JOINT IATTC AND WCPFC-NC WORKING GROUP MEETING ON THE MANAGEMENT OF PACIFIC BLUEFIN TUNA
NINTH SESSION (JWG-09)

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Stock Assessment of Pacific Bluefin Tuna in the Pacific Ocean in 2024
(ISC24 – Annex 13)

IATTC-NC-JWG09-2024/IP-01

ISC[1]

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

FINAL

ISC/24/ANNEX/13

ANNEX 13

24th Meeting of the
International Scientific Committee for Tuna
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STOCK ASSESSMENT OF PACIFIC BLUEFIN TUNA IN THE PACIFIC OCEAN IN 2024

June 2024

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Table of Contents

ISC PBFWG

EXECUTIVE SUMMARY

1. Stock Identification and Distribution

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

2. Catch History

While there are few Pacific bluefin tuna (PBF) catch records prior to 1952, PBF landing 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 1952-2022 (Figure 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 2021 and 2022 was 15,107 t and 17,458 t, respectively, including non-member countries of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC). Catch management measures were implemented by Regional Fisheries Management Organizations (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 the catch is currently made by purse seine fisheries (Figure 2). Catches during 1952-2022 were predominantly composed of juvenile PBF; the catch of age 0 PBF has increased significantly since the early 1990s but declined as the total catch in weight declined since the mid-2000s and due to stricter control of juvenile catch (Figures 1 and 3).

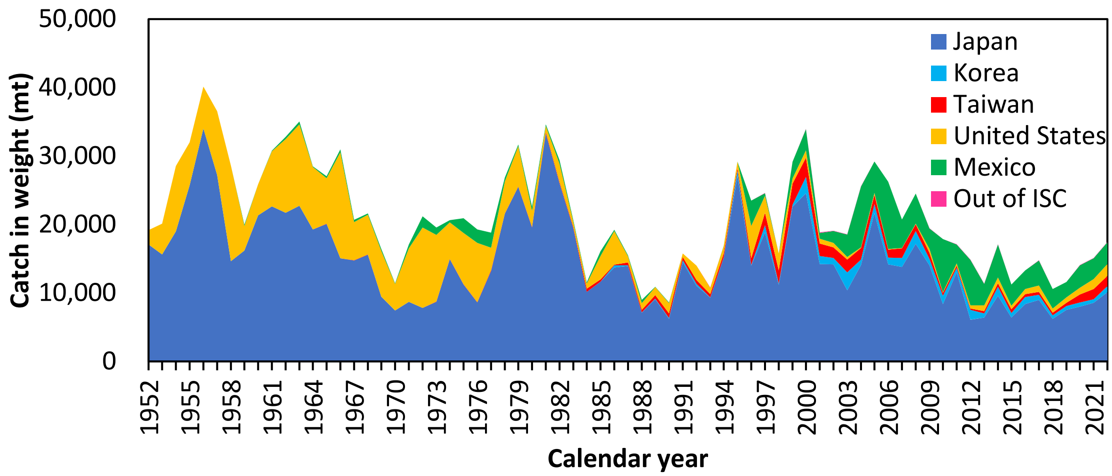

Figure 1. Annual catch (tons) of Pacific bluefin tuna (*Thunnus orientalis*) by ISC member countries from 1952 through 2022 (calendar year) based on ISC official statistics.

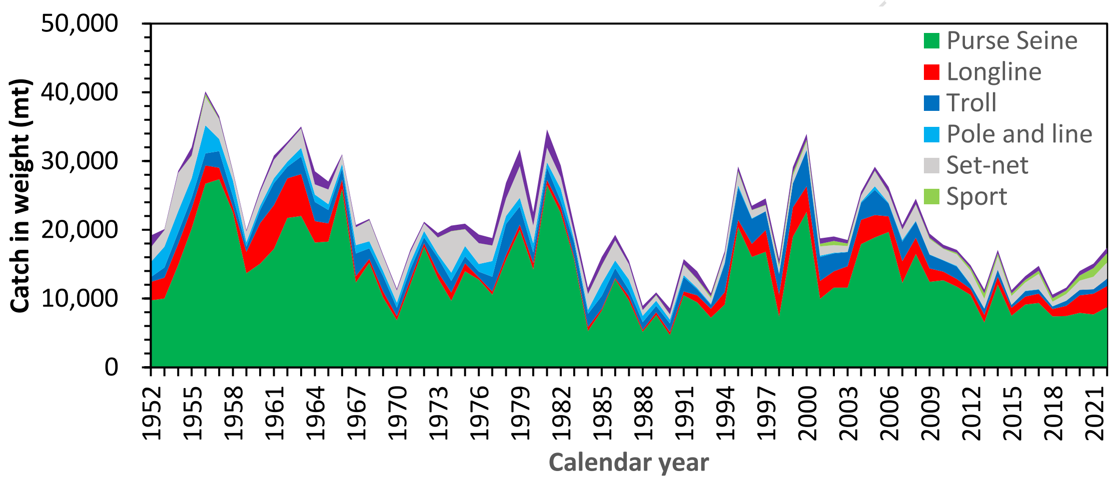

Figure 2. Annual catch (tons) of Pacific bluefin tuna (*Thunnus orientalis*) by gear type by ISC member countries from 1952 through 2022 (calendar year) based on ISC official statistics.

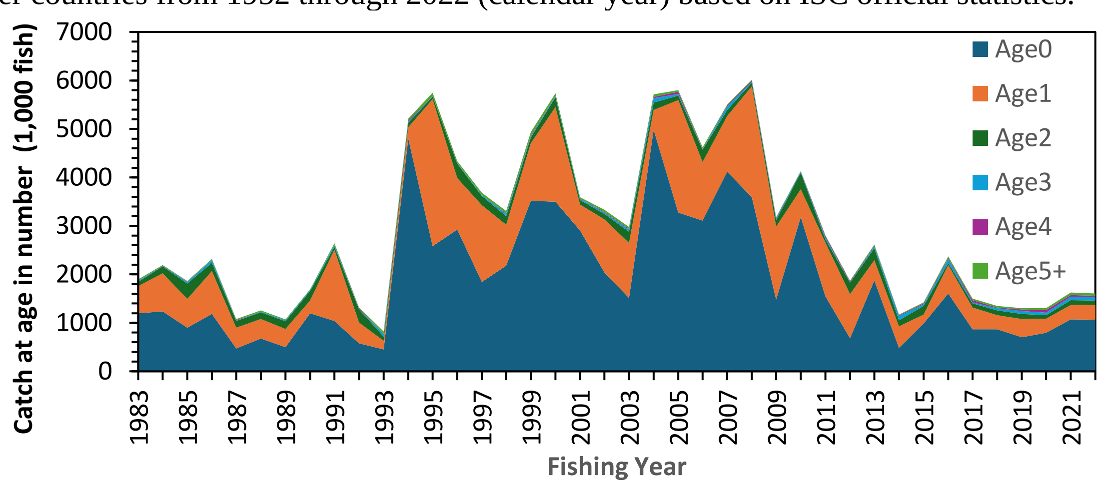

Figure 3. Estimated annual catch-at-age (number of fish) of Pacific bluefin tuna (*Thunnus orientalis*) by fishing year estimated by the base-case model (1983-2022).

3. 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 1983 to 2023, provided by Members of (ISC), Pacific Bluefin Tuna Working Group (PBFWG) and non-ISC countries obtained from the WCPFC official statistics. 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.

In 2024, the PBFWG conducted a benchmark stock assessment. The PBFWG critically reviewed all aspects of the model, and some modifications were made to improve the model. A total of 26 fleets were defined for use in the stock assessment model based on country/gear/season/region stratification until the end of the fishing year 2022 (June 2023). 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 Chinese Taipei longline, and the Japanese troll fleets were used as measures of the relative abundance of the population. The CPUE of Japanese longline (adult index) after 2020 and Japanese troll (recruitment index) after 2010 were not included in the model, as these observations may be biased due to additional management measures in Japan. 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.

One of the major changes made in this assessment is that the PBFWG decided to shorten the stock assessment model by starting in 1983 instead of 1952. This adjustment was implemented because more reliable data are available after 1983. Additionally, the adoption of a shorter model period enhances flexibility and can accommodate diverse productivity assumptions. This flexibility is an important feature as this model will be used in the upcoming PBF management strategy evaluation (MSE). The PBFWG confirmed that the results and management quantities of the longer period model and the shorter period model are consistent and that the change in the duration of the assessment model does not affect the management advice (Figure 4). A simple update of the 2022 stock assessment with new data estimated slightly higher relative biomass after 2011, reflecting an underestimating tendency of the past model (Figure 4). Other changes include refined parameterization of selectivity to reduce model residuals and shortening of the recruitment index from 1983-2016 to 1983-2010. The truncation of the recruitment index was supported by various analyses as described in the main body of the assessment report and was considered appropriate to reduce the SSB retrospective bias (Mohn's ρ for 10 years-retrospective analysis in the base case is -0.06), which was observed in several previous assessment models. After these modifications, the base-case model fits better to the input data and shows good prediction skill (the root mean square error of the Taiwanese longline CPUE for the predicted 7-year period was 0.24, see Figure 5). The PBFWG therefore concluded that the model is appropriate for generating management advice. Due to those changes, recent relative biomass was scaled up to some extent (see Figure 4) as the retrospective bias was reduced.

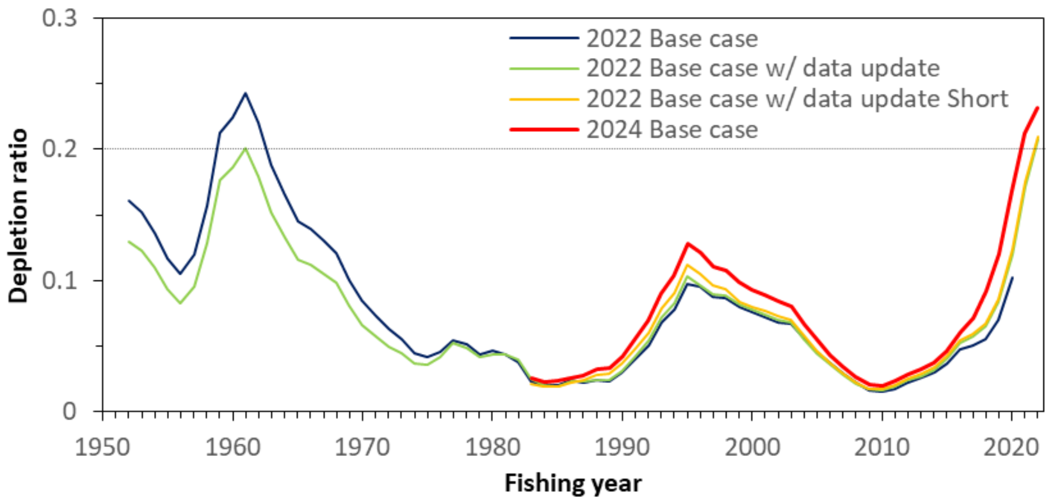

Figure 4. Comparison of the trajectory of relative biomass ($SSB/SSB_{F=0}$, depletion ratio) of the assessment models bridging from the 2022 base-case to the 2024 base-case (2022 base-case, 2022 base-case with data-update, 2022 base-case with data-update Short (1983-), and the 2024 base-case model). The 2022 base-case with data-update and 2022 base-case with data-update Short (1983-) almost overlap towards the end. SSB is spawning stock biomass and $SSB_{F=0}$ is the expected SSB under average recruitment conditions without fishing. The horizontal line represents $20\%SSB_{F=0}$ (the second biomass rebuilding target).

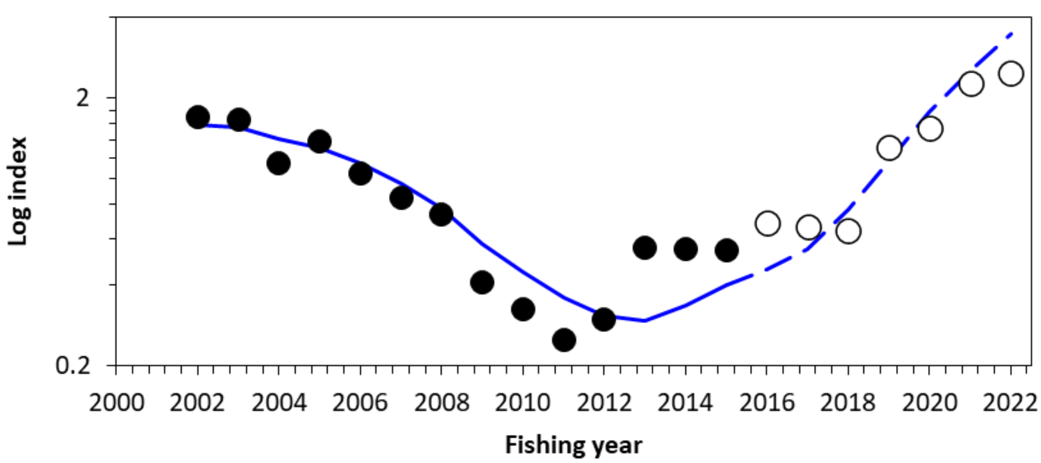

Figure 5. Result for hindcasting of the recent 7 years (2016-2022) based on the catch at age. The expected (blue solid line) and predicted (blue dashed lines) Taiwanese longline CPUE index from the age-structured production model, where CPUE observations were removed for the recent 7 years. The solid circles represent the observations used in the model, and open circles represent the missing values.

After conducting thorough reviews and implementing necessary modifications, the PBFWG found that the 2024 base-case model is consistent with the previous assessment results, that it fits the data well, that the results are internally consistent among most of the data sources, and that the model has improved overall by addressing the issues previously identified. The model diagnostics have confirmed that the base-case model captures the production function of PBF well, thus its estimated biomass scale is reliable, and that the model has good predictability. Based on these findings, the PBFWG concluded that the 2024 assessment model reliably represents the population dynamics and provides the best available scientific information for the PBF stock.

4. Stock Status and Conservation Information

The base-case model results show that: (1) spawning stock biomass (SSB) fluctuated throughout the assessment period (fishing years 1983-2022); (2) the SSB steadily declined from 1996 to 2010; (3) the SSB has rapidly increased since 2011; (4) fishing mortality ($F_{\%SPR}$) decreased from a level producing about 1% of SPR[1] in 2004-2009 to a level producing 23.6% of SPR in 2020-2022; and (5) SSB in 2022 increased to 23.2% of $SSB_{F=0}$[2], achieving the second rebuilding target by WCPFC and IATTC in 2021. Based on the model diagnostics, the estimated biomass trend throughout the assessment period is considered robust. The SSB in 2022 was estimated to be 144,483 t (Table 1 and Figure 6), more than 10 times of its historical low in 2010. An increase in immature fish (0-3 years old) is observed in 2016-2019 (Figure 7), likely resulting from reduced fishing mortality on this age group. This led to a substantial increase in SSB after 2019. The method to estimate confidence interval was changed from bootstrapping in the previous assessments to normal approximation of the Hessian matrix.

Historical recruitment estimates have fluctuated since 1983 without an apparent trend (Figure 6). Currently, stock projections assume that future recruitment will fluctuate around the historical (1983-2020 FY) average recruitment level. Previously, no significant autocorrelation was found in recruitment estimates, supporting the use in the projections of recruitment sampled at random from the historical time series. In addition, now that SSB has recovered to 23.2%$SSB_{F=0}$, the PBFWG considers the assumption that the future recruitment will fluctuate within the historical range to be reasonable. The PBFWG also confirmed that the distributions of historical recruitment from the updated long-term model (1952-2022) and the present base-case model (1983-2022) are comparable.

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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).

[2] SSBF=0 is the expected spawning stock biomass under average recruitment conditions without fishing.

Table 1. Total biomass, spawning stock biomass, recruitment, spawning potential ratio, and depletion ratio of Pacific bluefin tuna (*Thunnus orientalis*) estimated by the base-case model, for the fishing years 1983-2022.

Year	Total Biomass (mt)	Spawning Stock Biomass (mt)	Recruiment (x1000 fish)	Spawning Potential Ratio	Relative biomass over $SSB_{F=0}$
1983	31,993	15,429	11,827	3.7%	2.5%
1984	34,852	13,898	8,176	7.1%	2.2%
1985	38,514	14,280	9,207	4.6%	2.3%
1986	38,713	15,925	8,094	1.8%	2.6%
1987	36,385	16,934	6,956	10.4%	2.7%
1988	40,630	19,967	8,977	16.4%	3.2%
1989	47,141	20,590	4,187	18.1%	3.3%
1990	57,723	26,079	21,138	22.1%	4.2%
1991	75,302	34,208	7,400	13.2%	5.5%
1992	84,406	43,037	4,375	16.8%	6.9%
1993	93,667	55,854	3,985	19.0%	9.0%
1994	103,163	64,267	30,951	12.0%	10.3%
1995	116,349	79,269	15,247	7.3%	12.7%
1996	109,419	75,121	17,967	9.2%	12.1%
1997	108,955	68,311	11,344	7.5%	11.0%
1998	104,534	66,696	15,469	5.2%	10.7%
1999	100,748	60,915	21,993	5.6%	9.8%
2000	94,830	57,366	13,910	1.9%	9.2%
2001	82,675	54,907	16,944	9.6%	8.8%
2002	83,931	51,822	13,375	6.3%	8.3%
2003	79,217	49,650	6,748	2.3%	8.0%
2004	70,699	41,296	27,619	1.3%	6.6%
2005	65,488	33,668	15,323	0.6%	5.4%
2006	51,886	26,737	13,854	1.1%	4.3%
2007	45,705	20,791	23,619	0.5%	3.3%
2008	44,337	16,082	21,038	1.0%	2.6%
2009	39,232	12,526	7,983	1.7%	2.0%
2010	37,537	12,275	17,593	2.8%	2.0%
2011	39,632	14,236	13,822	5.8%	2.3%
2012	43,506	17,447	7,663	9.6%	2.8%
2013	48,901	19,711	14,239	7.6%	3.2%
2014	54,166	22,690	4,882	15.9%	3.6%
2015	62,945	28,019	13,367	20.9%	4.5%
2016	77,523	37,762	16,040	21.5%	6.1%
2017	94,213	44,541	11,417	31.4%	7.2%
2018	118,007	56,986	9,991	37.1%	9.2%
2019	146,407	74,734	7,485	29.5%	12.0%
2020	168,571	104,243	6,828	28.4%	16.8%
2021	182,567	131,729	8,275	20.5%	21.2%
2022	186,632	144,483	11,467	21.9%	23.2%
Median (1983-2022)	73,000	35,985	11,647	8.4%	5.8%
Average (1983-2022)	78,528	44,112	12,769	11.5%	7.1%
Unfished (Equilibrium)	785,281	622,254	13,261	100%	100%

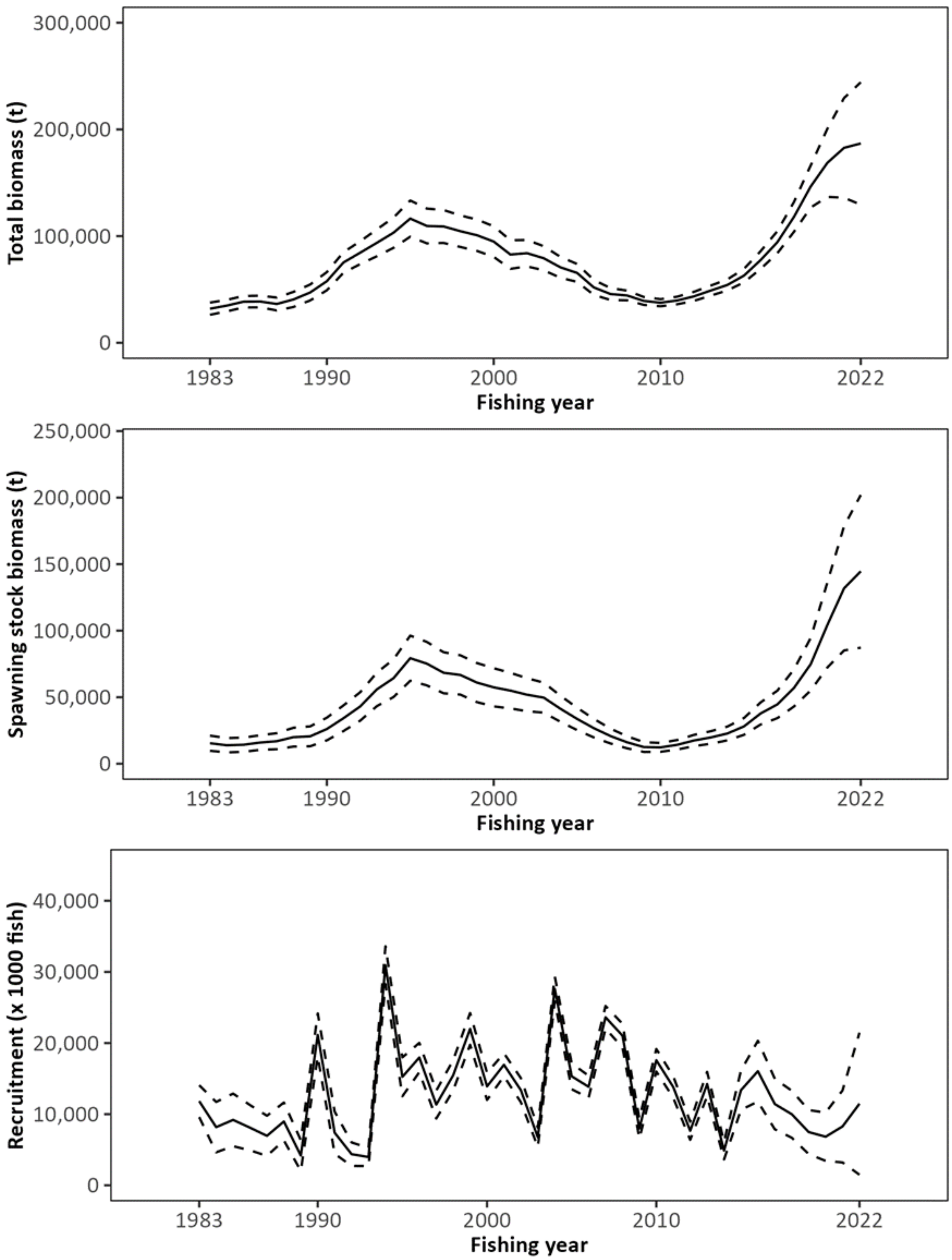


Figure 6. Trajectory of total stock biomass (top), spawning stock biomass (middle), and recruitment (bottom) of Pacific bluefin tuna (*Thunnus orientalis*) (1983-2022) estimated from the base-case model. The solid line is the point estimate, and dashed lines delineate the 90% confidence interval. The method used to estimate the confidence interval was changed from bootstrapping in the previous assessments to the normal approximation of the Hessian matrix.

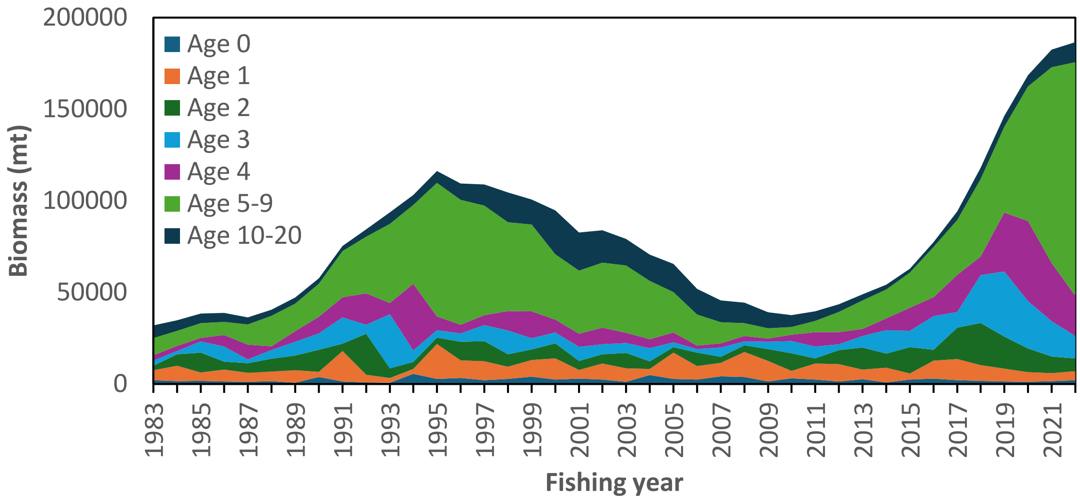


Figure 7. Total biomass (tons) by age of Pacific bluefin tuna (*Thunnus orientalis*) estimated from the base-case model (1983-2022). Note that the recruitment estimates for 2019-2022 are more uncertain than for other years.

The recruitment index based on the Japanese troll CPUE has proven to be an informative indicator of recruitment in PBF assessments. However, the PBFWG found that the catchability of the recruitment index may have been affected by the adoption of a new licensing system and an increase in troll catch for farming operations after 2010, as well as management interventions after 2016. In addition, an examination of model diagnostics suggested that fitting to the recruitment index after 2010 degraded model prediction skill and increased the SSB retrospective pattern. Therefore, for this assessment, the PBFWG extended the approach of the 2022 assessment and terminated the recruitment index after 2010. This was considered appropriate because even in the absence of a recruitment index, the model still has other reliable and mutually consistent data to estimate SSB and recruitments, in particular the adult indices.

Although the recruitments are well estimated for most of the time series, the recruitment estimates in the terminal period (2019-2022) are more uncertain than other years (Figure 6), which is also shown in the retrospective analysis of recruitment. The recruitment estimate in the terminal year (2022) is uninformed by data and was hence based on the stock recruitment relationship and close to the estimated unfished recruitment. Therefore, recent recruitment estimates should be treated with caution.

Additional evidence on recent recruitment trends was examined by the PBFWG using the newly developed standardized CPUE index from the Japanese troll monitoring program for 2011-2023 (Figure 8). Although the PBFWG concluded that it was premature to include this index in the base-case model, this index is believed to provide a good qualitative indication of recruitment trends. With regard to the recent low recruitment period estimated by the base-case model (2019-2021), the monitoring index showed relatively low recruitment in 2019 and 2020, but relatively high recruitment in 2021-2023. Based on this evidence and the uncertainty in the retrospective analysis of recruitment previously noted, the PBFWG considered the 2021 recruitment estimate from the base-case model to be less reliable. Therefore, the PBFWG decided to start using resampled historical recruitment from 2021, rather than 2022, for the projections.

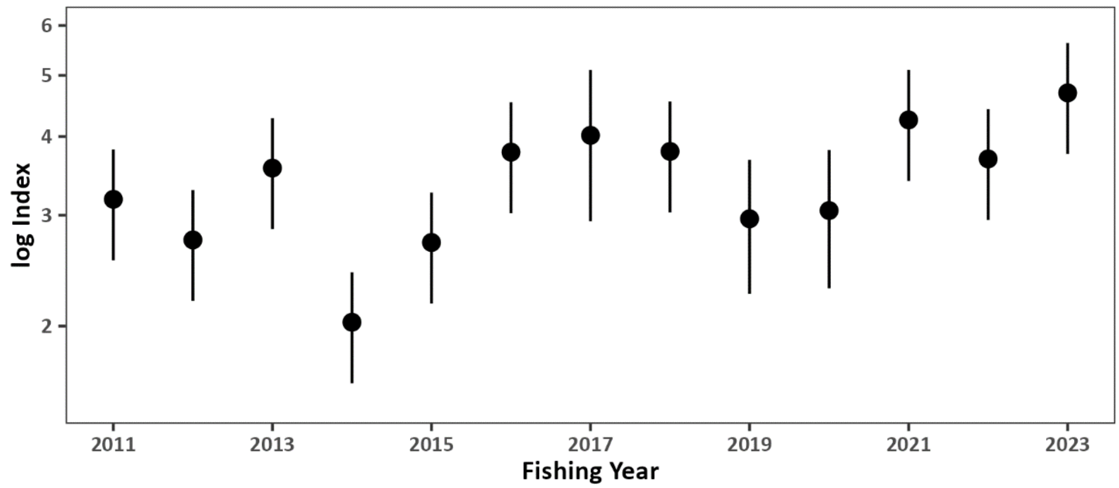


Figure 8. Standardized CPUE index from the Japanese recruitment monitoring program (2011-2023). The bar represents the 95% confidence interval.

This, in effect, means that the recruitment in 2021 is assumed to be around the historical average, and if in fact it is lower than assumed, though the PBFWG believes it unlikely from the survey index (Figure 8), the near-term projection results would become more pessimistic.

Estimated age-specific fishing mortalities (F) on the stock during the periods of 2012-2014 and 2020-2022, compared with 2002-2004 estimates (the reference period for the WCPFC Conservation and Management Measure), are presented in Figure 9.

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) but not a fishing mortality reference level. The previous (2022) assessment estimated the initial rebuilding biomass target ($SSB_{MED1952-2014}$) to be 6.3%$SSB_{F=0}$ and the corresponding fishing mortality expressed as SPR of $F_{6.3\%SPR}$ (Table 2). The Kobe plot shows that the point estimate of the SSB_{2022} was 23.2%$SSB_{F=0}$ and that the recent (2020-2022) fishing mortality corresponds to $F_{23.6\%SPR}$ (Table 1 and Figure 10). The apparent increase in F in the terminal period compared to the historical low in 2018 ($F_{37.1\%SPR}$) is a result of low recruitment in this period. As noted, the recruitment estimates in recent years are more uncertain and this result needs to be interpreted with caution.

Figure 11 depicts the historical impacts of the harvest by the fleets on the PBF stock, showing the estimated biomass when fishing mortality from the respective fleets is zero. Note that trends in fishery impact back to 1970 were computed using the base-case model extended to 1952. 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 2022 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. In 2022, the estimated cumulative impact proportion between WPO and EPO fisheries is about 83% and 17%, respectively. There is greater uncertainty regarding discards than other fishery impacts because the impact of discarding is not based on observed data. Currently, the amount of discard mortality is assumed to be 6% of the reported release in EPO and 5% of the catch in WPO.

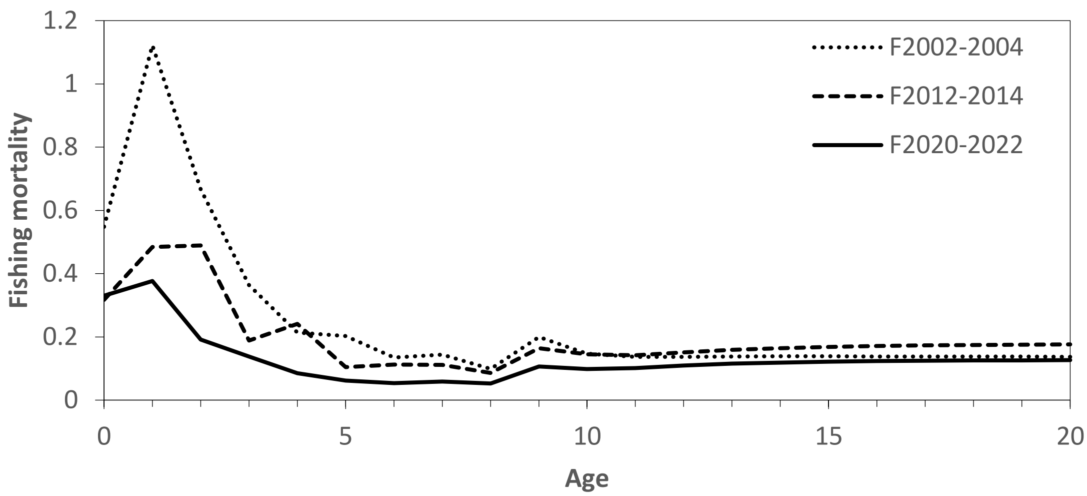


Figure 9. Geometric means of annual age-specific fishing mortalities (F) of Pacific bluefin tuna (*Thunnus orientalis*) for 2002-2004 (dotted line), 2012-2014 (dashed line), and 2020-2022 (solid line).

Table 2. Ratios of the estimated fishing mortalities (Fs and 1-SPRs for 2002-04, 2012-14, 2020-2022) 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). Fxx%SPR: F that produces a given % of the unfished spawning potential (biomass) under equilibrium conditions.

Reference Period	Fmax	(1-SPR)/(1-$SPR_{xx\%}$)				Estimated SSB for terminal year of each period (ton)	Depletion rate for terminal year of each period (%)
		$SPR_{20\%}$	$SPR_{25\%}$	$SPR_{30\%}$	$SPR_{40\%}$		
2002-2004	1.88	1.21	1.29	1.38	1.61	41,296	6.6%
2012-2014	1.24	1.11	1.19	1.27	1.48	22,690	3.6%
2020-2022	0.84	0.95	1.02	1.09	1.27	144,483	23.2%

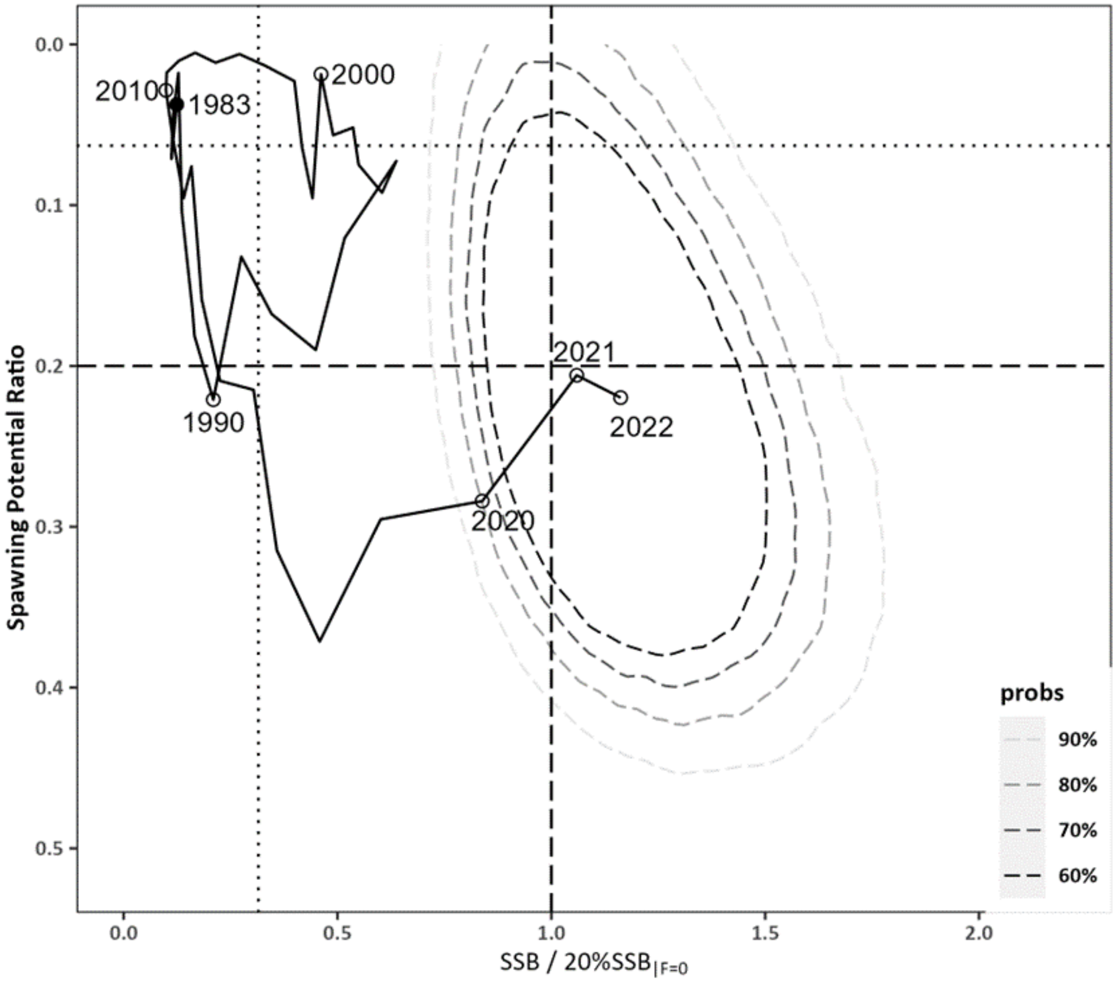


Figure 10. Kobe plot for Pacific bluefin tuna (*Thunnus orientalis*) estimated from the base-case model from 1983 to 2022. The X-axis shows the annual SSB relative to 20%$SSB_{F=0}$ and the Y-axis shows the spawning potential ratio (SPR) as a measure of fishing mortality. Vertical and horizontal dashed lines 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 dotted lines show the initial biomass rebuilding target (SSB_{MED} = 6.3%$SSB_{F=0}$) and the corresponding fishing mortality that produces SPR, respectively. SSB_{MED} is calculated as the median of estimated SSB over 1952-2014 from the 2022 assessment. The apparent increase of F in the terminal period is a result of low recruitment in this period. As noted, the recruitment estimates in recent years are more uncertain and this result needs to be interpreted with caution. Contour plots represent 60% to 90% of two probability density distributions in SSB and SPR for 2022. The method used to estimate the confidence interval was changed from bootstrapping in the previous assessments to resampling from the multi-variate log-normal distribution. The probability distribution for the area where SPR is below zero is not shown as such SPR values are not biologically possible.

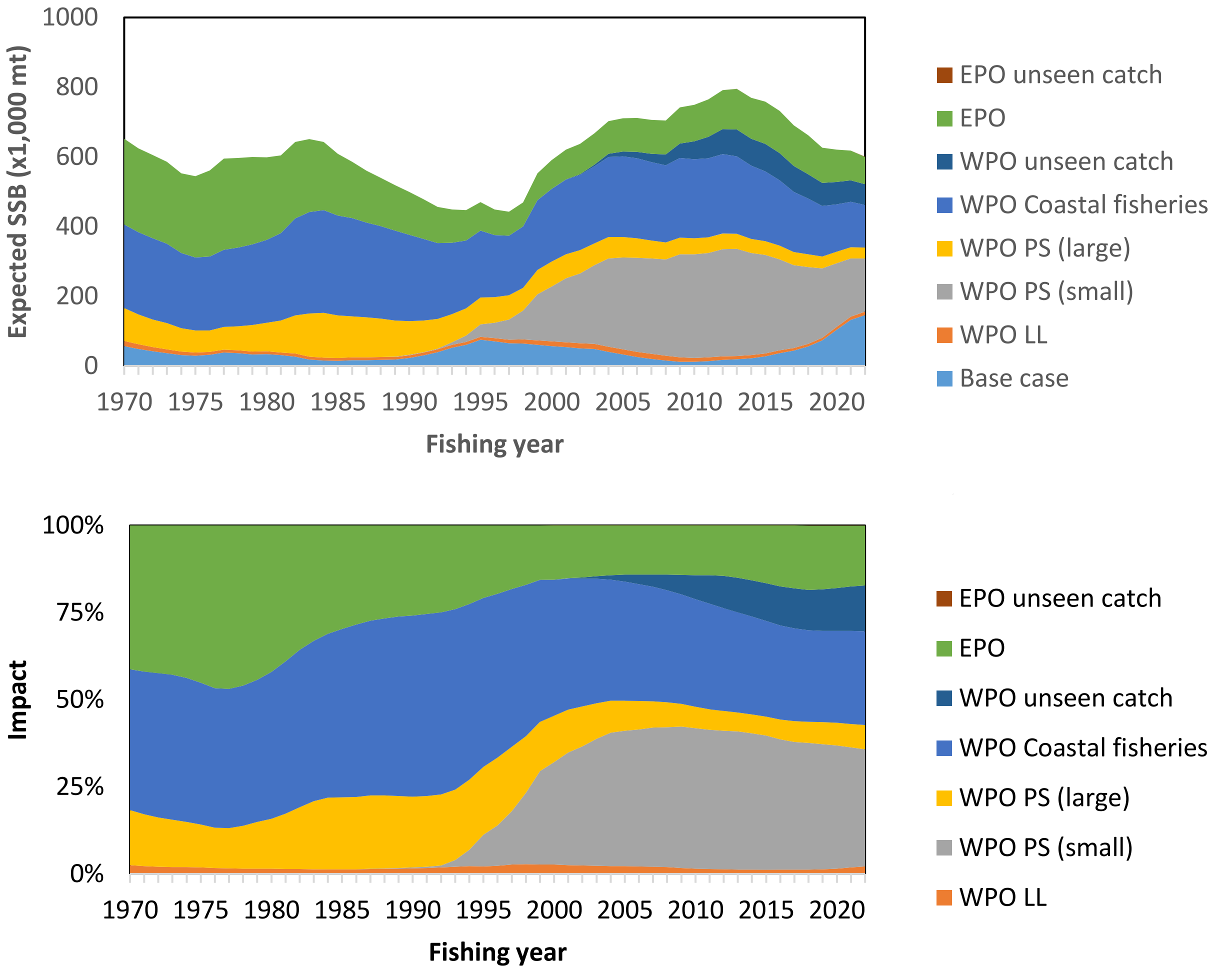


Figure 11. The trajectory of the spawning stock biomass of a simulated population of Pacific bluefin tuna (*Thunnus orientalis*) when zero fishing mortality is assumed, estimated by the base-case long-term model. (top: absolute SSB, bottom: relative SSB). In 2022, the estimated cumulative impact proportion between WPO and EPO fisheries is about 83% and 17%, respectively. Fisheries group definition: WPO longline fisheries: F1-4. WPO purse seine fisheries for large fish: F5-7. WPO purse seine fisheries for small fish: F8-11. WPO coastal fisheries: F12-19. EPO fisheries: F20-23. WPO unaccounted fisheries: F24, 25. EPO unaccounted fisheries: F26. For exact fleet definitions, please see the 2024 PBF stock assessment report. Although larger PBF have been caught by the Korean offshore large-scale purse seine in recent years, this fleet is included in “WPO PS (small)” because of their historical selectivity.

