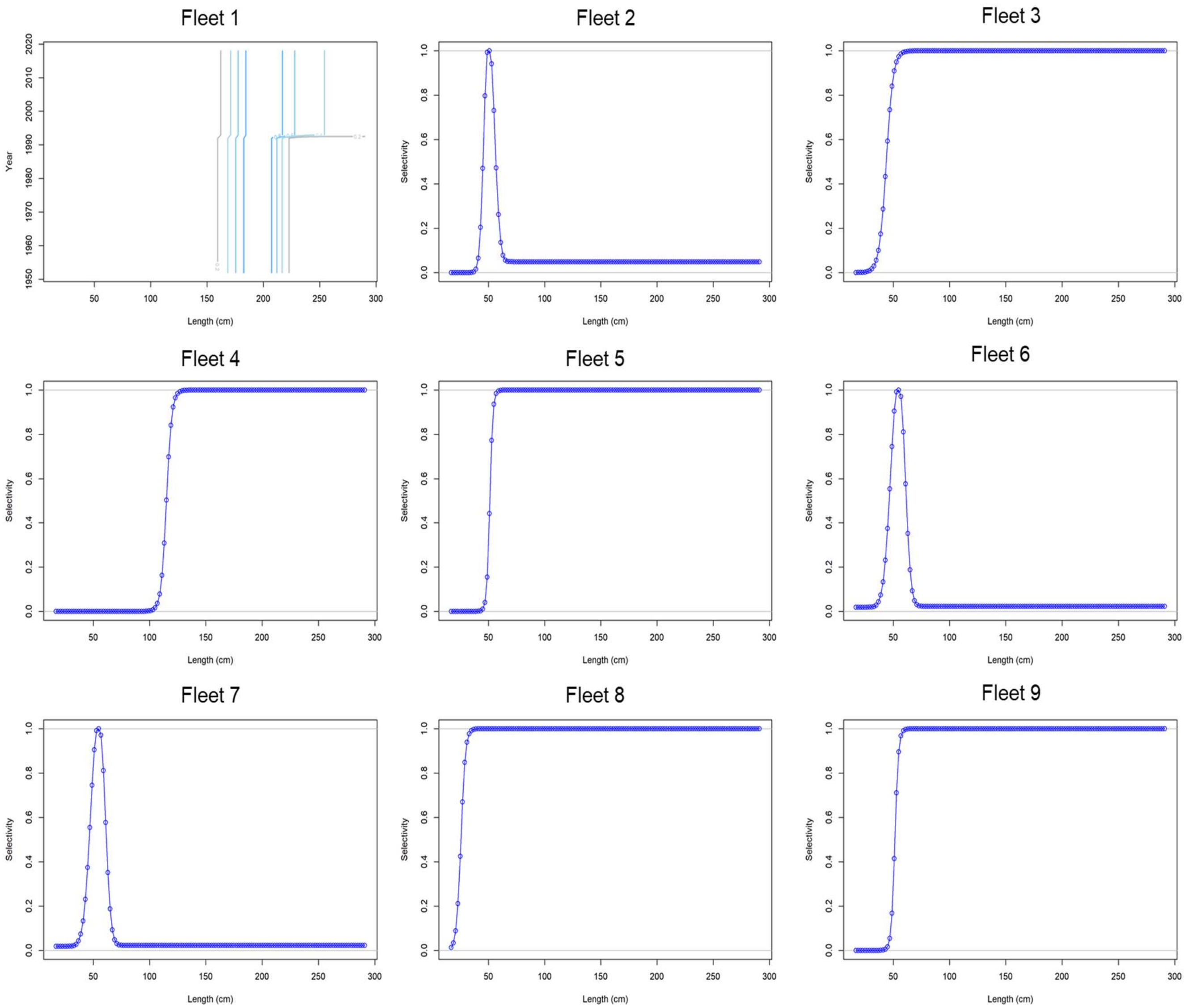


Figure 5-9. Time series of recruitment deviations in log space (upper panel) and spawning stock-recruitment relationship (lower panel) in the base-case stock assessment model for Pacific bluefin tuna (*Thunnus orientalis*). In the upper panel, vertical lines are the 95% CI and horizontal dotted lines indicate σ_R and $-\sigma_R$. In the lower panel, open circles are the paired estimates of spawning stock biomass and recruitment. Black line and blue line indicate the Beverton-Holt stock recruitment relationship estimated in the base-case and expected recruitment after bias adjustment corresponding to above relationship.


Fleet 1

Fleet 2

Fleet 3

Fleet 4

Fleet 5

Fleet 6

Fleet 7

Fleet 8

Fleet 9

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

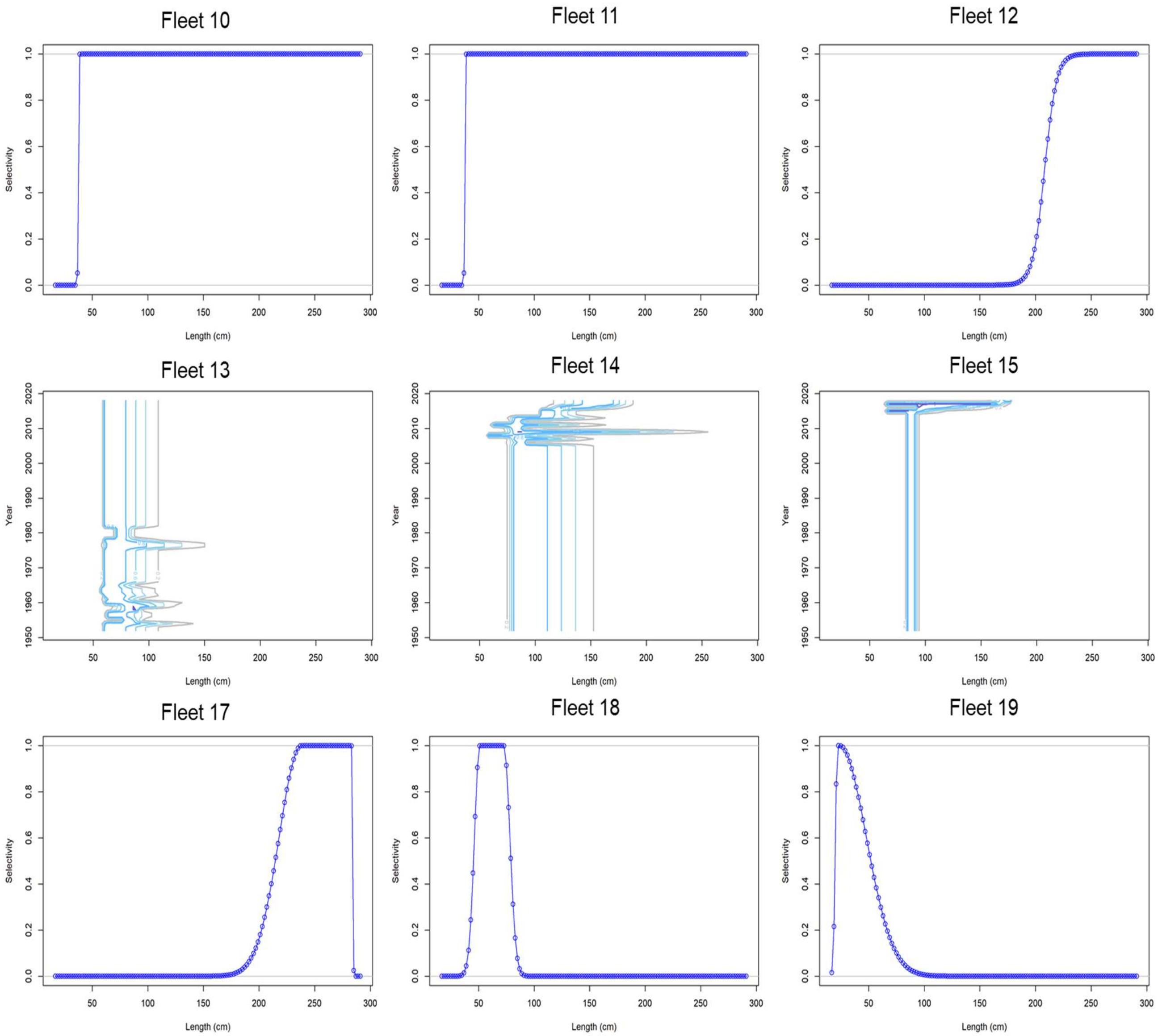
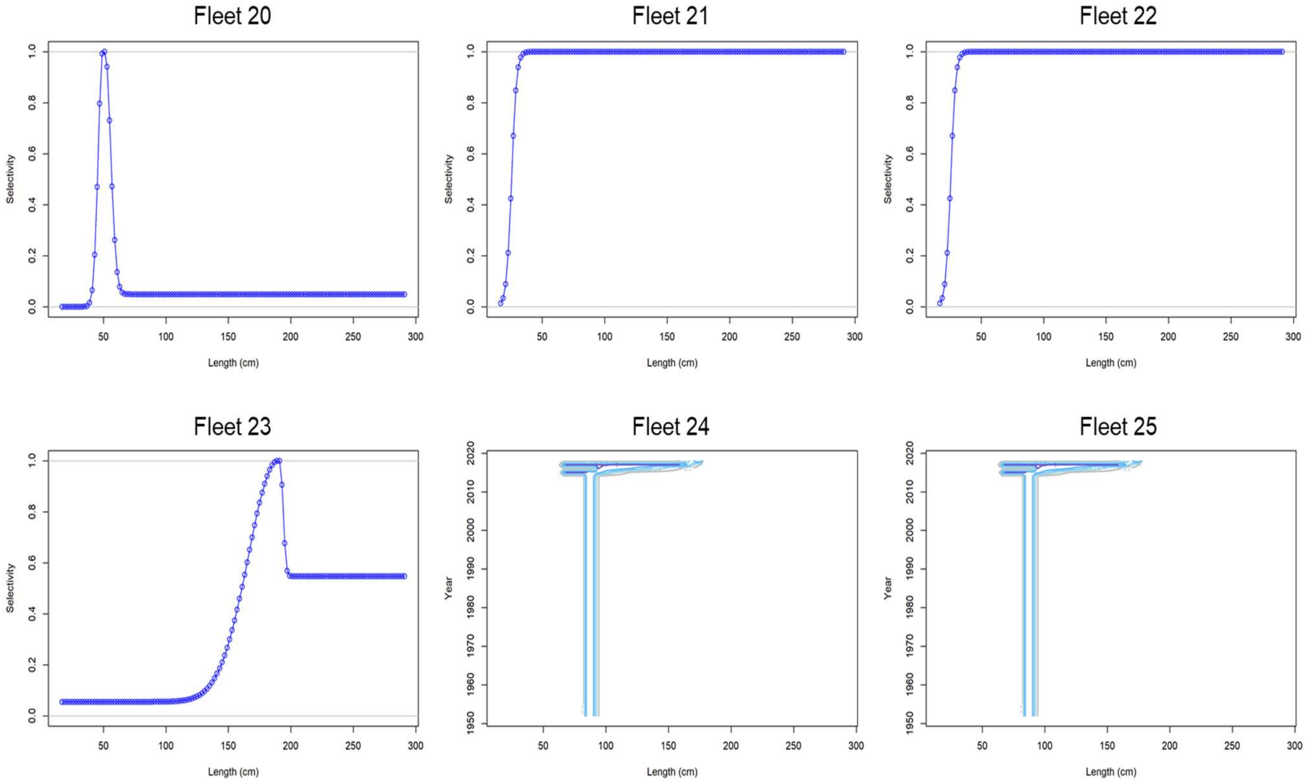


Figure 5-10. Cont.



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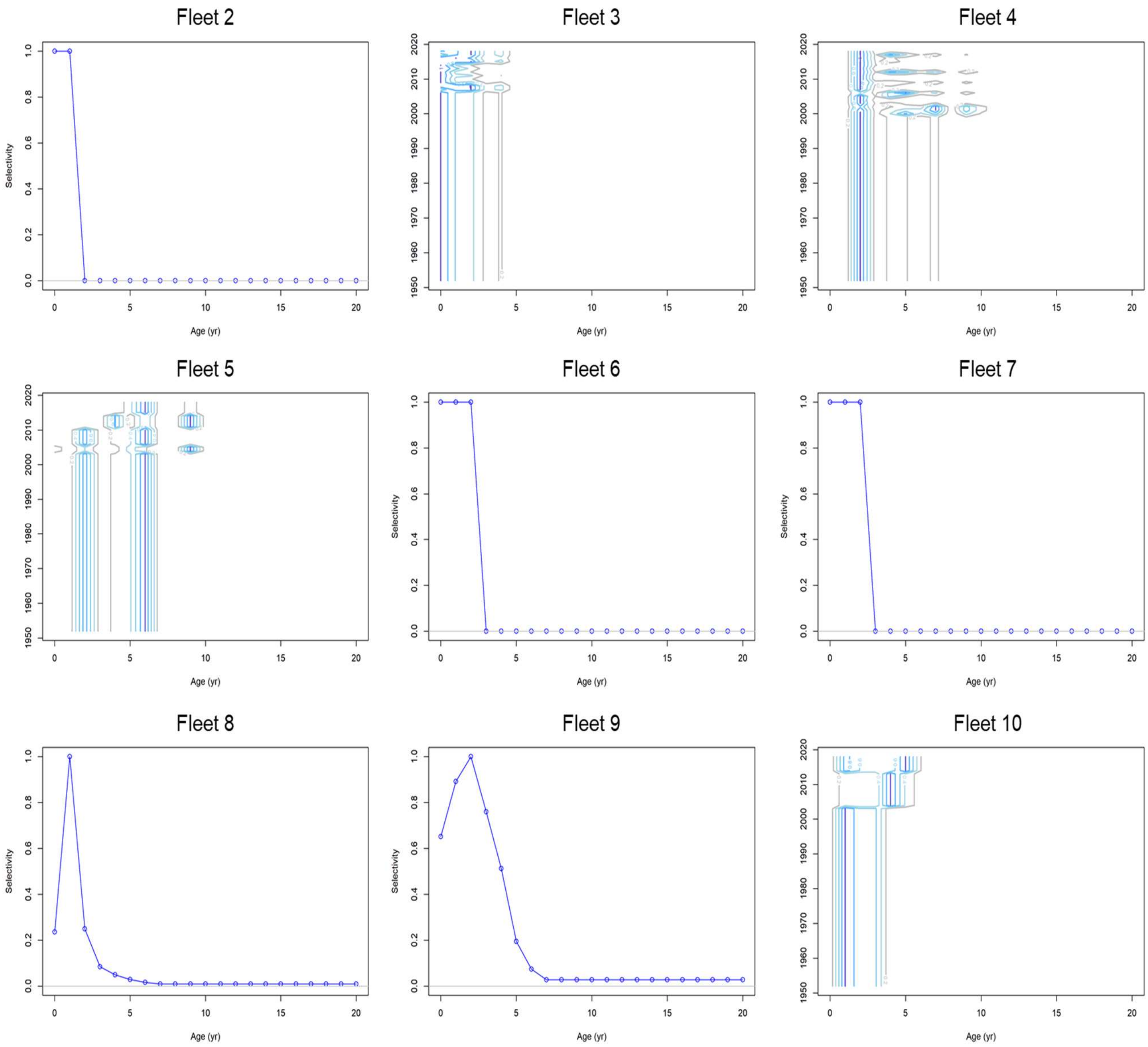


Figure 5-11. Age based selectivity for Pacific bluefin tuna (*Thunnus orientalis*) by fishery. Fisheries with time-varying selectivity patterns are displayed in contour plots.

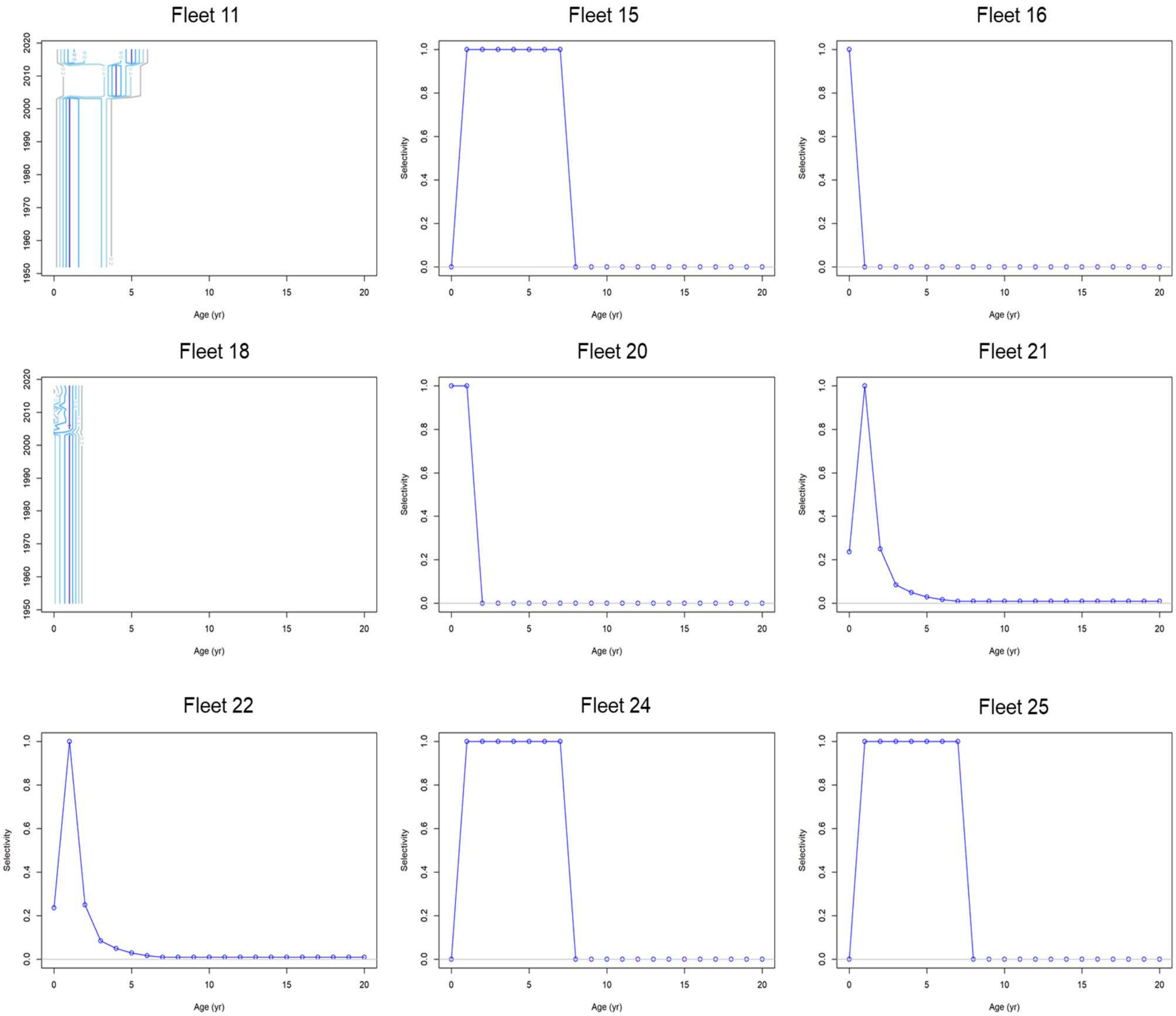


Figure 5-11. Cont.

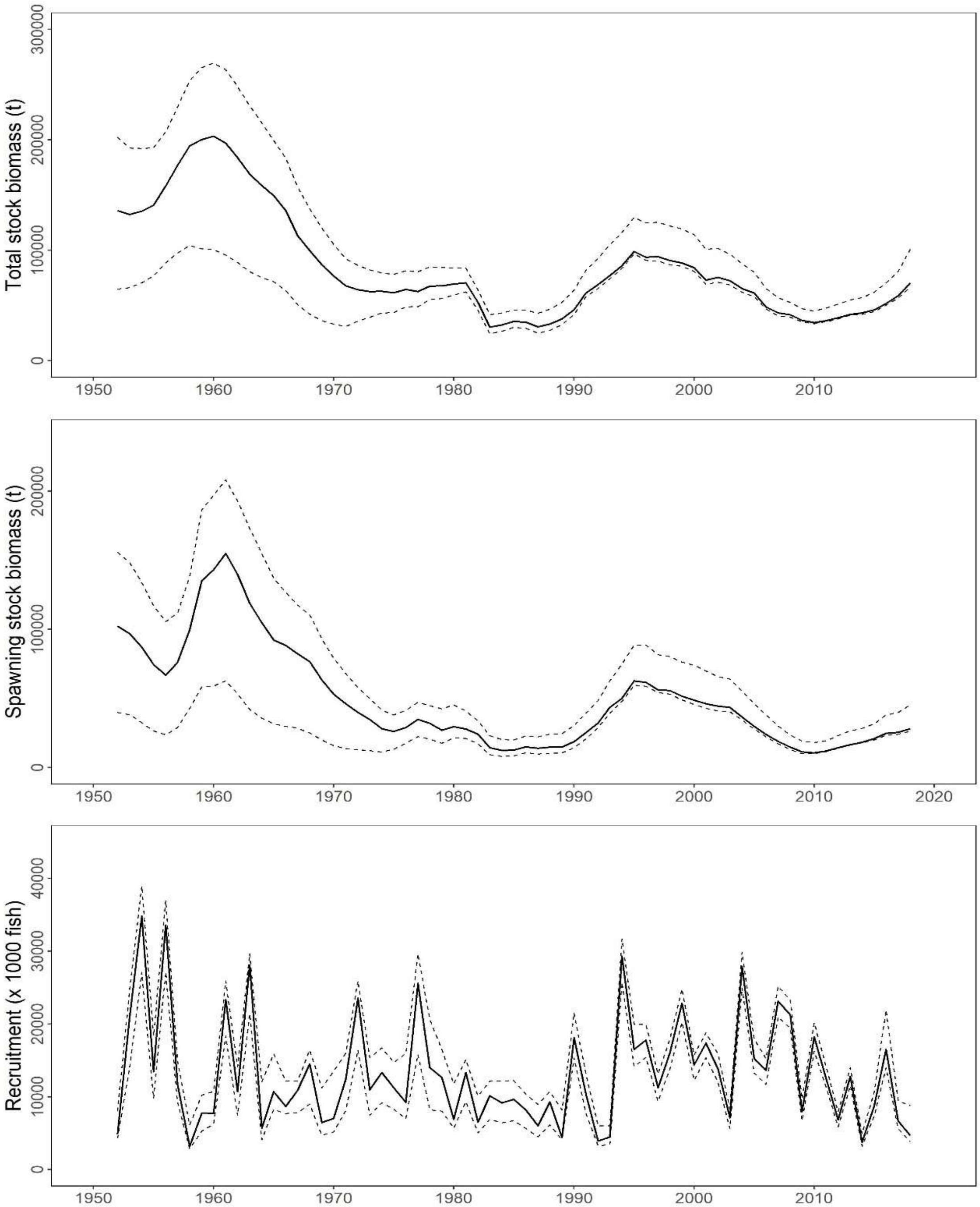


Figure 5-12. Total stock biomass (top), spawning stock biomass (middle) and recruitment (bottom) of Pacific bluefin tuna (*Thunnus orientalis*) from the base-case model. The solid line indicates point estimate and dashed lines indicate the 90% confidence interval.