Stock Status

PBF spawning stock biomass (SSB) has increased substantially in the last 12 years. These biomass increases coincide with a decline in fishing mortality, particularly for fish aged 0 to 3, over the last decade. The latest (2022) SSB is estimated to be 23.2% of $SSB_{F=0}$ and the probability that it is above $20\%SSB_{F=0}$ is 75.9%. Based on these findings, the following information on the status of the Pacific bluefin tuna stock is provided:

1. **No biomass-based limit or target reference points have been adopted for PBF, but the PBF stock is not overfished relative to $20\%SSB_{F=0}$, which has been adopted as a biomass-based reference point for some other tuna species by the IATTC and WCPFC. SSB of PBF reached its initial rebuilding target ($SSB_{MED} = 6.3\%SSB_{F=0}$) in 2017, 7 years earlier than originally anticipated by the RFMOs, and its second rebuilding target ($20\%SSB_{F=0}$) in 2021; and**
2. **No fishing mortality-based reference points have been adopted for PBF by the IATTC and WCPFC. The recent (2020-2022) F%SPR is estimated to be 23.6% and thus the PBF stock is not subject to overfishing relative to some of F-based reference points proposed for tuna species (Table 2), including F20%SPR.**

Conservation Advice

After the steady decline in SSB from 1996 to the historically low level in 2010, the PBF stock has started recovering, and recovery has been more rapid in recent years, coinciding with the implementation of stringent management measures. The 2022 SSB was 10 times higher than the historical low and is above the second rebuilding target adopted by the WCPFC and IATTC, which was achieved in 2021. The stock has recovered at a faster rate than anticipated when the Harvest Strategy to foster rebuilding (WCPFC HS 2017-02) was implemented in 2014. The fishing mortality (F%SPR) in 2020-2022 is at a level producing 23.6%SPR. According to the requests from WCPFC and IATTC, future projections under various scenarios were conducted. The projection scenarios and their results, the figure of projection results, "future Kobe plot", and "future impact plot" are provided as Tables 3-5, Figures 12, 13, and 14, respectively. In addition, the results of additional projections which were requested by the Join Working Group of IATTC-WCPFC NC is provided in Appendix 2 of the stock assessment report (ISC 2024 Annex13).

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

1. **The PBF stock is recovering from the historically low biomass in 2010 and has exceeded the second rebuilding target ($20\%SSB_{F=0}$). The risk of SSB falling below $7.7\%SSB_{F=0}$ (interim LRP for tropical tunas in IATTC) at least once in 10 years is negligible;**
2. **The projection results show that increases in catches are possible. However, the risk of falling below the second rebuilding target will increase with larger increases in catch;**
3. **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. Discard mortality may need to be considered as part of future increases in catch; and

4. **Given the uncertainty in future recruitment and the influence of recruitment on stock biomass as well as the impact of changes in fishing operations due to the management, monitoring recruitment and SSB should continue. Research on a recruitment index for the stock assessment should be pursued, and maintenance of a reliable adult abundance index should be ensured. In addition, accurate catch information is the foundation of good stock assessment.**

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

Harvesting scenarios											
Reference No	Scenarios				Catch limit in the projection				Specified fishery impact at 2034		Note
	WCPO		EPO		WCPO		EPO				
	Small	Large	Small	Large	Small	Large	Small	Large	WCPO	EPO	
1	Status quo (WCPFC CMM2023-02, IATTC Resolution 21-05)				4,475	7,859	3,995		-	-	JWG's request 1(NC19 Summary Report, Attachment E; Maintaining the current CMM)
2	Maintaining the current CMM assuming maximum transfer utilizing the conversion factor				3,236	9,799	3,995		-	-	JWG's request 02 (Maximum utilization of transfer from small fish catch limit to large fish catch limit using the conversion factor).
3	No fishing allowed				0	0	0		-	-	JWG's request 03 (No fishing)
4	Status quo +60%	Status quo +60%	Status quo +60%		7,310	12,424	6,392		-	-	JWG's request 04-1 (scenario achieving 20%SSB0 with 60%probability by pro-rata change in catch).
5	Status quo	Status quo +180%	Status quo +180%		4,475	21,555	11,186		-	-	JWG's request 04-2 (scenario achieving 20%SSB0 with 60%probability by proportional change in catch among the WCPO large fish catch limit and EPO total catch limit).
6	Status quo +20%	Status quo +163%	Status quo +108%		5,420	20,235	8,310		-	-	JWG's request 04-3 (scenario achieving 20%SSB0 with 60% probability by maintaining the total catch proportion between WCPO and EPO as status quo while limiting the catch limit increase for WCPO small fish as 20% of its original catch limit).
7	Status quo +30%	Status quo +131%	Status quo +92%		5,893	17,789	7,670		-	-	JWG's request 04-4 (scenario achieving 20%SSB0 with 60% probability by maintaining the total catch proportion between WCPO and EPO as status quo while limiting the catch limit increase for WCPO small fish as 30% of its original catch limit).
8	Status quo +30%	Status quo +30%	Status quo +190%		5,893	10,142	11,586		70	30	JWG's request 05-1 (explored constant catch scenario achieving 20%SSB0 with 60% probability and fishery impact ratio between WCPO and EPO as 70% and 30% while maintaining the catch proportion of small and large fish in WCPO as status quo).
9	Status quo +55%	Status quo +55%	Status quo +80%		7,074	12,044	7,191		80	20	JWG's request 05-1 (explored constant catch scenario achieving 20%SSB0 with 60% probability and fishery impact ratio between WCPO and EPO as 80% and 20% while maintaining the catch proportion of small and large fish in WCPO as status quo).
10	Status quo +10%	Status quo +130%	Status quo +190%		4,948	17,751	11,586		70	30	JWG's request 05-2 (explored constant catch scenario achieving 20%SSB0 with 60% probability and fishery impact ratio between WCPO and EPO as 70% and 30% while maintaining the catch proportion of small fish in WCPO lower than that of status quo).
11	Status quo +40%	Status quo +120%	Status quo +80%		6,015	17,540	7,191		80	20	JWG's request 05-3 (explored constant catch scenario achieving 20%SSB0 with 60% probability and fishery impact ratio between WCPO and EPO as 80% and 20% while maintaining the catch proportion of small fish in WCPO lower than that of status quo).
12	SPR30%				-				-	-	SPR30% Scenario F1719 multiplied 1.4

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

* Fishing mortality in scenario 3 was kept at zero. The catch limit for scenario 12 is calculated to achieve SPR 30% and allocated to fleets proportionately.

* The Japanese unilateral measure (transferring 250 mt of the catch upper limit from that for small PBF to that for large PBF during 2022-2034) is reflected in the projections.

Table 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.

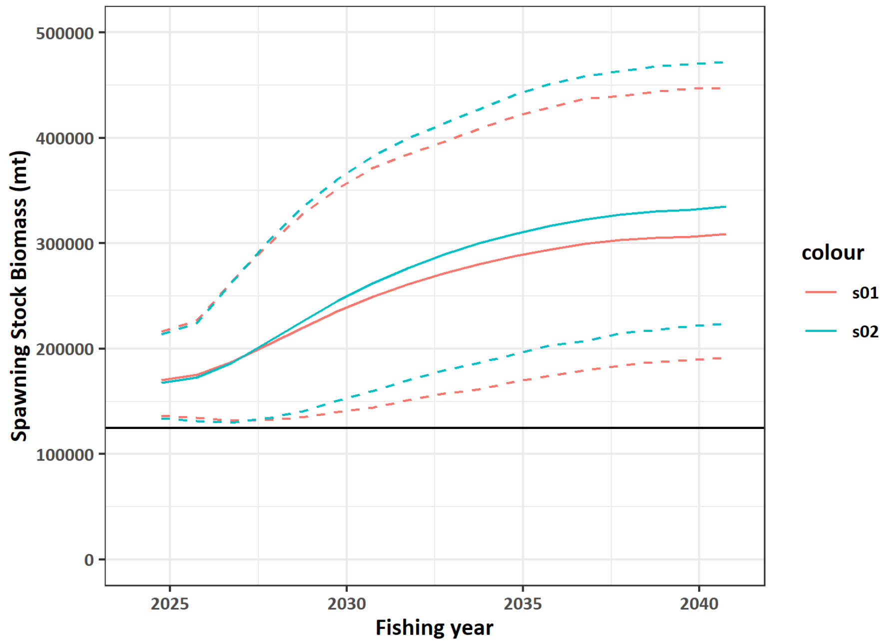
Harvesting scenarios							Performance indicators								
Reference No	Scenarios				Specified fishery impact		Median SSB at 2034	Fishery impact ratio of WPO fishery at 2034	Fishery impact ratio of EPO fishery at 2034	Probability of achiving the 2nd rebuilding target at 2041	Risk to breach $SSB_{7.7\%F=0}$ at least once by 2041	Probability of overfishing compared to 20%SSB0 at 2041	Probability of overfishing compared to 25%SSB0 at 2041	Probability of overfishing compared to 30%SSB0 at 2041	Probability of overfishing compared to 40%SSB0 at 2041
	WCPO		EPO												
	Small	Large	Small	Large	WCPO	EPO									
1	Status quo (WCPFC CMM2023-02, IATTC Resolution 21-05)				-	-	287,844	78%	22%	100%	0%	0%	1%	4%	20%
2	Maintaining the current CMM assuming maximum transfer utilizing the conversion factor				-	-	308,868	77%	23%	100%	0%	0%	0%	1%	10%
3	No fishing allowed				-	-	536,653	86%	14%	100%	0%	0%	0%	0%	0%
4	Status quo +60%	Status quo +60%	Status quo +60%		-	-	158,658	82%	18%	61%	8%	39%	57%	71%	89%
5	Status quo	Status quo +180%	Status quo +180%		-	-	143,211	71%	29%	60%	19%	40%	57%	71%	90%
6	Status quo +20%	Status quo +163%	Status quo +108%		-	-	148,332	78%	22%	60%	18%	40%	56%	69%	89%
7	Status quo +30%	Status quo +131%	Status quo +92%		-	-	156,324	80%	20%	63%	14%	37%	53%	67%	87%
8	Status quo +30%	Status quo +30%	Status quo +190%		70	30	158,245	69%	31%	61%	14%	39%	55%	68%	88%
9	Status quo +55%	Status quo +55%	Status quo +80%		80	20	162,242	79%	21%	63%	9%	37%	54%	69%	88%
10	Status quo +10%	Status quo +130%	Status quo +190%		70	30	147,825	70%	30%	60%	19%	40%	57%	70%	89%
11	Status quo +40%	Status quo +120%	Status quo +80%		80	20	153,985	80%	20%	61%	14%	39%	56%	69%	88%
12	SPR30%				-	-	190,088	77%	23%	99%	0%	1%	14%	43%	91%

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

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

Reference No	Harvesting scenarios: Scenarios WCPO Small	WCPO Large	EPO Small	EPO Large	Catch limit in the projection WCPO Small	WCPO Large	EPO Small	EPO Large	Expected catch 2029 WPO Small	WPO Large	EPO Commercial	EPO Sport	2034 WPO Small	WPO Large	EPO Commercial	EPO Sport
1	Status quo (WCPFC CMM2023-02, IATTC Resolution 21-05)				4,475	7,859	3,995		4,184	8,219	4,010	1,797	4,179	8,232	4,011	2,005
2	Maintaining the current CMM assuming maximum transfer utilizing the conversion factor				3,236	9,799	3,995		3,256	9,884	4,016	1,933	3,256	9,895	4,018	2,189
3	No fishing allowed				0	0	0		0	0	0	0	0	0	0	0
4	Status quo +60%	Status quo +60%	Status quo +60%		7,310	12,424	6,392		6,509	13,111	6,348	996	6,540	12,969	6,332	926
5	Status quo	Status quo +180%	Status quo +180%		4,475	21,555	11,186		4,386	21,718	11,223	1,033	4,383	20,799	11,224	1,055
6	Status quo +20%	Status quo +163%	Status quo +108%		5,420	20,235	8,310		5,388	20,361	8,321	1,030	5,394	19,989	8,330	1,035
7	Status quo +30%	Status quo +131%	Status quo +92%		5,893	17,789	7,670		5,727	17,911	7,669	1,035	5,739	17,717	7,673	1,026
8	Status quo +30%	Status quo +30%	Status quo +190%		5,893	10,142	11,586		5,488	10,540	11,562	993	5,508	10,420	11,556	950
9	Status quo +55%	Status quo +55%	Status quo +80%		7,074	12,044	7,191		6,594	12,521	7,194	1,011	6,620	12,456	7,196	953
10	Status quo +10%	Status quo +130%	Status quo +190%		4,948	17,751	11,586		4,704	18,017	11,581	1,020	4,707	17,667	11,589	1,025
11	Status quo +40%	Status quo +120%	Status quo +80%		6,015	17,540	7,191		5,991	17,424	7,197	1,027	6,006	17,233	7,205	1,000
12	SPR30%				-				4,820	18,091	5,607	715	4,812	19,436	5,668	733

* Korean catch reflects the recent catch proportion for small and large, thus expected catches do not match with catch allocations.



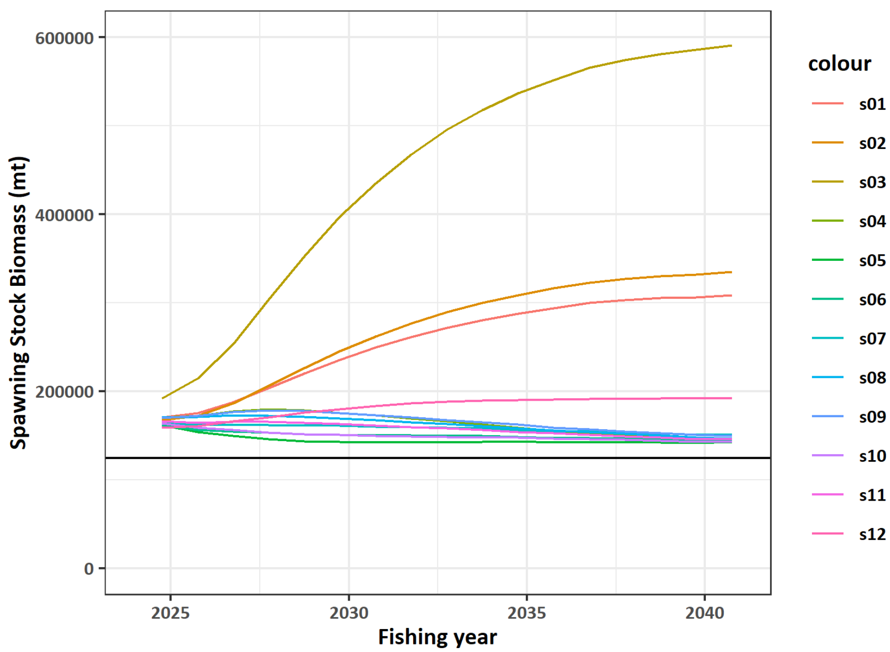


Figure 12. Comparisons of various projection results for Pacific bluefin tuna (*Thunnus orientalis*) obtained from projection results. (Top) Median of scenarios 1 and 2 (solid lines) and their 90% confidence intervals (dotted lines). (Bottom) Median of all harvest scenarios examined from Table 3. The horizontal line represents the second rebuilding target.

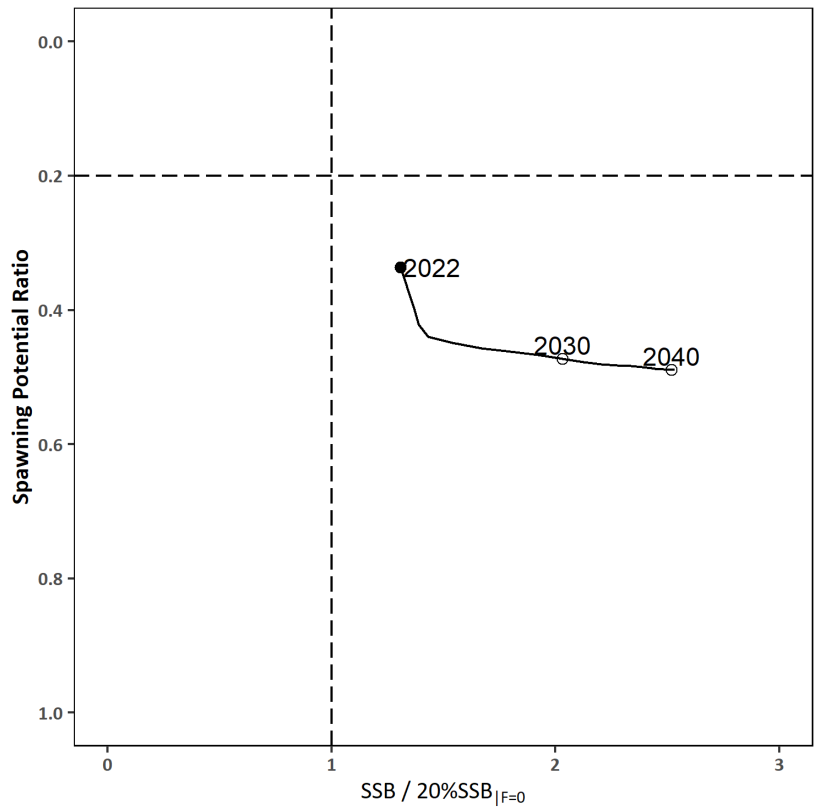


Figure 13. "Future Kobe Plot" of projection results for Pacific bluefin tuna (*Thunnus orientalis*) from Scenario 1 in Table 3. Vertical and horizontal dashed lines show 20%$SSB_{F=0}$ (which corresponds to the second biomass rebuilding target) and the corresponding fishing mortality that produces SPR, respectively.

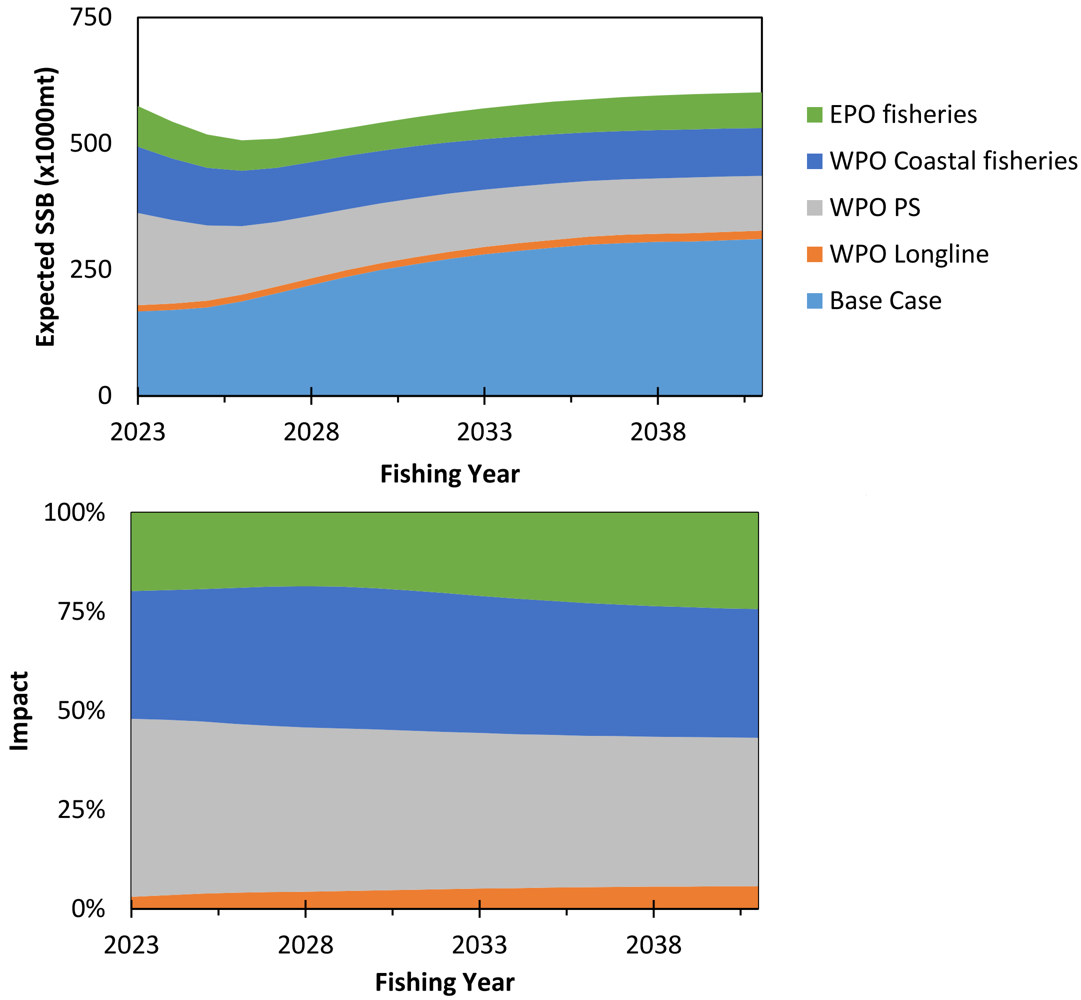


Figure 14. "Future impact plot" from projection results for Pacific bluefin tuna (*Thunnus orientalis*) from Scenario 1 in Table 3. The top figure shows absolute biomass and the bottom figure shows relative impacts. The impact is calculated based on the expected increase of SSB in the absence of the respective group of fisheries.

1. INTRODUCTION

Pacific bluefin tuna (PBF) *Thunnus orientalis* is a highly migratory species of great economic importance, predominantly found 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, is tasked with conducting regular stock assessments. These assessments involve compiling fishery statistics and biological information, estimating population parameters, forecasting the population under various harvesting scenarios, summarizing stock status, and developing conservation information. The results are submitted to two Pacific tuna regional fisheries management organizations (RFMOs), the Western Central Pacific Fisheries Commission (WCPFC) and the Inter-American Tropical Tuna Commission (IATTC), for review and serve as the basis for management actions (the Conservation and Management Measures (CMMs) of WCPFC and IATTC resolutions).

The PBFWG completed the last benchmark stock assessment in 2020, followed by the updated stock assessment in 2022 using fishery data from 1952 (Fishing Year, FY) through 2020 FY (ISC 2022). The 2022 assessment model was developed and tested using a suite of diagnostics. All diagnostic results did not indicate any fatal misspecification of the assessment model; rather, they demonstrated the internal consistency of the model and its good predictive skill of future biomass (ISC 2022). The 2022 stock assessment concluded that (1) the 2020 (FY) spawning stock biomass (10.2%SSB_0) fell between the biomass rebuilding targets ($SSB_{med\ 1952\text{-}2014}$ of 6.3%SSB_0 and 20%SSB_0) adopted by the WCPFC and IATTC, (2) the recent (2018-2020) F%SPR was estimated to produce a fishing intensity of 30.7%SPR, below the level corresponding to overfishing for many F-based reference points proposed for tuna species, including SPR20%, and (3) under all examined projection scenarios, the second rebuilding target of WCPFC and IATTC, rebuilding to 20%$SSB_{F=0}$ by the 2029 fishing year (FY) (10 years after reaching the initial rebuilding target) with at least 60% probability, would be reached, and the risk of SSB falling below the historically lowest observed SSB at least once in 10 years would be negligible.

For the 2024 benchmark assessment, the PBFWG developed the population dynamics model using fishery data up to the 2022 FY in Stock Synthesis (Methot and Wetzel 2013). In developing the 2024 assessment model, the PBFWG used the same philosophy underlying the 2022 model structure. Additionally, the PBFWG addressed the issues identified in the 2022 assessment model. For example, they conducted research on new abundance indices (Fujioka et al. 2023, Yuan et al. 2024), estimated coefficients of variation (CV) for length at ages based on over 7,000 conditional age at length data (Tsukahara et al. 2024), elucidated the cause of the systematic retrospective pattern in the SSB (Fukuda et al. 2023), developed a more flexible assessment model to ensure convergence against alternative assumptions about the productivity of the stock (Fukuda 2021), and elucidated the importance of parameter specifications in achieving a more stable solution and robust stock assessment results (Lee 2023). These advancements were incorporated into the 2024 assessment's base case model.

The 2024 benchmark assessment of Pacific bluefin tuna was conducted during 29 Feb-11 April 2024. This report summarizes the assessment results using newly available seasonal fishery data (i.e., catch, discards, size composition data) and annual abundance index through the 2023 calendar year.

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. The 1st of July is assumed to be the date of birth (recruitment) for PBF in the model. For example, the 2022 fishing year corresponds to the period from the 1st of July, 2022, to the 30th of June, 2023.

2. BACKGROUND on BIOLOGY and FISHERIES

2.1. Biology

2.1.1. 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 distinct species (*Thunnus orientalis* and *Thunnus thynnus*, respectively) based on genetic and morphometric studies (Collette 1999). This taxonomic distinction is adopted by pertinent tuna RFMOs, the Food and Agriculture Organization of the United Nations (FAO), and ISC.

The major spawning grounds of PBF are found in the western North Pacific Ocean (WPO): one is in waters between the Ryukyu Islands in Japan and the eastern coast of Taiwan, another one is in the southern portion of the Sea of Japan (Schaefer 2001), and the other possible one is around the Kuroshio-Oyashio transition area in the coastal region of northeastern Japan (Ohshimo et al. 2018, Tanaka et al. 2020) (Figure 2-1). Conversely, no evidence of PBF reproduction has been observed in the eastern Pacific Ocean (EPO) (Dewar et al. 2022). Studies on the natal origins of adult PBFs caught either in the waters around the Ryukyu Islands or in the Sea of Japan indicate that they originate from both of these spawning grounds (Uematsu et al. 2018). Similarly, elemental analysis of otoliths indicates that adult PBFs caught in the waters around Taiwan also originate from both known spawning grounds (Rooker et al. 2021). Additionally, age-1 PBFs caught in EPO have been traced back to both known spawning grounds using trace elements in their otoliths (Wells et al. 2020). These findings support the notion of a single stock for PBFs, as there is no significant difference in the natal origin between the two known spawning grounds. Genetics and tagging studies (e.g., Bayliff 1994, Tseng and Smith 2012) further support the assumption of a single stock for PBFs. A review conducted by Nakatsuka (2020) concluded that there is no evidence exclusively suggesting the existence of multiple stocks after examining available genetic and reproductive information, otolith and vertebrae data, and fishery data. As a result, a single stock is adopted in the PBF assessment within the ISC and is acknowledged by RFMOs (WCPFC and IATTC).

2.1.2. Reproduction

PBFs are known as iteroparous spawners, meaning they spawn multiple times throughout their lifespan. Spawning events are confined to specific areas and seasons: from April to July in the waters surrounding the Ryukyu Islands and off eastern Taiwan, and from July to August in the Sea of Japan. These conclusions are drawn from histological studies on PBF gonads (Yonemori

1989, Ashida et al. 2015, Okochi et al. 2016, Ashida et al. 2021, Ashida et al. 2022) and the distribution of PBF larvae (Yabe et al. 1966). Recent histological studies showed that approximately 80% of fish weighing around 30 kg (corresponding to 3 years old or 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). Nearly all fish caught in the waters surrounding the Ryukyu Islands and eastern Taiwan were larger than 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 all were mature.

In addition, active spawning females (Ohshimo et al. 2018) and larvae (Tanaka et al. 2020) have been recently observed in the Kuroshio-Oyashio transition area (Figure 2-1). Given the velocity of the Kuroshio current, the presence of spawning females, and the presence of larvae, there is possibility of another spawning ground from May to August in this region. However, it remains to be verified if these PBF larvae can recruit to the stock.

Although large PBFs have also been observed in the EPO, particularly in recent years in Southern California, Dewar et al. (2022) reported no evidence of PBF reproduction in the EPO based on histological examinations of ovaries and ichthyoplankton data.

2.1.3. Distribution and Movements

PBFs are mainly distributed in subtropical and temperate latitudes between 20^{o} N and 50°N, although they are occasionally encountered in tropical waters and in the southern hemisphere (Figure 2-2) (Smith et al. 2001).

Despite substantial inter-annual variations in movement in terms of numbers of migrants, the timing of migration, and migration routes, the movements of PBFs are among the most extensively documented among highly migratory species. Mature adults in the WPO typically migrate northward to feeding grounds following spawning, although a small proportion of fish may move southward or eastward (Itoh 2006). Fish aged 0-1 that have hatched in the waters surrounding the Ryukyu Islands and eastern Taiwan migrate northward with the Kuroshio Current during the summer as they grow, while age-0 fish that have hatched in the Sea of Japan migrate along the coastlines of Japan and Korea (Inagake et al. 2001, Itoh et al. 2003).

Depending on oceanic conditions, an undetermined portion of immature fish aged 1-3 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 several years as juveniles in the EPO before returning to the WPO (Inagake et al. 2001). The mechanism behind this trans-Pacific migration is hypothesized to be driven by limitations in food sources in the WPO and favorable oceanographic conditions (Polovina 1996). While PBFs are in the

EPO, juveniles make seasonal north-south migrations along the west coast of North America (Kitagawa et al. 2007, Boustany et al. 2010). In spring, PBFs are found in the waters off the southern coast of Baja California, and as summer approaches and waters warm, they move northwest into the southern California bight. By fall, PBFs are distributed in the waters off central and northern California. After spending 3-4 years in the EPO, PBFs migrate westward, presumably for purposes of spawning, as no spawning grounds have been observed outside of the WPO. This westward migration typically occurs from December to March as PBFs begin their migration along the coast of California (Boustany et al. 2010). The considerable seasonal (Fujioka et al. 2021) and inter-annual variations in trans-Pacific movement make it challenging to quantify migration rates accurately.

2.1.4. Growth

Age determination of PBF has been established through various methods such as vertebral ring counts (Aikawa and Kato 1938), scale ring counts (Yukinawa and Yabuta 1967), tag-recapture studies (Bayliff et al. 1991), and otolith observations (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 otolith samples was developed at the Pacific Bluefin and North Pacific Albacore Tuna Age Determination Workshop in 2014 (Shimose and Ishihara 2015) by the ISC. This workshop initiated the large-scale age determination of annuli rings of otolith samples for PBF collected from troll, purse seine, set-net, handline, and longline fisheries landed at Japan and Taiwan between 1992 and 2014. The work also examined the daily increments of otolith samples caught by the troll and set-net fisheries on the west coast of Japan between 2011 and 2014. In addition to analyzing the number of opaque zones in otoliths, post-bomb radiocarbon dating was used to validate age estimation, and the results were consistent with otolith thin sections (Ishihara et al. 2017).

Fukuda et al. (2015b), further contributed by estimating growth curves based on the analysis of annuli data from 1,782 fish (70.5-271 cm in fork length [FL], corresponding to 1-28 years old) and daily increment data from 228 fish (18.6-60.1 cm in FL, corresponding to 51-453 days old after hatching). Their analyses indicated annual and seasonal variability in growth rates, particularly with PBFs exhibiting rapid growth during the first six months after hatching (Fukuda et al. 2015a). To estimate growth curves based on the data described above, two methods were tested. First, a traditional estimation method treated the paired age-length data, derived from annuli and daily rings, 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 (referred to as conditional age-at-length (CAAL) data);

These 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 various growth patterns using both traditional and length-conditional methods in the earlier integrated model runs. They found that the simple VBGF model (using traditional method) and the seasonal growth model (using length-conditional method) better fit the length compositions than the other growth models. However, as the CAAL data did not adequately represent the age structure of the population due to un-modeled age-based movement and possible sampling bias, including these CAAL data in the integrated model can introduce bias and imprecision in estimates of growth and population dynamics (Lee et al. 2019). Consequently, the PBFWG adopted the simple VBGF using a traditional method (Fukuda et al. 2015b) in the 2016 assessment. In 2023, Ishihara et al. analyzed the same dataset using different sampling methods to estimate growth parameters and revealed that the growth rate and asymptotic length were robust and estimated similarly to Fukuda et al. (2015a) regardless of sampling methods.

The examination of variances in length at age was also conducted using a dataset consisting of over 7,000 paired age-length samples collected between 1992 and 2022 (Tsukahara et al. 2024). These paired length at age samples showed a gradual decrease in CV of length across ages from 15% to 7% for ages 2-7, stabilizing at 5-6% for those aged 8 and older. It was hypothesized that the CV of length at ages 0 and 1 would be higher despite the absence of estimates for these ages (referenced as Figure 1 in the ISC 2024). These samples were subsequently integrated into the previous assessment model as CAAL data to estimate CVs of length at age. This integration was imperative as the model’s expectations necessitated an understanding of the age structure of the population, with CAAL data predominantly used within population dynamics models (Piner et al. 2016, Lee et al. 2017a). A quasi-age-structured production model with recruitment variation (ASPM-R) was produced, wherein the recruitment deviations and length-based selectivity were specified at MLE from the previous assessment model. The scale-related parameters and age-based selectivity were estimated to eliminate the influence of the length composition data on the CV estimation (Tsukahara et al. 2024). The CV estimate at age-0 was approximately 28%, gradually decreased to around 4% by age 3. The heightened CV at age-0 was potentially attributed to the variation in size among age-0 fish originating from the two spawning grounds with distinct main spawning periods, although the assessment model assumed that age-0 fish originated from a singular spawning ground for the sake of simplicity. The 2024 assessment applied the CVs of length estimated by Tsukahara et al. (2024) (see section 4.2.2).

The growth curve assumed in this assessment was generally consistent with previous studies (Shimose et al. 2009, Shimose and Takeuchi 2012, Shimose and

Ishihara 2015, Fukuda et al. 2015b); fish grow rapidly up to age 5 (approximately 160 cm FL), after which growth slows down (Figure 2-3). By age 12, the fish reach 226 cm FL on average, corresponding to 90% of the maximum FL for PBF. 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 growth parameterization is detailed further in Section 4.2.

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.

2.1.5. Natural Mortality

Natural mortality coefficients (*M*) are 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). *M* for the 2024 assessment was assumed to be age-specific: high at a young age, decreasing as fish mature, and stabilizing afterwards (Figure 2-5).

Natural mortality for age-0 fish was derived from findings of conventional tagging studies conducted on PBF (Takeuchi and Takahashi 2006, Iwata et al. 2012a, Iwata et al. 2014). In the absence of direct estimates beyond age 0, natural mortality for age-1 fish was estimated based on length-adjusted *M* values derived from conventional tagging studies conducted on southern bluefin tuna (Polacheck et al. 1997, ISC 2009). This adjustment accounted for the differences in the life-history between PBF and southern bluefin tuna. A constant natural mortality coefficient for mature fish was then derived from the median value obtained through 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 the EPO, where young fish (1-5 years old) are commonly found. However, it is important to note that using *M* estimates from Whitlock et al (2012) has faced criticism due to the incomplete tagging samples, which solely represent the EPO population. This stock assessment used the same *M* schedule as previous assessments. Refer to section 4.2.5 for detailed information on the actual model settings for the *M* values.

2.2. Historical Trends and Regional Perspectives in PBF management

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

While PBF catch records were sparse prior to 1952, some PBF landing records date back to 1804 from coastal Japan and the early 1900s for U.S. fisheries operating in the EPO. PBF catch estimates were high from 1929 to 1940, with a peak catch of approximately 47,635 t (36,217 t in the WPO and 11,418 t in the EPO) in 1935 but sharply declined during World War II. PBF catches increased significantly after 1949 as Japanese fishing activities expanded across the North Pacific Ocean (Muto et al. 2008).

By 1952, most fishing nations had adopted a more consistent catch reporting process. From 1952 to 2022, annual catches of PBF by ISC member countries exhibited wide fluctuations (Figure 2-6). Among these nations, five countries mainly harvest PBF, with Japan leading in catches, followed by Mexico, the USA, Chinese Taipei, and Korea. Although catches in tropical waters and in the southern hemisphere have historically been small and sporadic, there was a notable increase in the southern hemisphere catch in 2020, reaching around 50 tons (WCPFC 2023). During this period, reported catches peaked at 40,383 t in 1956 and 34,612 t in 1981, reaching the low of 8,653 t in 1990, followed by an increase to over 30,000 t in 2000 and 2004 before declining to about 12,000 t in 2017.

The trend in catch is associated with RFMOs' management efforts. In 2011, the WCPFC started the conservation and management measures to regulate catches of small PBF (<30 kg in body weight) within its convention area (WCPFC CMM 2010-04). The catch limit was further reduced in 2014 (WCPFC CMM 2013-09) and 2015 (WCPFC CMM 2014-04) to ensure that the catches of small PBF remained below 50% of the 2002-2004 average level, and the catches of large PBF (>30 kg in body weight) remained below the 2002-2004 average level. In the IATTC area, conservation and management measures were introduced in 2012 (IATTC resolution C-12-09) to regulate the catches for all size ranges of PBF within its convention area. Additional reductions in catch limits were established in 2015 to ensure that total commercial catches remained below 6,200 tons. In 2021, both the WCPFC and IATTC adopted the new conservation and management measures for PBF to be implemented for 2022-2024, allowing for an increase in the catch upper limits to catch large PBF. The current measures (WCPFC CMM 2023-02 and IATTC resolution C-23-01) limit the catch in WCPFC and IATTC convention areas to less than 12,334 tons annually and 7,990 tons biannually, respectively.

While a suite of fishing gears catches PBF, most of the catch is from purse seine fisheries (Figure 2-7). In Japan, major active PBF fisheries include longlines, purse seines, trolling, and set-nets, and some other gear types such as poles-and-lines, drift nets, and hand-lines used to take a considerable amount of catches. Most of PBF fisheries in Japan operate inside of its Exclusive Economic Zone (EEZ). 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: Sections 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 (sport) fisheries) catch PBF off the west coast of North America. Initially, the U.S. purse seine fishery harvested a large amount of PBF for canning in the waters off Baja California until Mexico established its EEZ in 1976, leading to the exclusion of U.S. purse seine vessels. Subsequently, after 1983, the U.S. purse seine fishery opportunistically caught PBFs (Aires-da-Silva et al. 2007). Currently, the 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 experienced rapid development after Mexico established its EEZ and is now the most important large pelagic fishery in Mexico. This fishery is closely monitored through 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). While seine sets target yellowfin tuna *Thunnus albacares* (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 primarily caught by the offshore large purse seine fishery (OLPS), although there have been reports of small amounts of catches from the coastal fisheries in recent years. The catch of the OLPS fishery was below 500 t until the mid-1990s, peaked at 2,601 t in 2003, and since then has fluctuated between 600 t and 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, with the vessels occasionally operating 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 (including 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 gradually increased 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, followed by a rapid decline to less than 1,000 t in 2008 and a subsequent drop to about 200 t in 2012. The catch then slightly increased to around 500 t in 2018 and showed a significant increase to more than 1,800 t in 2022.