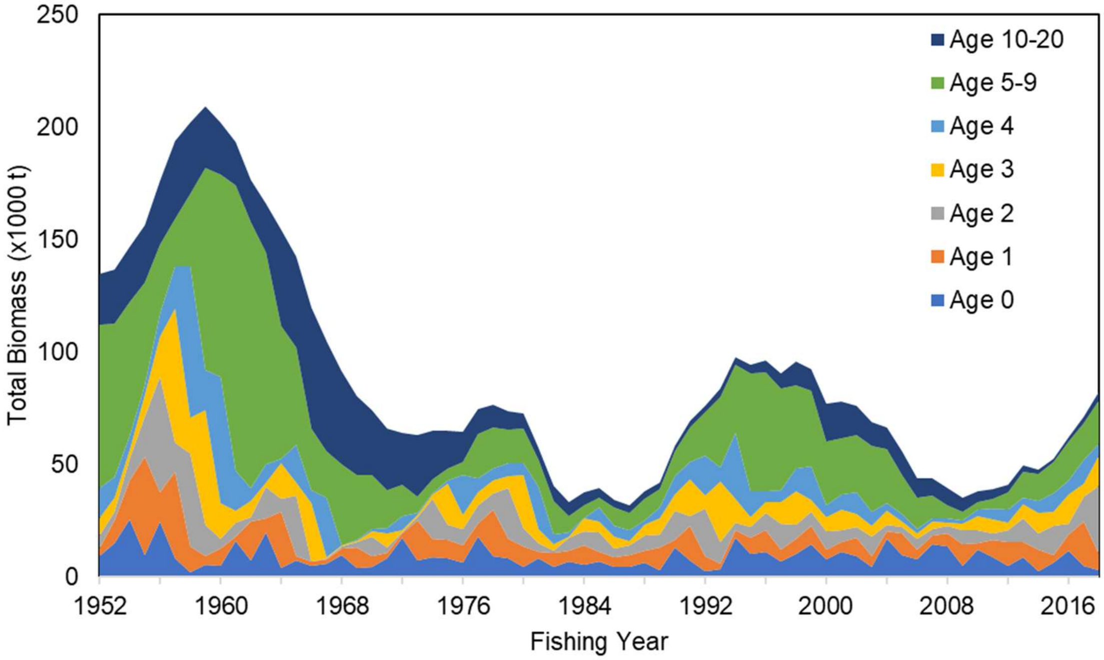


Figure 5-13. Total biomass (ton) by age of Pacific bluefin tuna (*Thunnus orientalis*) estimated from the base-case model (1952-2018).

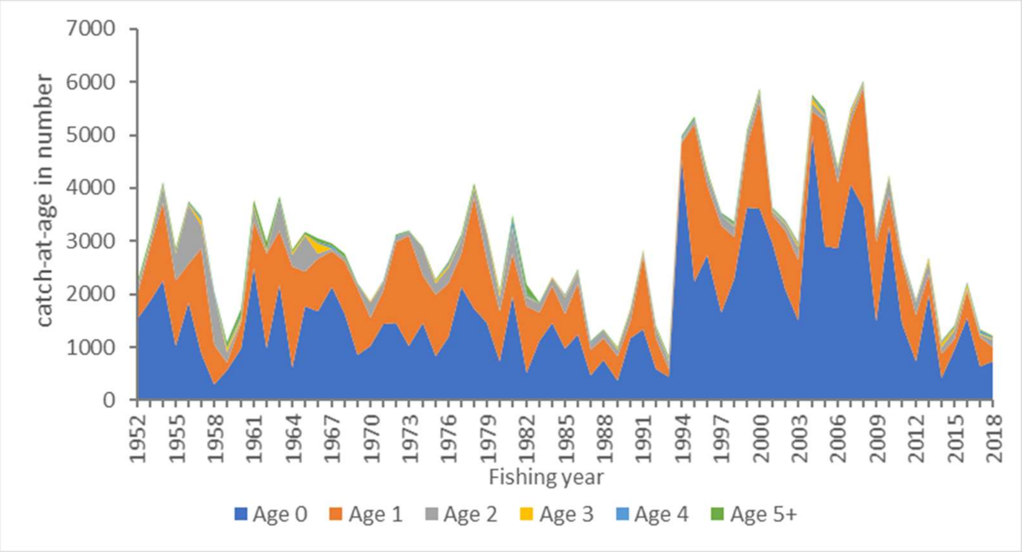


Figure 5-14. Annual catch-at-age (in number) of Pacific bluefin tuna (*Thunnus orientalis*) by fishing year (1952-2018) from the base case.

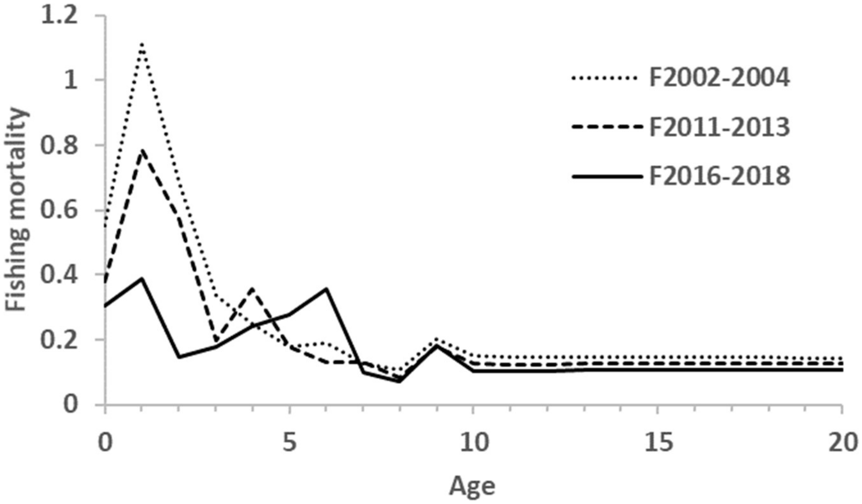


Figure 5-15. Geometric means of annual age-specific fishing mortalities of Pacific bluefin tuna (*Thunnus orientalis*) for 2002-2004 (dot-line), 2011-2013 (dashed line) and 2016-2018 (solid line) from the base case.

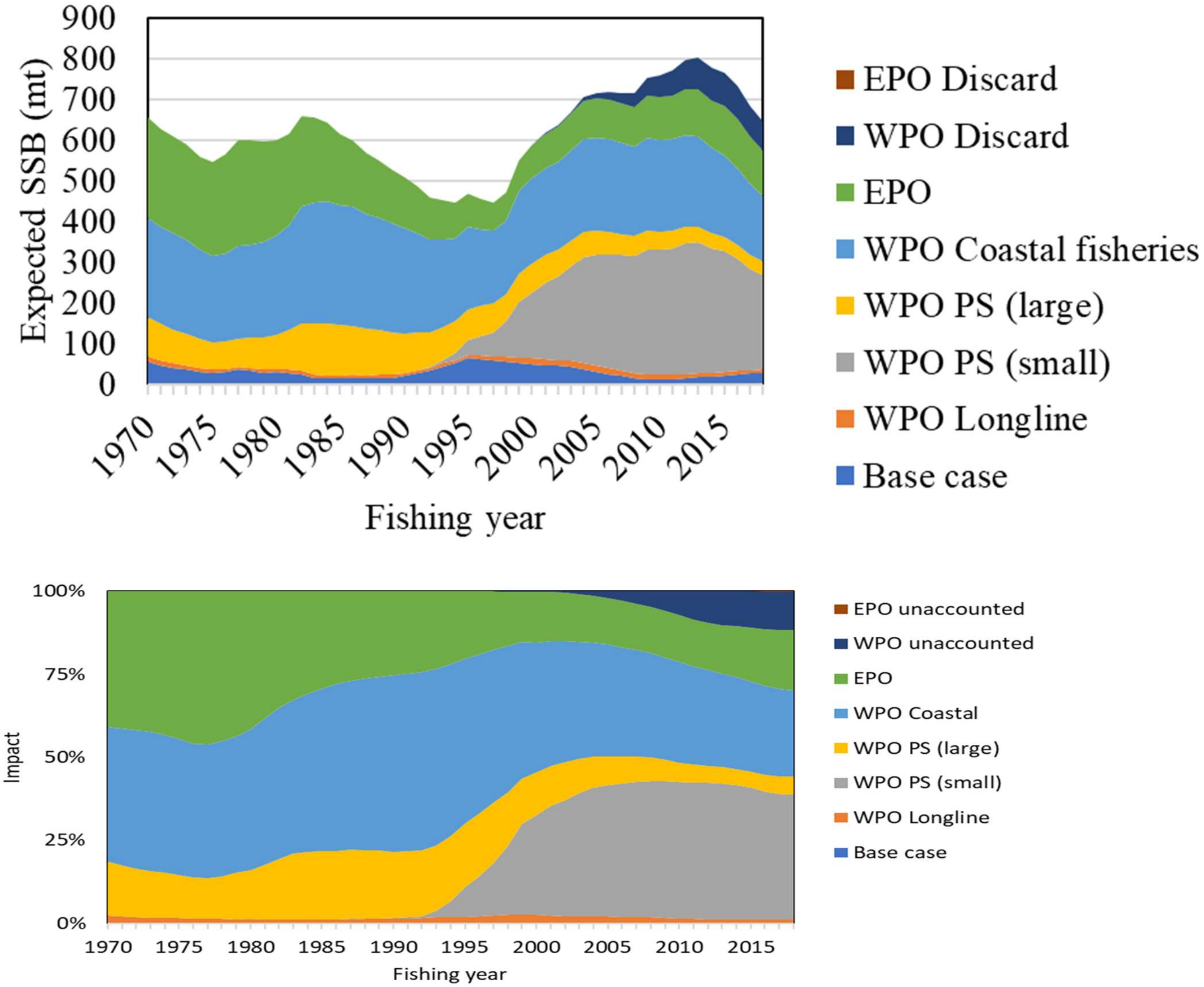


Figure 5-16. Trajectory of the spawning stock biomass of a simulated population of Pacific bluefin tuna (*Thunnus orientalis*) when zero fishing mortality is assumed, estimated by the base-case model. (top: absolute impact, bottom: relative impact). Fleet definition; WPO longline: F1, F12, F17, F23. WPO purse seine for small fish: F2, F3, F18, F20. WPO purse seine: F4, F5. WPO coastal fisheries: F6-11, F16, F19. EPO fisheries: F13, F14, F15, F24. WPO unaccounted F21, F22. EPO unaccounted: F25.

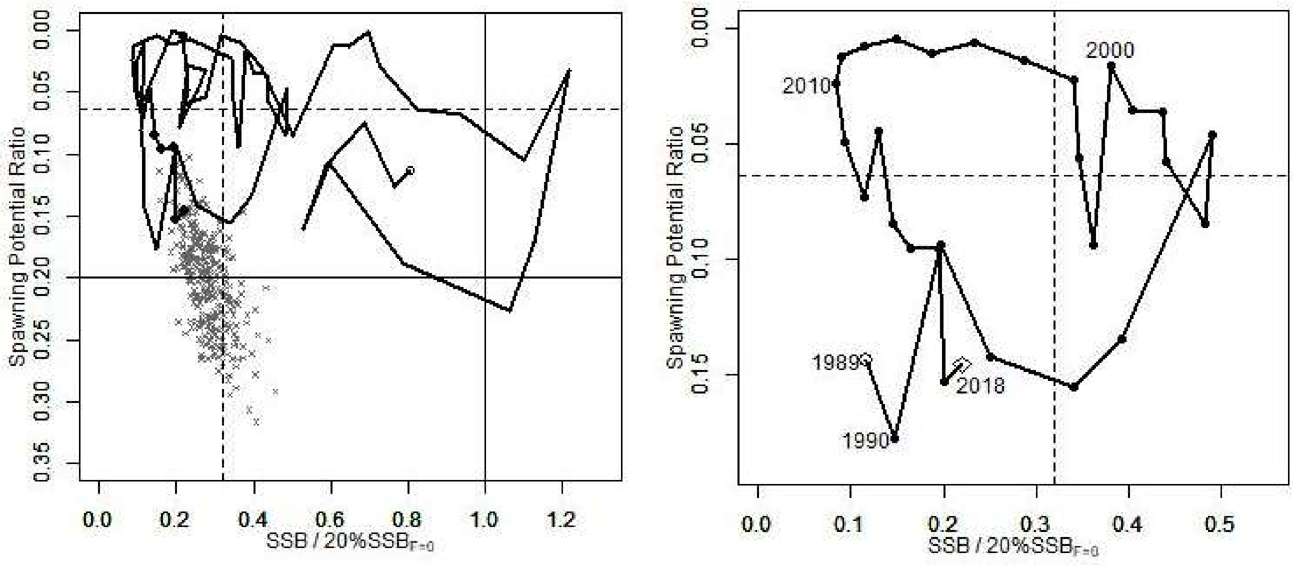


Figure 5-17. Kobe plots for Pacific bluefin tuna (*Thunnus orientalis*) estimated from the base-case model. The X-axis shows the annual SSB relative to 20%SSB$_{F=0}$ and the Y-axis shows the spawning potential ratio (SPR) as a measure of fishing mortality. Vertical and horizontal solid lines in the left figure show 20%SSB$_{F=0}$ (which corresponds to the second biomass rebuilding target) and the corresponding fishing mortality that produces SPR, respectively. Vertical and horizontal broken lines in both figures show the initial biomass rebuilding target (SSB$_{MED}$ = 6.4%SSB$_{F=0}$) and the corresponding fishing mortality that produces SPR, 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), solid circles indicate the last five years of the assessment (2014-2018), and grey crosses indicate the uncertainty of the terminal year estimated by bootstrapping. The right figure shows the trajectory of the last 30 years.