3. STOCK ASSESSMENT INPUT DATA

3.1. Spatial Stratification

PBFs are widely distributed across the North Pacific Ocean and are 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 for spawning. However, due to the absence of direct information on movement rates, a true spatial model has not yet been used for assessment purposes. Instead, this and previous assessments have relied on the assumption of an instantaneously mixed population and have incorporated regional selection patterns to implicitly model space (referred to as the "areas-as-fleets approach", Waterhouse et al. 2014). The effectiveness of the areas-as-fleets approach used by the PBFWG was evaluated in a simulation study, indicating that while the use of alternative model processes (i.e., selectivities) is not as effective as a true spatially explicit model, management quantities can still 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). The development of a spatially explicit model remains to be an area for future research.

3.2. Temporal Stratification

A "fishing year" is defined as the period from July 1st to June 30th of the following calendar year. For example, the 2022 fishing year spans from July 1st, 2022 to June 30th, 2023. Unless stated otherwise, the term "year" in this report refers to the fishing year. The assessment of PBF covers the period from 1983 to 2022, 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 "fishing month 1" (July in the calendar month) in the assessment model. The relationships between calendar year, fishing year, and year class are shown in Table 1-1.

3.3. Fishery Definition

A total of 26 fisheries were delineated for the PBF stock assessment based on stratification of country, gear type, season, area, and size of fish caught (Table 3-1). Below are the representative fisheries for each fleet:

Fleet 1: Japanese longline fisheries (JPN_LL) for all seasons for 1983-1992, and for season 4 for 1993-2016,

Fleet 2: Japanese longline fisheries (JPN_LL) for seasons 1-3 for 1993-2016 and all seasons for 2017-2022,

Fleet 3: Taiwanese longline fishery (TWN_LL) in southern fishing ground for 1983-2022,
Fleet 4: Taiwanese longline fishery (TW_LL) in northern fishing ground for 2000-2022,
Fleet 5: Japanese tuna purse seine fishery off the Pacific coast of Japan (JPN_TPS_ PO) for 1983-2022,
Fleet 6: Japanese tuna purse seine fishery in the Sea of Japan (JPN_TPS_SOJ) for 1983-2022,
Fleet 7: Japanese tuna purse seine fishery in the Sea of Japan for farming (JPN_TPS_SOJ Farming) for 2016-2022,
Fleet 8: Japanese small pelagic fish purse seine fishery in the East China Sea (JPN_SPPS) for seasons 1, 3, and 4 for 1987-2022,
Fleet 9: Japanese small pelagic fish purse seine fishery in the East China Sea (JPN_SPPS) for season 2 for 1988-2022,
Fleet -10: Japanese small pelagic fish purse seine fishery in the East China Sea for farming (JPN_SPPS Farming) for 2014-2022,
Fleet 11: Korean offshore large scale purse seine fishery (KOR_LPPS) for 1983-2022,
Fleet 12: Japanese troll fishery (JPN_Troll) for seasons 2-4 for 1983-2022 ,
Fleet 13: Japanese troll fishery (JPN_Troll) for season 1 for 1983-2022,
Fleet 14: Japanese troll fishery for farming (JPN_Troll Farming) for season 1 for 1998-2022,
Fleet 15: Japanese pole and line fishery (JPN_PL) for 1983-2022,
Fleet 16: Japanese set-net fisheries (JPN_Setnet) for seasons 1-3 for 1983-2022,
Fleet 17: Japanese set-net fisheries (JPN_Setnet) for season 4 for 1983-2022,
Fleet 18: Japanese set-net fisheries in Hokkaido and Aomori (JPN_Setnet (HK_AM)) for 1983-2022,
Fleet 19: Japanese other fisheries (JPN_Others), mainly small-scale fisheries in the Tsugaru Strait for season 2 for 1983-2022,
Fleet 20: Eastern Pacific Ocean commercial purse seine fishery (U.S. dominant) (EPO_COMM(-2001)) for 1983-2001,
Fleet 21: Eastern Pacific Ocean commercial purse seine fishery (Mexico dominant) (EPO_COMM(2002-)) for 2001-2022,
Fleet 22: Eastern Pacific Ocean sports fishery (EPO_SP(2014-)) for 2014-2022,
Fleet 23: Eastern Pacific Ocean sports fishery (EPO_SP(-2013)) for 1983-2013,
Fleet 24: Unaccounted mortality fisheries (in weight) in WPO (WPO_Disc_Weight) for 2017-2022,
Fleet 25: Unaccounted mortality fisheries (in number) in WPO (WPO_Disc_Num) for 1998-2022,
Fleet 26: Unaccounted mortality fisheries (in number) in EPO (EPO_Disc_Num) for 1999-2022.

Certain fisheries, characterized by minimal PBF catch, were integrated into fleets with similar size compositions. This determination was informed by expert insights from each country, emphasizing consistent compositions. For example, the catches from Korean trawl, set net, and troll fisheries were consolidated into Fleet 11. Taiwanese purse seine catches were designated to Fleet 6. The driftnet catches from Japan and Taiwan were allocated into season 1 of Fleet 15, with the remaining Taiwanese catches, excluding longline fisheries, allocated to season 4 of the same Fleet. Japanese miscellaneous catches for seasons 1-3 were included into Japanese set net Fleet 16, and those for season 4 were designated to Fleet 17. Additionally, the residual Japanese catches, comprising trawl and small longline catches, were accommodated within Fleet 19. Post-2014 catches from non-ISC members, including New Zealand and Australia, were incorporated into Fleet 3.

3.4. Catch and Discard Data

3.4.1. Catch data

While fisheries catching PBF have been operational since at least the early 20th century in the EPO (Bayliff 1991) and for several centuries in the WPO (Ito 1961), detailed fishery statistics, particularly from the WPO, were not available before 1952. Therefore, 1952 was chosen as the starting year for previous stock assessments due to the adoption of a more consistent catch reporting process and the availability of catch and effort data from the Japanese longline fleet from that year onwards. These assessment models faced challenges due to relatively data-poor periods before 1980, which constrained the estimation of productivity of population dynamics and led to convergence issues when alternative assumptions were examined. During the course of model improvement, a short time series model was developed to enhance flexibility by reducing these data-poor periods (Fukuda 2021, Fukuda et al. 2021, 2022).

In this assessment, the short-period model starting in 1983 serves as the base case model. Throughout the assessment period, the total annual catch fluctuated widely, with the historical maximum and minimum total catches recorded in any calendar year being 33,975 t in 2000 and 8,585 t in 1990, respectively (Table 3-2, Figure 2-6). Annual catches averaged about 14,000 t over the last decade (2013-2022). The majority of PBF catches were attributed to the purse seine fisheries, including the Japanese tuna purse seine fishery operating off the Pacific coast of Japan (Fleet 5), the U.S. purse seine fishery (Fleet 20) with a large portion of the catch until the 1990s, the Japanese small pelagic fish purse seine fishery in the East China Sea (Fleets 8 and 9), the Japanese tuna purse seine fishery in the Sea of Japan (Fleet 6), the Korean Offshore large-scale purse seine fishery (Fleet 11), and the Mexican purse seine fishery (Fleet 21) (Figure 3-2).

For the assessment model, catches were compiled quarterly for each fleet (Table 3-3). Quarterly catches for some fisheries during the early period were estimated by applying recent quarterly catch proportions to annual catch data, as seen in Fleets 8 and 9 before 1994 (Kai 2007a). For most fleets, recent quarterly catches were directly derived from logbook or landing statistics. Some fleets primarily operate in only one season, such as Fleet 19, which includes small-scale Japanese fisheries (e.g., trawl, small longline, etc.), with their annual total catch allocated to Season 2. Catch data for the stock assessment were expressed in tons for all fleets except for Fleets 7, 10, 14, 22, 23, 25, and 26, where quarterly catches were expressed in thousands of fish (Figure 3-2). The quarterly catch data were updated up to Season 4 of the fishing year 2022 (2023 calendar year Quarter 2). Corrections were made in the terminal year of the previous assessment (2020 FY) as fishery data in the terminal year are often provisional and subject to corrections when finalized as the official statistics.

3.4.2. Unaccounted Mortality

It is recognized that recent impactful management measures may have altered fishery practices. The PBFWG has agreed that the assessment should include catches from "unaccounted mortality" (ISC 2019). "Unaccounted mortality" refers to fishery-induced deaths not reflected in landing data, which can include predation from sportfishing catches and 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 recommendations. Mexico indicated no reported discard or post-release mortality from the IATTC/AIDCP onboard observers with a 100% coverage rate. Taiwan also stated no sign of releasing PBF from their fishery, with a sufficient margin in their fishing quota.

Fleet 24 (unaccounted mortality fisheries from WPO, 2017-2022) includes estimated dead discards from Japanese fisheries (setnet, purse seine, longline, troll, etc.) and Korean purse seine fisheries by weight. Meanwhile, Fleet 25 (Unaccounted mortality fisheries in WPO, 1998-2022) and Fleet 26 (Unaccounted mortality fisheries in EPO, 1999-2022) include estimated dead discards from Japan fisheries for penning (troll and small pelagic purse seine) and from U.S. sport fisheries, respectively, by number.

Japanese discard mortality has been estimated as 5% of reported catch for all Japanese fisheries since 2017, recognizing the significance of PBF release (Nakatsuka and Fukuda 2020), and Korean discard amounts were estimated in the same manner (Lee et al. 2020a) (Fleet 24). Fleet 25, representing discards from Japan fisheries for penning, is assumed to be the same as the reported catch for the Japanese troll fishery for penning (Fleet 14) and 5% of the reported catch of the purse seine for penning (Fleets 7 and 10). For the U.S. sport fishery (Fleet 26), 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, with a mortality rate (6%) determined through random-effect inverse variance meta-analysis (Piner et al. 2020). To account for the uncertainty of these removals, the CV for these unaccounted mortality fleets was set at the higher value (0.3).

3.5. Abundance Indices

3.5.1. Overview

Potential CPUE-based abundance indices discussed in the ISC PBFWG are detailed in Tables 3-4 and 3-5, and Figure 3-3. These series were derived from fishery-specific catch and effort data, standardized using appropriate statistical methods. In the previous assessment, the PBFWG used four longline CPUE series as adult abundance indices: Japanese longline (1993-2019), Japanese longline (1952-1973), Japanese longline (1974-1992), and Taiwanese longline in the south fishing ground (2002-2020). Additionally, a Japanese troll index (1980-2016) served as the recruitment index for the base-case model (ISC 2022).

In this assessment, three longline CPUE series serve as the adult abundance indices: Japanese longline (1993-2019), Japanese longline (1974-1992), and Taiwanese longline in the south fishing ground (2002-2022). Also, a Japanese troll index (1980-2010) served as the recruitment index. While the indices used in this assessment are not substantially different from those in the previous one, further details and decisions will be addressed in the following sections.

The input coefficients of variation (CV) for abundance indices were uniformly set at 0.2 for all indices, years, and seasons when the CV statistically estimated by the standardization model was below 0.2. In instances where the CV estimated by the standardization model exceeded 0.2, the actual CV value was utilized to accurately depict the sampling variability for the observation (Table 3-6). This approach mirrors that of the previous assessment conducted by PBFWG in 2022.

3.5.2. Japanese Longline CPUE indices (S1 and S2)

While Japanese longline indices have traditionally been a crucial indicator of spawning stock trends, they were discontinued after 2020 due to the implementation of an individual quota scheme in the 2020 FY (Tsukahara et al. 2022). Substantial declines in catch and nominal CPUE for this fishery during the main fishing season (April to June) in the 2020 FY were observed, despite recent increases in catch within their allocation. To mitigate the potential impact of changes in catchability resulting from the new management scheme on the CPUE time series, data from 2020 onwards were excluded from standardization for this assessment.

Derived from logbook data, Japanese longline CPUE indices comprise two components: one for coastal operations (post-1993) and one for offshore and distant water fisheries (pre-1993). The offshore and distant water longline CPUE index used in the 2024 stock assessment covers the period from 1983 to 1992 (S2; Yokawa 2008), while the coastal longline CPUE index (S1; Tsukahara et al. 2022) covers the period from 1993 to 2019.

Reviewing the coastal longline CPUE for the recent period revealed a trend of smaller fish sizes caught since 2017 compared to previous years. This shift could be attributed to various factors such as changes in fish availability, alterations in fishery operations like area or season, or a combination of both. While the exact cause of this change remained unclear, an additional data filtering method was introduced to maintain consistent size selectivity over time by excluding small-sized fish (Tsukahara et al. 2022).

3.5.3. Japanese Troll CPUE index (S3, S4)

While the Japanese troll index has been traditionally proven to be an informative indicator of recruitment, it was discontinued after 2017 due to the implementation of an individual quota scheme and minimum size limits in the 2017 FY (Nishikawa et al. 2021). Substantial increases in live releases at sea were observed thereafter. Notably, the data points from 2017 to 2020 of the Japanese troll fishery index were not included in the likelihood function of the previous assessment.

The index is derived from catch and effort data collected from five fishing ports in the Nagasaki prefecture from Japanese coastal troll fisheries targeting age 0 PBF. The troll fishery in the Nagasaki prefecture dominates Japanese troll catch, and the fishery can target age 0 PBF from both spawning grounds (Ryukyu Islands and the Sea of Japan) due to the geographical location of the troll fishing ground (Ichinokawa et al. 2012). The units of effort in the catch and effort data are the cumulative daily number of days of unloading troll vessels, which is nearly equivalent to the total number of trolling trips because most troll vessels make one-day trips. The effort data only records information when at least one PBF is caught; zero catch data is unavailable. Therefore, a lognormal model was applied for the standardization of the CPUE (S3).

The troll index post-2010 was identified as the cause of the negative retrospective pattern in the previous assessments (Fukuda 2023). The substantial increase in catch for juvenile PBF farming after 2010, coupled with the implementation of mandatory licensing for troll vessels starting after 2010, may have compromised the representativeness of the troll index after 2010. To mitigate the potential impact of changes in catchability resulting from the aforementioned changes in operations, this index (S3) was used in this assessment for the 1983-2010 period only.

An alternative information on recent recruitment trends was examined using the newly developed standardized CPUE index from the Japanese troll monitoring program for 2011-2023 (S4; Fujioka et al. 2023). This index, however, is also impacted by the same management measures (implementation of an individual quota scheme and minimum size limits), resulting in possible changes in catchability from 2017. In 2021, a supplementary monitoring program called the charter monitoring (CM) program was started. This CM program chartered the same troll monitoring vessels to continue fishing even after their quota was reached, for a maximum of 10 days per fishing season. Although it was viewed premature to include this index in the base-case model, it was still considered that the index provided a good qualitative indication of recent recruitment trends. This index (S4) is included for the sensitivity analysis of the assessment and projections (See 4.5.7 and 5.5.1) but is not used in the base case model.

3.5.4. Taiwanese Longline CPUE indices for southern area (S5-S14)

An adult index of relative abundance was developed using data from Taiwanese longline fishing operations. The fishing grounds of the Taiwanese longline fleet are divided into southern and northern areas, with the southern area historically regarded as the main fishing ground in terms of both catch volume and historical importance. The CPUE utilized in previous and this assessments was derived from operations in the southern area and standardized using a Generalized Linear Mixed Model (GLMM) approach (S5: 2002-2022, as detailed by Yuan et al. 2024).

The development of this index followed a multi-step process: (1) estimation of PBF catch in terms of fish numbers from landing data in weight for the year 2003 based on Markov Chain Monte Carlo (MCMC) simulation techniques, (2) determination of fishing days for the years 2007-2009 using data from the vessel monitoring system (VMS) and voyage data recorder (VDR), (3) calculation of fishing days for the years 2003-2006 based on vessel trip information, establishing linear relationships between fishing days and days spent at sea for each trip, categorized by vessel size and fishing port for 2007-2022, and (4) estimation and subsequent standardization of CPUE (catch per unit effort, measured in fish number per fishing day) for the years 2003-2022, as outlined by Yuan et al. (2024).

In addition to the aforementioned indices, the assessment model also incorporates nine additional indices from the Taiwanese longline, although they are not included in the likelihood function. These supplementary indices encompass various aspects of CPUE standardization such as spatial extent, type of statistical model used, or age-group specificity:

- An index representing both the southern and northern areas derived from the GLMM model for the years 2002 to 2022 (denoted as S6).
- Two indices for the southern or combined areas, derived from a spatiotemporal model covering the period from 2006 to 2022 (denoted as S7 and S8).
- Six indices representing the combined area categorized by age classes, including all age classes (designated as S9), as well as specific age ranges such as 6-8, 9-11, 12-14, 15-17, and 18+ (denoted as S10-S14).

These indices are currently under evaluation for potential integration into future stock assessments, highlighting the ongoing efforts to refine and enhance the assessment methodology.

3.6. Size composition data

3.6.1. Overview

Quarterly size composition data (length or weight) for PBF from 1952 to 2022 were compiled for the stock assessment (Table 3-7, Fig. 3-4). All length data (fork length (FL)) were measured to the nearest centimeter (cm), while weight data were measured to the nearest kilogram (kg). In the assessment model, the length data was categorized into bins of 2, 4, and 6 cm width, representing fish lengths of 16-58, 58-110, and 110-290 cm FL, respectively. Weight composition data were organized into the following 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 13, 14, 15, and 23 were excluded from the negative log-likelihood (NLL) function of the model, consistent with the previous assessment (ISC 2022). Fleets 13-14 (JPN_Troll), focusing solely on age-0 fish, does not require size composition data. Because of concerns about an ill-defined sampling process and the representativeness of their catch, size compositions of Fleet 15 (JPN_PL) were not fitted into the NLL function. Fleet 23 (EPO_SP(-2013)) size data was excluded due to the lack of information on how the size sampling program for the EPO sports fishery operated prior to 2012. Fleets 18-19 had their size compositions combined to streamline the assessment model (Table 3-7). Length and weight composition data were updated to 2022 FY for Fleets 2-12, 18, 21 and 22, while the composition data for the other fleets were not updated. Figure 3-5 shows the quarterly size compositions for each fleet.

Input sample sizes for the size composition data were sourced from various criteria for each fleet. Depending on the corresponding fisheries and available data, the input sample size includes “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", as summarized in Table 3-7.

3.6.2. Japanese Longline (Fleets 1 and 2)

The Japanese longline fisheries were classified into two fleets based on the sizes of fish caught during different seasons in the coastal longliners. Fleet 1, representing the CPUE fishery with catch time-series in weight for all seasons in 1983-1992 and season 4 in 1993-2016, operates under the assumption of consistent catchability and selectivity. Conversely, Fleet 2, with catch time-series in weight for seasons 1-3 in 1993-2016 and all seasons in 2017-2022, primarily targets smaller fish. Length-composition data from the Japanese coastal longline fisheries in season 4 from 1993 to 2016 for Fleet 1 and in seasons 3 and 4 from 2021 to 2022 for Fleet 2 were used in the assessment (Figure 3-5).

The time-series of available length composition data was shorter compared to that of landings from the fishery. During the period from 1983 to 1993, length measurements were relatively sparse, raising concerns about their representativeness. Consequently, these data are not included in the assessment. Since the 1990s, sampling and market data have been collected at the major PBF unloading ports (e.g., Okinawa, Miyazaki, and Wakayama prefectures). Quarterly landing amounts and length measurements in each prefecture were used to compile quarterly catch-at-length data, with length compositions being raised based on landing weight (Ohashi and Tsukahara 2019).

The majority of length samples were collected during seasons 3 and 4, with season 3 generally targeting smaller adults compared to season 4 (Tsukahara et al. 2021). Additionally, season 4 recorded higher numbers of both samples and catches. However, size composition data for both seasons 3 and 4 from 2017 to 2019 showed a notable increase in observations of smaller-sized fish. This was attributed to catches occurring earlier in the fishing season (season 3) than usual, leading to the consumption of the catch quota, comprising mainly of smaller-sized adults. While the implications of these observations remain uncertain, they could suggest a shift in selectivity (i.e., operating smaller fish in more eastern areas not factored into CPUE calculations) and/or a change in availability (i.e., an influx of the newly abundant young cohorts into the fishery). Catch-at-length data for season 3 from 1993 to 2020 were not included in this assessment due to low sample sizes.

The implementation of Individual Quota management since 2021 has led to a more balanced distribution in the size of fish caught, encompassing both small and large adults. Hence, catch-at-length data during seasons 3 and 4 from 2021 to 2022 were included in Fleet 2 in this assessment.

3.6.3. Taiwanese longline (Fleets 3 and 4)

The Taiwanese longline fisheries were classified into two fleets based on the sizes of fish caught in two regions. Fleet 3 representing the CPUE fishery with catch time-series in weight from 1983 to 2022, operates primarily in the southern region targeting largest adults under the assumption of consistent catchability and selectivity. In contrast, Fleet 4, with catch time-series in weight beginning after 2000, operates in the northern region.

Length-composition data for PBF from the Taiwanese longline fishery (Fleets 3 and 4) have been derived from the market landing information and port sampling, which had high coverage since most landings were sampled. Since 2010, the catch documentation scheme (CDS) program has provided additional data, enhancing the quality and quantity of size samples (Chang et al. 2015). Catch-at-length data after 1992 for fleet 3 and after 2009 for fleet 4 were used in the assessment (Figure 3-5).

3.6.4. Japanese purse seines off the Pacific coast of Japan (Fleet 5)

The Japanese purse seine fisheries off the Pacific coast of Japan recorded catch time-series in weight from 1983 to 2022 (Fleet 5) and was the largest fleet in terms of catch before 2000. Size composition data have been collected by weight pre-1994 and by length and weight post-1994. Weight measurements were initially collected at Tsukiji market and several unloading ports in the Tohoku region between 1983 and 1993 and converted to length measurements. However, concerns arose regarding the conversions from gilled and gutted weight and round weight to length and the very low coverage rate of certain weight categories (<10 kg) during this period, resulting in doubts about the representativeness of these data. Since 1994, comprehensive length and weight composition data have been collected at primary landing sites, namely Shiogama and Ishinomaki ports (Abe et al. 2012).

With a sharp decline in catch amounts in weight since 1999, size measurements were unable to be conducted after 2006. Consequently, the length compositions for this fleet included in past assessments were limited to the fishing years 1995-2005 (Figure 3-5). During this period, the size composition data exhibited high variability from 50 cm to over 200 cm, with multiple size modes varying year over year, highlighting the need for further research, particularly focusing on smaller fish.

Since the 2014 fishing year, catch amounts by this fleet have increased compared to previous years (2007-2013). In response to the change, the port sampling program was strengthened, resulting in composition data becoming available for the fishing years 2014-2022 (Fukuda 2019). During this period, the size of fish caught was predominantly composed of fish larger than 120 cm, whereas in the 2000s, this fleet also caught smaller fish, such as those measuring around 50 cm.

Quarterly landing amounts, length measurements, and length conversions from weight measurements in each size category were used to compile the quarterly catch-at-length data before 2006 (Abe et al. 2012). After 2014, quarterly landing amounts and length measurements in each landing were used to compile the quarterly catch-at-length data (Fukuda 2019). Catch-at-length data from 1995 to 2006 and from 2014 to 2022 were used in the assessment.

3.6.5. Japanese purse seines in the Sea of Japan (Fleets 6 and 7)

The Japanese purse seine fisheries in the Sea of Japan, targeting larger-sized PBF aged older than 3 years (Fukuda et al. 2012), were classified into two fleets based on their types of operation and units of catch (Nishikawa and Fukuda 2023). Fleet 6 comprises typical tuna purse seiners with catch time-series in weight from 1983 to 2022, while Fleet 7 consists of the same fishery but for farming, with catch time-series in number beginning after 2016. This fishery was one of the largest fisheries in terms of catch in the 2000s until the introduction of catch quotas in 2011. A portion of the PBF caught by this fishery has been used for farming since the early 2010s, resulting in an increased ratio of farming large PBF over the catch for the fisheries.

Length-composition data for Fleet 6 have been collected by port samplers in Sakai-minato and have been available since 1987, except for 1990 when there was no catch (Figure 3-5). The size measurements have high coverage, with most of the landings being sampled. Additionally, length composition data for Fleet 7 have been collected by fishermen and farming companies in farming locations using stereoscopic camera and have been available since 2017 (Nishikawa et al., 2024).

Quarterly landing amounts and length measurements in each landing or operation were used to compile the quarterly catch-at-length data (Kanaiwa et al 2012, Nishikawa and Fukuda 2023). Catch-at-length data from 1987 to 2022 for Fleet 6 and from 2017 to 2022 for Fleet 7 were used in the assessment.

3.6.6. Japanese small pelagic fish purse seines in the East China Sea (Fleets 8-10)

The Japanese purse seine fisheries in the East China Sea, targeting smaller-sized PBF aged 0-1 years, were classified into three fleets based on their types of operation, the size of fish caught in different seasons, and units of catch. Fleet 8 comprises typical small pelagic purse seiners with catch time-series in weight from 1987 to 2022, mainly targeting age 0 fish during seasons 1, 3, and 4. Fleet 9 shares the same fishery, with catch time-series from 1988 to 2022, capturing both age 0 and 1 fish in season 2. Fleets 8 and 9 were once the largest fisheries in terms of catch during the 1990s and 2000s until the introduction of catch quotas in 2011, and have subsequently been under stricter management year after year. Fleet 10 consists of the same fishery but for farming during seasons 1 and 4, with catch time-series in number beginning after 2014.

Length composition data for the fisheries are derived from the port sampling program at the major landing ports (Fukuoka and Matsuura ports) (Kumegai et al. 2015) and have been available since 2002 for Fleet 8, with exceptions for seasons 3-4 in 2014 when measurements were uncertain due to changes in the landing procedures at the ports. Length composition data have been available since 2003 for Fleet 9, with exceptions for 2013 and 2015 when catches were very limited. Additionally, measurements have been collected since 2016 using a stereoscopic camera for farming operations in Fleet 10 during season 4 when catch amounts are higher compared to season 1 (Fukuda and Nakatsuka 2019).

Quarterly landing amounts and length measurements in each landing or operation were used to compile the quarterly catch-at-length data (Kumegai et al. 2015, Fukuda and Nakatsuka 2019). Catch-at-length data from 2002 to 2021 for Fleet 8, from 2003 to 2022 for Fleet 9, and from 2016 to 2022 for Fleet 10 were used in the assessment.

3.6.7. Korean offshore large purse seine (Fleet 11)

The Korean offshore large purse seine fisheries in Korean waters have documented catch time-series in weight from 1983 to 2022 (Fleet 11) (Park et al. 2023, Kwon et al. 2024). Typically targeting PBF weighing less than 30 kg (ages 0-2), purse seiners have observed an increase in fish over 30 kg since 2019. Fleet 11 also includes PBF caught from Korean setnet, trawl, and other fisheries, with purse seiners being the primary source of catch. Set net catch has been on the rise since 2018**,** contributing over 20% of Fleet 11’s catch in 2021-2022.

The composition data for purse seiners are available during season 3 for 2003-2022 through the size sampling at port by scientists or observers as well as the measurement at the laboratory by scientists (Lim et al. 2021). Quarterly landing amounts and length measurements in each size category were used to compile the quarterly catch-at-length data, with length compositions being raised based on landing weight in each size category (Kwon et al. 2024).

3.6.8. Japanese Troll and Pole-and-Line (Fleets 12-15)

The Japanese troll fisheries, targeting age 0 PBF, were classified into three fleets based on their types of operation, the size of fish caught in different seasons, and units of catch. Fleet 12, representing the CPUE fishery, has a catch time-series in weight from 1983 to 2022 during seasons 2, 3, and 4. It primarily operates in the Sea of Japan under the assumption of consistent catchability and selectivity. Fleet 13 comprises the same fishery with catch time-series in weight from 1983 to 2022 during season 1. It typically catches smaller-sized young of year PBF (< 50 cm, Fukuda et al. 2015a) hatched from April to August. Fleet 14 consists of the same fishery but for farming during season 1, with a catch time-series in number beginning after 1998. Additionally, the Japanese pole-and-line fisheries, which occasionally capture PBF, target age 0 fish and have a catch time-series in weight from 1983 to 2022 (Fleet 15).

Length composition data for Fleets 12 and 13 are obtained from the port sampling program at major landing ports in Nagasaki, Wakayama, and Kochi Prefectures (Fukuda 2012), with records available since 1994. In contrast, representative size composition data for Fleet 14 are lacking. For Fleet 15, length composition data are available for limited years between 1994 and 2010. Since Fleet 15 operates in the same fishing ground as Fleet 12 and catches similar-sized fish, length compositions for Fleet 15 were not used, and its selectivity is mirrored to that of Fleet 12.

Quarterly landing amounts and length measurements in each port and area were used to compile the quarterly catch-at-length data for Fleets 12 and 13, with exceptions applied when more than 20% of the catch lacked corresponding size data (Fukuda et al. 2015a). Following this criterion, catch-at-length data for certain quarters were excluded from the assessment model. The catch-at-length data for Fleet 13 were not fitted into the log-likelihood function due to its spiky nature, focusing on a very narrow range of sizes for age 0. Consequently, its selectivity is specified as full-selection for age-0 fish.

3.6.9. Japanese set-net and other fisheries (Fleets 16-19)

The Japanese set-net fisheries, operating along the coastal regions of Japan, target a wide range of PBF sizes. These fisheries were classified into three fleets based on locations, units of size measurement, and the size of fish caught in different seasons (Nishikawa and Fukuda 2023). Fleet 16 represents a typical set-net fishery in all prefectures except for Hokkaido and Aomori, with catch time-series in weight from 1983 to 2022 during seasons 1, 2, and 3. Fleet 17 comprises the same fishery as Fleet 16, with catch time-series in weight from 1983 to 2022 during season 4. Additionally, Fleet 18 comprises the same fishery operating in Hokkaido and Aomori prefectures, with catch time-series in weight from 1983 to 2022 throughout the year. Fleet 19 consists of hand line and small-scaled longline fisheries in the Tsugaru Strait and its adjacent waters, with catch time-series in weight from 1983 to 2022 during season 2 (Nishikawa et al. 2015).

Length measurement data for Fleets 16 and 17 from Japanese set-net fisheries have been collected since 1993 by port samplers, while weight measurement data for Fleet 18 are obtained in Hokkaido and Aomori prefectures (Sakai et al. 2015). The size range for Fleet 16 is generally smaller than that for Fleet 17, with small-sized PBF (< 50cm) being rarely observed. Fleet 19 also has weight composition data, with records available since 1994. Since Fleets 18 and

19 captured similar sizes, the weight composition data were combined, and one selectivity was estimated for both fleets.

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 strata (i.e., Small/Medium/Large) and limiting over-strata calculation (Hiraoka et al. 2018). These data showed that the catch-at-size data were highly variable from year to year and quarter to quarter, probably because of the influence of environmental conditions and migration (Kai 2007a).

Likely due to the COVID-19 pandemic and other reasons such as opportunistic fishery unloading due to domestic management to protect small (young) fish, the data sampling in FY 2019-2022 for those coastal fisheries was sparser than in the past period (Nishikawa et al. 2022). Accordingly, the composition data for those years were not included in this assessment.

3.6.10. EPO commercial purse seine fisheries (U.S. dominant) for 1983-2001 (Fleet 20) and (Mexico dominant) after 2002 (Fleet 21)

The commercial fisheries operate along the coastal regions of the U.S. and Mexico in the Eastern Pacific Ocean, primarily using purse seine techniques. Minor fisheries such as hook and line, and large-mesh drift gillnet are included in the commercial fisheries. These fisheries were classified into two fleets based on the relative importance of the catch between the U.S. and Mexico. Fleet 20 represents the EPO catch time-series in weight from 1983 to 2001, which encompasses a transition phase involving the decline of the U.S. fisheries and the rise of Mexican PBF opportunistic fisheries, with U.S. purse seine landings still being higher during this period. Subsequently, after 2001, Mexican landings increased, while U.S. landings decreased substantially. Fleet 21 represents the EPO catch time-series in weight from 2001 to 2022 when Mexican purse seine landings were dominant.

Length composition data for PBF from the EPO purse seine fishery have been collected by port samplers from IATTC and national/municipal at-sea observers and sampling programs (Bayliff 1993, Aires-da-Silva and Dreyfus 2012) since 1952. Due to the low representation of the sample sizes during the transition phase (1983-2001) when catches were relatively low, size measurements from 1983 were used to estimate selectivity for Fleet 20. In the assessment, length measurements for Fleet 21 were used after 2005 from port samplers and after 2013 from stereoscopic cameras provided by the largest farming company (Dreyfus and Aires-da-Silva 2015). Landing amounts and length measurements in each set were used to compile the quarterly catch-at-length data (Dreyfus 2024).

3.6.11. EPO sports fisheries (Fleets 22 and 23)

The sports fisheries in the Eastern Pacific Ocean operate along the coastal regions of the U.S. and Mexico. These fisheries were classified into two fleets based on the years when size sampling was conducted. Fleet 22 represents the EPO sports catch time-series in number from 2014 to 2022 throughout the year, while Fleet 23 represents the EPO sports catch time-series in number from 1983 to 2013 throughout the year.

Length measurement data from the sport fishery had been collected by IATTC staff from 1993 to 2011 (Hoyle 2006). There was no information about how the size sampling program operated prior to 2012, thus the PBFWG has agreed that the size composition data before 2012 are not used. Selectivity for Fleet 23 was assumed to be similar to that for Fleet 22.

Since 2014, NOAA took over the sampling program (Heberer and Lee 2019), and size composition data are measured by port samplers. However, due to the COVID-19 pandemic, the port sampling program by the SWFSC NOAA was discontinued (Lee 2021). As an alternative, another on-board sampling program by the Sportfishing Association of California (SAC) was suggested for the size data during 2019-2022, although it had a lower coverage than the port sampling by NOAA. Despite the variability in both the SAC data and NOAA data, each dataset seemed to provide more appropriate information on the catch-at-age than borrowing the information from the EPO commercial fleet or relying solely on the most recent data in the same fleet. Therefore, for the 2022 stock assessment, the WG agreed to use the annual aggregated port sampling data from 2014 to 2018 and the annual aggregated on-board sampling data from 2019 to 2022.

3.6.12. Unaccounted mortality fleets (Fleets 24, 25 and 26)

Unobserved mortality related to the possible post-release mortality of discards were included as removals. This unobserved mortality was separated into three separate fleets. 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 that of the associated fisheries (Section 4.3.2).

4. MODEL DESCRIPTION

4.1. Stock Synthesis

An annual time-step length-based, age-structured, forward-simulation population model, fit to seasonal data (with expectations generated quarterly), was used to assess the status of PBF. The model was implemented using Stock Synthesis (SS) Version 3.30.22 (Methot and Wetzel 2013). SS3 is a stock assessment model that estimates the population dynamics using a variety of fishery-dependent, fishery-independent, and biological information. Although it was originally designed for coastal pelagic fishes (sardines and anchovies), it has evolved as a standard tool for tunas and other highly migratory species in the Atlantic, Indian, and Pacific Oceans (IOTC 2016, IATTC 2017).

The model's framework accommodates both maximum likelihood and Bayesian estimation methods, integrating parameter space using a Monte Carlo Markov Chain algorithm. This assessment uses the maximum likelihood estimation (MLE) to estimate parameters and uses normal approximation or bootstrapping to quantify parameter uncertainty.

SS3 comprises three subcomponents: (1) a systems dynamics subcomponent, which recreates estimates of the numbers/biomass at age using estimates or pre-specified values of movement patterns, natural mortality rates, growth curves, fecundity, and spawner-recruitment relationship, etc., (2) an observational subcomponent, which relates observed (measured) quantities such as CPUE or proportion at length/age to the population dynamics through estimating catchability or selectivity, and (3) a statistical subcomponent, which uses likelihoods to quantify the degree of fits between observations and the recreated population.

4.2. Biological and Demographic Assumptions

4.2.1. Sex Specificity

The assessment assumes that there is no difference in sexual dimorphism. Previous studies have consistently reported that the sex ratio between females and males is not statistically different from 1:1 (Chen et al. 2006, Shimose and Takeuchi 2012). Regarding growth, males generally exhibit larger sizes than females after reaching sexual maturity (Maguire and Hurlbut 1984, Shimose et al. 2009, Shimose and Takeuchi 2012). Shimose and Takeuchi (2012) and Takeuchi (2012) have further provided estimates of sex-specific growth for PBF. However, samples of paired age-length data by sex are often skewed. Due to the absence of sex records in the fishery data, a single-sex population was assumed for this assessment.

4.2.2. Growth

A time-invariant sex-combined length-at-age relationship was externally estimated from paired age-length otolith samples, as detailed in section 2.1.4 (annual rings: Shimose et al. 2009, Shimose and Takeuchi 2012, Shimose and Ishihara 2015; annual and daily rings: Fukuda et al. 2015b, Ishihara et al. 2023). This relationship was re-parameterized to fit 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 L1 and L2 are the lengths (cm) associated with ages (years) near the first (A1) and second (A2) ages, L∞ is the asymptotic average length-at-age (Francis 1988), and K is the growth coefficient (y^{-1}). The growth parameters K, L1, and L2 were fixed in the SS model, with K at 0.188 y^{-1} and L1 and L2 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∞ was 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, $CV = f(length - at - age)$. Based on the estimated variances from the conditional age-at-length data (Tsukahara et al. 2024), the CV was then fixed at 0.278 and 0.0401 for ages 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 to be 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
Lt = length at age t;
L∞ = 249.917 cm = theoretical maximum length;
K = 0.188

4.2.3. Ages Modeled

Ages from 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). The maximum age of 20 was set at the age where approximately 0.15% of an unfished cohort remains based on the *M* schedule.

4.2.4. Weight-Length Relationship

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

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

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

4.2.5. Natural Mortality

Natural mortality (*M*) was assumed to be time-invariant and 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: 1.6 year^{-1} for age 0, 0.386 year^{-1} for age 1, and 0.25 year^{-1} for age 2 and older fish (Figure 2-5).

4.2.6. Recruitment and Reproduction

PBF spawn throughout spring and summer (April-August) in various areas of the western Pacific Ocean, as inferred from egg and larvae collections and examination of female gonads. In the SS model, spawning was assumed to commence 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: 0.2 at age 3, 0.5 at age 4, and 1.0 at age 5 and older fish as of April 1st. 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-1}), an estimated unfished equilibrium spawning biomass (SSB_0), a specified steepness parameter (h), and an estimated unfished recruitment (R0).

$$R_y = \frac{4hR_0 SSB_{y-1}}{SSB_0(1-h) + SSB_{y-1}(5h-1)} e^{-0.5b_y\sigma_R^2 + \tilde{R}_y} \tilde{R}_y \sim N(0, \sigma_R^2)$$

Annual recruitment deviations from the SR relationship ($\tilde{R}_y$) were estimated from 1982 to 2021 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, penalizing 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 a tuning σ_R approach was used to match the standard deviation of the estimated recruitment deviations. Several repeated model runs were conducted to numerically estimate a value of σ_R in SS3 based on Methot and Taylor 2011, resulting in a σ_R set to be 0.6 in the assessment model, which was about the variability of deviates estimated by the model. A 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 1982-2019 to assure unbiased estimation of mean recruitment. Because the b was calculated in SS3, a two-step procedure was used to apply the estimation of b based on Methot and Taylor 2011. The first model run estimated recruitment deviations and variability around these values without adjusting bias accurately. The b was also calculated in the first model run based on the estimated recruitment deviations and σ_R, which was 0.9336. The assessment model applied this estimated b obtained from the first run. The closer b is to the max value of 1, the more informative the data are about recruitment deviations, and vice versa, because 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 $SSB_{F=0}$, 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 the 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’s early life history stages.

4.2.7. Stock Structure

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

4.2.8. Movement

PBF is a highly migratory species, with juveniles known to move widely between the EPO and WPO (Section 2.1.3). In this assessment, the 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. Despite the lack of spatial specificity in the model, 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 enabled the separate estimation of fishery-specific time-varying length- and age-based selectivity patterns, demonstrating the model's ability to approximate the changes in cohorts due to movement and gear selectivity (see Section 4.3.2).

4.3. Model Structure

4.3.1. Initial Conditions

When populations are exploited prior to the onset of data collection, stock assessment models must make assumptions about what occurred before the start of the dynamic period. Assessment models often make equilibrium assumptions about this pre-dynamic period, which can result in a population in the initial year being either at an unfished equilibrium, in equilibrium with an estimated mortality rate influenced by data on historical equilibrium catch, or exhibiting estimable age-specific deviations from equilibrium. Two approaches describe 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 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 1983, this assessment used the second method (estimate) to develop non-equilibrium initial conditions that estimated: 1) R1 offset, 2) initial fishing mortality rates, and 3) early recruitment deviations. The R_1 offset was estimated to reflect the initial equilibrium recruitment relative to R_0, which had 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 (having no influence on the total likelihood function for deviating from assumed equilibrium catch), equilibrium Fs were freely estimated. Equilibrium F was estimated for the Japanese set-net fleet for seasons 1-3 (Fleet 16) because it represented a fleet that mainly took small fish.

Nine-year 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.

4.3.2. Selectivity

4.3.2.1. Selectivity assumptions for Fishery fleet

Selectivity is the observation model process that links composition data to underlying population dynamics. For non-spatial models, this observation model 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 2016).

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 (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. 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 and weight composition data for each fleet except for Fleets 13, 14, 15, 19, 23, 24, 25, and 26, whose selectivity patterns were borrowed from other fleets based on the similarity of the size of fish caught (Table 4-1). The weight composition data for Fleet 19 were combined with Fleet 18, whereas the size composition data for Fleets 14, 15, and 23 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 24, 25, and 26) were not available, but it was assumed that their selectivity pattern was similar to that of the retained catch. The selectivities for Fleet 13 and 14 were assumed to be 100% selected at only age 0. Consequently, their size data were not used.

Fleets with CPUE index (Fleets 1, 3, and 12) were modeled as time-invariant 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 a previous study and it was indicated that the Taiwanese longline fleet (Fleet 3) 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 tested through sensitivity analysis in the past several assessments, and it was confirmed that this assumption does not have a critical impact on the stock status (ISC 2022). Selection patterns were assumed to be dome-shaped (double normal curves) for Fleets 1 and 12.

Fleets without CPUE were categorized into fleets taking fish of non-migratory ages (mainly age-0 fish for Fleets 8 and 10, or spawners for Fleets 2 and 4) and fleets taking fish of migratory ages (mainly ages 1-6 for Fleets 5, 6, 7, 9, 11, 16, 17, 18, 20, 21, and 22).

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 and time-invariant age-based availability patterns to account for the additional ages available to the fleets (e.g., Fleet 8). 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. In general, 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 (Fleets 5, 6, 9, 11, and 18). Because of the large number of parameters involved, fleets without a significant catch (Fleets 7, 16, and 17) did not include the time-varying age-based component. Additionally, three EPO fleets (Fleets 20, 21, and 22) were modeled with time-varying length-based selection due to the possible difference in growth between EPO and WPO.

4.3.2.2. Selectivity assumptions for Abundance index

Selectivity for each relative abundance index was assumed to be time-invariant and the same as the fishery from which each respective index was derived. The size selectivity for the S1 index (Japanese longline: 1993-2019) and S2 index (Japanese longline: 1983-1992) mirrors that of Fleet 1, while the size selectivity for S3 index (Japanese troll: 1983-2010) mirrors that of Fleet 12. The size selectivity for the S5 (Taiwanese longline from the southern fishing ground: 2002-2022) index mirrors that of Fleet 3.

4.3.3. Catchability

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

4.4. Likelihood Components

4.4.1. Observation error structure

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

4.4.2. Weighting of the Data

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

Weights given to catch data were set at S.E.=0.1 (in log space) for all fleets, which is relatively precise for catches, except for unaccounted mortality fleets (S.E.=0.3). Weights given to the CPUE observations were assumed to be CV=0.2 across years and fleets unless the standardization model produced larger uncertainty. In that case, a larger CV estimated from the standardization was used.

The weights given to fleet-specific quarterly composition data via effective sample size were based on an ad-hoc method. Generally, sample sizes were low (<15 effective sample sizes) based on the number of well-measured samplings from the number of hauls or daily/monthly landings (Table 3-7) except for the longline fleets. For longline fleets, because only the numbers of fish measured are available (the numbers of trips or landings measured were not available), the sample size was scaled relative to the average sample size and standard deviation of the sample size of all other fisheries based on the number of fish sampled.

4.5. Model Diagnostics

Multiple diagnostic tests were used to detect misspecification of the observation model (i.e., the model processes relating to data) and the system dynamics model (i.e., the population dynamics) (Maunder and Piner 2015).

4.5.1. Convergence Criteria

A model was not considered converged unless the Hessian was positive definite. To ensure convergence to a global minimum, further examination included randomly perturbing the starting values of all parameters by 10% and randomly changing the ordering of phases of selectivity parameters used in optimizing likelihood components before refitting the model (i.e., jittering analyses). The primary goal of these jittering analyses was to verify that none of the randomly generated processes led to a solution with a lower total negative log-likelihood (NLL) than the reference model. The best-case model had the lowest total NLL and a positive-definite Hessian matrix. These analyses served as a quality control measure to prevent the model from converging on a local minimum.

4.5.2. 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 data about absolute abundance (i.e., catch and index data) could provide information about the population scale given the specified model processes and selectivity. It also assesses whether the system dynamics model is correctly specified (Carvalho et al. 2017). The ASPM was developed by simplifying the base-case model. The deterministic ASPM retained the fleet structure (number of fleets) of the base-case model. However, three main changes were made: 1) elimination of fitting to composition data (now only including catch by fleet and the CPUEs from Japanese longline and Taiwanese longline fisheries S1, S2, and S5, as contributors to the total likelihood function), 2) removal of estimation of annual recruitment variation, and 3) specification of selectivity patterns for each fleet to those estimated in the base-case model. Because annual recruitment deviations were not estimated in the ASPM, recruitment follows the stock-recruitment curve. The ASPM only estimates the global scaling parameters, such as the logarithm of unfished recruitment (Log R_0) and equilibrium fishing mortality rate (Initial F). A satisfactory ASPM is determined when the model's estimates of abundance matches the patterns observed by the longline CPUE series. The performance test involves visually examining estimates of the long-term (decadal) trends, with robust evidence for good ASPM performance seen in matching periods of both increasing and declining abundance (two-way trip).

After determining if the ASPM performed well, the reliability of the age-0 CPUE index (Japanese troll index, S3) was assessed using an ASPM with annual recruitment deviations specified as those estimated in the base-case model (ASPM-R). The ASPM-R includes the addition of temporal recruitment variation that exactly matches the age-0 troll index. If the ASPM-R improves fits of the adult indices, this is evidence that the age-0 troll index is consistent with the other data sources in the model and provides good information on recruitment variability.

4.5.3. Residual analyses

Residual analyses are commonly used to detect the misspecifications in the observation model. Initially, a visual examination comparing observed and estimated values was conducted to ensure that the fit was good. To further determine the goodness-of-fit, the root-mean-square error (RMSE) was used for the CPUE data, and the ratio of inputted sample weights to model estimates of the weights was used for the size composition data. Residual plots were used to evaluate trends in residuals and their magnitude. Inputted weights exceeding model estimates of the weight for a particular data source were considered as indicative of lack of fit.

4.5.4. R_0 likelihood component profiling analyses

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

4.5.5. Retrospective analysis

A retrospective analysis was performed on the base-case model by subsequently removing the terminal year of data. The underlying assumption is that the estimates of historical abundance from the base-case model, which uses all the data, are more accurate than the estimates of abundance from the retrospective models that ignore recent data. Therefore, this analysis shows the possible bias of model predictions. A 10-year retrospective analysis was conducted to assess temporal trends in spawning biomass, and the Mohn's rho statistic (Mohn 1999, Hurtado-Ferro et al. 2014) was calculated to quantify the severity of retrospective patterns. In other words, a larger absolute Mohn's rho indicates a more obvious consistent pattern of change in the peeled models relative to the base-case model.

4.5.6. Hindcasting

Hindcasting was used to assess the prediction quality of the base-case model (Kell et al. 2016). The underlying assumption is that an assessment model which performs well in the past and accurately predicts the past, has good prediction skill. We first retrospectively analyzed 7-years of stock dynamics (i.e., peeling off 7-years of data sources) and made a 7-years past prediction using the age-structured production model. We chose the 7-years based on the generation time of this species. This work can be thought of as if we conducted the assessment seven years ago using data only up to that year and forecasted forward with the catches by fleets as they occurred in the next seven years. The goal was to determine if we could have predicted what would happen to the stock.

4.5.7. Sensitivity analyses

The effects of different assumptions regarding the system dynamics model and observation model were examined via sensitivity analyses. Two groups of models were conducted, and several sensitivity runs were performed for each group. The first group of models addressed the observation model, while the second group addressed the system dynamics model processes.

In each sensitivity run, an assumption of the model was changed, and the model was rerun to examine its effects on derived quantities. The sensitivity runs are as follows:

1. Models assuming alternative observation processes
    a. Different data weighting of size composition data
    b. Doubling the amount of unseen catch
    c. Fitting the troll recruitment index for the entire period (1983-2016)
2. Models assuming alternative system dynamics processes
    a. Alternative steepness
    b. Higher and lower natural mortality for age 2 and older
    c. Higher and lower assumed variation in recruitment (sigma R)

4.6. Projections and Biological Reference Points

4.6.1. Projections

Stochastic projections were conducted outside the integrated model using forecasting software, assuming age-structured population dynamics with a quarterly time step in a forward direction. These projections were based on the results of the stock assessment model and incorporated parameter and observation uncertainty from bootstrap replicates in SS3, followed by stochastic simulations (Ichinokawa 2012, Akita et al. 2015, 2016, Nakayama et al. 2018). These bootstrap replicates were generated using the same error structures as the base-case model and then fit in the base-case model using SS3. In the projections presented in this report, the projected SSB estimates represent the medians of 6,000 individual SSB values calculated for each set of 300 bootstrap replicates, followed by 20 stochastic simulations based on different future recruitment time series.

Future recruitment values in each replicate are randomly resampled from the recruitment estimates for 1983-2020. Due to the high uncertainty of the recruitment estimates for 2021-2022, those years were not included for resampling. The PBFWG considered that the resampling of the estimated recruitments from the whole time series of the base case, except for the most recent two years, was appropriate.

Several alternative harvest scenarios, including the requested scenarios developed by the 8th IATTC-WCPFC JWG to the ISC (WCPFC NC 18, Attachment E), are shown in Table 4-2. Scenario 1 approximates the conservation and management measures currently in force in the WCPFC convention area (WCPFC CMM2021-02) and IATTC convention area (IATTC Resolution C21-05). For the EPO commercial fisheries, since the IATTC Resolution applies only a catch limit, a constant catch limit of 3,995 tons with a high F level, similar to that in 2002-2004, is assumed in this future projection to consume its quota. For the WPO fisheries, the maximum F level is assumed to be the average level during 2002-2004, approximating the effort control prescribed in the WCPFC CMM.

Scenarios 2 to 11 were based on the requests from the JWG. Scenario 2 analyzed the impacts of transferring 30% of the small fish limit (PBF weighing of less than 30 kg of its body weight) for Japan and 40% for Korea limit to the large fish (PBF weighing 30 kg and larger) limit, using a conversion factor of 0.68:1 for the small and large fish catch limits. Scenario 3 depicted zero removals (no fishery) to illustrate the potential for stock recovery.

Scenarios 4-11 explored the impacts of the less conservative management measures, which depict possible increases in catch limits by specified amounts or fractions from the currently specified limit.

Scenarios 4-7 aimed to achieve a 20% $SSB_{F=0}$ biomass target with 60% probability by exploring harvesting scenarios to achieve this biomass level in the last year of the projection (i.e., 2041 FY). On the other hand, scenarios 8-11 explored the future catch amounts needed to achieve a 20% $SSB_{F=0}$ with 60% probability by 2041, while maintaining two specified future fishery impact ratios on SSB between WCPO and EPO fisheries: approximately 70% and 30%, and 80% and 20%, respectively. It is noteworthy that because the proportion of historically accumulated WCPO versus EPO impact gradually changed to achieve the specified ratio, the impact proportion is dynamic and may further change in the longer term if the same harvest scenario continues beyond the target year.

In addition to the above-mentioned scenarios, scenario 12 projected the stock and fishery with a constant fishing mortality of F30%SPR, which is listed in the HCRs for the PBF MSE as one of the candidate target reference points. For this scenario, the average fishing mortality at age during 2017-2019 was used as the basic exploitation pattern in recent years (Tommasi and Lee 2022), and a multiplier for Fs at each age was applied to maintain F30%SPR.

As performance metrics for each harvesting scenario, the PBFWG provided the following: the probability of achieving a 20%$SSB_{F=0}$ by 2041, the probability of SSB falling below the candidate target reference points (20%, 25% , 30%, and 40% of $SSB_{F=0}$) by 2041, the probability of SSB dropping below 7.7% $SSB_{F=0}$, which was used as the interim limit reference point at the IATTC during any projection period, the ratio of the future expected fishery impact between WCPO and EPO in ten years after reaching the initial rebuilding target, and the expected future catch at specified years.

4.6.2. Biological Reference Points

The WCPFC has adopted 20%$SSB_{F=0}$ as the second rebuilding target in their CMM, which was prepared by the joint WCPFC-NC and IATTC working group (JWG). While formal adoption of the biological reference point has not occurred, this rebuilding target could serve as an interim biomass-based reference point, and the corresponding fishing mortality producing that SPR could serve as an interim fishing mortality reference point.

In addition to the rebuilding target, two commonly used biological-based reference points were calculated. The first is equilibrium depletion, which is the ratio of terminal SSB to unfished SSB from the base-case model. This metric characterizes the current stock status. The second is the spawning potential ratio (SPR), which characterizes current fishing intensity. 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. Given the substantial changes in overall selectivity over different years, it was considered inadvisable to compare fishing mortality directly. Thus, the spawning potential ratio serves as a more appropriate measure of fishing intensity. These reference points were calculated for the terminal year of the 2024 assessment (the 2022 FY) and compared to the candidate target reference points (e.g., 20%, 25%, 30%, and 40% of $SSB_{F=0}$) adopted in the 8th meeting of the JWG in 2023 for the PBF MSE work. Additionally, we calculated Fmax as one of the yield-per-recruit-based biological reference points.

5. STOCK ASSESSMENT MODELLING RESULTS

5.1. Model Convergence

All estimated parameters in the base-case model fell within their respective boundaries, and the final gradient of the model was 1.28×10^{-5}. The model Hessian was positive-definite, enabling estimation of the variance-covariance matrix. Based on the results from 140 model runs with random perturbations of initial values and 500 model runs with random perturbations of phases of selectivity parameters, 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 to the base case model. Consequently, the best-fitting model was chosen as the base-case model. The PBFWG considered it to have likely converged to a global minimum, as there was no evidence of further improvements in the total likelihood (Figure 5-1).

5.2. Model Diagnostics

5.2.1. Age Structured Production Model (ASPM) Diagnostics

The ASPM model generally captures the overall trends of the abundance indices for adult PBF for S1 (Japanese longline; 1993-2019) and S5 (Taiwanese longline south; 2002-2022), 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), along with 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 on the population scale (unfished stock size).

An ASPM with fixed annual recruitment deviations specified at those estimated in the base-case model (ASPM-R) improved the model fits for both Japanese longline and Taiwanese longline indices (Figure 5-2). Compared to the base-case model, the ASPM-R had very similar scale and population trends, while the ASPM model showed a slightly larger scale (Figure 5-3). Moreover, the predicted recruitment index (S3 Japanese troll; 1983-2010) by the ASPM-R was also very close to the observed index. These findings suggest that incorporating recruitment variation, as indicated by the recruitment index (S3), improved the performance of ASPM, highlighting the valuable information provided by the S3 index into recruitment variability.

Furthermore, these results confirm that composition data are not the primary drivers of the estimated scale but serve as a source of information regarding removals at specific ages.

5.2.2. Likelihood Profiles on Fixed Log-scale Unfished Recruitment (log R_0)

The results of the profile of total and component likelihoods across a range of fixed log R_0 values from 9.2 to 9.8 for the base-case model are shown in Figure 5-4. The y-axis represents relative likelihood values, indicating 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 of 0 indicates the best fit of the log R_0 value for that data component. In general, all likelihood components showed very low relative likelihood values (< 1.5 units) at the log R_0 value estimated by the base-case model, where the estimate of log R_0 for the base-case model was 9.49261. Recruitment (penalty of the deviations) fit best at 9.60, all combined CPUEs at 9.36, and all combined size composition at 9.46.

The size compositions component showed informative gradients (a convex function in the negative log-likelihood context) on both the low and high sides of the log R_0, whereas the CPUE component showed informative gradients on the high side of the log R_0. While catch data is treated as a likelihood component in this model, the gradient for the catch component did not provide information about log R_0. The recruitment component strongly influenced the low side of the log R_0, which is reasonable given that greater recruitment variability is expected when the mean level of recruitment is specified as lower. It is important to note that the likelihood comes from contributions of time series of recruitment deviations, rather than the penalty applied to the difference between the log of recruitment in the initial equilibrium regime and log of R_0. Additionally, the observed variability of recruitment deviations, which was 0.51, is slightly lower than the assumed recruitment variability (fixed $\sigma R = 0.6$).

Composition data from Fleet 3, assuming an asymptotic selectivity shape (Taiwanese longline in the southern fishing ground), had the most impact on the log R_0 profile and fit best at 9.44, which was close to the MLE of the base-case model (Figure 5-4). The composition data from most fleets showed a gradual slope of relative likelihood around a log R_0 value of 9.5, indicating less influence to the log R_0 estimation. This is expected as fleets without indices were fit using time-varying selectivity, reducing their direct influence on the global scale. Exceptions were noted in Fleets 2 (Japanese longline in other seasons), 5 (Japanese tuna purse seine in the Pacific Ocean), and 21 (EPO Commercial fisheries after 2000). A sensitivity run was conducted to assess the impact of these fleets on the estimation of population dynamics, revealing a limited impact (see section 5.5.1).

All abundance indices showed a gradual slope of relative likelihoods around a log R_0 value of 9.5, indicating consistent estimates of population scale. However, the abundance index for S1 (Japanese longline) indicated a gradual improvement in relative likelihood as log R_0 decreased (Figure 5-4).

Given the complexity of the biology and fleet structure, the PBFWG considers the base-case model to possess the desirable property of internal consistency regarding population scale. Furthermore, the undue influence of composition data on the population scale has been reasonably addressed, as evidenced by relative likelihood values for the composition component being less than 1.5 units from the base model estimate of log R_0.

5.2.3. 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 generally fall within 95% confidence intervals (CI) for all the observed abundance indices. In particular, the base-case model fits very well with the S2 and S3 indices (Japanese longline for the early period and Japanese troll). The root mean-squared-errors (RMSE) between observed and predicted abundance indices were less than 0.2, consistent with the input CVs for these indices.

Additionally, the model fits well with the S1 and S5 indices (Japanese longline for the late period and Taiwanese longline CPUEs) with RMSEs of 0.28 and 0.24, respectively. Therefore, the PBFWG considers both the data and model structure to provide a good prediction of recent changes in population abundance.

5.2.4. Goodness-of-fit to Size Compositions

The base-case model generally captures the size modes present in the aggregated data by fishery and season (Figure 5-6 and Table 5-1). The harmonic means of effective sample sizes (effNs, estimates of the model's expected precision) exceeds the average input sample sizes for all fleets. This indicates that the assessment model estimates greater precision for these data than initially assumed.

Residuals in Fleet 2 (Japanese longline in other seasons) and Fleet 22 (EPO sports after 2013) have substantially decreased compared to the previous assessment (Figure 5-7). This reduction can be attributed to the aggregation of observed size composition data over the year or season and subsequent down-weighting. Although the aggregation of these data ignored the annual or seasonal variation in size, it has been confirmed that the amount of catch from these fleets was not substantial. This suggests that the impact of the lack of fit on the dynamics was minimal. Also, the model's fit to the observed size composition data of Japanese PS fleets (Fleets 5-10) and Korean OLSPS (Fleet 11) were improved compared to the previous assessment by adding additional model process, including time-varying selectivity, separability of selectivity, and age-specific availability in the local fishing ground (see section 4.3.2).

The current base-case model, which integrated detailed gear-specific selectivity and spatial and temporal (seasonal) variation of availability, could replicate the observed size composition data for all the fleets.

5.2.5. Retrospective Analysis

The retrospective analysis showed a highly consistent estimation of terminal SSB over the past 10 years, with Mohn's rho = -0.06. This aspect was a focal point for improvement in the previous assessment, and the PBFWG successfully resolved the negative systematic retrospective pattern by reducing the residuals for the size composition data and eliminating the recruitment index during 2011-2016 (Fukuda 2023).

In the retrospective recruitment, the exclusion of data from 2020-2022 FY likely led to higher recruitments during 2019-2021 than those estimated by the full data series model, as the terminal year recruitment tends to be around the expected value based on the spawner-recruitment relationship (Figure 5-8). Conversely, the exclusion of data from 2018-2019 FY resulted in lower recruitments during 2017-2018 than those estimated by the full data series model. This retrospective pattern in recruitment might result from the absence of the recruitment index during these years in the model, causing instability in a few terminal recruitment estimates. The PBFWG recognized this as a subject for future research. Overall, the PBFWG concluded that the retrospective analysis of SSB did not indicate significant model misspecification.

5.2.6. Hindcasting

A 7-year hindcasting model, fitted to CPUE observations up to 2015, using the age-structured production model (ASPM) successfully predicted the abundance indices from Taiwanese longline CPUE over the last 7 years (from 2016 to 2022) with accuracy (Figure 5-9). This robust prediction capability stems from the PBF assessment model's production function, consisting of growth, natural mortality, and the spawner-recruitment function, which effectively captures the net effects of catches at age across a range of stock sizes. Consequently, the model can provide reliable predictions of stock dynamics based on historical data. The results suggest that the PBF assessment model, even when extrapolated beyond the observed data, accurately reflects the recent recovery trends in the abundance index.

5.3. Model Parameter Estimates

5.3.1. Recruitment Deviations

A Beverton-Holt relationship with a steepness value of h=0.999 was used for the base-case model, and stock and recruitment plots are presented in Figure 5-10. The estimated recruitment deviations were considerably precise between

1993 and 2012, indicating that data well informed these estimates. Additionally, smaller confidence intervals post-1993 compared to pre-1993 suggests the influence of the size composition data, which became available for most fleets since 1994. Conversely, the recruitment deviations post-2012 were less precise compared to those in the 2000's, likely affected by the elimination of the recruitment index from the model after 2010. The uncertainty notably increases in the most recent two years (2021-2022) due to limited information available for those cohorts from catch and size data. Consequently, the PBFWG opted to exclude these recruitments from future projections although these were used to assess the stock status.

The variability of recruitment deviations (σR) in the base case ([1953-2022] $\sigma R = 0.51$) is close to, but slightly lower than, the assumed recruitment variability ($\sigma R = 0.6$). Given their proximity, the estimated population scale and recruitment are unlikely to be substantially affected by the recruitment penalty.

5.3.2. Selectivity

The estimated selectivity curves for each fleet in the base-case model are shown in Figures 5-11 and 5-12. Both length-based and age-based selectivities were estimated for Fleets 5, 6, 9, 11, 16, 17, and 18 (Table 4-1). Length-based selections were modeled as asymptotic or dome-shaped, whereas age-based selections were estimated for each age. Temporal variations in the age-based selectivity were observed for Fleets 5, 6, 9, 11, and 18. Among fleets with estimated length-based selectivity (Fleets 1, 2, 3, 4, 7, 8, 10, 12, 20, 21, and 22), dome-shaped patterns were predominant, with the exception of Fleet 3 with the asymptotic pattern. Temporal variations were captured for Fleets 21 and 22. A combination of length and age selections was used to approximate the gear-specific contact selectivity and the spatial and temporal (seasonal) variation in availability, respectively. This modeling approach primarily contributed to the increased number of estimated parameters since the 2016 assessment, totaling 372 selectivity parameters in the base-case model.

Overall, the length- or age-based selectivity of fleets with time-varying selection indicated a gradual or distinct change in selection patterns, transitioning from catching small (young) fish to large (old) fish in recent years (Figures 5-11 and 5-12). Particularly, the larger (older) fish have become more available in recent years for Fleets 5, 6, 11, 21, and 22.

5.4. Stock Assessment Results

5.4.1. Bridging analysis from the 2022 stock assessment

As noted in the above sections, the 2024 base-case model incorporated several key modifications aimed at enhancing its quality compared to the previous assessment. These included: 1) updating the fishery data up to 2022 FY if available, 2) changing the assessment start year from 1952 to 1983, 3) eliminating the Japanese troll CPUE-based recruitment index (S3) for 2011-2016 from the model, 4) using newly available size composition data and catch data in units of numbers for Japanese tuna PS farming operations, 5) improving the residuals for size composition data by adding model processes, aggregating the observed data, and/or adjusting the weighting. Among these changes, the data update was a necessary step, while altering the start year and removing the recruitment index for 2011-2016 were the major modifications likely to affect the demographic estimates. Here, five model runs were conducted to bridge the results from the 2022 assessment to the 2024 assessment (Figure 5-13).

Model 1: 2022 PBF assessment base case;

Model 2: Simple data update on the 2022 PBF assessment base case;

Model 3: Short-term model of the model 2;

Model 4: Based on model 3, elimination of the recruitment index for 2011-2016;

Model 5: 2024 PBF assessment base case.

Comparison between models 1 and 2 highlighted the effect of the simple data update, revealing a downscaling of the relative SSB during the historical period (1950s to 1970s) and a slightly higher SSB in model 2 after 2010. This indicates a pessimistic bias in the 2022 stock assessment base case, which was confirmed by a retrospective diagnostic conducted in the previous assessment (ISC 2022). Comparison between models 2 and 3 indicated that the assessment start year did not affect the estimated relative SSB for this assessment. Similarly, comparison between models 3 and 4 showed a slightly higher SSB in model 4. The decision to eliminate the recruitment index for 2011-2016 aimed to reduce the pessimistic retrospective bias seen in the 2022 stock assessment, justifying the slightly higher SSB in Model 4. Additionally, Model 5 showed a slightly elevated relative SSB during the late 1990s to the early 2000s compared to model 4 but a slightly smaller relative SSB in the terminal year. Based on these results, the PBFWG concluded that each difference resulting from adjustments in the assessment model was justified in light of the modifications objectives.

5.4.2. Total and Spawning Stock Biomass

The point estimates of total stock biomass from the base-case model showed long-term fluctuations (Table 5-2 and Figure 5-14), ranging from about 32,000 t in 1983 to about 187,000 t in 2022. The estimated total stock biomass showed a gradual increase since 2010. Spawning stock biomass (SSB) estimates mirrored this long-term fluctuation pattern (Figure 5-14). The highest SSB, reaching about 160,000 t, occurred in the early 1960s in the 2022 assessment. This assessment confirmed that SSB peaked at about 80,000 t in 1995 and declined to a historical low of about 12,000 t in 2010 (Table 5-2). Since 2011, there has been a consistent increase in SSB, resulting in a resurgence to a historic high of about 144,000 t in 2022. Particularly, moderately strong cohorts that emerged in 2016 and 2017 accelerated the rapid recovery of the biomass at age 5 and older after 2020 (Figure 5-15). The increase in total and spawning stock biomass coincides with an overall decline in fishing mortality over the last decade (see section 5.4.5).

The quadratic approximation to the likelihood function at the global minimum, using the Hessian matrix, indicated that the CV of SSB estimates was about 17% on average for 1983-2022 and 24% for 2022. The notable high CV in the terminal year could result from limited data on the recent recruitments.

The unfished SSB ($SSB_{F=0}$) was estimated by extrapolating the estimated spawner-recruit relationship under the equilibrium assumptions to about 622,000 t (R_0 = 13.2 million fish). The depletion ratios ($SSB/SSB_{F=0}$) during the assessment period ranged from 2.0% to 23.2%. Specifically, the 1995, 2010, and 2022 SSB corresponded to 12.7%, 2.0%, and 23.2% of $SSB_{F=0}$, respectively.

5.4.3. Recruitment

Recruitment estimates (age-0 fish on July 1st) fluctuated widely without an apparent trend. Recent strong cohorts were observed in 2007 (23.6 million) and 2008 (21.0 million), while moderate cohorts occurred in 2010 (17.6 million) and 2016 (16.0 million) (Table 5-2 and Figure 5-14). The average estimated recruitment was approximately 12.8 million fish for the entire stock assessment period (1983-2022). However, the 2009, 2012, 2014, 2019, and 2020 recruitments were relatively low (8.0, 7.6, 4.9, 7.5, and 6.8 million fish, respectively).

Recruitment estimates were relatively more uncertain at the start of the assessment period until 1993 (average CV = 22%, maximum CV = 31%). Precision improved (average CV = 7.3%) during 1994-2010 with the initiation of comprehensive size data collection for Japanese fisheries and availability of a recruitment index. However, the recruitment estimates for the past nine years (2012-2022) were more uncertain due to the lack of a recruitment index (average CV = 25.5%, maximum CV = 53%).

5.4.4. Catch at Age

The catch numbers of PBF at each age were estimated internally in the stock assessment model based on growth assumptions, observed catch, and selectivity. PBF catches have predominantly been comprised of juveniles (ages 0-2) (Figure 5-16) throughout the assessment period, displaying distinct phases. Prior to 1994, the catch at age 0 was less than 1 million fish. However, the significant difference in the amount of composition information available before and after 1994 (Figure 3-1) has led to greater uncertainty in the estimated catch numbers at younger ages before the early 1990s. From the early 1990s to the 2000s, the catch of age-0 PBF experienced a substantial increase, resulting in fluctuating estimates averaging around 4 million fish.

After the introduction of management measures by the RFMOs (WCPFC in 2011 and IATTC in 2012), the catch in the number of fish decreased to less than 2 million on average. Subsequent to this, recent management measures, strengthened since the 2015 calendar year (i.e., WCPFC CMM 2019-02, IATTC Resolution C-18-01), have maintained the catch number at about 1.5 million fish on average. The catch of age 0 PBF, which has the largest fishery impact on future biomass, has also significantly decreased since the mid-2010s due to stricter controls on juvenile catch in both the EPO and the WCPO, resulting in a decline in total catch weight.

5.4.5. Fishing Mortality

Historically, the PBF stock has experienced a very high fishing mortality (Table 5-2). SPR values from 1983 to 2014 were consistently below 20%, leading to a low likelihood of the stock being above 20%$SSB_{F=0}$ (Table 5-2). Particularly, SPR during the late 2000s averaged about 1% (2005-2009). This very low SPR was caused by the high fishing mortality rate for ages 0-2 (see F2002-2004 in Figure 5-17).

After 2010, SPR gradually increased, coinciding with the implementation of the first catch upper limit on both sides of the Pacific Ocean (2011 in the WCPFC and 2012 in the IATTC). The fishing mortality for ages 0-2 during 2012-2014 declined compared to that during 2002-2004 (Figure 5-17). Since 2015, SPR has increased above 20%, indicating the effectiveness of the strengthened management measures in conjunction with a couple of moderate recruitments in 2015-2017.

5.4.6. Fishery Impact

The cumulative impact of the different fishery groups on the SSB was evaluated by simulating the population dynamics while removing each fishery using the base-case model (Wang et al. 2009). Figure 5-18 showed (a) the historical fishery impact on the SSB of PBF and (b) the ratio of fishery impact within each fishery group. It should be noted that these plots were developed using the long-term base-case model to illustrate the historical trajectories of the fishery impact.

Historically, the WPO coastal fisheries group has had the greatest impact on the PBF stock. However, since the early 1990s, the WPO purse seine fishery group targeting small fish (ages 0-1) has had a greater impact. 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 after that. The WPO longline fisheries group has had a limited effect on the stock throughout the analysis period. This is because the impact of a fishery on a stock depends on both the number and size of 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.

5.4.7. Biological Reference Points

The base case results show that the point estimate of $SSB_{2022}/SSB_{F=0}$ was 23.2%. As shown in the Kobe plot (Figure 5-19), there was a continuous recovery in SSB and short-term fluctuations in fishing mortality (SPR) at the levels below 20% of SPR. It is noteworthy that the SPR, at least in the terminal two years, might be skewed higher. This is because the estimated recruitments for recent years have high uncertainty due to limited information in the data and are lower than average, which is one of the main causes of the recent increase in SPR.. SSB reached the initial rebuilding target (the median of SSB point estimates during 1952-2014; 6.3%$SSB_{F=0}$) in 2017, as well as the second rebuilding target (20%$SSB_{F=0}$) in 2021. Additionally, fishing mortality in the most recent years (2018-2022) is F23.6%SPR, which is a lower rate than some commonly used F-based reference points such as F_{max} or F20%SPR (Table 5-3).

5.5. Sensitivity Analyses

5.5.1. Sensitivity runs assuming alternative observation processes

a. Different data-weighting of size composition data

Given the abundance of fleet composition data, data weighting is an important topic that could potentially impact the stock assessment results. In the 2024 assessment, the harmonic mean values of the estimated effective sample sizes for all fleets fitted in the model were higher than the inputted sample sizes. This indicates a higher predictability of the base case model than initially anticipated.

A sensitivity run was conducted using an alternative weighting approach on size composition data. This approach involved down-weighting the size composition data from Fleets 2 (Japanese longline in season 1~3), 5 (Japanese Purse seine operating in the Pacific Ocean), and 21 (EPO commercial fishery after 2001). These fleets were chosen because, in the likelihood profile diagnostics over the log R_0 parameter, they had a relatively steep slope around the log R_0 value estimated as MLE by the base-case model.

Comparatively, the fits to the abundance indices were slightly improved in the down-weighting model, resulting in a decrease of 2 units of negative log-likelihood when aggregated across all indices. However, there was no improvement in the fits to the size composition data. Overall, this alternative weighting model had minimal impact on the estimated spawning biomass (Figure 5-20). The PBFWG concluded that the base-case results remained robust to the size composition data that exhibited potential influence on the global scale estimate. The PBFWG recommended further exploration and research into the nuances of data weighting.

b. Doubling amount of unseen mortality

Recent management measures may have led to more discards or releases for certain fleets. Although data on discards are limited, the base-case model assumed unseen mortality levels for these fleets (see section 3.6.13). The implication of this assumption remained uncertain; thus, a sensitivity run was conducted, assuming that unseen mortality were double the assumed values. The model results were nearly identical to the base case, with the model able to predict the catches in the discard fleets (Figure 5-21). This result was anticipated, as undocumented mortalities have only arisen in recent years. The PBFWG concluded that the uncertainty in the discard levels is not critical for this assessment but could influence future assessments.

c. Fitting the troll recruitment index for the whole period (1983-2016)

In previous assessments, the recruitment index based on the Japanese troll CPUE proved to be a good indicator of recruitment trends (ISC 2018). However, this continuity was disrupted because of changes in catchability following the introduction of the new fishery management schemes after 2016 (e.g., individual quotas) (Nishikawa et al. 2021). Additionally, the model diagnostics suggested potential catchability changes due to shifts in fishing practices after 2010 (Fukuda 2023). Consequently, the PBFWG decided to exclude the Japanese troll index after 2010 from the 2024 assessment. A sensitivity run was conducted that included the troll recruitment index for the whole period (1983-2016). This model estimated lower recruitment levels in 2013-2022 compared to the base-case model, resulting in lower estimated SSB (Figure 5-22). However, this run showed a degraded fit to the Taiwanese longline CPUE based index (1.4 NLL unit). This further supported findings from Fukuda (2023), suggesting that Japanese troll CPUE data in the 2010s could contribute to the pessimistic bias shown in the retrospective diagnostics of the 2022 assessment.

5.5.2. Sensitivity runs assuming alternative system dynamics processes

a. Steepness

The convergence of the previous assessment models were found to be sensitive to changes in the assumed level of steepness. Even small adjustments to the specified steepness level resulted in a non-positive definite Hessian. To develop a more flexible model capable of accommodating alternative assumptions for steepness and other productivity assumptions, the PBFWG developed the short time-series model (Fukuda 2021, Fukuda et al. 2022), adopting it as the base-case model for the 2024 assessment.

Various steepness values (h= 0.9~1.0) were meticulously applied to the base-case model to illustrate the likelihood profile of the steepness parameter. The base case model converged for almost all runs tested, with the Hessian being positive definite, except for the runs with h=0.905 and 0.950. The total likelihood had the lowest value within the range of steepness values from 0.991 to 0.995 (Figure 5-23), although the improvement in the total likelihood was marginal (0.3 NLL unit).

Both size compositions and recruitment penalty components showed informative gradients (convex function in the negative log-likelihood context) on both low and high sides of the log R_0, with the lowest steepness value at around 0.97 (Figure 5-23). On the other hand, the CPUE component showed a one-way decreasing trend in NLL as steepness increased. Given the presence of both spawner and recruitment indices during the same time period with internal consistency among these data as indicated by model diagnostics, the CPUE component might have information regarding the steepness. However, the profile likelihoods on steepness did not show any preference regarding the strength of the stock recruitment relationship.

In the run with a lower steepness value at h=0.97, where the recruitment penalty component showed the lowest NLL, the estimated SSB was similar to the base case, although relative SSB (SSB/ $SSB_{F=0}$) was slightly lower due to the higher $SSB_{F=0}$ associated with the lower steepness (Figure 5-23).

The PBFWG concluded that further investigation into this area was warranted, although there was no indication of the critical model misspecification in this regard.

b. Higher and lower natural mortality for age 2 and older

While the age-specific M used in the assessment is mostly based on empirical evidence, there is still uncertainty in the M value for older fish. Sensitivity runs were conducted, assuming either higher or lower values (by 20%) for age 2 and older. The higher and lower M for age 2+ resulted in higher and lower relative SSB than the base-case model (Figure 5-24), respectively, as anticipated. The PBFWG concluded that the current base-case model exhibits insensitivity to the assumptions regarding natural mortality for age 2 and older.

c. Higher and lower expected variation in the recruitment (sigma R)

Although the estimated variation in recruitment values (0.51) was smaller than the assumed variation (sigmaR = 0.6) in the base case, the likelihood profile over the log R_0 showed that the recruitment penalty seems to be pushing the population scale higher. To assess the effect of different strengths of constraint on the assumed recruitment variation, both higher (1.0) and lower (0.52) sigmaR values were tested.

A run with higher (1.0) recruitment variation showed an apparently higher negative log-likelihood (12 NLL units) in the recruitment penalty component than the base case, despite similar or slightly smaller NLL values for both CPUE and size composition components (Table 5-4). Additionally, the estimated population scale was higher than the base case (Figure 5-25). On the other hand, a run with a lower recruitment variation assumption showed a slightly lower NLL value (-1.5 units) in the recruitment penalty component than the base case, although it showed slightly higher NLL for the CPUE and size composition components. Thus, it was evident that there existed a trade-off among likelihood components stemming from the recruitment penalty and data. Consequently, the PBFWG chose to retain the recruitment variation selected in the base-case model.

6. Future Projection

The WCPFC and IATTC defined the median SSB from MLE point estimates between 1952 and 2014 as the initial rebuilding target and 20% $SSB_{F=0}$ as the second rebuilding target[3]. The 2024 PBF assessment base case estimated that the PBF stock achieved these rebuilding targets in the 2017 and 2021 fishing years, respectively. Then, the PBFWG evaluated the probability of the stock remaining above the second target or other candidate target reference points using simulation-based projections. The projected SSB estimates represent the medians of 6,000 individual SSB calculated for each of the 300 bootstrap replicates, followed by 20 stochastic simulations based on different future recruitment time series. The projection started in the 2021 FY, since the estimated recruitments for 2021 and 2022 were unreliable to include in the projection (sections 5.3.1 and 5.4.3). A 20-year demography projection was conducted, and the probability of the stock remaining above a certain biomass level in 2041 was calculated based on 6,000 replicates.