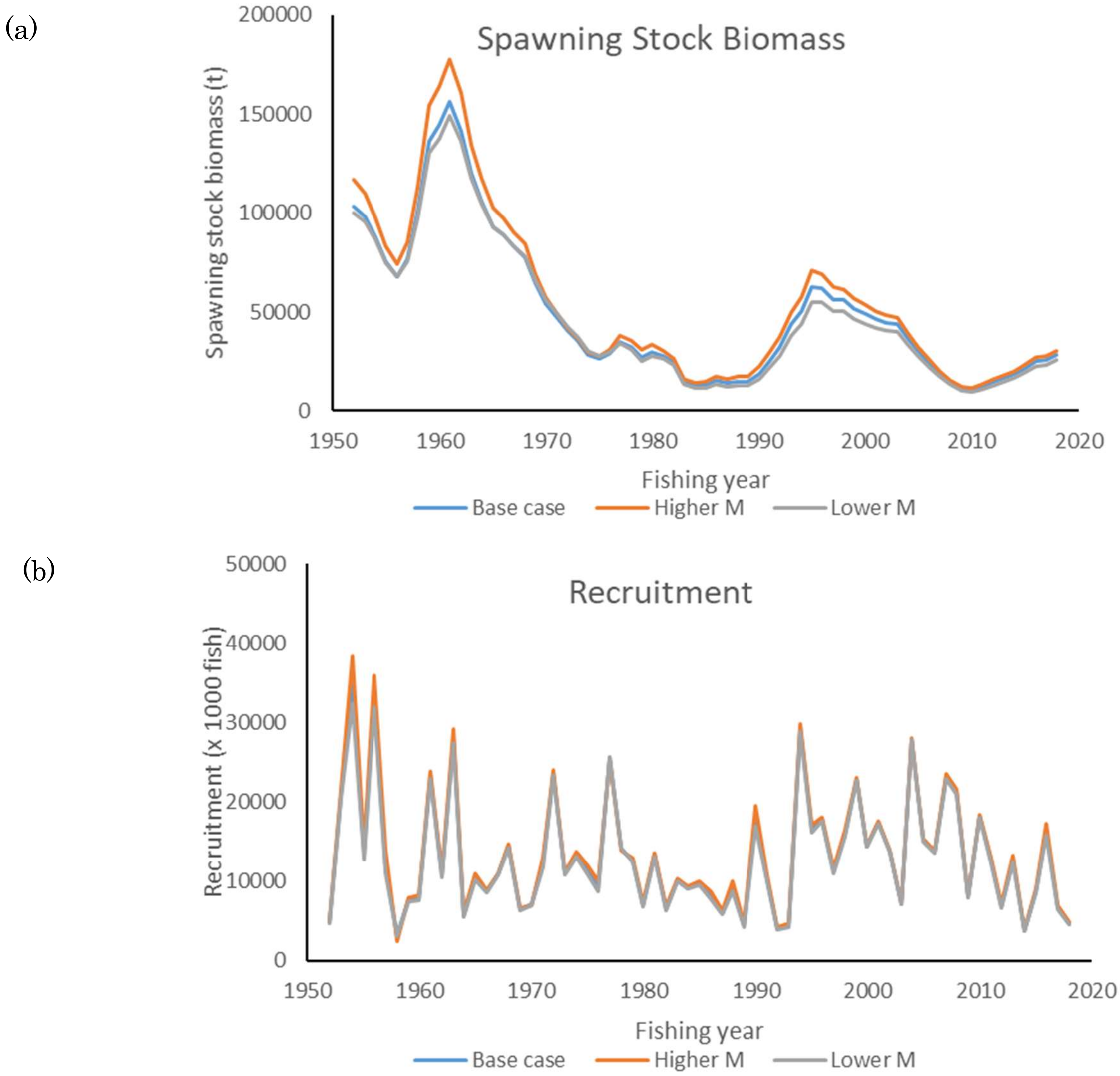


Figure 5-18. Estimated (a) spawning stock biomass and (b) recruitment of Pacific bluefin tuna (*Thunnus orientalis*) for the base-case model and sensitivity analyses using alternative high and low natural mortality assumptions for age 2 and older fish.

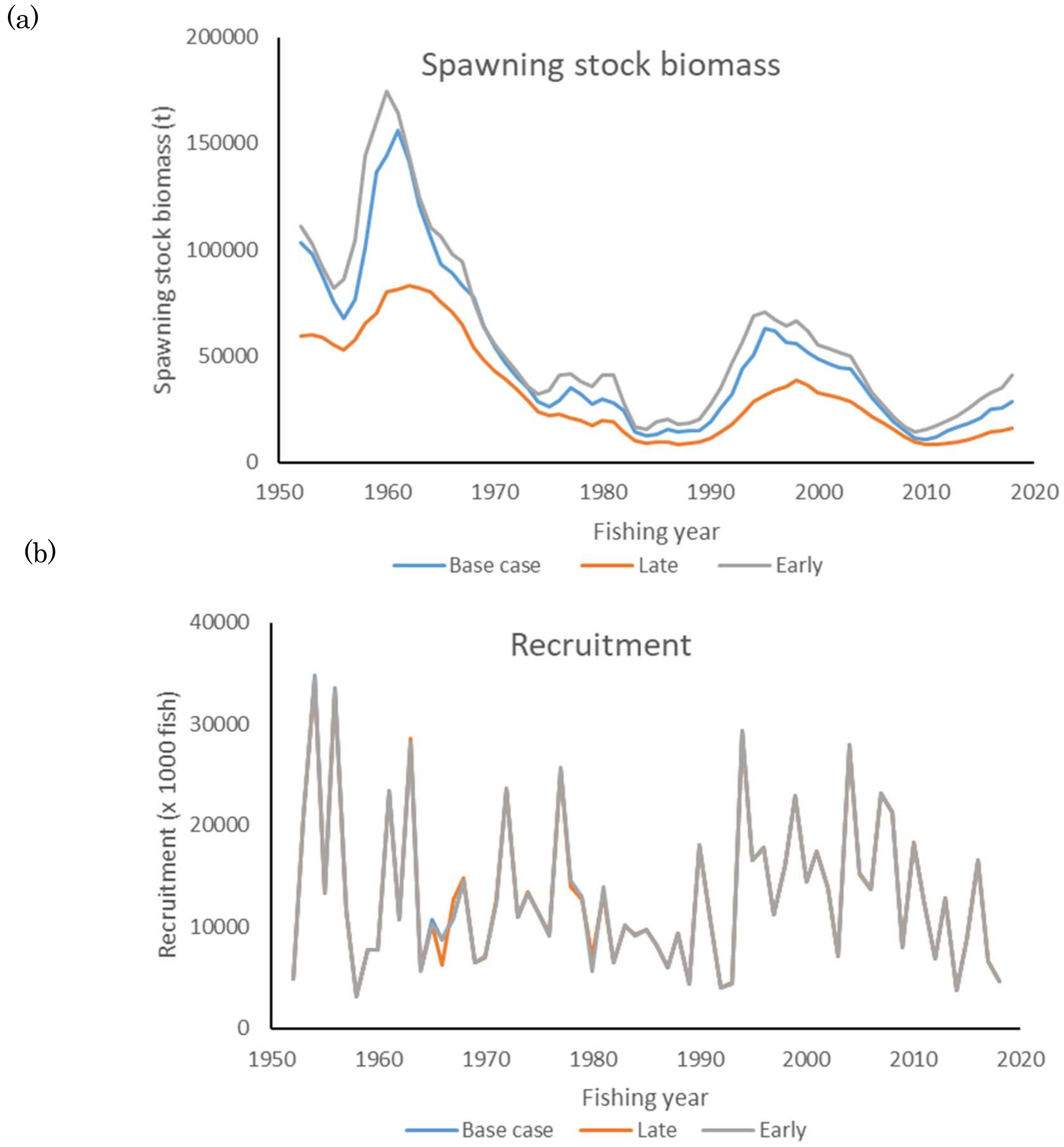


Figure 5-19. Estimated (a) spawning stock biomass and (b) recruitment of Pacific bluefin tuna (*Thunnus orientalis*) for the base-case model and sensitivity analysis using early and late maturity schedule.

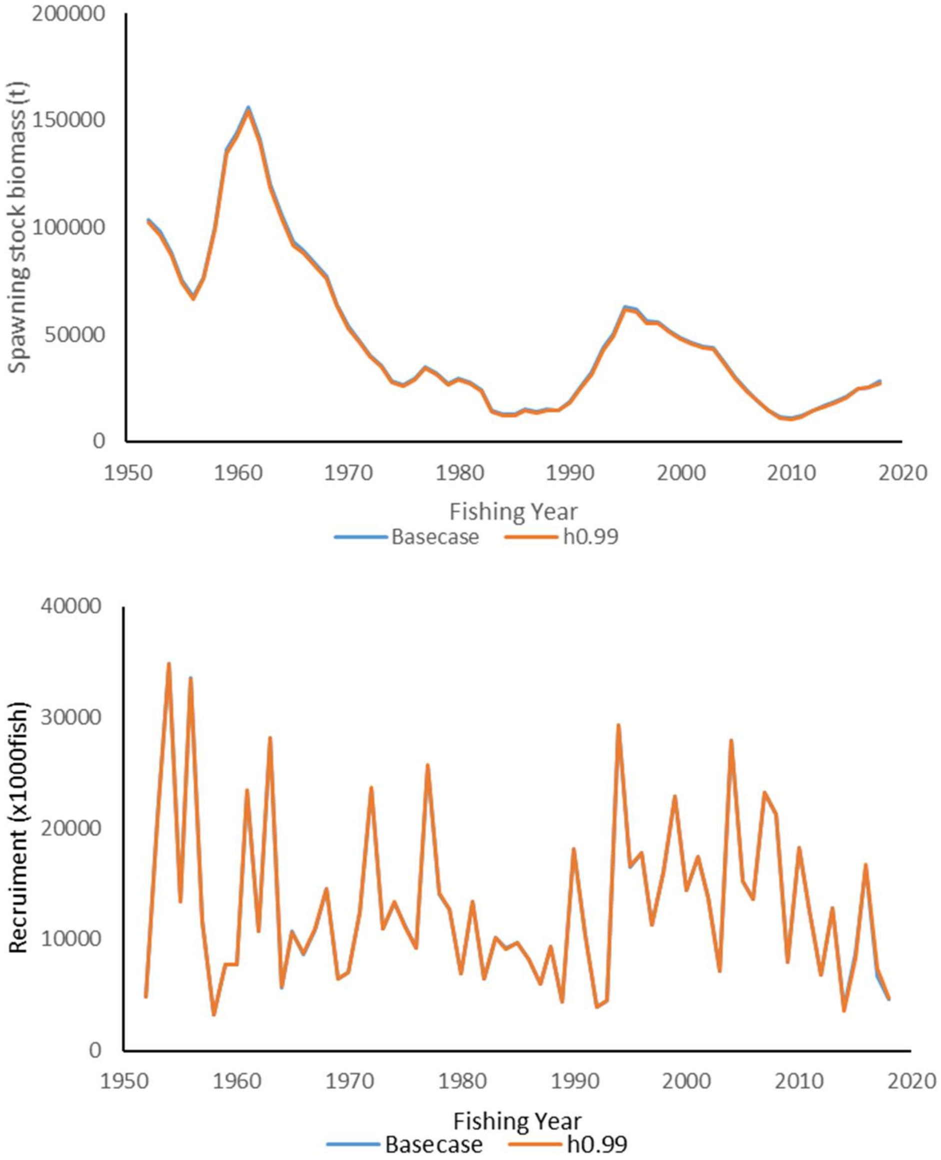


Figure 5-20. Estimated (a) spawning stock biomass and (b) recruitment of Pacific bluefin tuna (*Thunnus orientalis*) for the base-case model and sensitivity analysis using lower steepness(h=0.99).