Tables 6-1 and 6-2 summarize the results of the future projections for each harvesting scenario and provide the probability of recovery and future expected yields, respectively. All examined scenarios show that the probability of the stock being above 20%$SSB_{F=0}$ in 2041 (Table 6-1) is higher than 60%. The expected fishery impact on the projected SSB in each scenario are illustrated in Appendix 1.

Scenario 1 approximates the current management measures, indicating that the stock would achieve the relative biomass associated with all the candidate target reference points (20%, 25%, 30%, and 40% of $SSB_{F=0}$) by the 2041 FY. This scenario shows a gradual increase in SSB, reaching a level where the 2034 SSB is higher than 40%$SSB_{F=0}$ (Table 6-1, Figure 6-1). The expected fishery impact on the projected SSB for most fishery groups in scenario 1 generally remains constant throughout the projected period (Figure 6-2), with the exception of WPO purse seiners.

Scenario 2, which applies the conversion of small fish quota to large fish quota at the current conversion factor of 1.47, projects a similar trend but a higher SSB in 2034 compared to scenario 1 (Figure 6-3). In scenario 3, where no fishing is allowed, the SSB would achieve a higher biomass than 80% of $SSB_{F=0}$ by 2034 (Table 6-1 and Figure 6-4). This scenario highlights the potential productivity of the population. The expected fishery impact on the projected SSB in scenarios 2 and 3 are shown in Appendix 1.

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[3] The second rebuilding target defined as "20%$SSB_{F=0}$ under average recruitment" by the WCPFC Harvest Strategy is conceptually different from the R_0 based (expected recruitment at unfished biomass), which has been done by the PBFWG, although the two estimates were close.

In scenarios 4-11, as requested by the RFMOs, the specified recovery probability and/or impact ratio was approximated during the search for the appropriate increase levels. More specifically, these scenarios were fine-tuned to achieve the 20%$SSB_{F=0}$ with a 60% probability in 2041. As a result, the catch increases in these scenarios are notably more aggressive than in others, exhibiting a decreasing trend from a peak biomass in the late 2020s to the end year of the projection. The balance of quota between small and large PBF categories in scenarios 8-11 confirms that measures restricting the catch of small fish are more effective than those on large fish to maximize the total yields (Table 6-2). The expected fishery impact on the projected SSB varies among catch increase scenarios, especially when the catch distribution between small and large PBF is altered (Appendix 1).

Scenario 12, which applies a constant fishing mortality of F30%SPR, leads to the 2034 SSB achieving 30%$SSB_{F=0}$. Unlike scenarios 4-11, this scenario does not show any decreasing trend in the stock because of the nature of the constant fishing mortality (Figure 6-4). This scenario achieves a higher biomass level compared to scenarios 4-11, with a better total yield than some of those scenarios (e.g., scenarios 4, 8, and 9) (Figure 6-4, Table 6-2).

The projection results assume that the CMMs are fully implemented and are based on specified biological and other assumptions. For example, these future projection results do not incorporate assumptions about discard mortality. Although the impact of discards on SSB is relatively small compared to other fisheries, discards may need to be considered as part of future increases in catch.

7. Resolved Issues and Major Unresolved or Future Issues

This section highlights the major issues identified by the PBFWG in the previous assessment, categorized into 1) resolved issues and 2) unresolved issues or areas for future consideration. These unresolved issues require attention in future assessments. This list is not meant to be an all-inclusive list.

Resolved Issues

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. Matching the length composition data in the assessment model requires estimating both length-based and age-based selection. This resulted in 366 selectivity parameters estimated in the 2022 assessment. Subsequently, a short time-series model starting in 1983 limited issues associated with composition misfit in the early years (1952-1982) and reduced the number of estimated parameters. This short time-series model also resolved the convergence issue with lower steepness values (Fukuda 2021).

Although the current base-case model did not encounter serious convergence issues, given that the increasing trend in the number of parameters is expected to continue as more years are included, ongoing efforts to reduce the number of parameters might mitigate the risk of convergence issues in future assessments.

Size Composition Data for Key Longline Indices

The current assessment relies on two longline fleets' abundance indices to represent annual changes in the abundance of large mature PBF. To limit the 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 Japanese longline (Fleet 1), which associated with CPUE, is seeing an influx of new migrants in the observed size compositions and CPUE (Tsukahara et al. 2021). The influx of new migrants is smaller in size and may represent newly recruited spawners to this fleet as the population rebuilds, changes in how fishermen fished making smaller fish more likely to be caught caused by management, or seasonal migrants that the data preparation, as mentioned earlier, attempted to remove. To address this, sub-setting of recent composition data and removal of smaller sizes of fish from Fleet 1 were conducted so that the observed CPUE would be a reliable indicator of changes in abundance with a consistent selectivity pattern.

Additionally, area-weighted size composition data for Fleet 1 (Tsukahara e al. 2024) were presented to estimate the selectivity of the S1 Japanese longline index during the 2024 assessment meeting, and the PBFWG considered that standardization of the size composition data by the index value would further improve the internal consistency of the observation model. This approach is also applicable to the Taiwanese longline index (S5).

Unresolved or future issues

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. Exploration of alternative model structures or data preparation methods (e.g., smaller size bins) may be necessary to resolve this issue. This issue is somewhat related to issue 7.1.1, as these poorly informed parameters can cause convergence issues.

CPUE for Key Longline Indices

The current assessment relies on two longline fleets' abundance indices to represent annual changes in the abundance of large mature PBF. Changes in the catchability of longline fleets, particularly due to management measures such as Individual Quota (IQ), pose challenges for the reliability of CPUE indices. This is why the Japanese longline Index (S1) halted in 2019. Although the Taiwanese longline fleet has not reached its catch upper limit so far, their future catch is expected to approach their limit more rapidly than before, given the rapid recovery of the SSB. In future assessments, the WG may need to put more effort into ensuring that any new regulations for Fleet 3 do not cause the changes in catchability. Additional efforts should be made to develop a new index of abundance for large, mature PBF.

Unseen Mortality or Discards

Management measures enacted over the last 7 years have resulted in the increasing abundance of juvenile age classes. More restrictive management, coupled with the potential for rapid increases in local abundance, may result in increased bycatch and subsequent release of unwanted sized PBF. The working group attempted to deal with this potential problem by adding unseen mortalities, but its magnitude is poorly understood. Depending on the relative magnitude of this unseen fishery mortality, this issue, unless adequately understood, may potentially weaken the strong relationship between observed catches, the production function, and the model's ability to predict changes in the abundance of fishes taken in the longline fleets. This understanding of '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.

Recruitment Estimates in the Terminal Decade

To resolve the negative systematic retrospective pattern, the recruitment index during 2011-2016 was eliminated from the 2024 base-case model. While this action improved the consistency of the base-case model, it resulted in the absence of a recruitment index for the last 12 annual cohorts. Some of these cohorts have already been subject to selection by the longline fleets associated with the abundance index for large PBF, allowing for estimation of their strength. However, there is only catch and size data about the cohorts recruited in the terminal several years, leading to a data gap and large CVs in the estimated recruitments after 2012 in the base-case model.

The current PBF assessment applied SPR to characterize the fishing intensity, which is impacted by the F at young ages (e.g., ages 0-2). Due to the large CVs in several terminal recruitments, there was also a large CV in the terminal SPR. To more precisely characterize the status of the stock in the terminal year, there is a strong need for an alternative recruitment index that can maintain the internal consistency of the model. Fujioka et al. (2024) presented updated results of the recruitment monitoring program conducted in Japan. Although there was a clear difference in the catchability between the monitoring results of conventional operations and chartered operations, this survey could be a step towards resolving terminal recruitment uncertainty. The program should be continued with additional evaluation of the catchability difference issue as well as ensuring the internal consistency within the stock assessment model.

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TABLES and FIGURES

Table 1-1. Definitions of calendar year, fishing year, and year class used in the Pacific bluefin tuna *Thunnus orientalis* stock assessment. Note the 2024 assessment base case model ends in fishing year 2022.

Fishing year	2020												2021												2022											
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		
Fishing month	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
SSB										SSB in 2020												SSB in 2021												SSB in 2022		
Day of birth in SS	Birthday of 2020 yr class												Birthday of 2021 yr class												Birthday of 2022 yr class											
Recruitment	Recruitment in 2020												Recruitment in 2021												Recruitment in 2022											
Year class	2020 yr class												2021 yr class												2022 yr class											
Calender year	2020						2021												2022												2023					
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

Table 2-1. Age-length-weight relationship at the beginning of the fishing year 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	JPN_LL (Seas 4)	Weight	JPN Longline (1952-1992)	JPN Longline (1993-2016, Season 4)			S1, S2
Fleet 2	JPN_LL (1993-) (Seas 1-3)	Weight	JPN Longline(1993-2016, Season 1-3)	JPN Longline(2017-2020)			
Fleet 3	TWN_LLSouth	Weight	TWN Longline (South area)	Out of ISC members (NZ, AU, etc.)*5			S5-9
Fleet 4	TWN_LLNorth	Weight	TWN Longline (North area)				
Fleet 5	JPN_TPS_PO	Weight	JPN Tuna Purse seine in Pacific Ocean				
Fleet 6	JPN_TPS_SOJ	Weight	JPN Tuna Purse seine in the Sea of Japan	TWN Purse seine*2			
Fleet 7	JPN_TPS_SOJ (Farming)	Number	JPN Tuna Purse seine in the Sea of Japan for Farming				
Fleet 8	JPN_SPPS (Seas 1,3,4)	Weight	JPN Small Pelagic Purse seine (Season 1,3,4)				
Fleet 9	JPN_SPPS (S2)	Weight	JPN Small Pelagic Purse seine (Season 2)				
Fleet 10	JPN_SPPS (Farming)	Number	JPN Small Pelagic Purse seine for Farming				
Fleet 11	KOR_LPPS	Weight	KOR Large Pelagic Purse Seine	KOR Trawl*1	KOR Setnet*1	KOR Troll*1	
Fleet 12	JPN_Troll (Seas 2-4)	Weight	JPN Troll (Season 2-4)				S3, S4
Fleet 13	JPN_Troll (Seas 1)	Weight	JPN Troll (Season 1)				
Fleet 14	JPN_Troll (Farming)	Number	JPN Troll for Farming				
Fleet 15	JPN_PoleLine	Weight	JPN Pole-and-Line	JPN Driftnet*3	TWN Driftnet*3	TWN Others*4	
Fleet 16	JPN_Setnet (Seas 1-3)	Weight	JPN Setnet (Season 1-3)	JPN Miscellaneous (Season 1-3)			
Fleet 17	JPN_Setnet (Seas 4)	Weight	JPN Setnet (Season 4)	JPN Miscellaneous (Season 4)			
Fleet 18	JPN_Setnet (HK_AM)	Weight	JPN Setnet in Hokkaido and Aomori				
Fleet 19	JPN_Other	Weight	JPN Others				
Fleet 20	EPO_COMM (-2001)	Weight	USA Commercial Fisheries (PS, Others)	MEX Commercial Fisheries (PS, Others)			
Fleet 21	EPO_COMM (2002-)	Weight	MEX Commercial Fisheries (PS, Others)	USA Commercial Fisheries (PS, Others)			
Fleet 22	EPO_Sports (2014-)	Number	USA Recreational Fisheries (2014-)				
Fleet 23	EPO_Sports early (-2013)	Number	USA Recreational Fisheries (-2013)				
Fleet 24	WPO_Disc_Weight	Weight	Discard amount for WPO				
Fleet 25	WPO_Disc_Num	Number	Discard number for WPO				
Fleet 26	EPO_Sports_Disc_Num	Number	Discard number for EPO				

*1 Catch for Korean Trawl, Korean Setnet and Korean Troll are **included** in the input data until the 2022 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 the calendar years 1952-2022. Blank indicates no effort. "0" indicates that fishing effort was reported but no catch. "+"indicates below 499kg catch and "-" indicates unreported catch or catch information not available.

Calendar Year	Japan (JP)[1]						Sub Total
	Purse Seine	Longline	Troll[2]	Pole and Line	Set Net	Others	
1952	7,680	2,694	667	2,198	2,145	1,700	17,084
1953	5,570	3,040	1,472	3,052	2,335	160	15,629
1954	5,366	3,088	1,656	3,044	5,579	266	18,999
1955	14,016	2,951	1,507	2,841	3,256	1,151	25,722
1956	20,979	2,672	1,763	4,060	4,170	385	34,029
1957	18,147	1,685	2,392	1,795	2,822	414	27,255
1958	8,586	818	1,497	2,337	1,187	215	14,640
1959	9,996	3,136	736	586	1,575	167	16,196
1960	10,541	5,910	1,885	600	2,032	369	21,337
1961	9,124	6,364	3,193	662	2,710	599	22,652
1962	10,657	5,769	1,683	747	2,545	293	21,694
1963	9,786	6,077	2,542	1,256	2,797	294	22,752
1964	8,973	3,140	2,784	1,037	1,475	1,884	19,293
1965	11,496	2,569	1,963	831	2,121	1,106	20,086
1966	10,082	1,370	1,614	613	1,261	129	15,069
1967	6,462	878	3,273	1,210	2,603	302	14,728
1968	9,268	500	1,568	983	3,058	217	15,594
1969	3,236	878	2,219	721	2,187	195	9,436
1970	2,907	607	1,198	723	1,779	224	7,438
1971	3,721	697	1,492	938	1,555	317	8,720
1972	4,212	512	842	944	1,107	197	7,814
1973	2,266	838	2,108	526	2,351	636	8,725
1974	4,106	1,177	1,656	1,192	6,019	754	14,904
1975	4,491	1,061	1,031	1,401	2,433	808	11,225
1976	2,148	320	830	1,082	2,996	1,237	8,613
1977	5,110	338	2,166	2,256	2,257	1,052	13,179
1978	10,427	648	4,517	1,154	2,546	2,276	21,568
1979	13,881	729	2,655	1,250	4,558	2,429	25,502
1980	11,327	811	1,531	1,392	2,521	1,953	19,535
1981	25,422	590	1,777	754	2,129	2,653	33,325
1982	19,234	718	864	1,777	1,667	1,709	25,969
1983	14,774	217	2,028	356	972	1,117	19,464
1984	4,433	142	1,874	587	2,234	868	10,138
1985	4,154	105	1,850	1,817	2,562	1,175	11,663
1986	7,412	102	1,467	1,086	2,914	719	13,700
1987	8,653	211	880	1,565	2,198	445	13,952
1988	3,605	157	1,124	907	843	498	7,134
1989	6,190	209	903	754	748	283	9,087
1990	2,989	267	1,250	536	716	455	6,213
1991	9,808	218	2,069	286	1,485	650	14,516
1992	7,162	513	915	166	1,208	1,081	11,045
1993	6,600	812	546	129	848	365	9,300
1994	8,131	1,206	4,111	162	1,158	398	15,166
1995	18,909	678	4,778	270	1,859	586	27,080
1996	7,644	901	3,640	94	1,149	570	13,998
1997	13,152	1,300	2,740	34	803	811	18,840
1998	5,391	1,255	2,876	85	874	700	11,181
1999	16,173	1,157	3,440	35	1,097	709	22,611
2000	16,486	953	5,217	102	1,125	689	24,572
2001	7,620	791	3,466	180	1,366	782	14,205
2002	8,903	841	2,607	99	1,100	631	14,181
2003	5,768	1,237	2,060	44	839	446	10,394
2004	8,257	1,847	2,445	132	896	514	14,091
2005	12,817	1,925	3,633	549	2,182	548	21,654
2006	8,880	1,121	1,860	108	1,421	777	14,167
2007	6,840	1,762	2,823	236	1,503	657	13,821
2008	10,221	1,390	2,377	64	2,358	770	17,180
2009	8,077	1,080	2,003	50	2,236	575	14,021
2010	3,742	890	1,583	83	1,603	495	8,396
2011	8,340	837	1,820	63	1,651	283	12,994
2012	2,462	673	570	113	1,932	343	6,093
2013	2,771	784	904	8	1,415	529	6,411
2014	5,456	683	1,023	5	1,907	499	9,573
2015	3,645	648	413	8	1,242	431	6,387
2016	5,095	691	778	54	1,228	508	8,354
2017	4,540	913	605	49	2,221	665	8,993
2018	4,049	700	371	9	645	431	6,205
2019	4,464	1,002	720	0	951	372	7,509
2020	3,960	1,416	760	1	1,342	532	8,011
2021	4,198	1,551	653	0	1,742	440	8,584
2022	4,702	1,587	1,079	13	2,126	605	10,112

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	Longline	Setnet	Troll	Trawl	Sub Total	Longline	Set-net	Purse Seine	Gill-net (not specified)	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		0					1						1
1972		0					14						14
1973		0					33						33
1974		0					47					15	62
1975		3					61					5	66
1976		5					17					2	19
1977		0					131					2	133
1978		3					66					2	68
1979		0					58					-	58
1980		0					114					5	119
1981		0					179					-	179
1982	31	0				31	207				2	-	209
1983	13	0				13	175		9		2	-	186
1984	4	1				5	477		5		-	8	490
1985	1	0				1	210		80		11	-	301
1986	344	0				344	70		16		13	-	99
1987	89	13				102	365		21		14	-	400
1988	32	0				32	108		197		37	25	367
1989	71	0				71	205		259		51	3	518
1990	132	0				132	189		149		299	16	653
1991	265	0				265	342		-		107	12	461
1992	288	0				288	464		73		3	5	545
1993	40	0				40	471		1			3	475
1994	50	0				50	559					-	559
1995	821	0				821	335					2	337
1996	102	0				102	956		-	-		-	956
1997	1,054	0				1,054	1,814		-	-		-	1,814
1998	188	0				188	1,910		-	-		-	1,910
1999	256	0				256	3,089		-	-		-	3,089
2000	2,401	0			0	2,401	2,780		-	1		1	2,782
2001	1,176	0			10	1,186	1,839		-	2		2	1,843
2002	932	0			1	933	1,523		-	3		1	1,527
2003	2,601	0			0	2,601	1,863		-	10		11	1,884
2004	773	0			0	773	1,714		-	1		2	1,717
2005	1,318	0			9	1,327	1,368	1	-	-		1	1,370
2006	1,012	0			3	1,015	1,149	1	-	-		-	1,150
2007	1,281	0			4	1,285	1,401	2	-	8		-	1,411
2008	1,866	0			10	1,876	979	1	-	1		-	981
2009	936	0			4	940	877	1	-	10		-	888
2010	1,196	0			16	1,212	373	29	-	7		-	409
2011	670	0		+	14	684	292	16	-	7		1	316
2012	1,421	0			2	1,423	210	2	-	-		2	214
2013	604	-	1	+	0	605	331	2	-	1		-	334
2014	1,305		6	0	-	1,311	483	38	-	4		-	525
2015	676		1	0		677	552	25	-	1		-	578
2016	1,024		3	0	2	1,029	454		-	+		-	454
2017	734		3		6	743	415		-	-		+	415
2018	523		7		5	535	381		-	3		+	384
2019	542		36		3	581	486	2	-	2		2	492
2020	567		35		3	605	1,149	1	-	-		-	1,150
2021	422		84		3	509	1,478		-	+		-	1,478
2022	654		221		6	881	1,496		-	+		-	1,496

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

Table 3-2. Cont.

Calendar Year	United States (US)[5]									Mexico (MX)			Sub total	Out of ISC members		Grand Total
	Drift gill-net	Longline	Pole and line	Troll	Hook and Line	Others	Purse seine	Sport	Sub Total	Others	Purse seine	Sub Total		New Zealand (NZ)[6]	Other[7]	
1952							2,076	2	2,078	-	-		2,078			19,162
1953							4,433	48	4,481	-	-		4,481			20,110
1954							9,537	11	9,548	-	-		9,548			28,547
1955							6,173	93	6,266	-	-		6,266			31,988
1956							5,727	388	6,115	-	-		6,115			40,144
1957							9,215	73	9,288	-	-		9,288			36,543
1958							13,934	10	13,944	-	-		13,944			28,584
1959			56				3,506	13	3,575	32	171	203	3,778			19,974
1960			+				4,547	1	4,548	-	-		4,548			25,885
1961			16				7,989	23	8,028	-	130	130	8,158			30,810
1962			+				10,769	25	10,794	-	294	294	11,088			32,782
1963			28				11,832	7	11,867	-	412	412	12,279			35,031
1964			39				9,047	7	9,093	-	131	131	9,224			28,517
1965			11	+		66	6,523	1	6,601	-	289	289	6,890			27,030
1966			12				15,450	20	15,482	-	435	435	15,917			30,986
1967			+				5,517	32	5,549	-	371	371	5,920			20,701
1968			8				5,773	12	5,793	-	195	195	5,988			21,615
1969			9				6,657	15	6,681	-	260	260	6,941			16,400
1970			+				3,873	19	3,892	-	92	92	3,984			11,422
1971			+				7,804	8	7,812	-	555	555	8,367			17,088
1972			3			42	11,656	15	11,716	-	1,646	1,646	13,362			21,190
1973			5	+		20	9,639	54	9,718	-	1,084	1,084	10,802			19,560
1974			+	+		30	5,243	58	5,331	-	344	344	5,675			20,641
1975			83			1	7,353	34	7,471	-	2,145	2,145	9,616			20,907
1976			22	+		3	8,652	21	8,698	-	1,968	1,968	10,666			19,298
1977			10			3	3,259	19	3,291	-	2,186	2,186	5,477			18,789
1978			4			2	4,663	5	4,674	-	545	545	5,219			26,855
1979			5			1	5,889	11	5,906	-	213	213	6,119			31,679
1980			+			24	2,327	7	2,358	-	582	582	2,940			22,594
1981	4		+	10		+	867	9	890	-	218	218	1,108			34,612
1982	9		1			+	2,639	11	2,660	-	506	506	3,166			29,375
1983	31		59			2	629	33	754	-	214	214	968			20,631
1984	6	1	5			18	673	49	752	-	166	166	918			11,551
1985	8					20	3,320	89	3,437	-	676	676	4,113			16,078
1986	16					41	4,851	12	4,920	-	189	189	5,109			19,252
1987	2					18	861	34	915	-	119	119	1,034			15,488
1988	4					46	923	6	979	1	447	448	1,427			8,960
1989	3					18	1,046	112	1,179	-	57	57	1,236			10,912
1990	11					81	1,380	65	1,537	-	50	50	1,587			8,585
1991	4	2				+	410	92	508	-	9	9	517	2		15,761
1992	9	38				14	1,928	110	2,099	-	0	0	2,099	0		13,977
1993	32	42				29	580	283	966	-	0		966	6	0	10,787
1994	28	30				1	906	86	1,051	2	63	65	1,116	2	1	16,894
1995	20	29				+	657	245	951	-	11	11	962	2	1	29,202
1996	43	25		2		+	4,639	40	4,749	-	3,700	3,700	8,449	4		23,509
1997	58	26		1		48	2,240	131	2,504	-	367	367	2,871	14	1	24,594
1998	40	54		128		59	1,771	422	2,474	-	1	1	2,475	20	3	15,777
1999	22	54		20		88	184	408	776	35	2,369	2,404	3,180	21	5	29,162
2000	30	19		1		11	693	319	1,073	99	3,019	3,118	4,191	21	8	33,975
2001	35	6		6		1	292	344	684	-	863	863	1,547	50	7	18,838
2002	7	2		1		2	50	613	675	2	1,708	1,710	2,385	56	6	19,088
2003	14	1				3	22	355	395	43	3,211	3,254	3,649	41	12	18,581
2004	10	1				+		50	61	14	8,880	8,894	8,955	67	10	25,613
2005	5	1				1	201	73	281	-	4,542	4,542	4,823	29	14	29,217
2006	1	1				+		94	96	-	9,806	9,806	9,902	23	5	26,262
2007	2	+				+	42	12	56	-	4,147	4,147	4,203	14	4	20,738
2008	1	+				+		63	64	15	4,407	4,422	4,486	14	3	24,540
2009	3	1		0		2	410	156	572	-	3,019	3,019	3,591	16	3	19,459
2010	1	0				0		88	89	-	7,746	7,746	7,835	14		17,866
2011	18	0		0		100		225	343	1	2,731	2,732	3,075	28	5	17,102
2012	4	0		0		38		400	442	1	6,668	6,669	7,111	13	1	14,855
2013	7	1		0		3		809	820		3,154	3,154	3,974	24		11,348
2014	5	+		+	2	-	401	420	828		4,862	4,862	5,690	12	8	17,119
2015	4	+			7	-	86	400	497		3,082	3,082	3,579	17	4	11,242
2016	9	1		0	31	-	316	372	729		2,709	2,709	3,438	19	2	13,296
2017	1	1		+	18	+	466	463	949		3,643	3,643	4,592	14	8	14,765
2018	18	1		+	31	4	12	535	601		2,840	2,840	3,441	20	9	10,594
2019	10	2		1	36	1	226	479	755		2,249	2,249	3,004	23	3	11,612
2020	28	2		+	87	1	116	750	984		3,285	3,285	4,269	46	0	14,081
2021	55	1		+	116	3	43	1,249	1,467		3,027	3,027	4,494	42	0	15,107
2022	20	2		0	149	1	198	1,367	1,737		3,194	3,194	4,931	34	4	17,458

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

7 Catches by Other countries are provided by WCPFC year book.

Table 3-3. Quarterly catch of Pacific bluefin tuna *Thunnus orientalis* by fleet and for the fishing year 1983-2022.

Fishing year	Season	Weight (mt)																			Number (1000 fish)						
		Fleet 1	Fleet 2	Fleet 3	Fleet 4	Fleet 5	Fleet 6	Fleet 8	Fleet 9	Fleet 11	Fleet 12	Fleet 13	Fleet 15	Fleet 16	Fleet 17	Fleet 18	Fleet 19	Fleet 20	Fleet 21	Fleet 24	Fleet 7	Fleet 10	Fleet 14	Fleet 22	Fleet 23	Fleet 25	Fleet 26
1983	1	8				2262	570			3	0	21	897	143		113		631							1.4		
1983	2	15				0	0			2	1925		131	210		74	310	125							1.1		
1983	3	41				0	0			1	287		33	380		3		72							0.0		
1983	4	94		477		2448	0			2	0		116		431	138		144							0.2		
1984	1	20				1184	807			1	0	28	588	311		343		563							2.7		
1984	2	9				0	0			1	1558		391	413		215	336	90							0.5		
1984	3	24				0	0			0	538		1011	265		3		62							0.0		
1984	4	74		210		2897	0			0	135		464		358	153		1572							0.0		
1985	1	8				889	448			0	0	12	961	229		714		1264							4.9		
1985	2	8				0	0			0	1165		120	352		488	447	1126							0.3		
1985	3	19				0	0			84	224		74	369		3		109							0.0		
1985	4	84		70		6340	0			130	0		460		547	118		428							0.1		
1986	1	8				1072	16			70	0	5	668	375		564		3759							0.6		
1986	2	5				0	0			60	1238		212	553		387	403	801							0.0		
1986	3	20				0	0			22	354		1089	274		2		93							0.0		
1986	4	195		365		4874	0			34	15		132		299	89		31							0.0		
1987	1	20				3550	250			18	0	6	519	193		612		813							0.8		
1987	2	9				0	0			15	505		98	297		432	187	63							1.2		
1987	3	19				0	0			8	89		146	94		1		0							0.0		
1987	4	123		108		1027	0	16		12	0		357		113	45		221							0.0		
1988	1	35				2010	742			7	0	15	796	87		228		974							0.2		
1988	2	10				0	0		6	6	1020		42	118		157	127	227							0.2		
1988	3	27				0	0	3		17	259		68	86		0		7							0.0		
1988	4	190		205		2134	0	3		27	27		356		125	24		0							0.0		
1989	1	20				3623	580	88		15	0	88	411	81		186		988							5.2		
1989	2	4				0	0		20	12	529		146	114		132	110	130							1.3		
1989	3	21				0	0			32	166		17	165		1		16							0.0		
1989	4	280		189		360	0	5		50	92		213		133	26		1							0.0		
1990	1	24				2474	149	32		27	0	3	830	64		90		1311							3.5		
1990	2	10				0	0		118	23	990		47	179		60	199	194							0.2		
1990	3	16				0	0	99		65	636		30	421		1		0							0.0		
1990	4	193		342		646	0	26		100	161		79		288	49		86							0.0		
1991	1	14		2		3466	224	182		54	0	82	429	123		146		334							4.9		
1991	2	14				0	0		5165	46	1191		103	363		95	414	5							0.4		
1991	3	36				0	0	394		71	274		18	183		2		0							0.0		
1991	4	462		464		1677	0	2061		109	0		35		332	68		11							0.1		
1992	1	10		0		2183	469	255		59	0		944	173		116		1650							8.3		
1992	2	20				0	0		198	50	642		65	269		66	193	328							0.2		
1992	3	15				0	0	582		10	145		12	102		1		0							0.0		
1992	4	708		471		1243	0	751		15	34		38		280	27		45							0.0		

Table 3-3. Cont.

Fishing year	Season	Weight (mt)																			Number (1000 fish)						
		Fleet 1	Fleet 2	Fleet 3	Fleet 4	Fleet 5	Fleet 6	Fleet 8	Fleet 9	Fleet 11	Fleet 12	Fleet 13	Fleet 15	Fleet 16	Fleet 17	Fleet 18	Fleet 19	Fleet 20	Fleet 21	Fleet 24	Fleet 7	Fleet 10	Fleet 14	Fleet 22	Fleet 23	Fleet 25	Fleet 26
1993	1		62	6		3831	83	99		8	0	48	204	161		32		525							10.4		
1993	2		37	0			0		12	7	320		36	230		16	207	113							0.1		
1993	3		42	0			0	25		12	67		0	70		1		2							0.0		
1993	4	1085		559		2677	0	562		19	15		17		481	16		4							0.1		
1994	1		77	3		3973	694	14		10	0	458	206	168		36		967							2.1		
1994	2		22	0			0		185	9	3570		65	356		31	272	58							0.0		
1994	3		11	1			0	406		202	2475		9	132		0		0							0.0		
1994	4	616		334		2040	0	254		309	733		136		256	23		0							0.0		
1995	1		35	2		2798	496	4055		168	0	440	143	243		213		716							16.0		
1995	2		25	0			0		8860	142	1130		94	788		205	476	0							0.0		
1995	3		31	0			0	1355		25	136		5	84		0		0							0.0		
1995	4	827		956		3124	0	140		38	57		1		253	16		757							1.6		
1996	1		25	4		1967	450	451		21	0	256	90	129		142		7652							1.1		
1996	2		26	0			0		158	18	3191		66	416		110	503	0							0.0		
1996	3		27	1			0	594		259	846		1	114		0		1							0.0		
1996	4	1215		1810		1402	0	1113		397	550		4		199	6		61							3.0		
1997	1		27	17		4027	708	3000		215	0	224	113	165		20		2638							5.4		
1997	2		44	2			0		2309	183	1120		25	246		53	702	41							0.0		
1997	3		18	1			0	559		46	605		2	158		1		4							0.0		
1997	4	1150		1899		13	0	518		71	515		2		131	15		8							0.7		
1998	1		53	32		2376	326	549		38	0	131	108	114		29		2017					23.5		20.5	23.5	
1998	2		46	1			0		1049	33	1613		64	359		68	609	24							0.8		
1998	3		33	1			0	686		63	798		10	317		1		0							0.0		
1998	4	1076		3076		5592	0	986		96	360		2		329	32		2280							0.6		
1999	1		25	34		5448	579	2228		52	0	129	65	133		16		442					107.2		35.2	107.2	
1999	2		41	4			0		653	44	2101		17	391		46	482	49							1.0		
1999	3		39	3			0	651		747	1456		1	168		0		0							0.1		0.0
1999	4	893		2773		3403	0	2380		1597	770		83		164	5		669							8.0		0.0
2000	1		15	31		4042	747	3214		30	0	117	66	154		87		3204					190.9		12.6	190.9	0.0
2000	2		12	2			0		2048	27	2780		6	475		72	638	0							0.0		0.0
2000	3		8	6			0	898		963	934		0	358		1		0							0.1		0.0
2000	4	749		1807	5	981	0	2914		179	464		4		189	45		382							0.7		0.0
2001	1		13	75		1918	239	409		9	0	83	167	73		174		821	0				274.6		20.8	274.6	0.0
2001	2		26	3			0		261	37	1847		113	293		232	683	0	0						1.4		0.0
2001	3		76	10			0	62		160	988		17	113		0		0	0						0.1		0.0
2001	4	671		1479	10	556	0	2126		175	697		51		117	6		0	275						1.3		0.0
2002	1		45	82		2767	599	959		509	0	37	224	157		235			1497				358.2		30.9	358.2	0.0
2002	2		56	5			0		1835	88	706		24	231		251	409		0						1.9		0.0
2002	3		95	9			0	99		238	520		11	84		0			0						0.0		0.0
2002	4	992		1807		185	0	1771		394	824		34		87	54			590						0.5		0.0

Table 3-3. Cont.

Fishing year	Season	Weight (mt)																			Number (1000 fish)						
		Fleet 1	Fleet 2	Fleet 3	Fleet 4	Fleet 5	Fleet 6	Fleet 8	Fleet 9	Fleet 11	Fleet 12	Fleet 13	Fleet 15	Fleet 16	Fleet 17	Fleet 18	Fleet 19	Fleet 20	Fleet 21	Fleet 24	Fleet 7	Fleet 10	Fleet 14	Fleet 22	Fleet 23	Fleet 25	Fleet 26
2003	1		78	95		200	571	783		88	0	80	58	96		291			2704				441.9		20.8	441.9	0.0
2003	2		85	4			0		2159	1881	416		6	156		71	403		0						0.9		0.0
2003	3		116	6			0	38		53	182		5	109		3			0						0.0		0.0
2003	4	1380		1636		609	0	1144		556	54		15		266	47			3620						0.7		0.0
2004	1		154	148		2225	2100	10		59	0	78	114	136		81			5285				525.6		2.8	525.6	0.0
2004	2		205	2			0		2131	105	1868		94	186		68	421		0						0.0		0.0
2004	3		122	1			0	586		720	1173		164	379		15			0						0.0		0.0
2004	4	1602		1270	43	264	0	1888		264	906		321		572	217			1986						0.4		0.0
2005	1		106	96		77	3694	3280		222	0	293	171	414		137			2764				453.8		5.3	453.8	0.0
2005	2		108	1			0		3029	121	1034		30	346		102	413		0						0.1		0.0
2005	3		81	8			0	59		220	513		68	284		7			640						0.0		0.0
2005	4	873		1061	49	940	0	2412		339	85		23		356	135			4714						5.4		0.0
2006	1		115	59		692	2012	252		354	0	251	315	148		328			4573				632.6		2.3	632.6	0.0
2006	2		62	1			0		2513	102	695		17	229		69	331		1						0.0		0.0
2006	3		61	3			0	485		376	228		32	253		10			0						0.0		0.0
2006	4	1022		1250	95	479	0	1059		13	70		15		270	127			1424						0.3		0.0
2007	1		66	66	4	364	2123	363		121	0	101	238	150		381			2723				876.4		0.7	876.4	0.0
2007	2		71	0			0		1968	776	1985		105	314		52	1013		44						0.0		0.0
2007	3		99	6			0	214		581	619		12	268		2			0						0.0		0.0
2007	4	802		772	175	1	0	1610		1003	220		30		844	239			1794						0.5		0.1
2008	1		33	41	2		3028	3007		62	0	72	287	389		186			2613				607.0		10.0	607.0	0.1
2008	2		40	1			0		2361	230	1163		14	455		95	797		1						0.0		0.0
2008	3		39	6			0	702		518	868		1	449		1			0						0.0		0.0
2008	4	662		612	186	1	0	2177		213	241		13		1031	276			1209						0.5		0.0
2009	1		26	88	3	828	1299	2891		97	0	62	108	180		181			2221				255.8		11.6	255.8	0.0
2009	2		23	1			0		181	112	703		43	143		106	677		3						0.3		0.0
2009	3		35	4			0	718		617	264		0	342		1			0						0.0		0.0
2009	4	400		255	78	35	0	1390		424	38		36		566	264			2447						3.5		0.0
2010	1		27	48		35	1052	123		26	0	20	179	190		79			5300				563.4		4.2	563.4	0.0
2010	2		10	1			0		388	145	979		44	237		9	693		1						0.8		0.0
2010	3		25	3			0	67		191	492		29	374		4			0						0.0		0.0
2010	4	372		183	76		0	3058		429	298		34		380	384			451						1.9		0.0
2011	1		49	58		320	1906	611		21	0	39	38	158		148			2379				375.0		28.6	375.0	0.0
2011	2		32	1			0		2377	43	789		22	217		36	567		19						1.2		0.0
2011	3		20	2			0	9		163	242		70	360		5			1						0.0		0.0
2011	4	189		139	50	3	0	530		674	7		45		500	151			1286						4.0		0.0
2012	1		24	32		199	841	261		559	0	2	103	205		514			5421				180.4		35.0	180.4	0.0
2012	2		13	1			0		620	28	233		0	176		54	644		3						1.0		0.0
2012	3		28	4			0	9		76	256		2	273		4			0						0.0		0.0
2012	4	237		180	123	12	0	743		493	19		6		372	170			1368						3.0		0.0

Table 3-3. Cont.