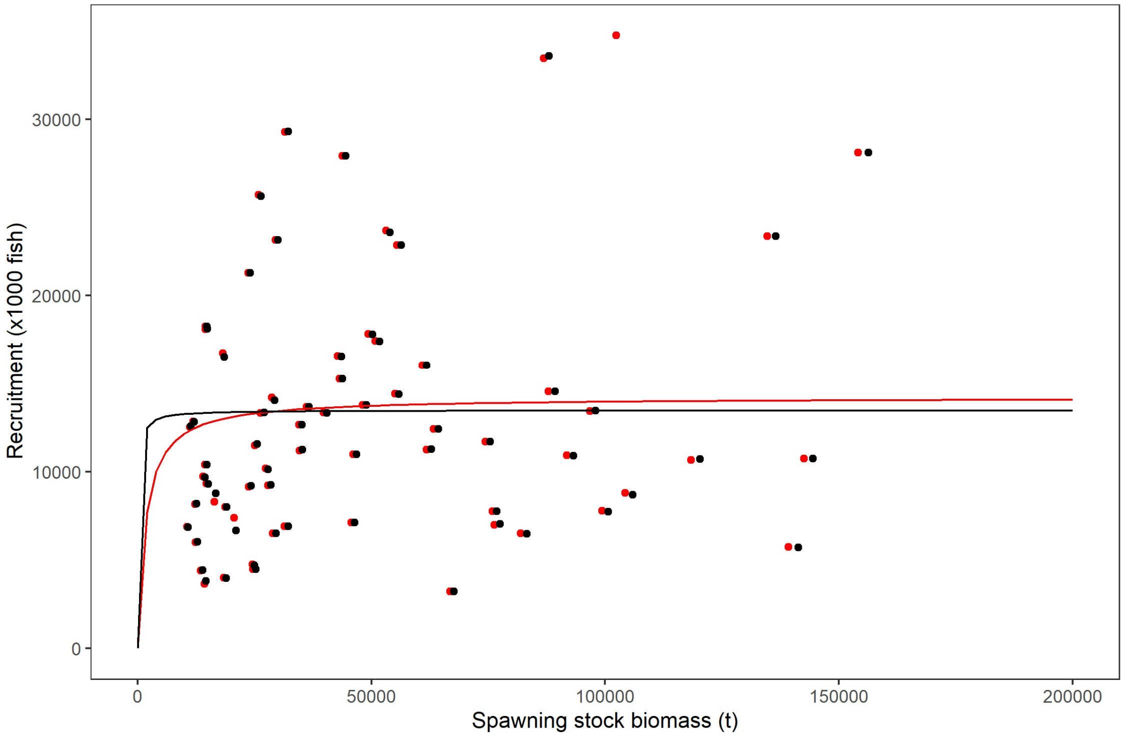


Figure 5-21. Estimated relationships between spawning stock biomass and recruitment of Pacific bluefin tuna (*Thunnus orientalis*) for the base-case model and a sensitivity run applying a lower steepness (h=0.99) assumption. Black circles and line show stock recruitment relationship estimated by the base-case. Red circles and line show those estimated by lower steepness(h=0.99) run.

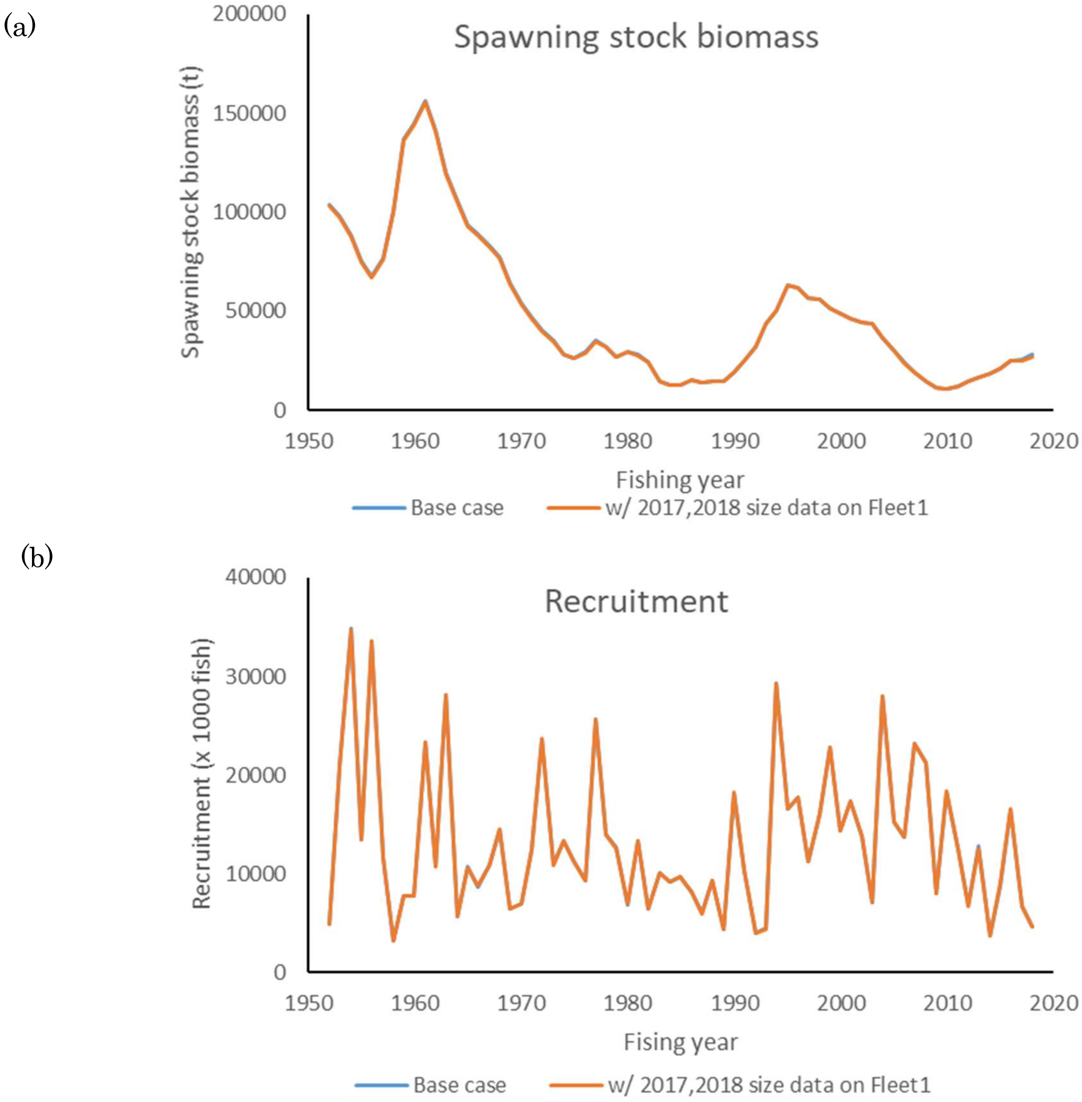


Figure 5-22. Estimated (a) spawning stock biomass and (b) recruitment of Pacific bluefin tuna (*Thunnus orientalis*) for the base-case model and a sensitivity analyses which fitting to the 2017 and 2018 size composition of Japanese Longline (Fleet1).

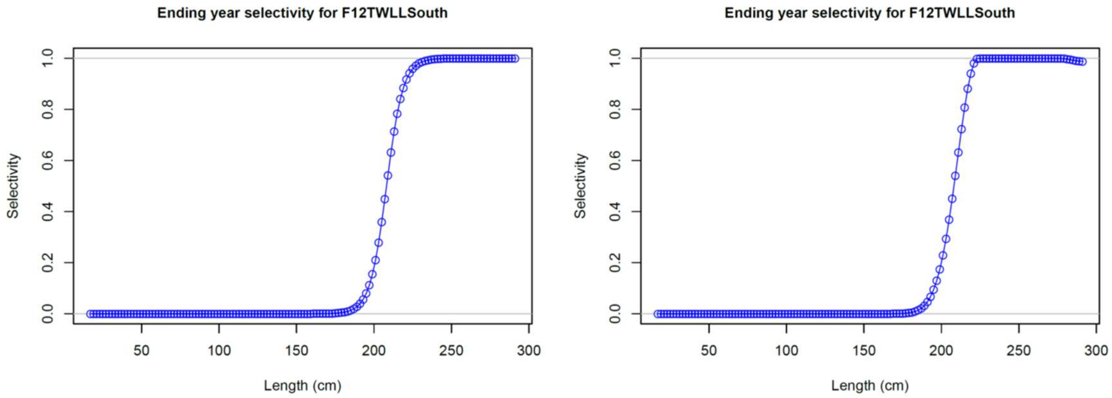


Figure 5-23. Estimated length based selectivities for Fleet 12 (Taiwanese longline south fishing ground) by the base-case model (left) and an a sensitivity run assuming the dome shape (6 parameters double normal) selectivity.

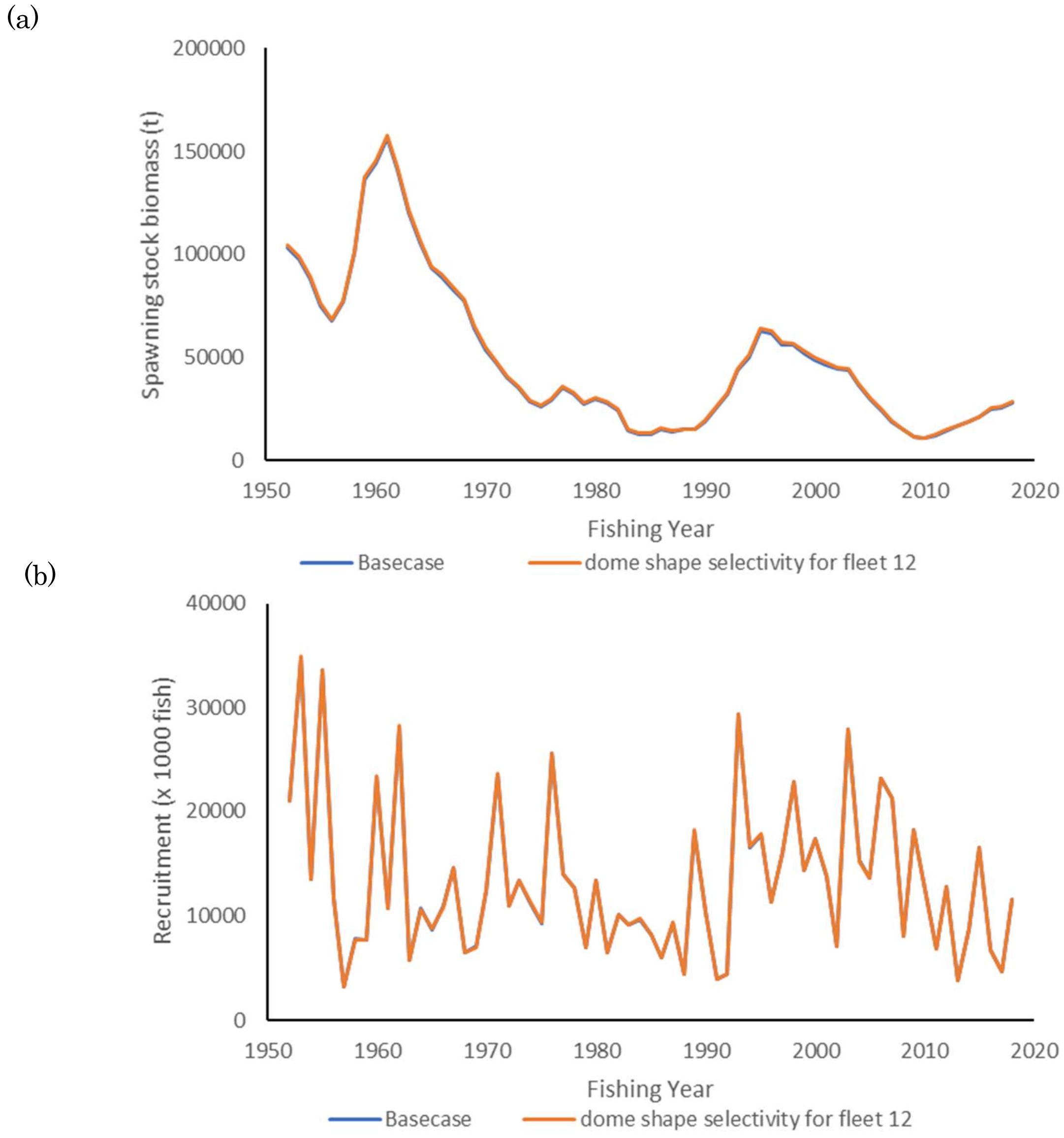


Figure 5-24. Estimated (a) spawning stock biomass and (b) recruitment of Pacific bluefin tuna (*Thunnus orientalis*) for the base-case model and a sensitivity analysis assuming dome shape selectivity for fleet 12.