Fishing year	Season	Weight (mt)																			Number (1000 fish)						
		Fleet 1	Fleet 2	Fleet 3	Fleet 4	Fleet 5	Fleet 6	Fleet 8	Fleet 9	Fleet 11	Fleet 12	Fleet 13	Fleet 15	Fleet 16	Fleet 17	Fleet 18	Fleet 19	Fleet 20	Fleet 21	Fleet 24	Fleet 7	Fleet 10	Fleet 14	Fleet 22	Fleet 23	Fleet 25	Fleet 26
2013	1		28	47		268	1729	10		1	0	22	81	132		204			1788				263.9		56.7	263.9	0.1
2013	2		15	1		0	0		2	35	477		3	217		82	895		8						4.6		0.0
2013	3		9	2			0	79		518	789		0	306		2			2						0.0		0.0
2013	4	311		252	216	0	0	2459		783	60		43		818	285			4036						1.4		0.0
2014	1		21	24	1	47	2203	654		5	0	40	125	92		231			1228				61.3	24.7		61.3	0.1
2014	2		26	1			0		14	0	97		1	107		110	679		2					1.7			0.1
2014	3		39	3			0	246		607	60		7	76		1			1					0.7			0.0
2014	4	191		315	237	989	0	86		5	18		12		388	261			3133			121.2		2.2			0.0
2015	1		25	16	0		1864	27		0	0	19	11	88		210			43			27.4	242.6	25.5		242.6	0.3
2015	2		47	1			0		7	65	233		6	77		167	808		3					0.2			0.0
2015	3		72	3				1		99	153		5	116		0			0					0.2			
2015	4	217		247	215	1287		97		33	82		5		199	283			2716			267.4		2.4			0.6
2016	1		83	10			1772	463		6		224	8	135		183			329			1.5	26.6	8.6		26.6	0.2
2016	2		20	1					85	9	213		52	254		62	769		16					2.2			0.2
2016	3		50	1				83		739	178		4	479		1			1					0.5			
2016	4	358		239	172	162		131		0	6		64		368	175			3650		1.9	218.7		1.7			0.3
2017	1		37	24	1		1412	111		3		82	32	259		519			479	0	1.5		163.9	9.6		163.9	0.3
2017	2		35	1					375	2	299		1	19		316	138			26				5.2			0.1
2017	3		59	3				11		530	82		3	148		1			418	26				0.6			0.3
2017	4		354	269	115	1571		81			15		28		29	36			2430	171	2.9	245.5		1.9		12.5	0.2
2018	1		2	23			1229	124				42	5	98		37			40		0.6	0.6	217.9	6.6		217.9	0.4
2018	2		33	0					95	5	196		8	11		8	533		17	168				5.0			0.7
2018	3		195	8				8		542	375		36	312		1			27	116				0.2			0.6
2018	4		429	313	173	1567		152		16	51		12		233	52			7	1	4.3	232.2		5.2		12.9	0.4
2019	1		15	17	0		172	449		10		39	7	11		172			248	0	2.1	3.3	155.0	1.3		155.0	0.5
2019	2		29	4					216	12	198		6	76		12	647		12	199				3.2			0.5
2019	3		126	19				9		447	293		20	433		0			3288	149				0.2			0.3
2019	4		74	968	194	1556		66		115	18		26		26	20			11	6	3.4	182.9		1.9		1.9	0.4
2020	1		19	12	2		138	2		32		55	8	146		124			165	2	0.8	3.7	126.8	28.4		126.8	0.3
2020	2		11	0					289	12	246		4	147		43	97		47	194				7.3			0.5
2020	3		124	12				5		99	35		23	799		1			329	193				1.0			
2020	4		591	1170	320	1495		2		327	44		16		282	176			5	16	4.2	24.4		18.5		12.7	0.7
2021	1		22	17	0		122	35		47		57	13	148		156			147	2	1.5	8.4	136.1	33.8		136.1	0.4
2021	2		279	1					37	37	197		3	159		27	972		56	193				4.9			0.3
2021	3		45	5				15		667	57		44	938		0			33	237				0.2			
2021	4		538	117	49	1676		50		7	176		29		472	145			14	4	5.5	287.7		22.7		14.9	0.3
2022	1		47	17	1		136	69		127		45	9	189		191			300	6	1.7	2.7	135.9	25.7		135.9	0.1
2022	2		111	4					257	17	273		4	163		58	152		42	213				1.9			0.6
2022	3		340	30				7		44	45		34	766		0			34	238				0.1			
2022	4		528	1560	588	716		5		18	254		34		451	17			15	5	7.8	244.0		16.9		12.6	0.3

Table 3-4 (a). CPUE-based abundance indices 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.	**1993-2019**	JPN Longline	Fleet 1 : JPN_LL(Seas4)	Standardized by VAST	ISC/22/PBFWG-1/01	
S2	Japanese offshore and distant water longliners CPUE	**1974-1992**	JPN Longline	Fleet 1 : JPN_LL(Seas4)	Standardized by lognormal model	ISC/08/PBFWG-1/05	
S3	Japanese troll CPUE in Nagasaki prefecture (Sea of Japan and East China sea)	**1980-2016**	JPN Troll	Fleet 12 : JPN Troll (Seas 2-4)	Standardized by lognormal model	ISC/20/PBFWG-1/04	
S5	Taiwanese longline GLMM CPUE (South area)	**2002-2022**	TWN Longline	Fleet 3 : TWN_LL (South)	Standardized by GLMM	ISC/24/PBFWG-1/05	X

Table 3-4 (b). CPUE-based abundance indices **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
S4	Japanese Recruitment monitoring in the East China Sea	**2017-2022**	JPN Troll	Fleet 12 : JPN Troll (Seas 2-4)	Standardized by VAST	ISC/24/PBFWG-1/0X	X
S6	Taiwanese longline GLMM CPUE (Whole area)	**2002-2022**	TWN Longline	Fleet 4 : TWN_LL (South)	Standardized by GLMM	ISC/24/PBFWG-1/05	X
S7	Taiwanese longline geo-stat CPUE (South area)	**2006-2022**	TWN Longline	Fleet 4 : TWN_LL (South)	Standardized by VAST	ISC/24/PBFWG-1/05	X
S8	Taiwanese longline geo-stat CPUE (Whole area)	**2006-2022**	TWN Longline	Fleet 4 : TWN_LL (South)	Standardized by VAST	ISC/24/PBFWG-1/05	X
S9	Taiwanese longline geo-stat CPUE (All age, Whole area)	**2009-2022**	TWN Longline	Fleet 4 : TWN_LL (South)	Standardized by VAST	ISC/24/PBFWG-1/05	X
S10	Taiwanese longline geo-stat CPUE (Age 6-8, Whole area)	**2009-2022**	TWN Longline		Standardized by VAST	ISC/24/PBFWG-1/05	X
S11	Taiwanese longline geo-stat CPUE (Age 9-11, Whole area)	**2009-2022**	TWN Longline		Standardized by VAST	ISC/24/PBFWG-1/05	X
S12	Taiwanese longline geo-stat CPUE (Age 12-14, Whole area)	**2009-2022**	TWN Longline		Standardized by VAST	ISC/24/PBFWG-1/05	X
S13	Taiwanese longline geo-stat CPUE (Age 15-17, Whole area)	**2009-2022**	TWN Longline		Standardized by VAST	ISC/24/PBFWG-1/05	X
S14	Taiwanese longline geo-stat CPUE (Age 18+, Whole area)	**2009-2022**	TWN Longline		Standardized by VAST	ISC/24/PBFWG-1/05	X
S15	Taiwanese longline GLMM CPUE (South area,SST)	**2006-2022**	TWN Longline		Standardized by GLMM	ISC/24/PBFWG-1/05	X
S16	Taiwanese longline GLMM CPUE (Whole area, SST)	**2006-2022**	TWN Longline		Standardized by GLMM	ISC/24/PBFWG-1/05	X

Table 3-5. Available abundance indices (CPUE) of Pacific bluefin tuna *Thunnus orientalis*. Indices S1, S2, S3, and S5 were fitted to the base-case model (numbers in bold).

Fishing year	JP LL		JP Troll	JPN Troll Monitoring	TW LL									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
1983		**0.36**	**0.91**											
1984		**0.39**	**0.92**											
1985		**0.36**	**0.86**											
1986		**0.42**	**0.98**											
1987		**0.42**	**0.71**											
1988		**0.48**	**0.82**											
1989		**0.73**	**0.65**											
1990		**0.73**	**1.27**											
1991		**1.17**	**1.32**											
1992		**1.26**	**0.58**											
1993	**2.29**		**0.48**											
1994	**1.67**		**2.00**											
1995	**2.03**		**1.09**											
1996	**2.09**		**1.60**											
1997	**1.93**		**0.94**											
1998	**1.49**		**0.82**											
1999	**1.06**		**1.51**											
2000	**0.77**		**1.14**											
2001	**0.92**		**1.15**											
2002	**1.40**		**0.74**		**1.70**	1.76								
2003	**1.50**		**0.64**		**1.65**	1.59								
2004	**1.53**		**1.28**		**1.14**	1.14								
2005	**0.88**		**1.41**		**1.38**	1.27								
2006	**0.96**		**0.73**		**1.04**	0.82	1.49	1.24						
2007	**0.60**		**1.41**		**0.85**	0.79	0.81	0.78						
2008	**0.35**		**1.44**		**0.73**	0.74	0.52	0.55						
2009	**0.22**		**1.14**		**0.41**	0.41	0.30	0.29	0.26	0.06	0.14	0.86	1.48	0.68
2010	**0.18**		**1.11**		**0.33**	0.34	0.21	0.26	0.24	0.06	0.08	0.84	1.50	0.92
2011	**0.14**		**0.97**	0.61	**0.25**	0.24	0.18	0.20	0.20	0.03	0.06	0.40	1.33	1.50
2012	**0.30**		**0.49**	0.46	**0.30**	0.35	0.19	0.23	0.19	0.07	0.05	0.42	1.11	1.38
2013	**0.30**		**0.89**	0.99	**0.55**	0.67	0.27	0.37	0.30	0.19	0.10	0.39	1.36	2.08
2014	**0.38**		**0.42**	0.23	**0.55**	0.64	0.33	0.44	0.38	0.36	0.20	0.37	0.82	2.07
2015	**0.40**		**0.49**	0.42	**0.54**	0.65	0.32	0.44	0.39	0.29	0.32	0.32	0.89	1.70
2016	**0.65**		**1.08**	1.46	**0.69**	0.65	0.42	0.46	0.42	0.28	0.45	0.53	0.50	0.82
2017	**0.66**			1.87	**0.66**	0.54	0.71	0.63	0.62	0.50	0.65	0.92	0.46	0.66
2018	**0.90**			1.26	**0.64**	0.71	0.65	0.73	0.76	0.74	0.78	0.81	0.84	0.54
2019	**1.38**			0.51	**1.31**	1.27	2.20	2.14	2.05	1.98	2.34	1.94	0.91	0.64
2020				0.64	**1.54**	1.38	2.26	2.11	2.10	2.70	2.12	1.36	0.70	0.36
2021				2.18	**2.26**	2.27	2.65	2.56	2.54	2.34	3.16	1.92	0.94	0.34
2022				1.37	**2.47**	2.75	3.50	3.57	3.54	4.40	3.55	2.92	1.16	0.34

Table 3-6. Coefficient of Variations for CPUE-based abundance indices of Pacific bluefin tuna *Thunnus orientalis*. Indices S1, S2, S3, and S5 were fitted to the base-case model.

Fishing year	JP LL		JP Troll	JPN Troll Monitoring	TW LL									
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14
1983		0.20	0.20											
1984		0.20	0.20											
1985		0.20	0.20											
1986		0.20	0.20											
1987		0.20	0.20											
1988		0.20	0.20											
1989		0.20	0.20											
1990		0.20	0.20											
1991		0.20	0.20											
1992		0.20	0.20											
1993	0.20	0.01	0.20											
1994	0.20	0.01	0.20											
1995	0.20	0.01	0.20											
1996	0.20	0.01	0.20											
1997	0.20	0.01	0.20											
1998	0.20	0.01	0.20											
1999	0.20	0.01	0.20											
2000	0.20	0.01	0.20											
2001	0.20	0.01	0.20											
2002	0.20		0.20		0.20	0.20								
2003	0.20		0.20		0.20	0.20								
2004	0.20		0.20		0.20	0.20								
2005	0.20		0.20		0.20	0.20								
2006	0.20		0.20		0.20	0.20	0.20	0.20	0.20					
2007	0.20		0.20		0.20	0.20	0.20	0.20	0.20					
2008	0.20		0.20		0.20	0.20	0.20	0.20	0.20					
2009	0.20		0.20		0.20	0.20	0.20	0.21	0.20	0.20	0.20	0.20	0.20	0.20
2010	0.20		0.20		0.20	0.20	0.21	0.23	0.21	0.20	0.20	0.20	0.20	0.20
2011	0.20		0.20	0.20	0.20	0.20	0.20	0.23	0.20	0.20	0.20	0.20	0.20	0.20
2012	0.20		0.20	0.20	0.20	0.20	0.23	0.23	0.23	0.20	0.20	0.20	0.20	0.20
2013	0.20		0.20	0.20	0.20	0.20	0.21	0.20	0.21	0.20	0.20	0.20	0.20	0.20
2014	0.20		0.20	0.20	0.20	0.20	0.21	0.20	0.21	0.20	0.20	0.20	0.20	0.20
2015	0.20		0.20	0.20	0.20	0.20	0.20	0.21	0.20	0.20	0.20	0.20	0.20	0.20
2016	0.20		0.20	0.20	0.20	0.20	0.21	0.20	0.21	0.20	0.20	0.20	0.20	0.20
2017	0.20			0.23	0.20	0.20	0.20	0.22	0.20	0.20	0.20	0.20	0.20	0.20
2018	0.20			0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
2019	0.20			0.21	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
2020				0.22	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
2021				0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
2022				0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20

Table 3-7. Characteristics of the available size composition data for 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			
Fleet 1	JPN_LL (Seas 4)	Length bin	JPN Longline (1993-2016, Season 4)	-	1952-1968, 1993-2016	Scaled Number of fish measured	X
Fleet 2	JPN_LL (1993-) (Seas 1-3)	Length bin	JPN Longline(2021-2022)	-	1993-2022	Scaled Number of fish measured	X
Fleet 3	TWN_LLSouth	Length bin	TWN Longline (South area)	-	1992-2022	Scaled Number of fish measured	X
Fleet 4	TWN_LLNorth	Length bin	TWN Longline (North area)	-	2009-2022	Scaled Number of fish measured	X
Fleet 5	JPN_TPS_PO	Length bin	JPN Tuna Purse seine in Pacific Ocean	-	1995-2006 and 2014-2022	Number of landing well measured	X
Fleet 6	JPN_TPS_SOJ	Length bin	JPN Tuna Purse seine in the Sea of Japan	-	1987-1989, 1991-2022	Number of landing well measured	X
Fleet 7	JPN_TPS_SOJ (Farming)	Length bin	JPN Tuna Purse seine in the Sea of Japan for Farming	-	1987-1989, 1991-2022	Number of operation well measured	X
Fleet 8	JPN_SPPS (Seas 1,3,4)	Length bin	JPN Small Pelagic Purse seine (Season 1,3,4)	-	2002-2022	Number of landing well measured	X
Fleet 9	JPN_SPPS (S2)	Length bin	JPN Small Pelagic Purse seine (Season 2)	-	2012-2022	Number of landing well measured	X
Fleet 10	JPN_SPPS (Farming)	Length bin	JPN Small Pelagic Purse seine for Farming	-	2016-2022	Number of operation well measured	X
Fleet 11	KOR_LPPS	Length bin	KOR Large Pelagic Purse Seine	-	2010-2022	Number of landing well measured	X
Fleet 12*1	JPN_Troll (Seas 2-4)	Length bin	JPN Troll (Season 2-4)	-	1994-2022	Total month of well sampled port	X
Fleet 13	JPN_Troll (Seas 1)	Length bin	JPN Troll (Season 1)	-	1994-2004, 2006-2008, 2011,2012, 2016, 2018	-	X
Fleet 14	JPN_Troll (Farming)	Age (age-0 only)	JPN Troll for Farming	-		-	
Fleet 15*1	JPN_PoleLine	Length bin	JPN Pole-and-Line	-	1994-1996, 1998-2004, 2006-2010	-	
Fleet 16	JPN_Setnet (Seas 1-3)	Length bin	JPN Setnet (Season 1-3)	-	1993-2018	Total month of well sampled port	
Fleet 17	JPN_Setnet (Seas 4)	Length bin	JPN Setnet (Season 4)	-	1993-2018	Total month of well sampled port	
Fleet 18 *2	JPN_Setnet (HK_AM)	Weight bin	JPN Setnet in Hokkaido and Aomori	JPN Others	1994-2022	Total month of well sampled port	X
Fleet 19 *2	JPN_Other	Weight bin	JPN Others	-	1994-2022	Total month of well sampled port	X
Fleet 20	EPO_COMM (-2001)	Length bin	USA Commercial Fisheries (PS, Others)	-	1952-1965, 1969-1982	Number of haul well measured	
Fleet 21	EPO_COMM (2002-)	Length bin	MEX Commercial Fisheries (PS, Others)	-	2005-2006, 2008-2022	Number of haul well measured	X
Fleet 22 *3	EPO_Sports (2014-)	Length bin	USA Recreational Fisheries (2014-)	-	2014-2022	Average number of landing well measured by season	X
Fleet 23 *3	EPO_Sports early (-2013)	Length bin	USA Recreational Fisheries (-2013)	-	1993-2003, 2005-06, 2008-11	-	-

*1 Size compotision data of Fleet 15 was not used in the assessment model. The selectivity pattern estimated for fleet 12 was mirrored.
*2 Size composition data of Fleet 18 and 19 were combined. A selectivity pattern was estimated and shared by those two fleets.
*3 Size composition data of Fleet 23 was not used in the assessment model. The selectivity pattern estimated for Fleet 22 was mirrored.

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	JPN_LL (Seas 4)	Spawners in WPO	High*	Length	Good	Yes	Low	Dome-shaped (double normal)	-	Constant on length-based	-
Fleet 2	JPN_LL (1993-) (Seas 1-3)	Migratory ages & Spawner	Low*	Length	Good	-	Low	Dome-shaped (double normal)	-	Constant on length-based	-
Fleet 3	TWN_LLSouth	Spawners in WPO	High*	Length	Very Good	Yes	Low	Asymptotic (logistic)	-	Constant on length-based	-
Fleet 4	TWN_LLNorth	Spawners in WPO	Low*	Length	Good	-	Low	Dome-shaped (double normal)	-	-	-
Fleet 5	JPN_TPS_PO	Migratory ages (ages 1-7)	Medium*	Length	Fair to Good (improvement after 2014 by systematic sampling)	-	High-Med	Asymptotic (logistic)	Age-specific (ages 1-11)	Constant on length-based; time-varying on ages 1-2, 4-7 after 2004	Block
Fleet 6	JPN_TPS_SOJ	Migratory ages (ages 1-5)	High*	Length	Very Good	-	High-Med	Asymptotic (logistic)	Age-specific (ages 3-10)	Constant on length-based; time-varying on ages 3-7 for 2000-2022	Deviation
Fleet 7	JPN_TPS_SOJ (Farming)	Migratory ages (ages 1-5)	Medium*	Length	Very Good	-	Med	Dome-shaped (double normal)	-		Deviation
Fleet 8	JPN_SPPS (Seas 1,3,4)	Age 0 fish in WPO	Medium*	Length	Good	-	High-Med	Dome-shaped (double normal)	Age-specific (age 0-1)	Constant on length-based	-
Fleet 9	JPN_SPPS (S2)	Migratory ages (ages 1-5)	Medium*	Length	Good	-	High-Med	Dome-shaped (double normal)	Age-specific (age 0-2)	Constant on length-based; Time–varying on ages 1-2 for 2004-2022	Deviation
Fleet 10	JPN_SPPS (Farming)	Age 0-1 in WPO	Medium*	Length	Good (improvement after 2016 due to the stereo-camera); Catch in # of fish are available	-	Med	Dome-shaped (double normal)	-	-	-
Fleet 11	KOR_LPPS	Age 0 and Migratory ages	Medium**	Length	Fair (opportunistically sampling was conducted for 2004-2009,	-	Med	Asymptotic (logistic)	Age-specific (ages 1-6)	Constant on length-based; time-varying on ages 1-2 for 2007-2020	Deviation
Fleet 12	JPN_Troll (Seas 2-4)	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 13	JPN_Troll (Seas 1)	Age 0 fish in WPO	Medium-Low*	Length	Good	-	High	-	Full selection at age 0	Constant on age-based	-
Fleet 14	JPN_Troll (Farming)	Age 0 fish in WPO	Low	-	Catch in # of Age-0 fish are available	-	Med	-	Full selection at age 0	Constant on age-based	-
Fleet 15	JPN_PoleLine	Age 0 fish in WPO	Low	Length	Bad	-	Historic	Mirror to Fleet 12			
Fleet 16	JPN_Setnet (Seas 1-3)	Migratory ages (ages 1-5)	Low*	Length	Fair	-	Med	Asymptotic (logistic)	Age-specific (ages 1-4)	Constant on length-based;	-
Fleet 17	JPN_Setnet (Seas 4)	Migratory ages (ages 1-5)	Low*	Length	Fair	-	Low	Asymptotic (logistic)	Age-specific (ages 1-5)	Constant on length-based;	-
Fleet 18	JPN_Setnet (HK_AM)	Migratory ages (ages 1-6)	Medium*	Weight	Good	-	Low	Asymptotic (logistic)	Age-specific (ages 1-6)	Constant on length-based; Time blocks on ages1, 4-5 for 2004-2013, 2014-2022)	Block
Fleet 19	JPN_Other	Migratory ages (ages 1-5)	Medium**	Weight	Good	-	Low	Mirror to Fleet 18			
Fleet 20	EPO_COMM (-2001)	Migratory ages (ages 1-5)	Medium*	Length	Fair (many samples)	-	High-historic	Dome-shaped (double normal)	-	Constant on length-based	-
Fleet 21	EPO_COMM (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 2006-2022	Block
Fleet 22	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 2014-2022	Block
Fleet 23	EPO_Sports early (-2013)	Migratory ages (ages 1-5)	Low	Length	Fair	-	Low	Mirror to Fleet 22			
Fleet 24	WPO_Disc_Weight	Not Available				-	NA	Mirror to Fleet 16			
Fleet 25	WPO_Disc_Num	Not Available				-	NA	Mirror to Fleet 16			
Fleet 26	EPO_Sports_Disc_Num	Migratory ages (ages 1-5)	Not Available			-	Low	Mirror to Fleet 22			

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

Harvesting scenarios											
Reference No	Scenarios				Catch limit in the projection				Specified fishery impact at 2034		Note
	WCPO		EPO		WCPO		EPO				
	Small	Large	Small	Large	Small	Large	Small	Large	WCPO	EPO	
1	Status quo (WCPFC CMM2023-02, IATTC Resolution 21-05)				4,475	7,859	3,995		-	-	JWG's request 1(NC19 Summary Report, Attachment E; Maintaining the current CMM)
2	Maintaining the current CMM assuming maximum transfer utilizing the conversion factor				3,236	9,799	3,995		-	-	JWG's request 02 (Maximum utilization of transfer from small fish catch limit to large fish catch limit using the conversion factor).
3	No fishing allowed				0	0	0		-	-	JWG's request 03 (No fishing)
4	Status quo +60%	Status quo +60%	Status quo +60%		7,310	12,424	6,392		-	-	JWG's request 04-1 (scenario achieving 20%SSB0 with 60%probability by pro-rata change in catch).
5	Status quo	Status quo +180%	Status quo +180%		4,475	21,555	11,186		-	-	JWG's request 04-2 (scenario achieving 20%SSB0 with 60%probability by proportional change in catch among the WCPO large fish catch limit and EPO total catch limit).
6	Status quo +20%	Status quo +163%	Status quo +108%		5,420	20,235	8,310		-	-	JWG's request 04-3 (scenario achieving 20%SSB0 with 60% probability by maintaining the total catch proportion between WCPO and EPO as status quo while limiting the catch limit increase for WCPO small fish as 20% of its original catch limit).
7	Status quo +30%	Status quo +131%	Status quo +92%		5,893	17,789	7,670		-	-	JWG's request 04-4 (scenario achieving 20%SSB0 with 60% probability by maintaining the total catch proportion between WCPO and EPO as status quo while limiting the catch limit increase for WCPO small fish as 30% of its original catch limit).
8	Status quo +30%	Status quo +30%	Status quo +190%		5,893	10,142	11,586		70	30	JWG's request 05-1 (explored constant catch scenario achieving 20%SSB0 with 60% probability and fishery impact ratio between WCPO and EPO as 70% and 30% while maintaining the catch proportion of small and large fish in WCPO as status quo).
9	Status quo +55%	Status quo +55%	Status quo +80%		7,074	12,044	7,191		80	20	JWG's request 05-1 (explored constant catch scenario achieving 20%SSB0 with 60% probability and fishery impact ratio between WCPO and EPO as 80% and 20% while maintaining the catch proportion of small and large fish in WCPO as status quo).
10	Status quo +10%	Status quo +130%	Status quo +190%		4,948	17,751	11,586		70	30	JWG's request 05-2 (explored constant catch scenario achieving 20%SSB0 with 60% probability and fishery impact ratio between WCPO and EPO as 70% and 30% while maintaining the catch proportion of small fish in WCPO lower than that of status quo).
11	Status quo +40%	Status quo +120%	Status quo +80%		6,015	17,540	7,191		80	20	JWG's request 05-3 (explored constant catch scenario achieving 20%SSB0 with 60% probability and fishery impact ratio between WCPO and EPO as 80% and 20% while maintaining the catch proportion of small fish in WCPO lower than that of status quo).
12	SPR30%				-				-	-	SPR30% Scenario F1719 multiplied 1.4

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

* Fishing mortality in scenario 3 was kept at zero. The catch limit for scenario 12 is calculated to achieve SPR 30% and allocated to fleets proportionately.

* The Japanese unilateral measure (transferring 250 mt of the catch upper limit from that for small PBF to that for large PBF during 2022-2034) 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. The 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 *eff* N	Harmonic mean *eff* N
1	24	9.4	56.6	34.6
2	4	8.9	29.5	25.7
3	31	12.1	101.5	40.5
4	14	3.8	81.9	48.5
5	20	12.5	57.3	38.3
6	35	10.9	29.8	15.2
7	6	4.8	16.5	11.3
8	44	10.1	32.1	15.9
9	18	9.2	17.8	10.4
10	7	17.1	22.1	19.8
11	20	12.9	51.9	24.4
12	63	7.9	37.0	16.5
13	20	6.0	10.4	6.9
16	76	6.5	18.5	12.0
17	26	7.0	19.8	14.0
18	29	8.4	47.5	16.2
20	1	6.5	401.3	401.3
21	20	10.6	31.0	18.6
22	9	14.3	130.1	84.3

Table 5-2. Total biomass, spawning stock biomass, recruitment, spawning potential ratio, and depletion ratio of Pacific bluefin tuna *Thunnus orientalis* estimated by the base-case model for the fishing years 1983-2022.

Year	Total Biomass (mt)	Spawning Stock Biomass (mt)	Recruiment (x1000 fish)	Spawning Potential Ratio	Relative biomass over $SSB_{F=0}$
1983	31,993	15,429	11,827	3.7%	2.5%
1984	34,852	13,898	8,176	7.1%	2.2%
1985	38,514	14,280	9,207	4.6%	2.3%
1986	38,713	15,925	8,094	1.8%	2.6%
1987	36,385	16,934	6,956	10.4%	2.7%
1988	40,630	19,967	8,977	16.4%	3.2%
1989	47,141	20,590	4,187	18.1%	3.3%
1990	57,723	26,079	21,138	22.1%	4.2%
1991	75,302	34,208	7,400	13.2%	5.5%
1992	84,406	43,037	4,375	16.8%	6.9%
1993	93,667	55,854	3,985	19.0%	9.0%
1994	103,163	64,267	30,951	12.0%	10.3%
1995	116,349	79,269	15,247	7.3%	12.7%
1996	109,419	75,121	17,967	9.2%	12.1%
1997	108,955	68,311	11,344	7.5%	11.0%
1998	104,534	66,696	15,469	5.2%	10.7%
1999	100,748	60,915	21,993	5.6%	9.8%
2000	94,830	57,366	13,910	1.9%	9.2%
2001	82,675	54,907	16,944	9.6%	8.8%
2002	83,931	51,822	13,375	6.3%	8.3%
2003	79,217	49,650	6,748	2.3%	8.0%
2004	70,699	41,296	27,619	1.3%	6.6%
2005	65,488	33,668	15,323	0.6%	5.4%
2006	51,886	26,737	13,854	1.1%	4.3%
2007	45,705	20,791	23,619	0.5%	3.3%
2008	44,337	16,082	21,038	1.0%	2.6%
2009	39,232	12,526	7,983	1.7%	2.0%
2010	37,537	12,275	17,593	2.8%	2.0%
2011	39,632	14,236	13,822	5.8%	2.3%
2012	43,506	17,447	7,663	9.6%	2.8%
2013	48,901	19,711	14,239	7.6%	3.2%
2014	54,166	22,690	4,882	15.9%	3.6%
2015	62,945	28,019	13,367	20.9%	4.5%
2016	77,523	37,762	16,040	21.5%	6.1%
2017	94,213	44,541	11,417	31.4%	7.2%
2018	118,007	56,986	9,991	37.1%	9.2%
2019	146,407	74,734	7,485	29.5%	12.0%
2020	168,571	104,243	6,828	28.4%	16.8%
2021	182,567	131,729	8,275	20.5%	21.2%
2022	186,632	144,483	11,467	21.9%	23.2%
Median (1983-2022)	73,000	35,985	11,647	8.4%	5.8%
Average (1983-2022)	78,528	44,112	12,769	11.5%	7.1%
Unfished (Equilibrium)	785,281	622,254	13,261	100%	100%

Table 5-3. Ratios of the estimated fishing mortalities (Fs and 1-SPRs for 2002-04, 2012-14, 2020-2022) 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} represents the fishing mortality (F) that maximizes equilibrium yield per recruit (Y/R), while $F_{xx\%SPR}$ represents F that produces a given % of the unfished spawning potential (biomass) under equilibrium conditions.

Reference Period	Fmax	(1-SPR)/(1-$SPR_{xx\%}$)				Estimated SSB for terminal year of each period (ton)	Depletion rate for terminal year of each period (%)
		$SPR_{20\%}$	$SPR_{25\%}$	$SPR_{30\%}$	$SPR_{40\%}$		
2002-2004	1.88	1.21	1.29	1.38	1.61	41,296	6.6%
2012-2014	1.24	1.11	1.19	1.27	1.48	22,690	3.6%
2020-2022	0.84	0.95	1.02	1.09	1.27	144,483	23.2%

Table 5-4. Likelihood table for the base case, the run with low sigmaR (0.52), and the run with high sigmaR (1).

		SigmaR	
	Base case	0.52	1
TOTAL	1247.7	1247.2	1257.9
Catch	0.3	0.3	0.3
Survey	-84.5	-84.3	-85.2
SizeFreq	1309.2	1310.0	1308.4
Recruitment	-4.0	-5.4	7.8
InitEQ_Regime	0.2	0.2	0.5
Parm_softbounds	0.0	0.0	0.0
Parm_devs	26.5	26.4	26.0

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

Harvesting scenarios							Performance indicators								
Reference No	Scenarios				Specified fishery impact		Median SSB at 2034	Fishery impact ratio of WPO fishery at 2034	Fishery impact ratio of EPO fishery at 2034	Probability of achiving the 2nd rebuilding target at 2041	Risk to breach $SSB_{7.7\%F=0}$ at least once by 2041	Probability of overfishing compared to 20%SSB0 at 2041	Probability of overfishing compared to 25%SSB0 at 2041	Probability of overfishing compared to 30%SSB0 at 2041	Probability of overfishing compared to 40%SSB0 at 2041
	WCPO		EPO												
	Small	Large	Small	Large	WCPO	EPO									
1	Status quo (WCPFC CMM2023-02, IATTC Resolution 21-05)				-	-	287,844	78%	22%	100%	0%	0%	1%	4%	20%
2	Maintaining the current CMM assuming maximum transfer utilizing the conversion factor				-	-	308,868	77%	23%	100%	0%	0%	0%	1%	10%
3	No fishing allowed				-	-	536,653	86%	14%	100%	0%	0%	0%	0%	0%
4	Status quo +60%	Status quo +60%	Status quo +60%		-	-	158,658	82%	18%	61%	8%	39%	57%	71%	89%
5	Status quo	Status quo +180%	Status quo +180%		-	-	143,211	71%	29%	60%	19%	40%	57%	71%	90%
6	Status quo +20%	Status quo +163%	Status quo +108%		-	-	148,332	78%	22%	60%	18%	40%	56%	69%	89%
7	Status quo +30%	Status quo +131%	Status quo +92%		-	-	156,324	80%	20%	63%	14%	37%	53%	67%	87%
8	Status quo +30%	Status quo +30%	Status quo +190%		70	30	158,245	69%	31%	61%	14%	39%	55%	68%	88%
9	Status quo +55%	Status quo +55%	Status quo +80%		80	20	162,242	79%	21%	63%	9%	37%	54%	69%	88%
10	Status quo +10%	Status quo +130%	Status quo +190%		70	30	147,825	70%	30%	60%	19%	40%	57%	70%	89%
11	Status quo +40%	Status quo +120%	Status quo +80%		80	20	153,985	80%	20%	61%	14%	39%	56%	69%	88%
12	SPR30%				-	-	190,088	77%	23%	99%	0%	1%	14%	43%	91%

* The numbering of Scenarios is different from those given by the IATTC-WCPFC NC Joint WG meeting and is the same as Table 4-2.

* Recruitment is resampled from historical values.

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

	Harvesting scenarios								Expected catch							
Reference No	Scenarios				Catch limit in the projection				2029				2034			
	WCPO		EPO		WCPO		EPO		WPO		EPO		WPO		EPO	
	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large	Commercial	Sport	Small	Large	Commercial	Sport
1	Status quo (WCPFC CMM2023-02, IATTC Resolution 21-05)				4,475	7,859	3,995		4,184	8,219	4,010	1,797	4,179	8,232	4,011	2,005
2	Maintaining the current CMM assuming maximum transfer utilizing the conversion factor				3,236	9,799	3,995		3,256	9,884	4,016	1,933	3,256	9,895	4,018	2,189
3	No fishing allowed				0	0	0		0	0	0	0	0	0	0	0
4	Status quo +60%	Status quo +60%	Status quo +60%		7,310	12,424	6,392		6,509	13,111	6,348	996	6,540	12,969	6,332	926
5	Status quo	Status quo +180%	Status quo +180%		4,475	21,555	11,186		4,386	21,718	11,223	1,033	4,383	20,799	11,224	1,055
6	Status quo +20%	Status quo +163%	Status quo +108%		5,420	20,235	8,310		5,388	20,361	8,321	1,030	5,394	19,989	8,330	1,035
7	Status quo +30%	Status quo +131%	Status quo +92%		5,893	17,789	7,670		5,727	17,911	7,669	1,035	5,739	17,717	7,673	1,026
8	Status quo +30%	Status quo +30%	Status quo +190%		5,893	10,142	11,586		5,488	10,540	11,562	993	5,508	10,420	11,556	950
9	Status quo +55%	Status quo +55%	Status quo +80%		7,074	12,044	7,191		6,594	12,521	7,194	1,011	6,620	12,456	7,196	953
10	Status quo +10%	Status quo +130%	Status quo +190%		4,948	17,751	11,586		4,704	18,017	11,581	1,020	4,707	17,667	11,589	1,025
11	Status quo +40%	Status quo +120%	Status quo +80%		6,015	17,540	7,191		5,991	17,424	7,197	1,027	6,006	17,233	7,205	1,000
12	SPR30%				-				4,820	18,091	5,607	715	4,812	19,436	5,668	733

* Korean catch reflects the recent catch proportion for small and large, thus expected catches do not match with catch allocations.

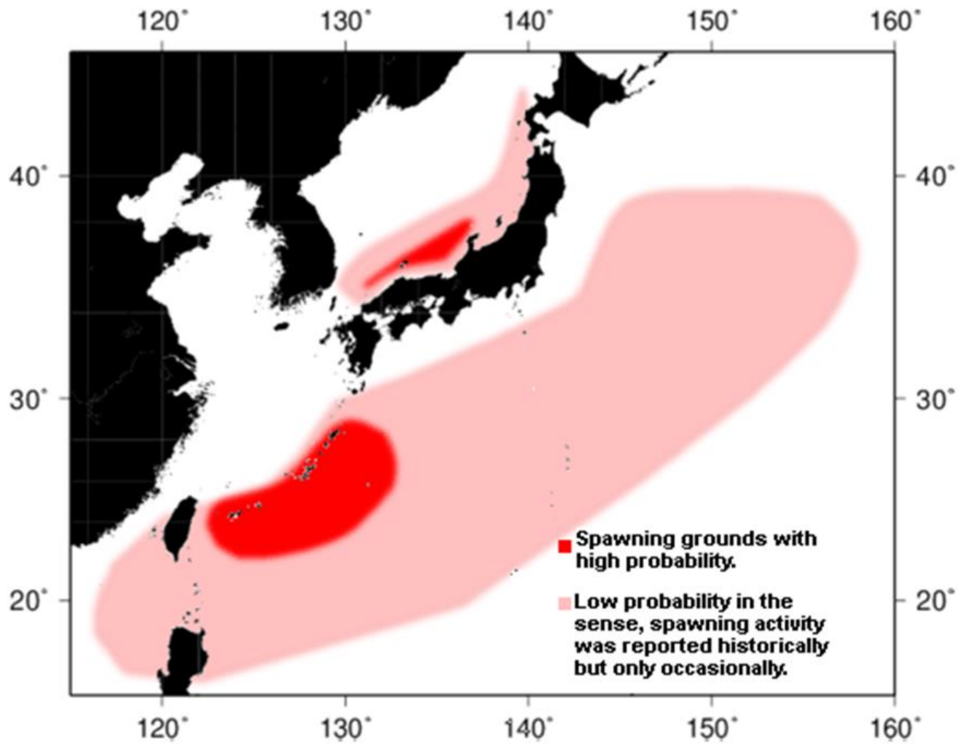


Figure 2-1. Generalized spawning grounds for Pacific bluefin tuna *Thunnus orientalis*. Red areas represent a higher probability of spawning.

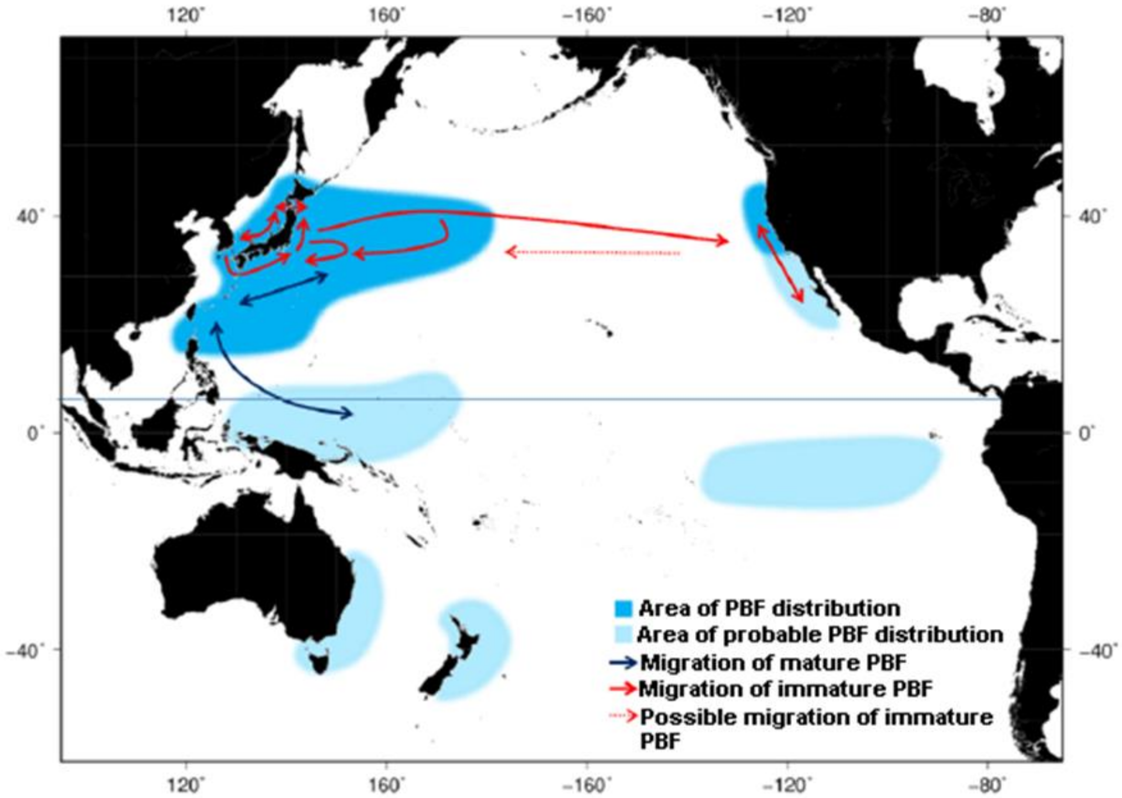


Figure 2-2. Generalized distribution of Pacific bluefin tuna *Thunnus orientalis*. Darker areas indicate the core habitat.

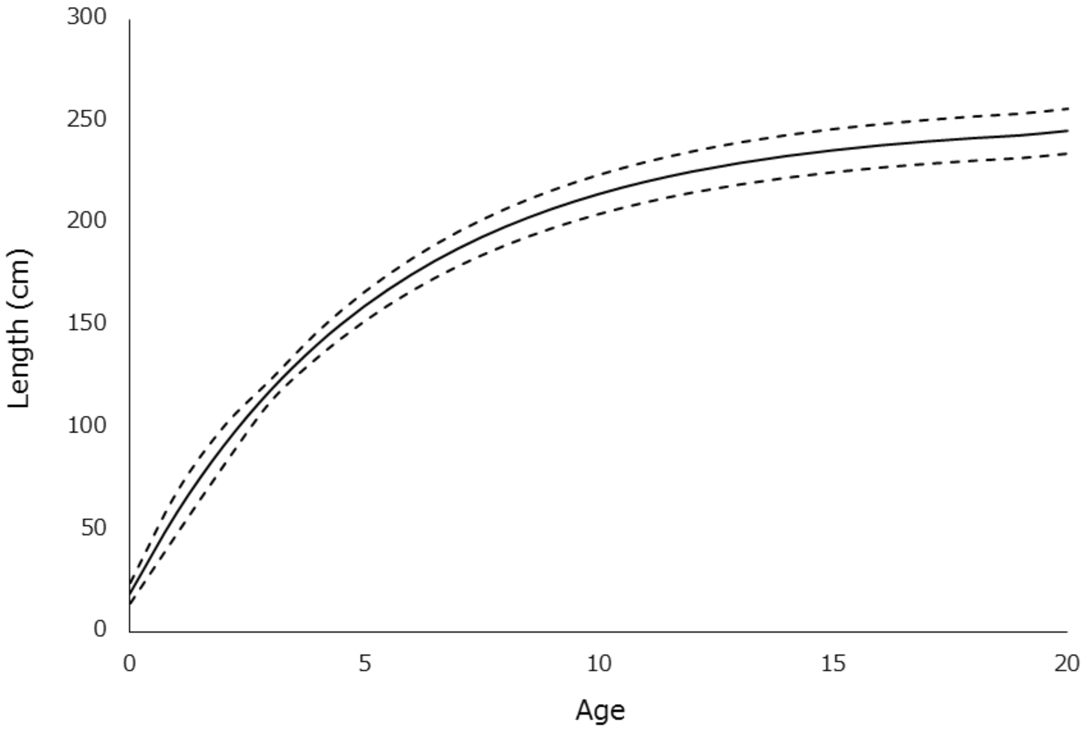


Figure 2-3. The von Bertalanffy growth curve for Pacific bluefin tuna *Thunnus orientalis* used in this stock assessment. Dotted lines are standard deviation of length. Each integer age (0,1,2,3,…) corresponds to the middle of the first quarter of each fishing year (i.e., August 15 in the calendar year).

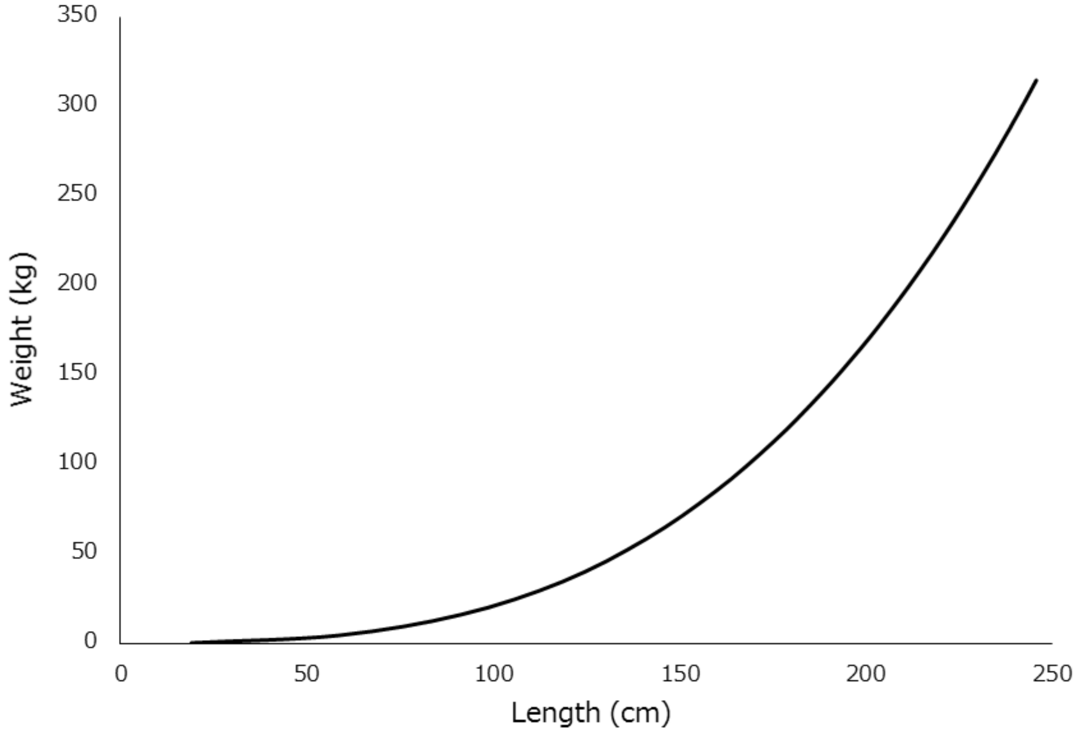


Figure 2-4. Length-weight relationship for Pacific bluefin tuna *Thunnus orientalis* used in this stock assessment.

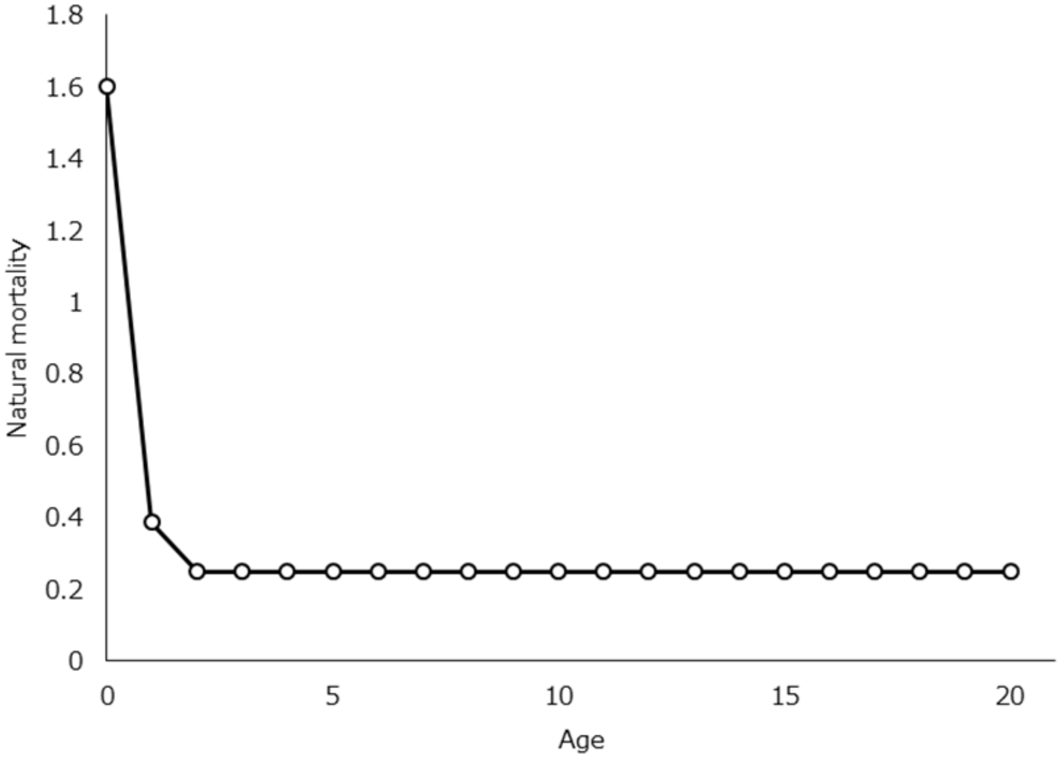


Figure 2-5. Assumed natural mortality (*M*) at age of Pacific bluefin tuna *Thunnus orientalis* used in this stock assessment.

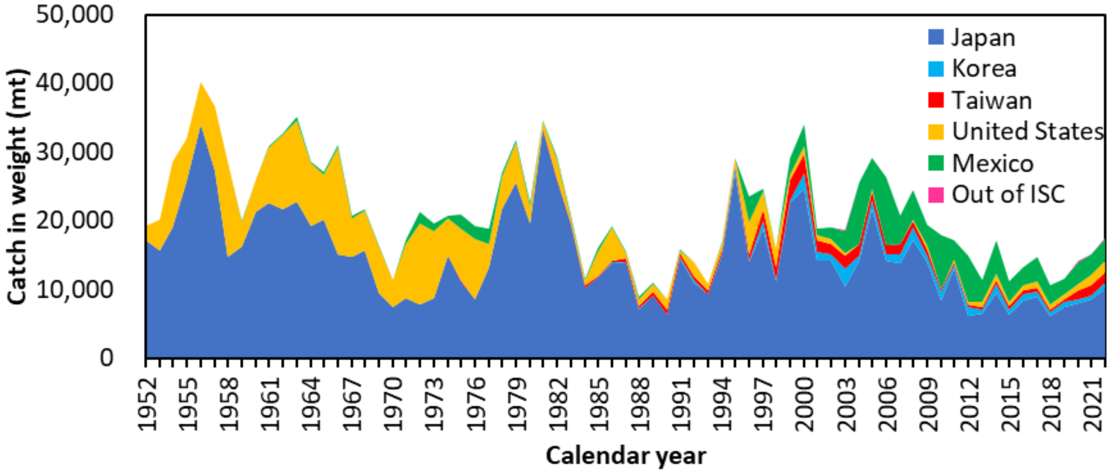


Figure 2-6. Annual catch (in tons) of Pacific bluefin tuna *Thunnus orientalis* by ISC member countries from 1952 through 2022 (calendar year) based on ISC official statistics.

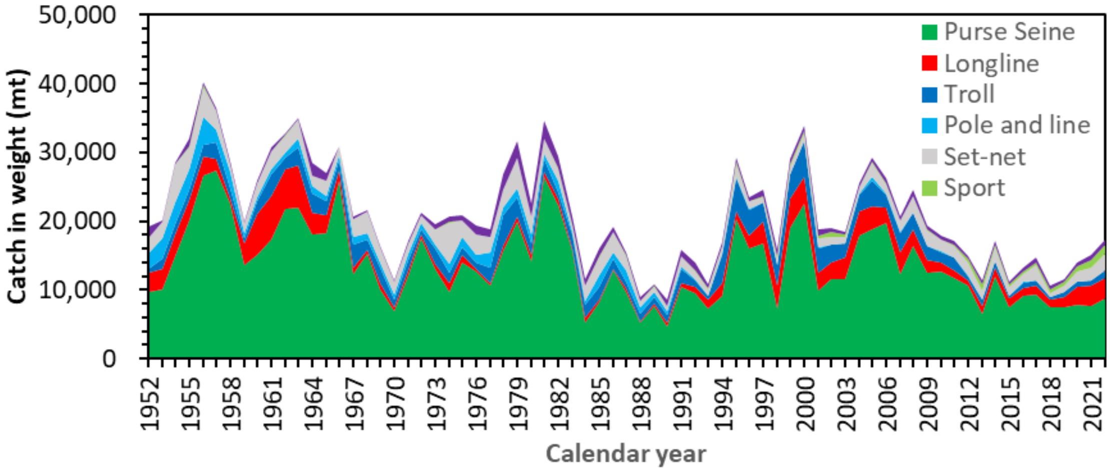


Figure 2-7. Annual catch (in tons) of Pacific bluefin tuna *Thunnus orientalis* by gear type by ISC member countries from 1952 through 2022 (calendar year) based on ISC official statistics.

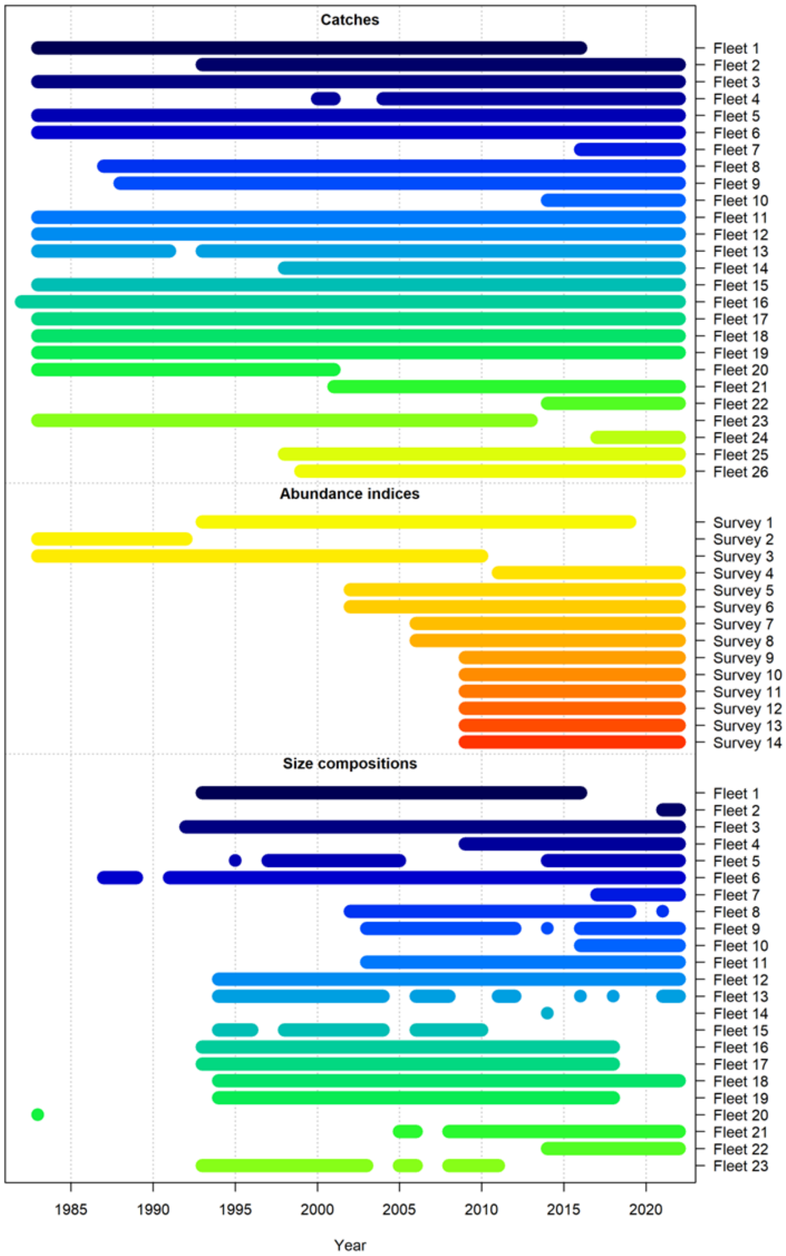


Figure 3-1. Data sources and temporal coverage of catch, abundance indices, and size composition data used in the stock assessment of Pacific bluefin tuna *Thunnus orientalis*.

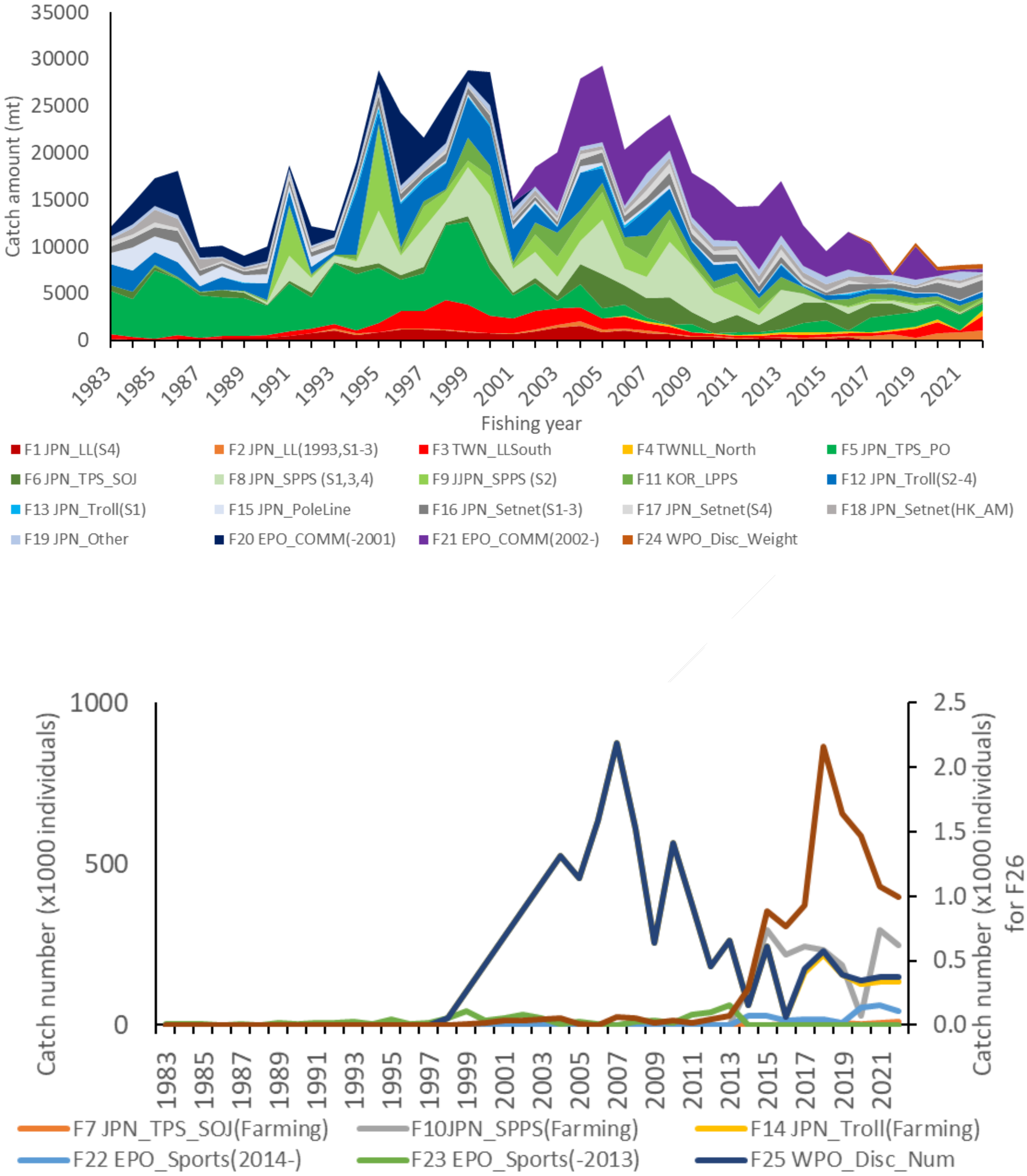


Figure 3-2. Historical annual catch of Pacific bluefin tuna *Thunnus orientalis* in weight for fleets 1-6, 8-9, 11-13, 15-19, 20, 23 and 24 (a: upper panel), and in number for fleets 7, 10, 14, 22, 23 and 25 (b: lower panel) for the fishing years 1983-2022.

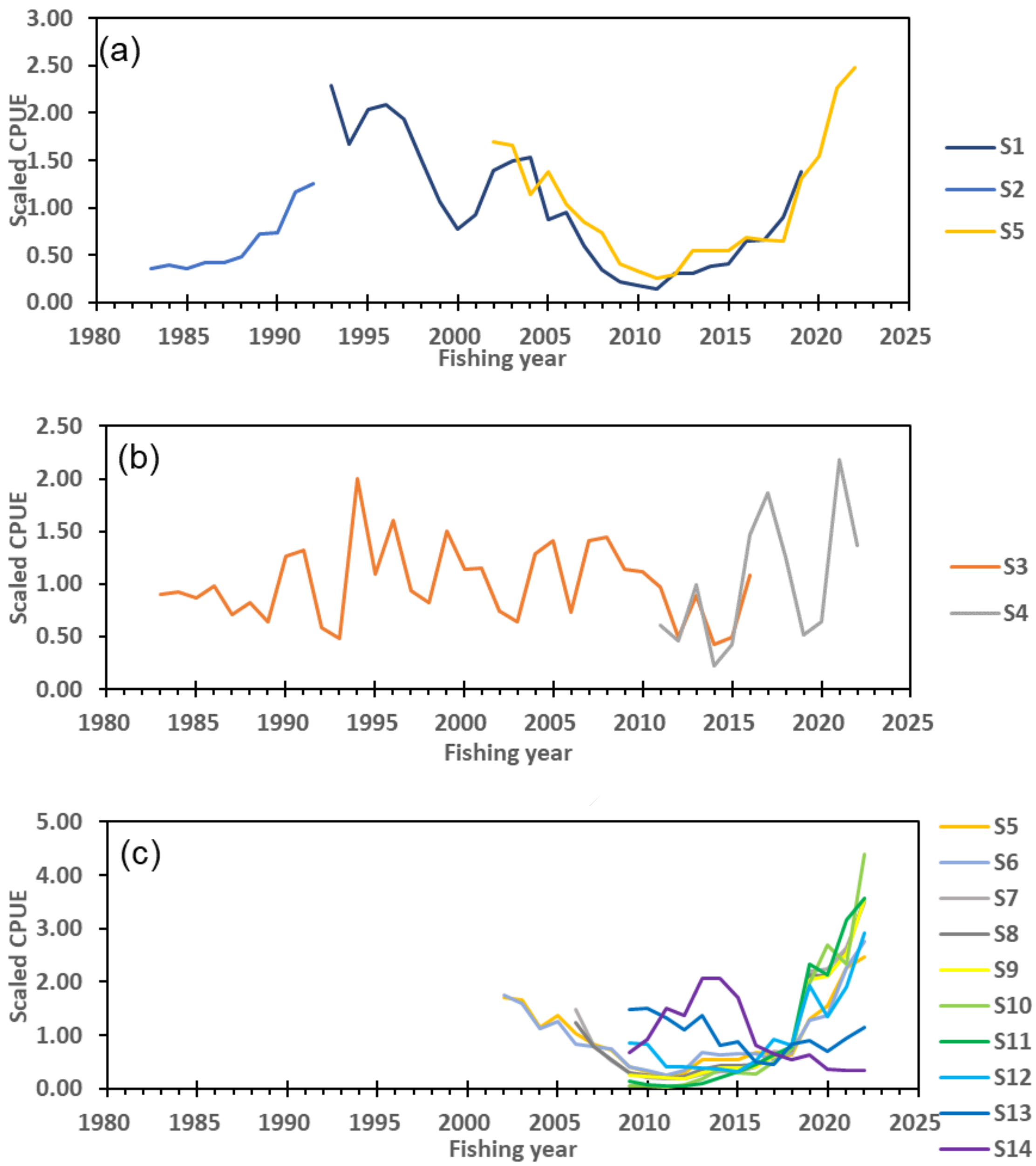


Figure 3-3. Abundance indices of Pacific bluefin tuna *Thunnus orientalis* submitted to ISC PBFWG. The longline indices of Japanese fisheries (S1 and S2) and Taiwanese fishery in the southern area (S5) were used to represent adult abundance (Fig.(a)), while the index of Japanese troll fishery (S3, 1983-2010) was used as the recruitment index (Fig.-(b)). The other indices were not fitted to the assessment model (Fig.(b) and (c)); e.g. the indices of Taiwanese longline fishery (S6-9) and Japanese troll monitoring (S4).

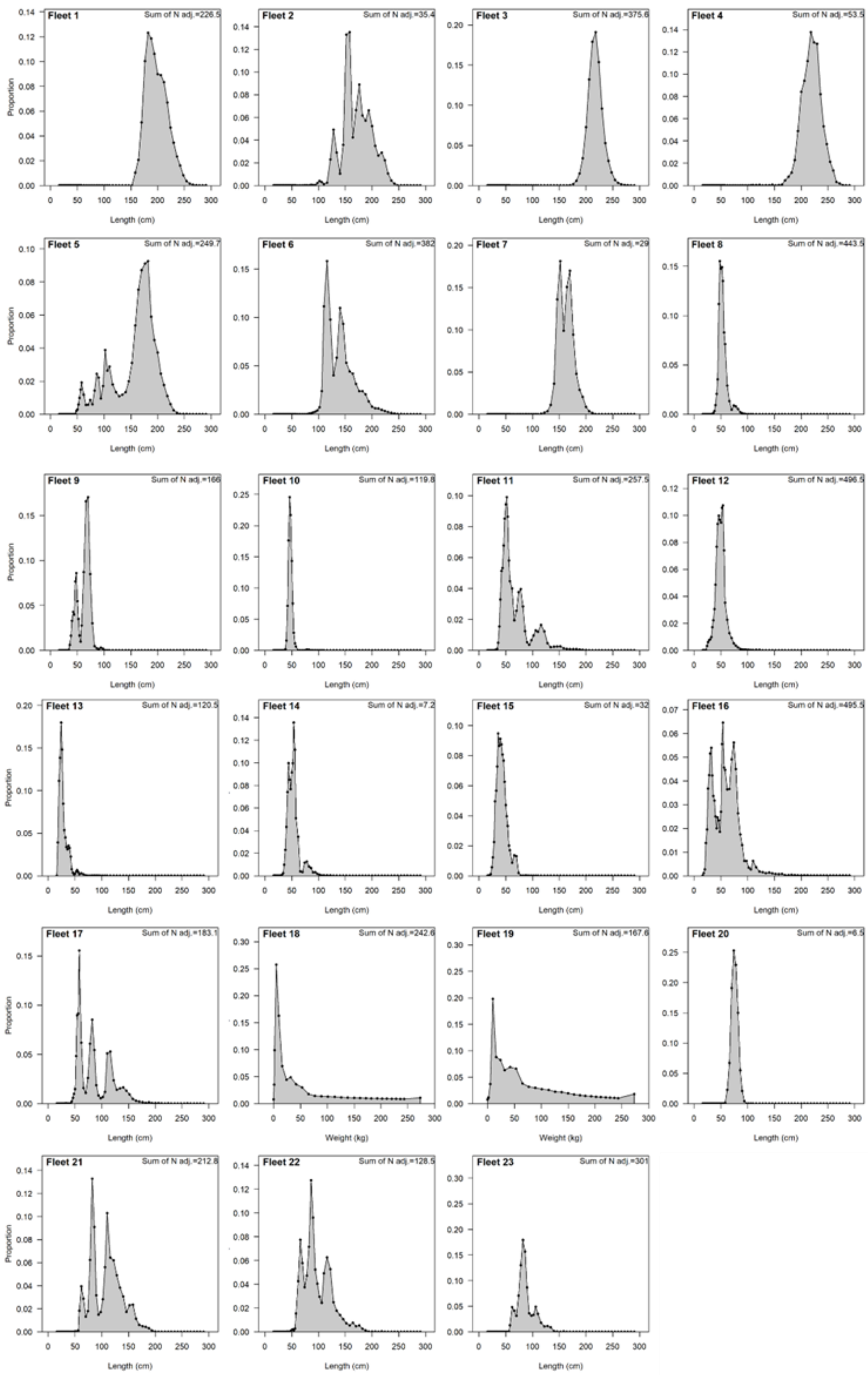


Figure 3-4. Aggregated size compositions of Pacific bluefin tuna *Thunnus orientalis* for each fleet used in the stock assessment. The data were aggregated across seasons and years. The x-axis is in fork length (cm) for all fleets except for Fleet 10-11 in weight (kg).

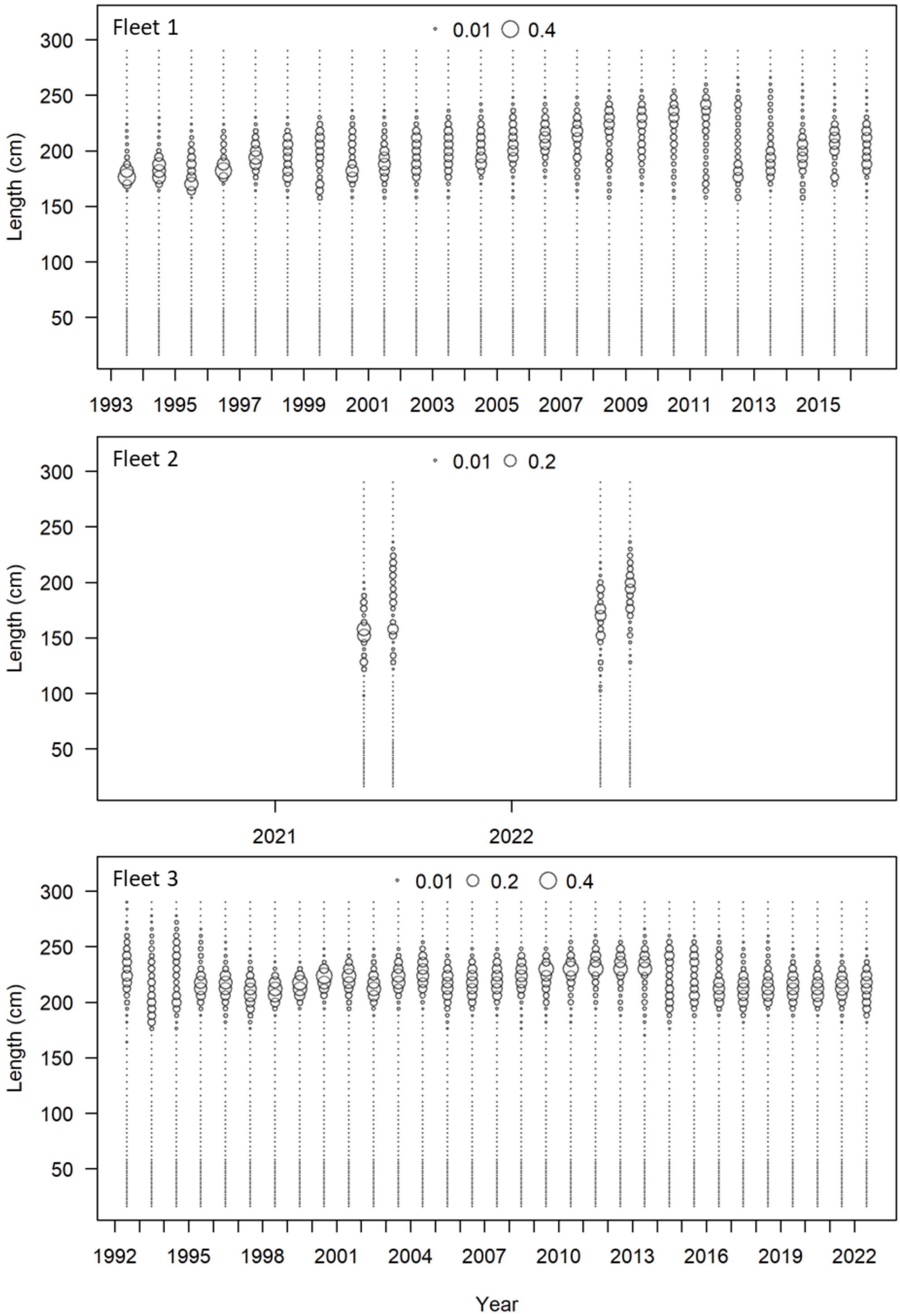


Figure 3-5. Size composition data by fleet and season considered to use in the stock assessment model for Pacific bluefin tuna *Thunnus orientalis*. Larger circles indicate higher proportions of fish.

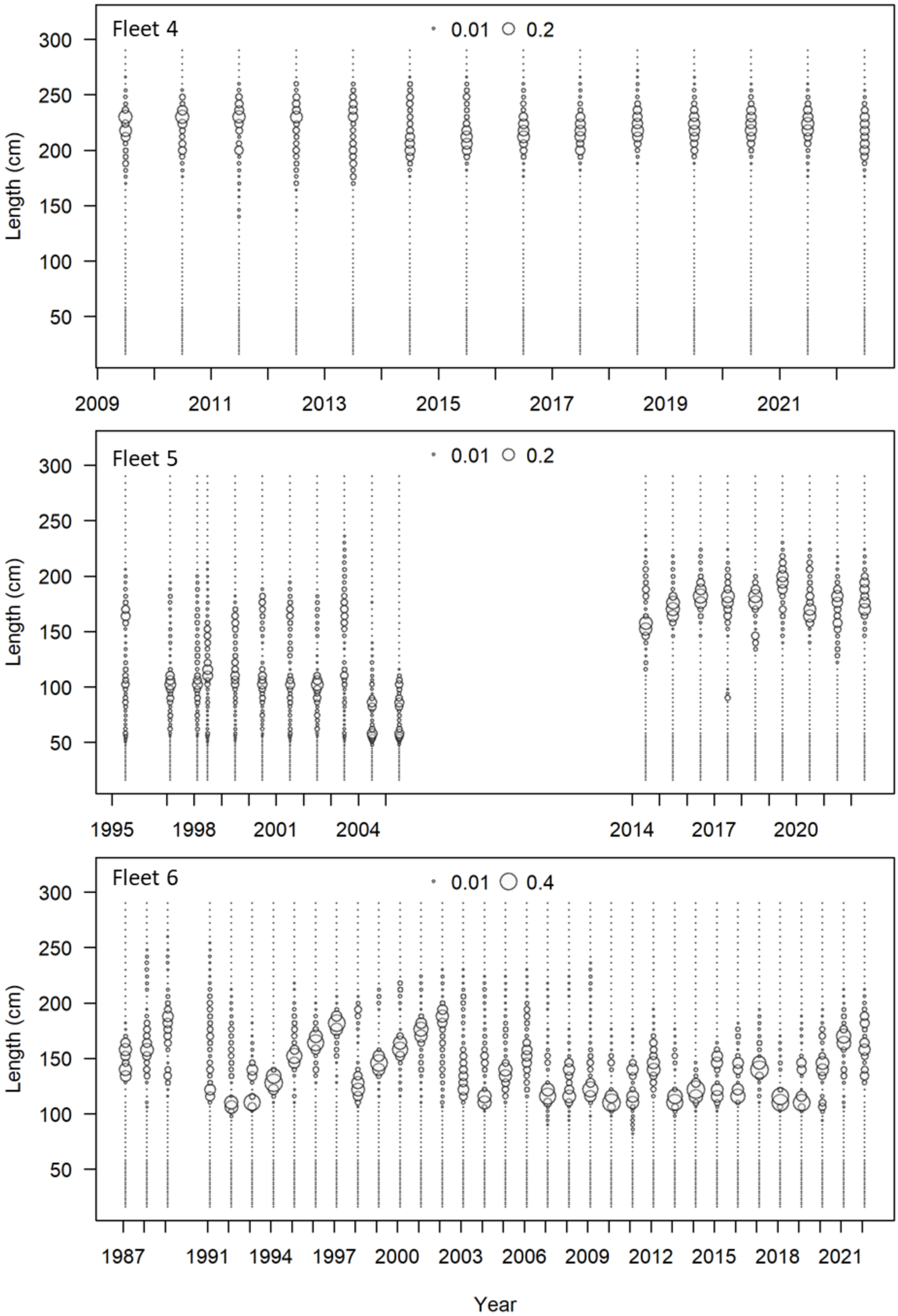
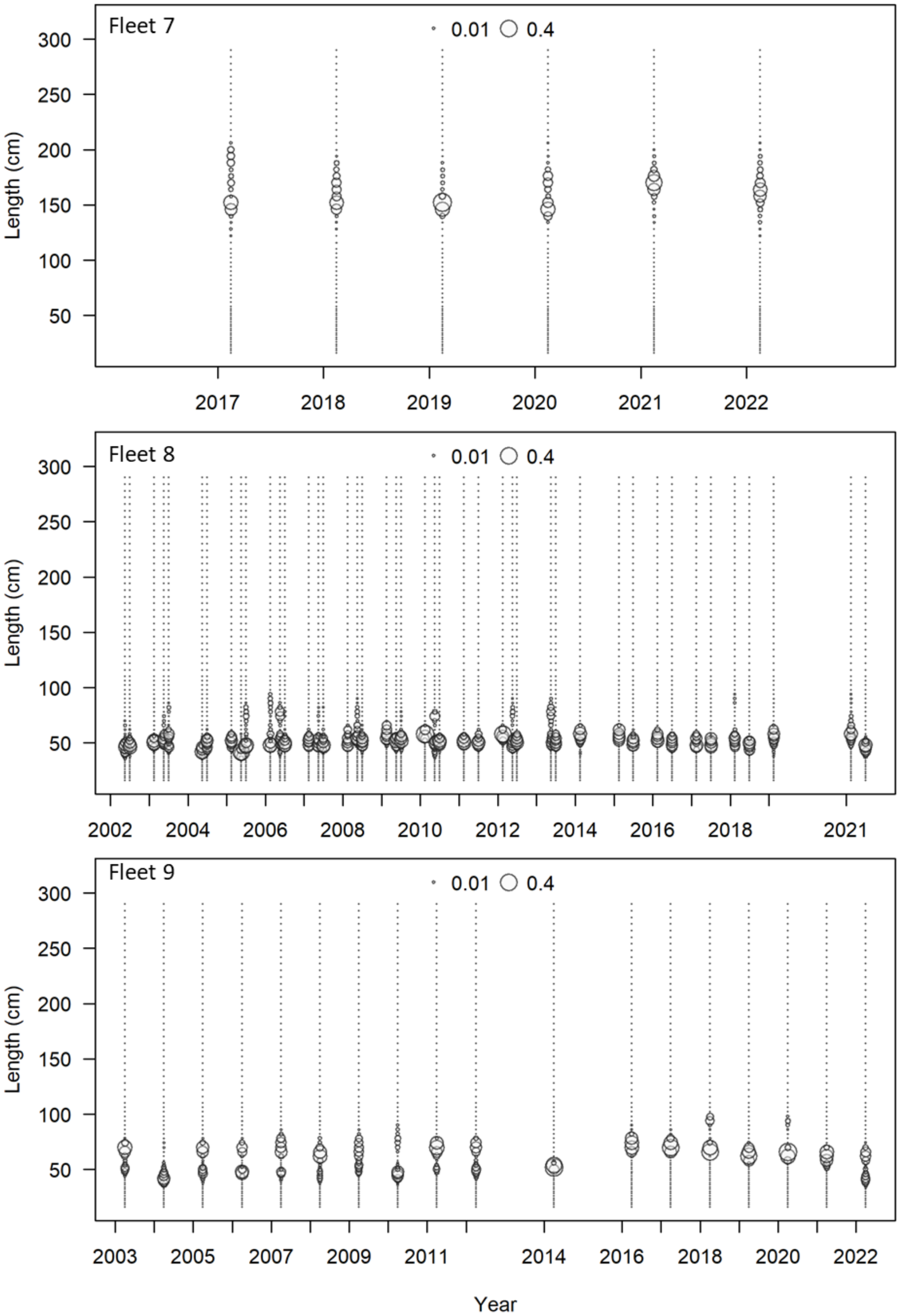


Figure 3-5. Cont.