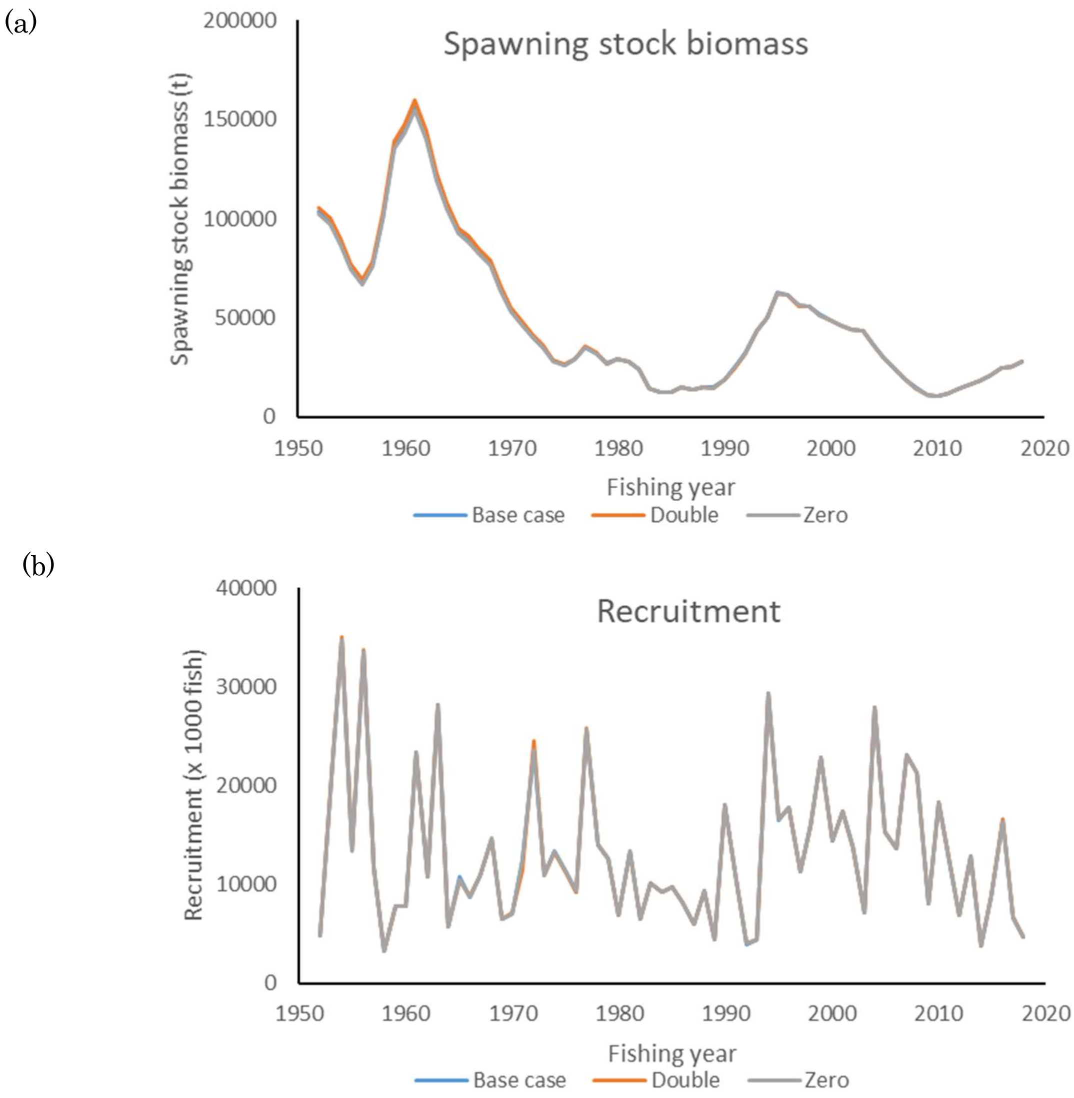
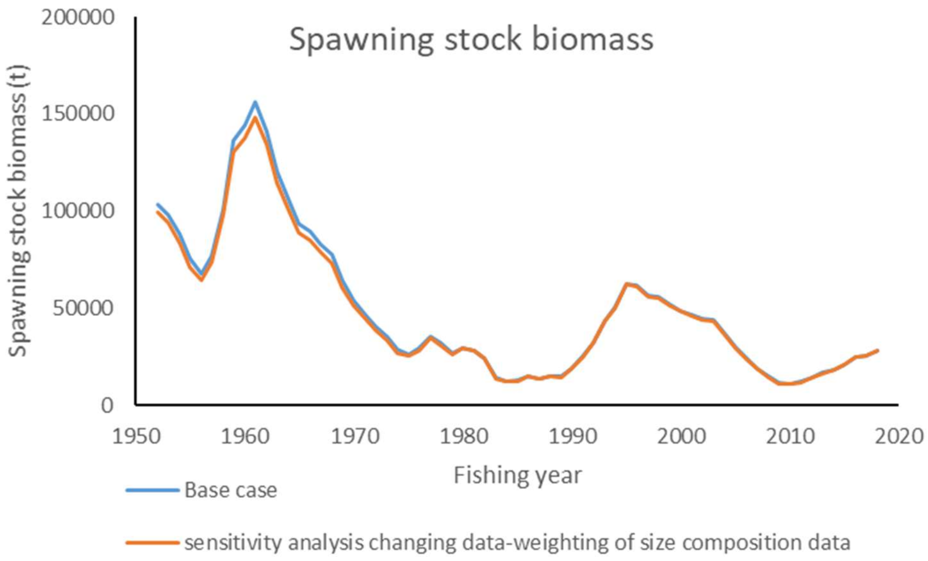


Figure 5-25. Estimated (a) spawning stock biomass and (b) recruitment of Pacific bluefin tuna (*Thunnus orientalis*) for the base-case model and sensitivity runs using high and low discard catch.

(a)



(b)

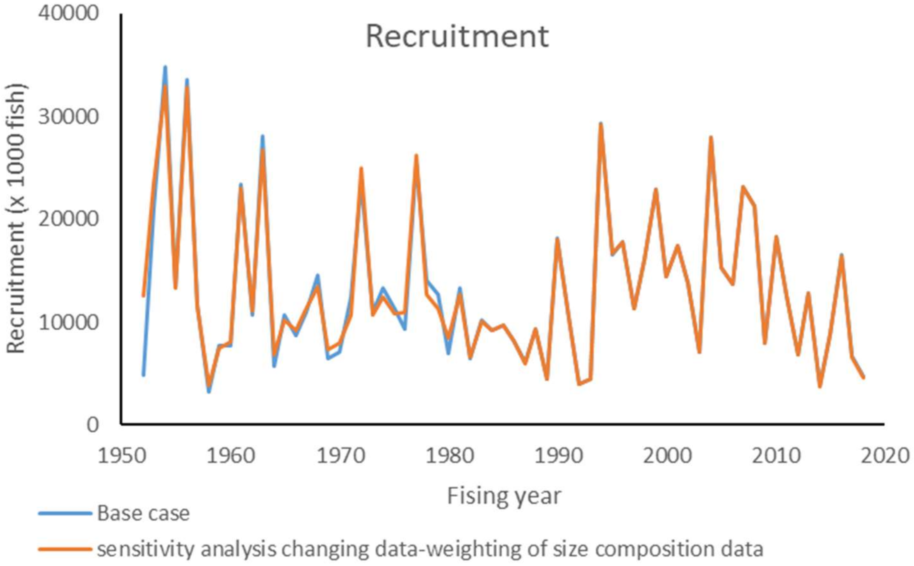


Figure 5-26. Estimated (a) spawning stock biomass and (b) recruitment of Pacific bluefin tuna (*Thunnus orientalis*) for the base-case model and a sensitivity run for data-weighting of size composition data.

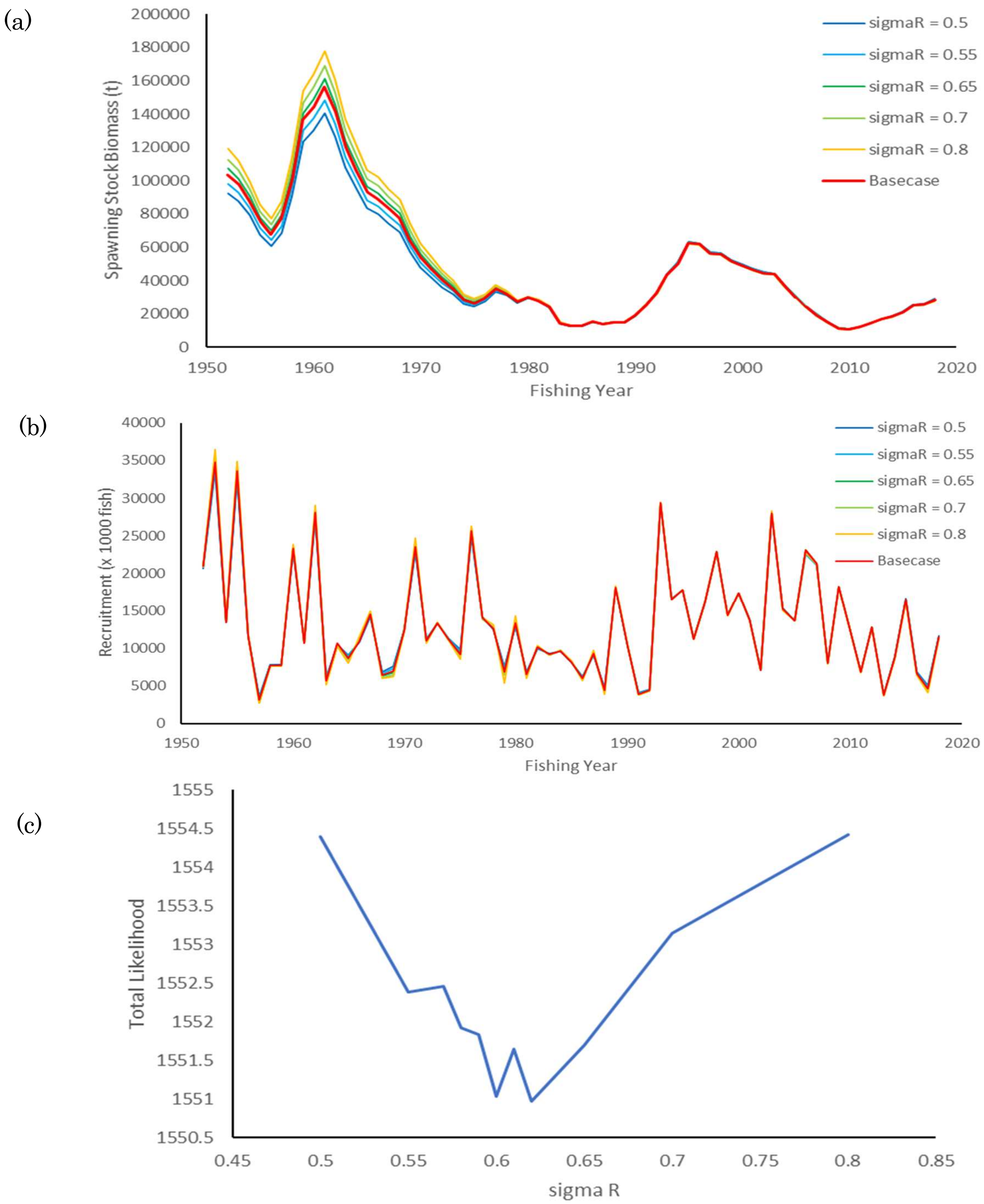


Figure 5-27. Estimated (a) spawning stock biomass, (b) recruitment and (c) likelihood by sigma R value of Pacific bluefin tuna (*Thunnus orientalis*) for the base-case model and Sigma R.

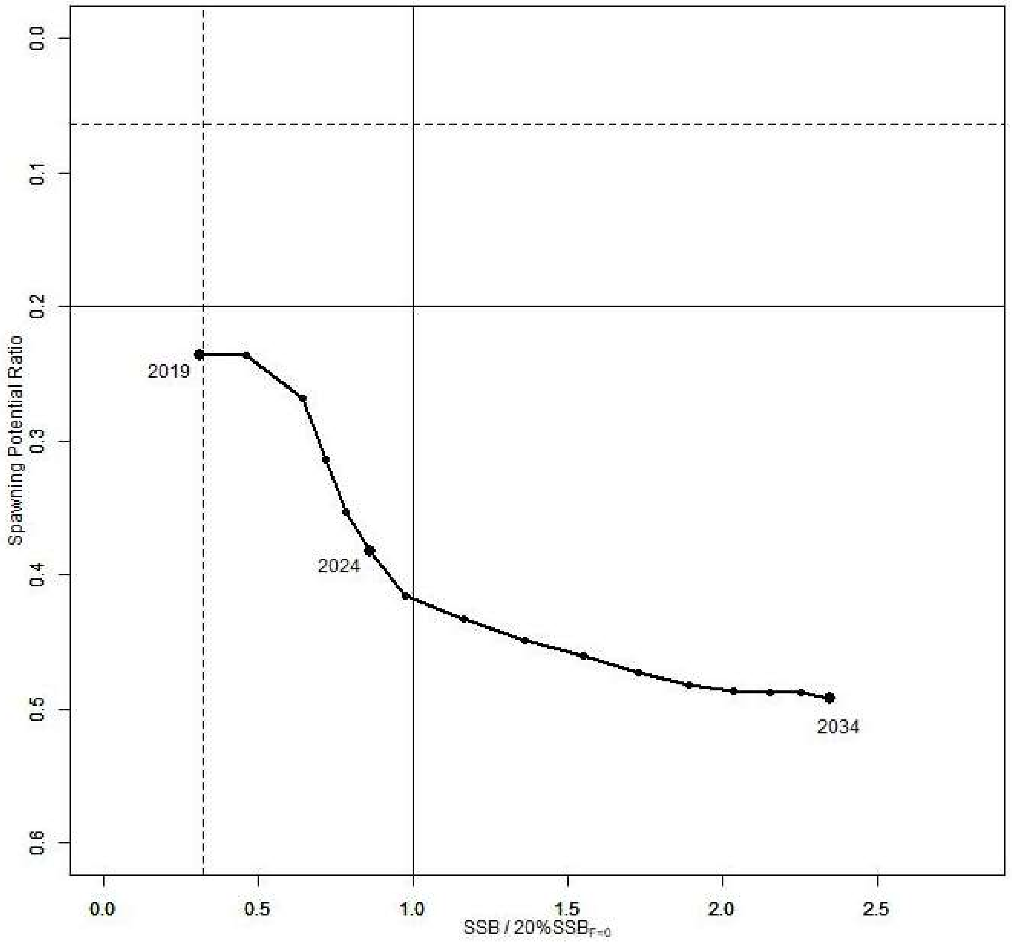


Figure 6-1. “Future Kobe Plot” of projection results for Pacific bluefin tuna (*Thunnus orientalis*) from Scenario 1 from Table 4-2.

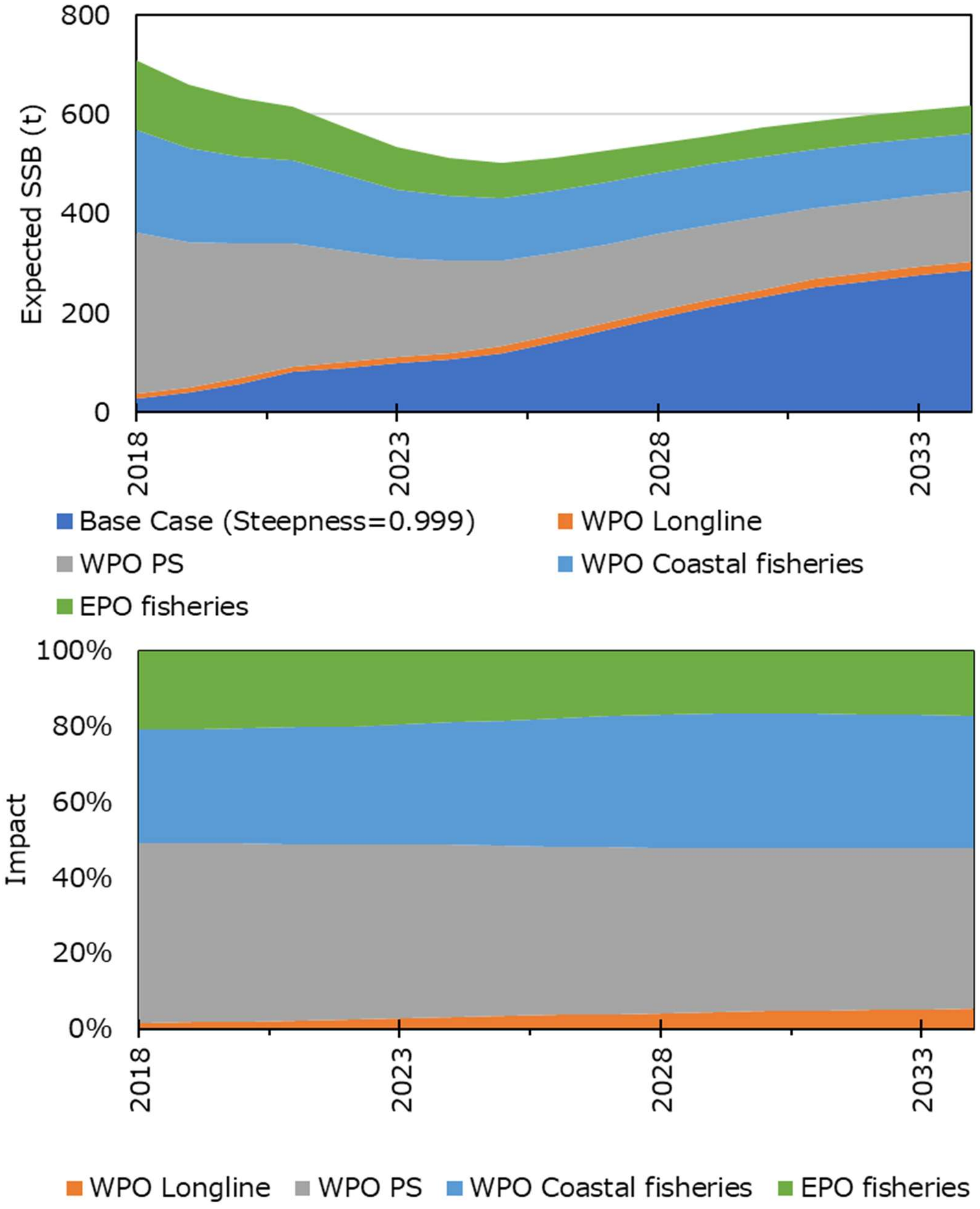


Figure 6-2. "Future impact plot" from projection results for Pacific bluefin tuna (*Thunnus orientalis*) from Scenario 1 of Table 4-2. The impact is calculated based on the expected increase of SSB in the absence of the respective group of fisheries.

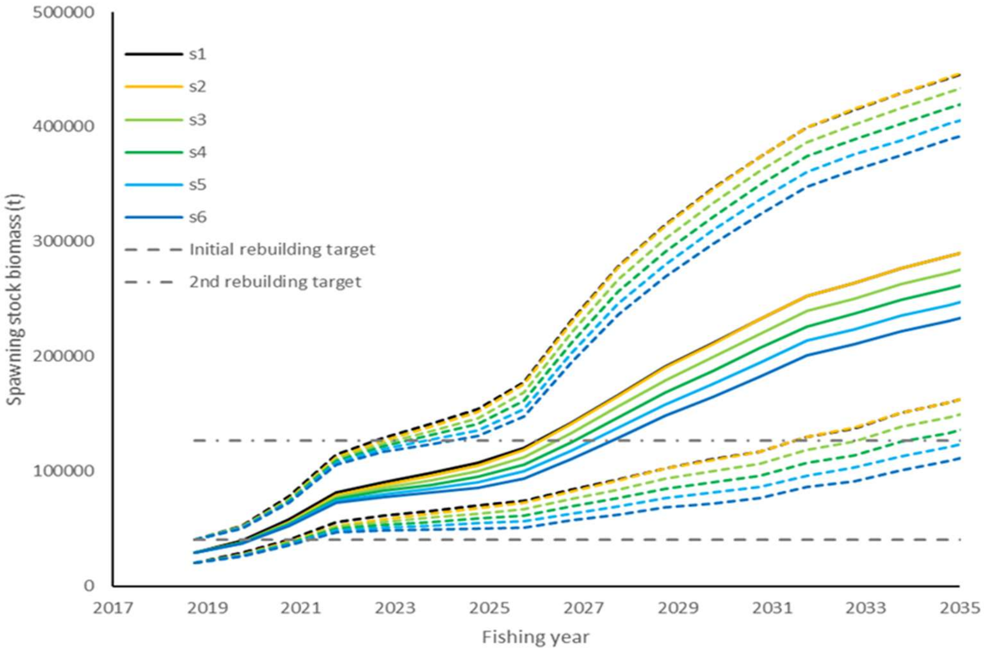


Figure 6-3. Comparisons of various projection results for Pacific bluefin tuna (Thunnus orientalis) obtained from bias-adjusted bootstrap projection results. Median of scenarios 1 to 6 (solid lines) and their 90% confidence intervals (dotted lines).

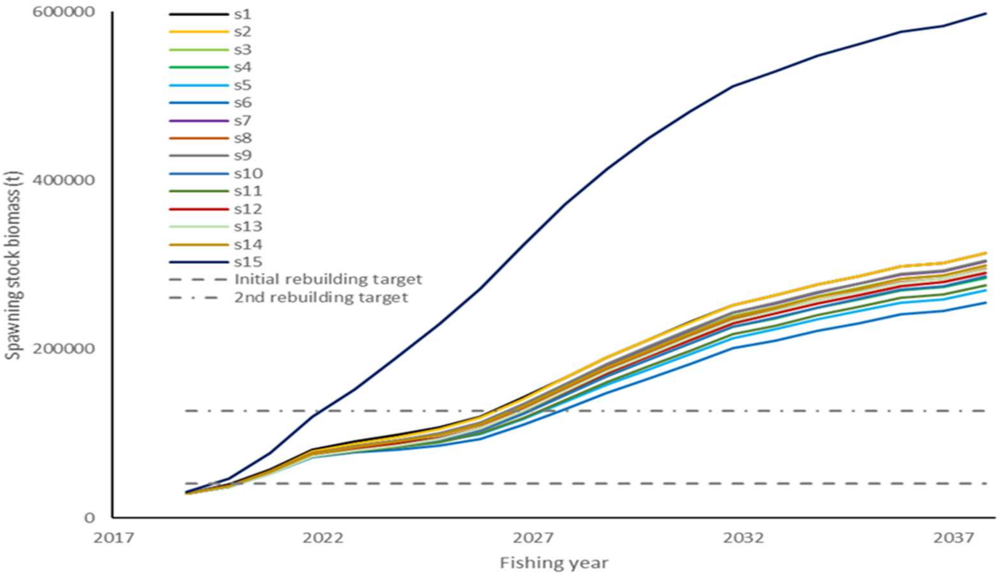


Figure 6-4. Comparisons of various projection results for Pacific bluefin tuna (Thunnus orientalis) obtained from bias-adjusted bootstrap projection results. Median of all harvest scenarios examined from Table 3.

APPENDIX 1

Future Impact plots from Future Projection

For additional information, impacts by fleets estimated from future projections under various harvest scenarios from Table 4-2 are provided.

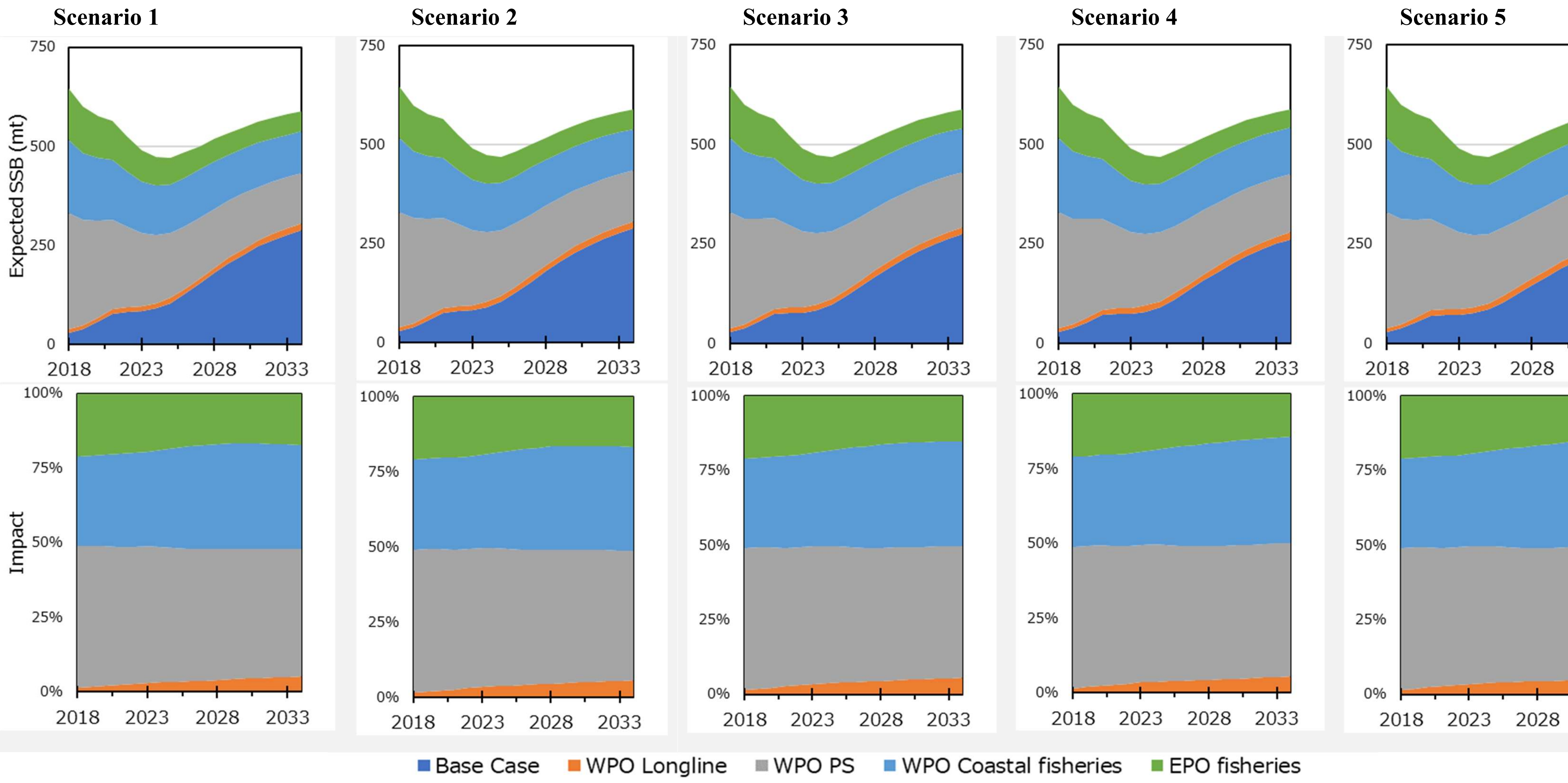


Figure A-1. Result of impacts by fleets estimated from future projections.

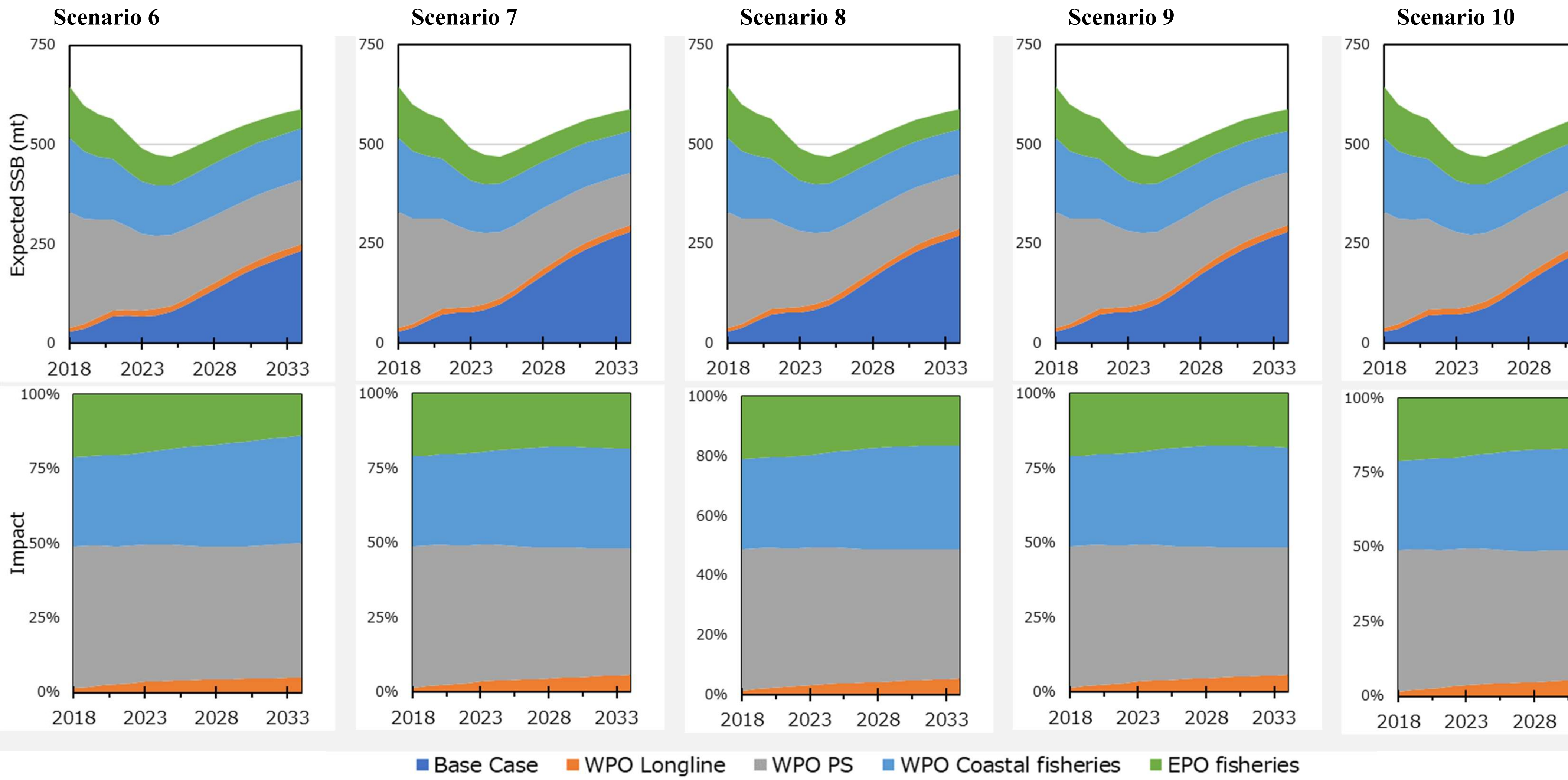


Figure A-1. Cont.

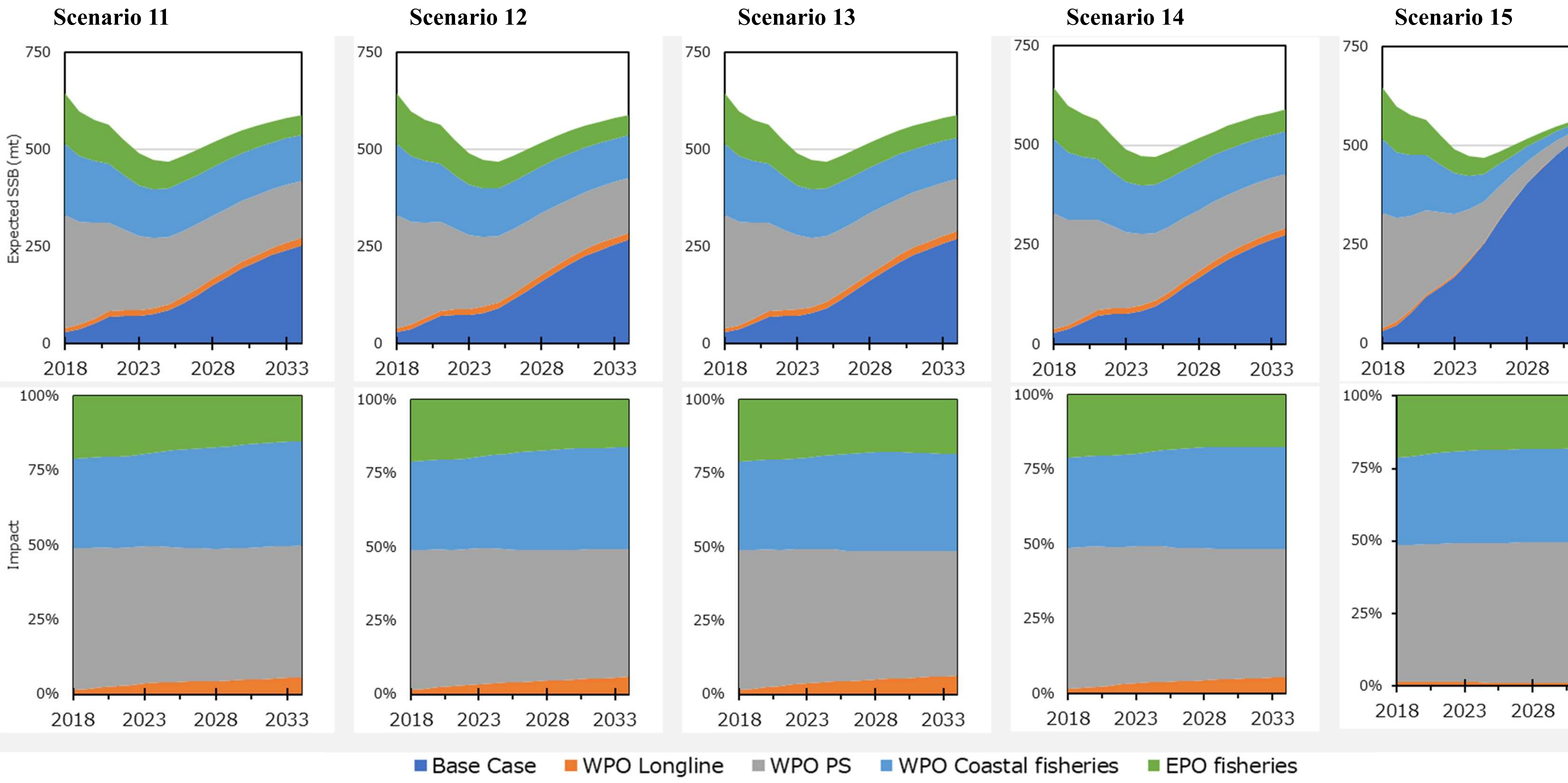


Figure A-1. Cont.