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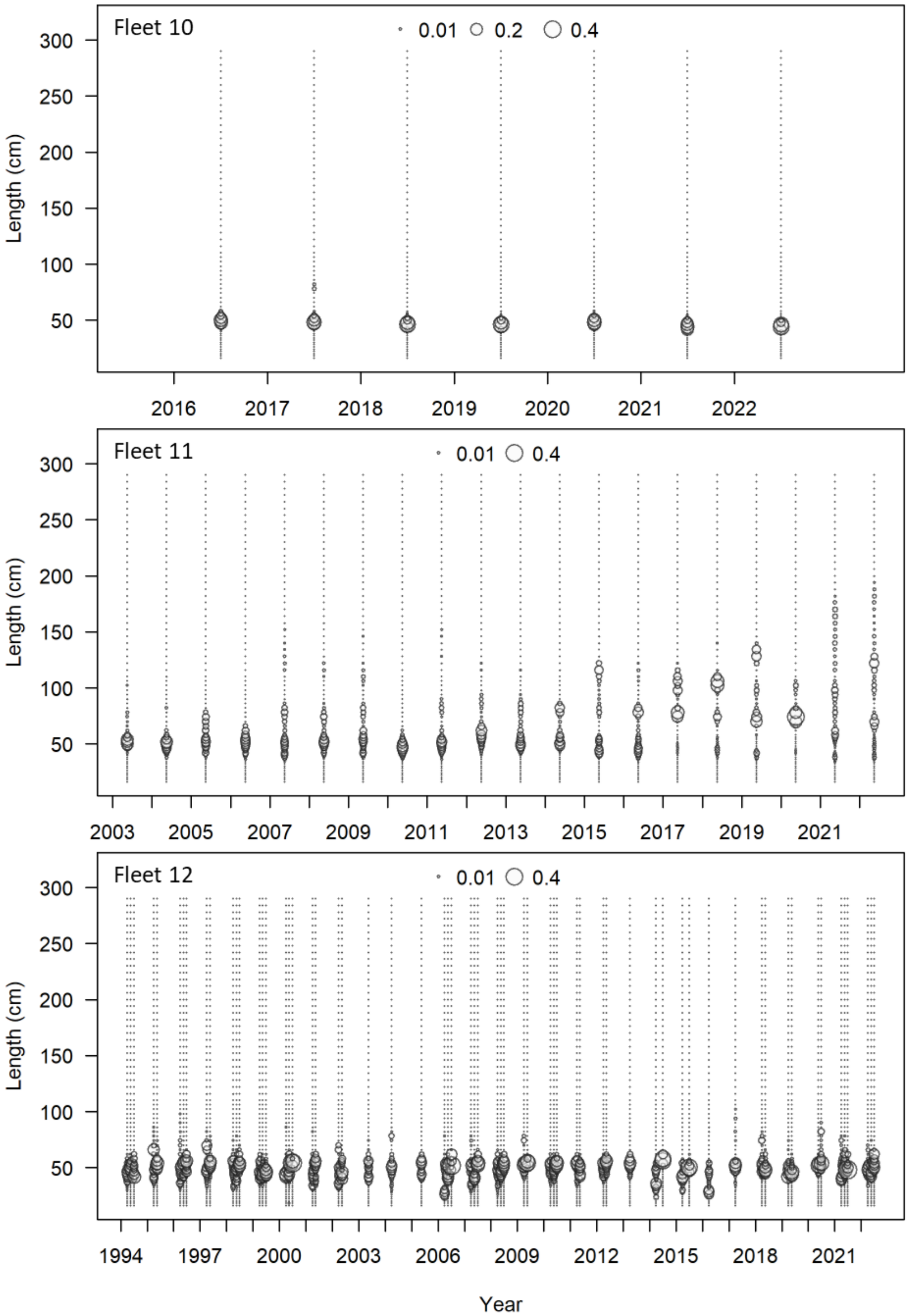

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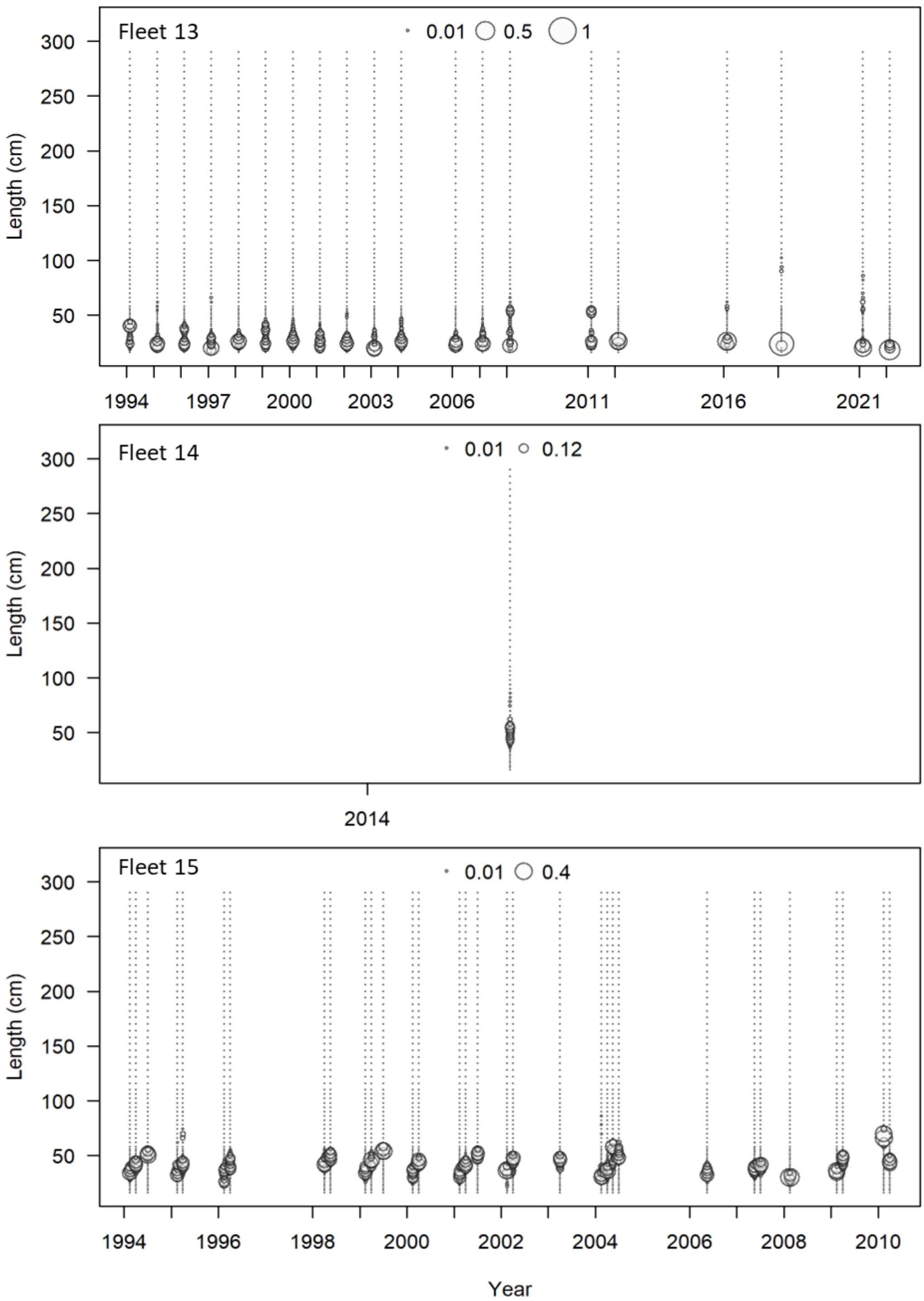

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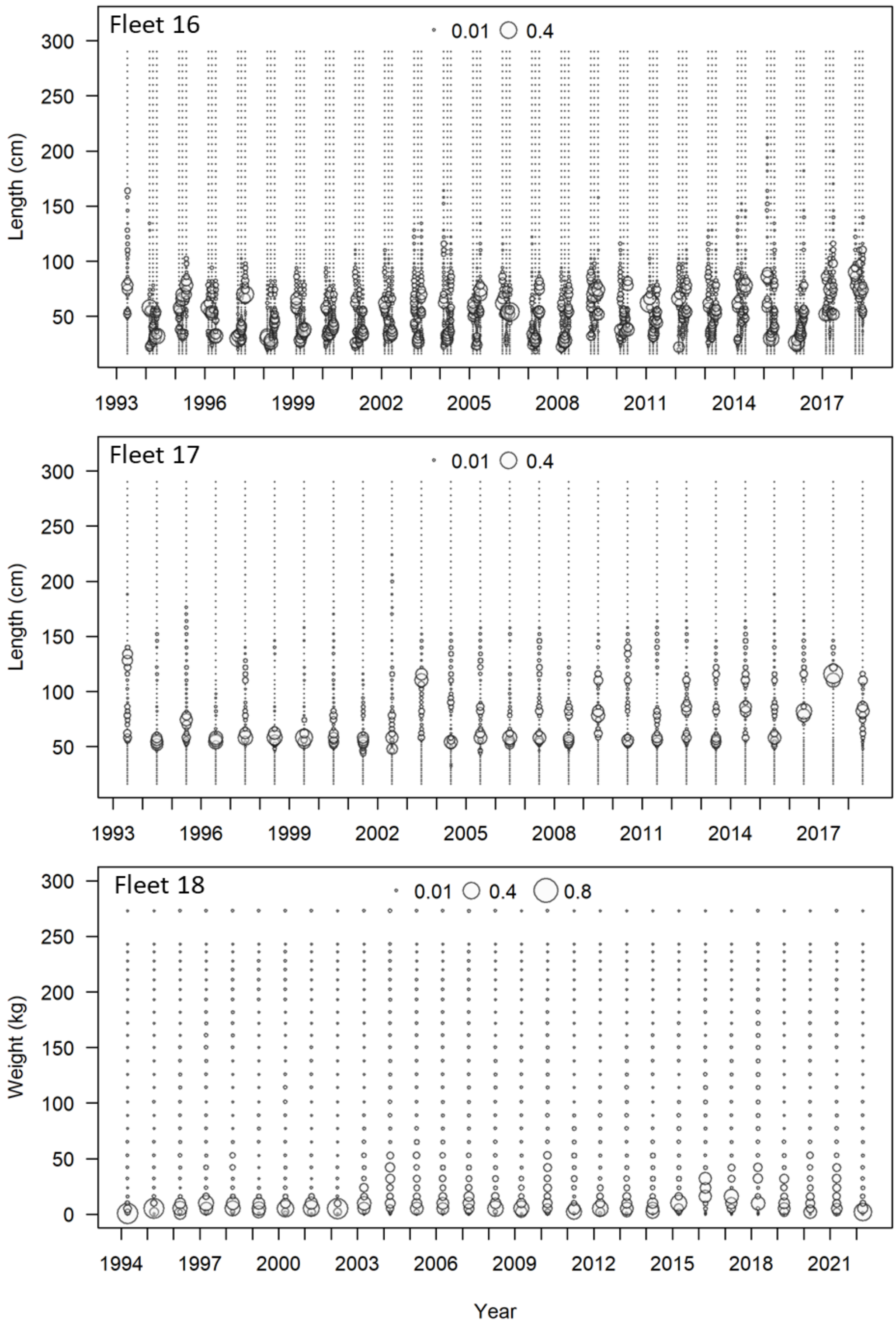

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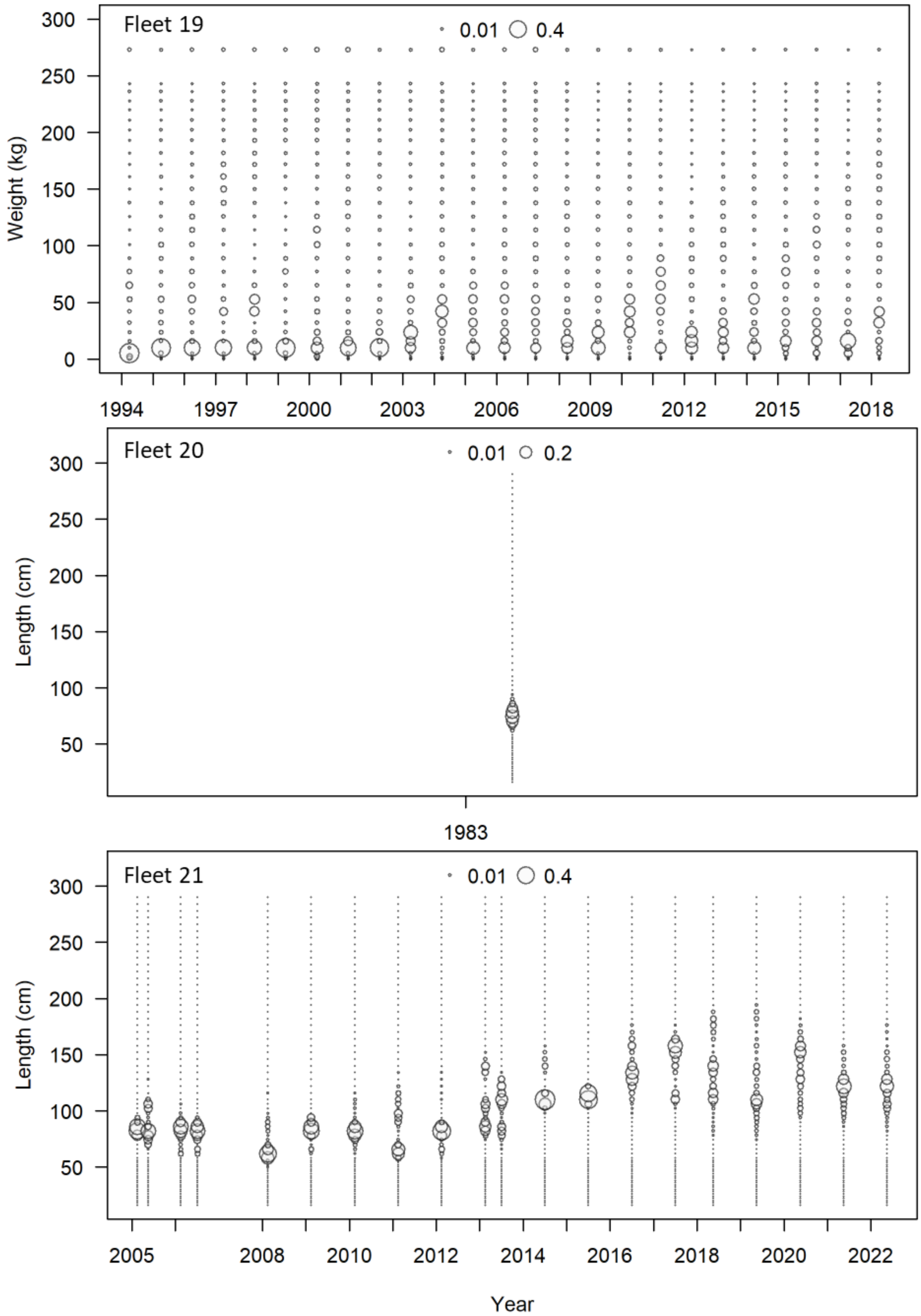

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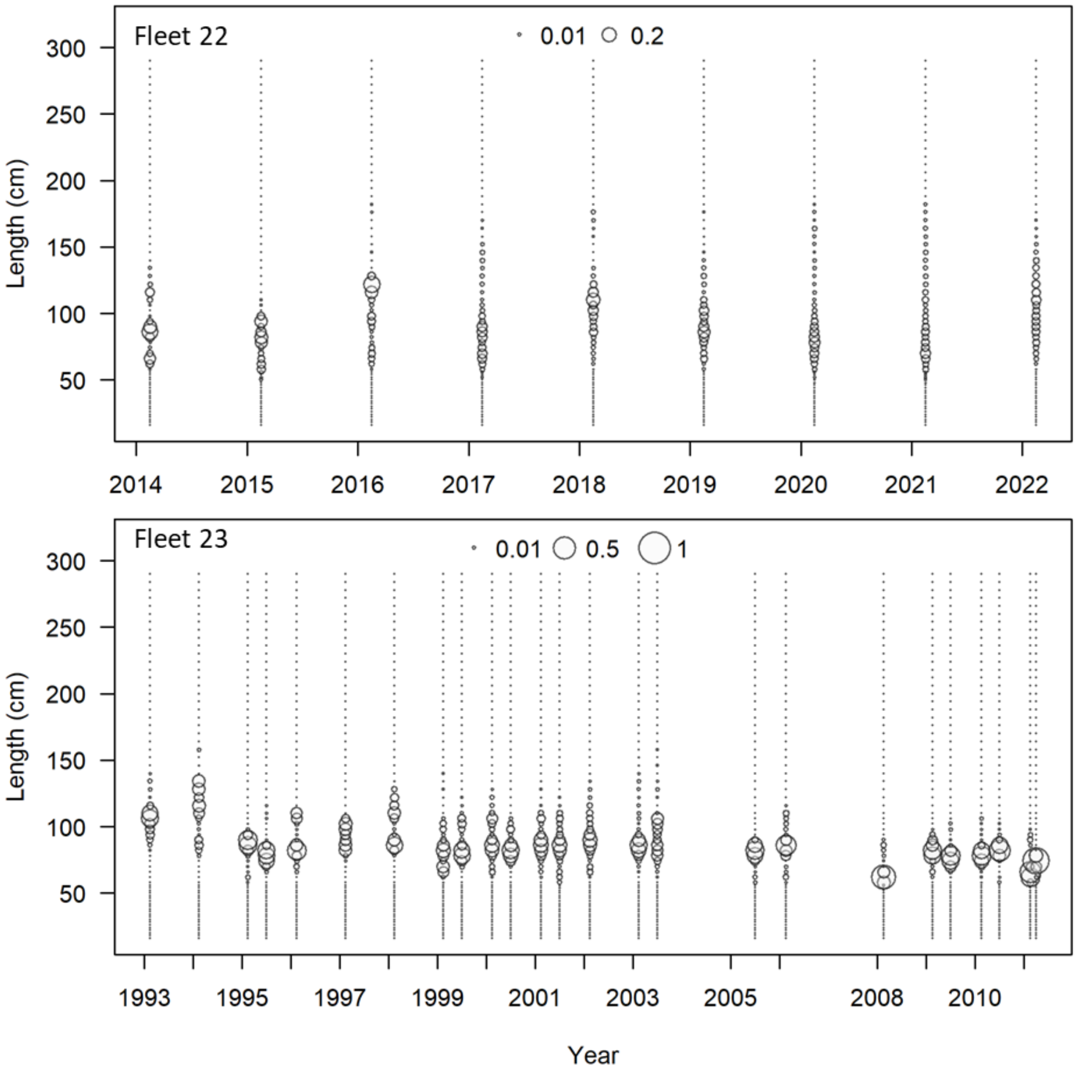

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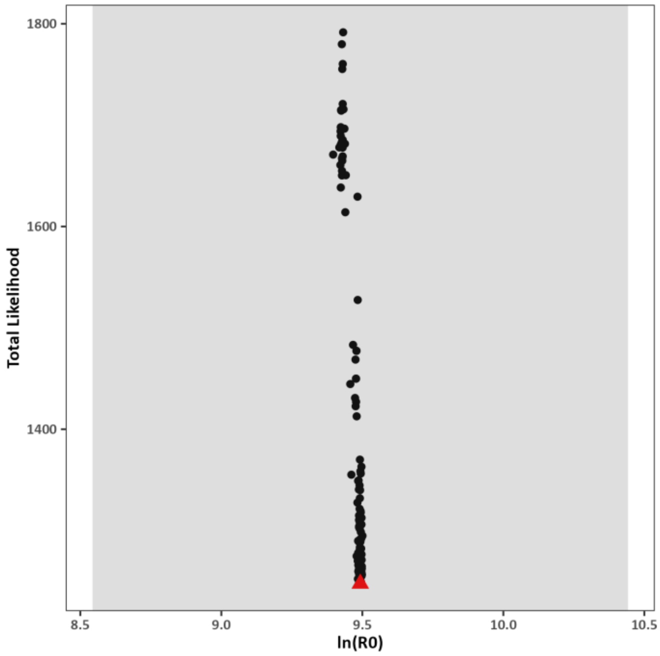


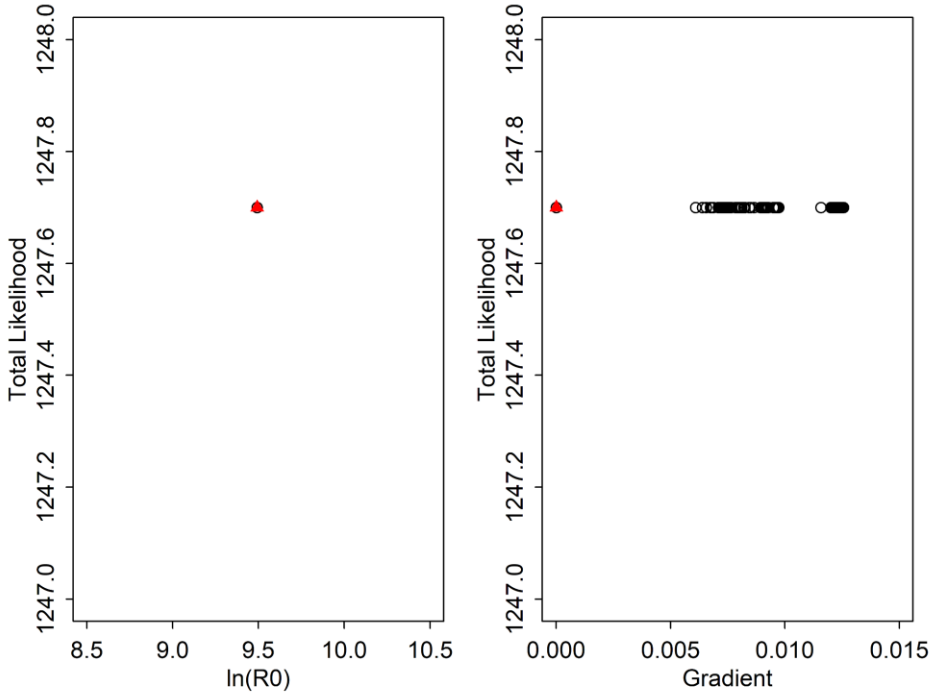


Figure 5-1. Effects of random perturbations of initial values (top panel) and phases of selectivity parameters (bottom panels) on estimated log (R0) and total likelihood by the base-case model for Pacific bluefin tuna *Thunnus orientalis*. Red triangle represents the value of the base-case model. Gray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

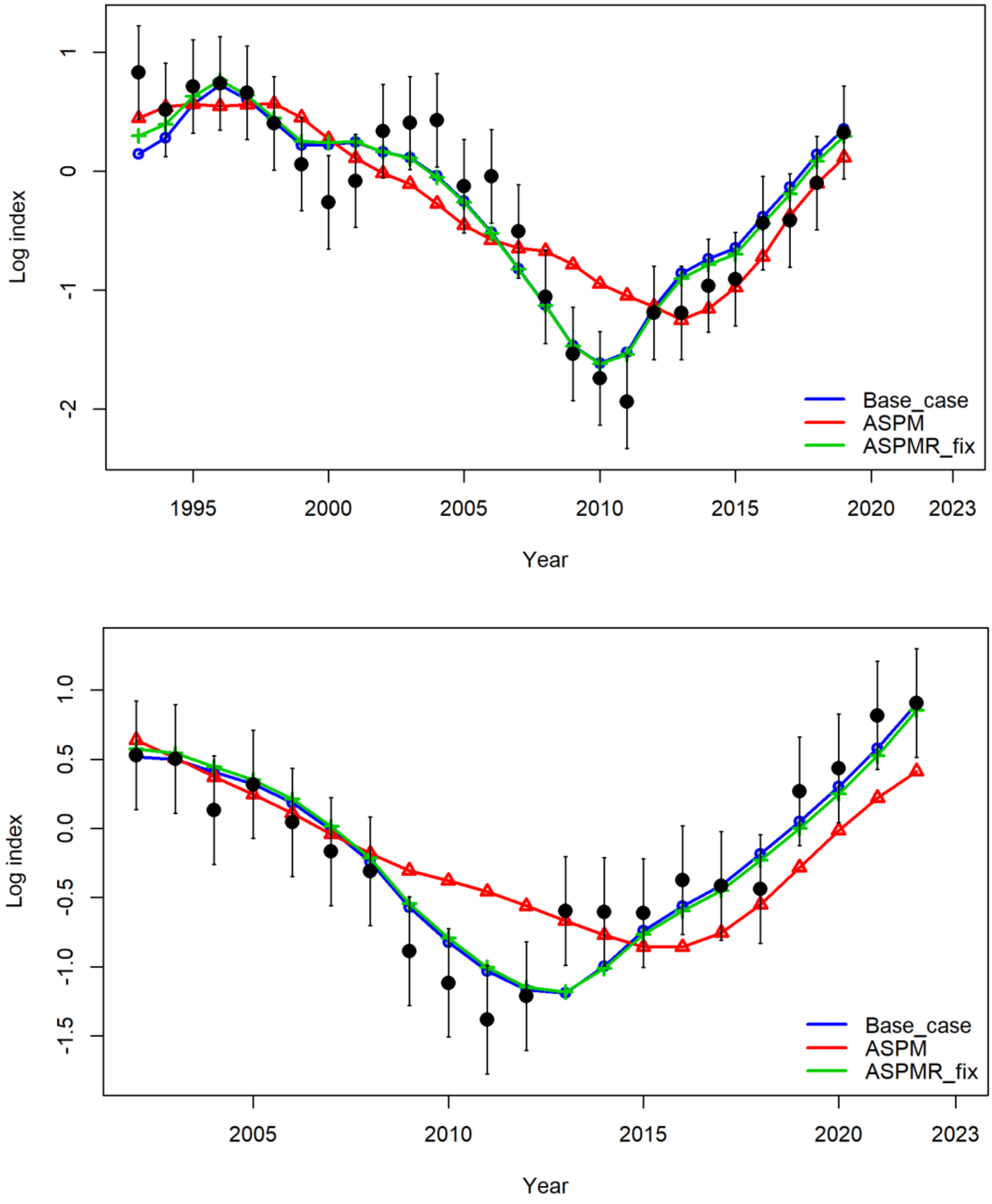


Figure 5-2. Comparisons of the (a) Japanese longline index and (b) Taiwanese longline index predicted by the base-case model (blue), age-structured production model (ASPM; red), and ASPM with annual recruitment deviations specified at those estimated in the base-case model (ASPMR; green). Black closed circles with error bars represent the observed abundance indices with a 95% CI.

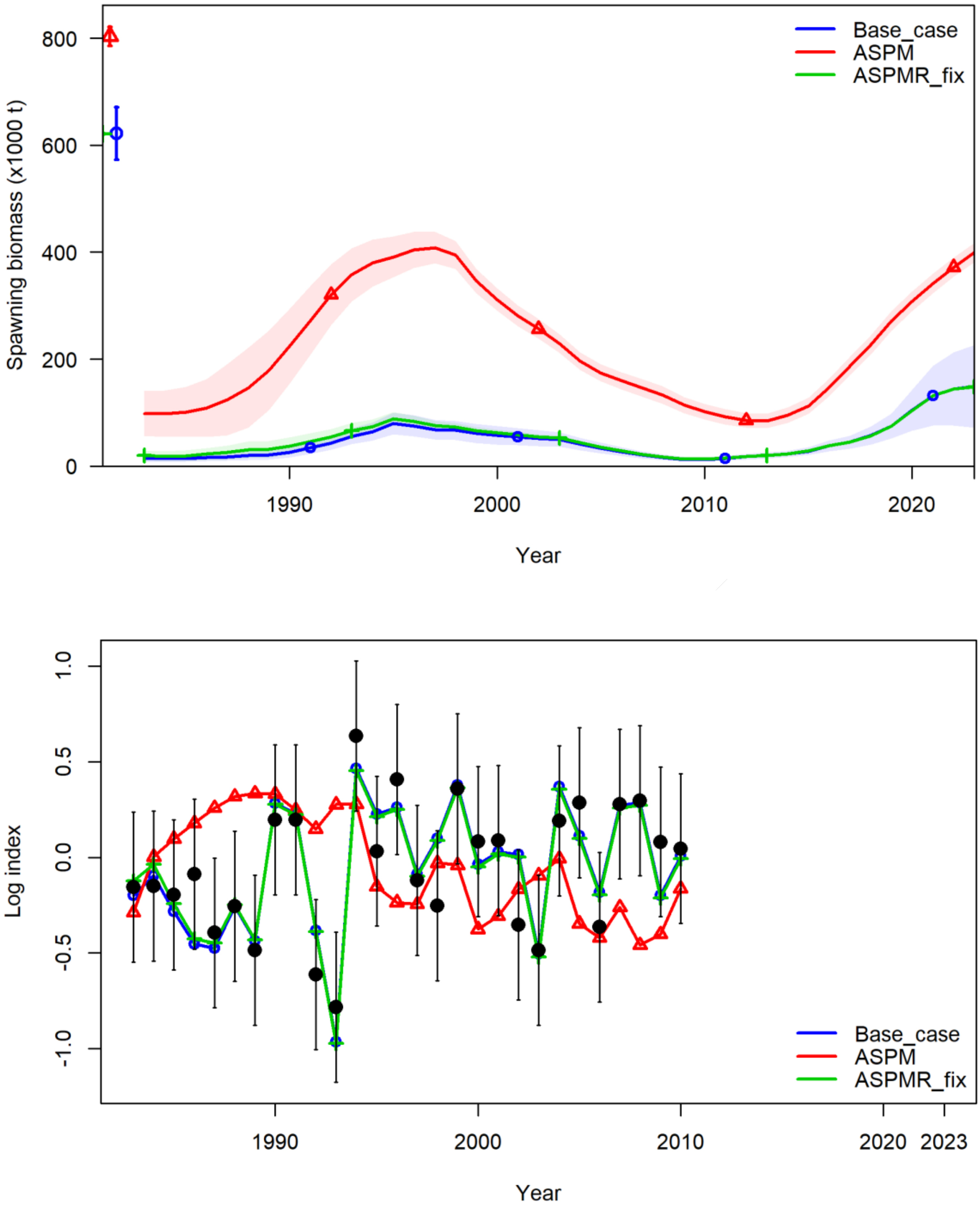


Figure 5-3. Spawning stock biomass (upper) by the base-case model (blue), age-structured production model (ASPM; red) and ASPM with specified recruitment deviations (ASPM Rfix; green) and the fit for the Japanese troll index (S3) (bottom).

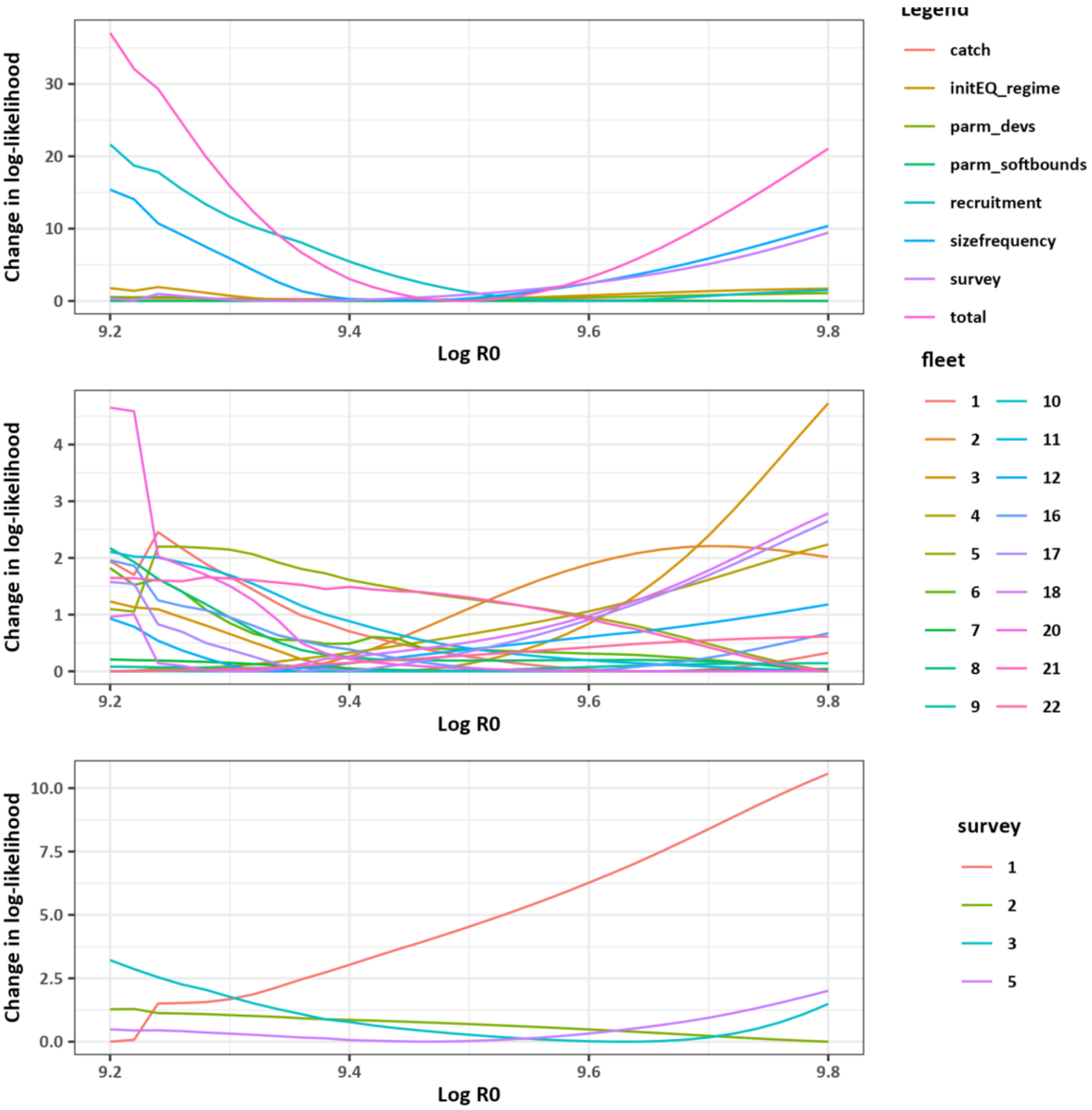


Figure 5-4. Profiles of (a) total and component likelihoods (b) likelihood for each size composition component, and (c) likelihood for each index component over fixed log(R0) for the base-case model of Pacific bluefin tuna *Thunnus orientalis*.

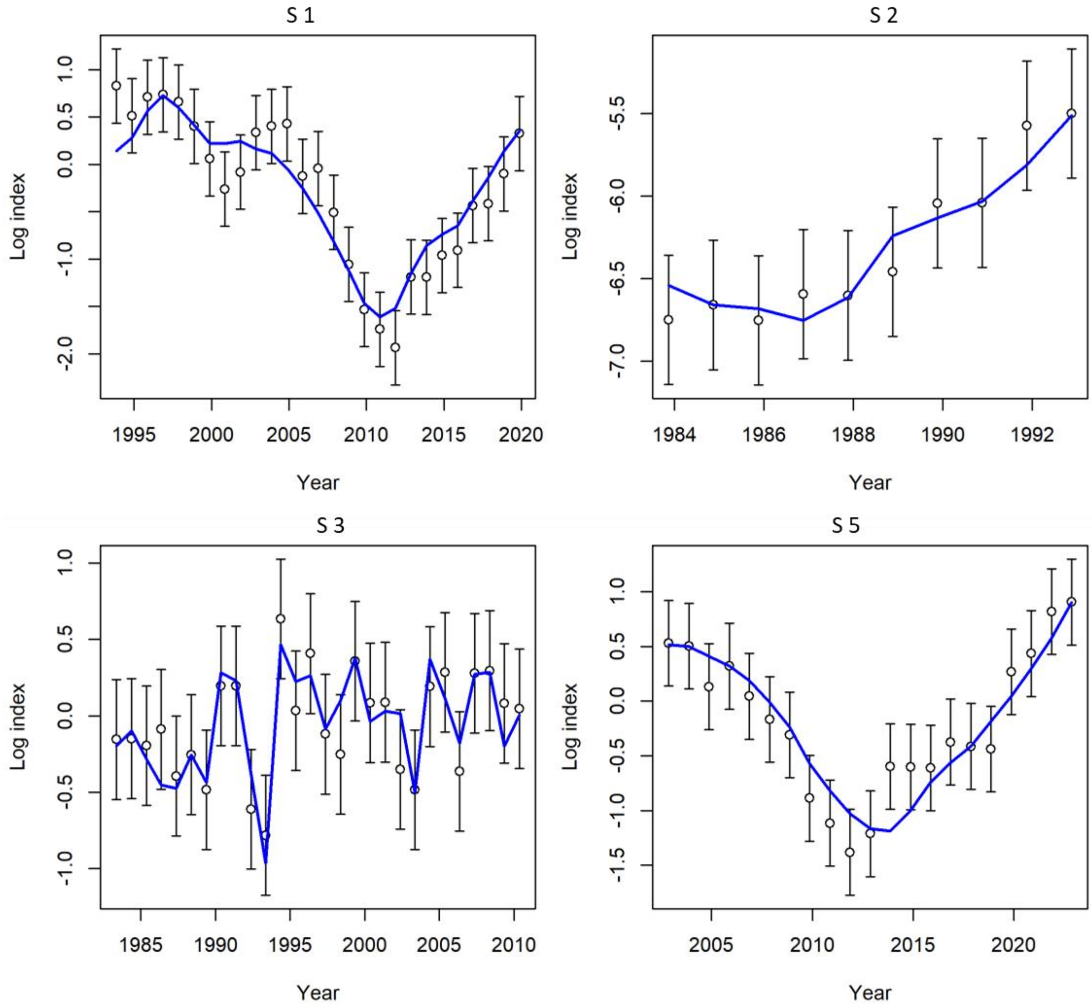


Figure 5-5. Predicted (blue lines) and observed (open dots) abundance indices for the base-case model of Pacific bluefin tuna *Thunnus orientalis*, where vertical lines represent the 95% CI of observations.

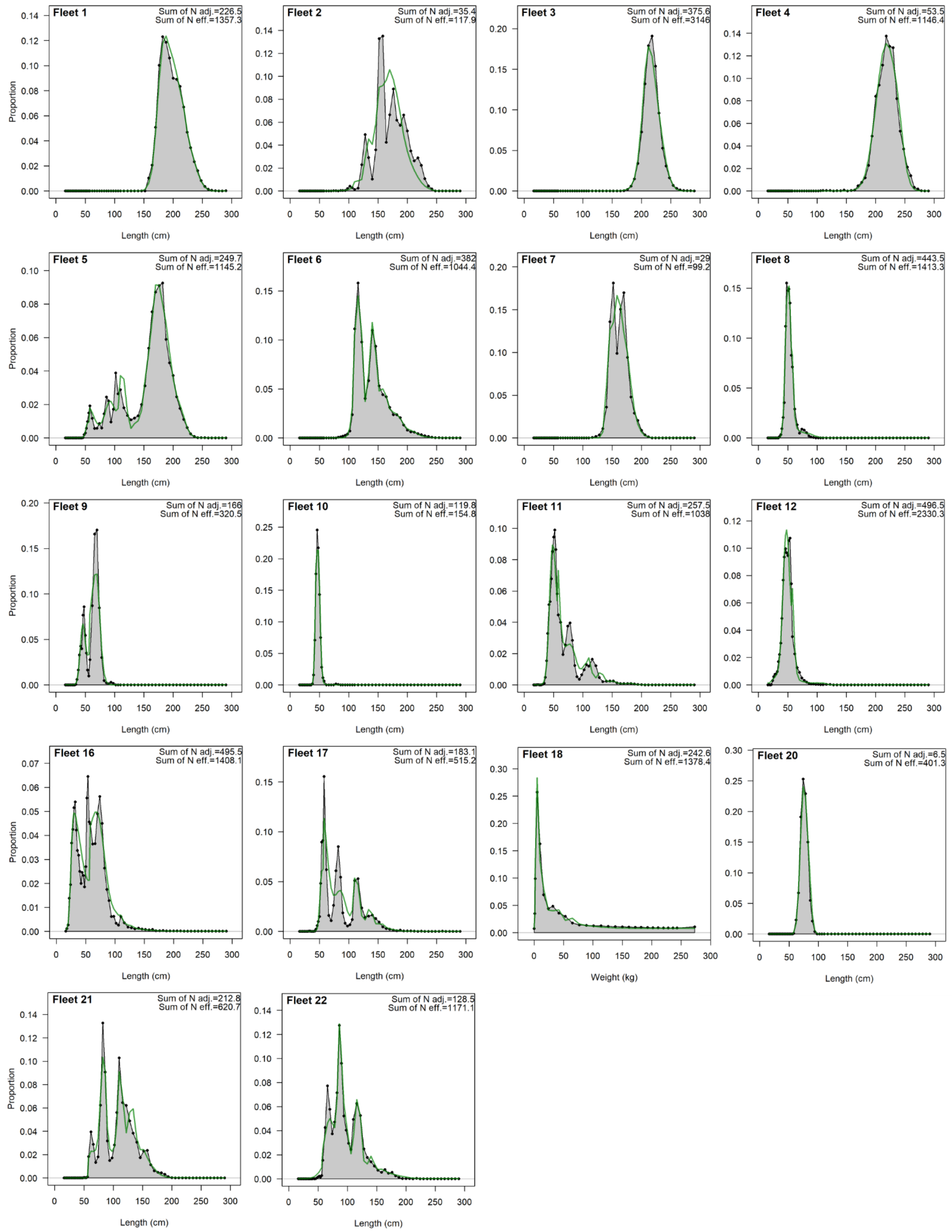


Figure 5-6. Overall fits (green line) to the size compositions by fleet across seasons in the base-case model for Pacific bluefin tuna *Thunnus orientalis*, where grey areas indicate the observations.

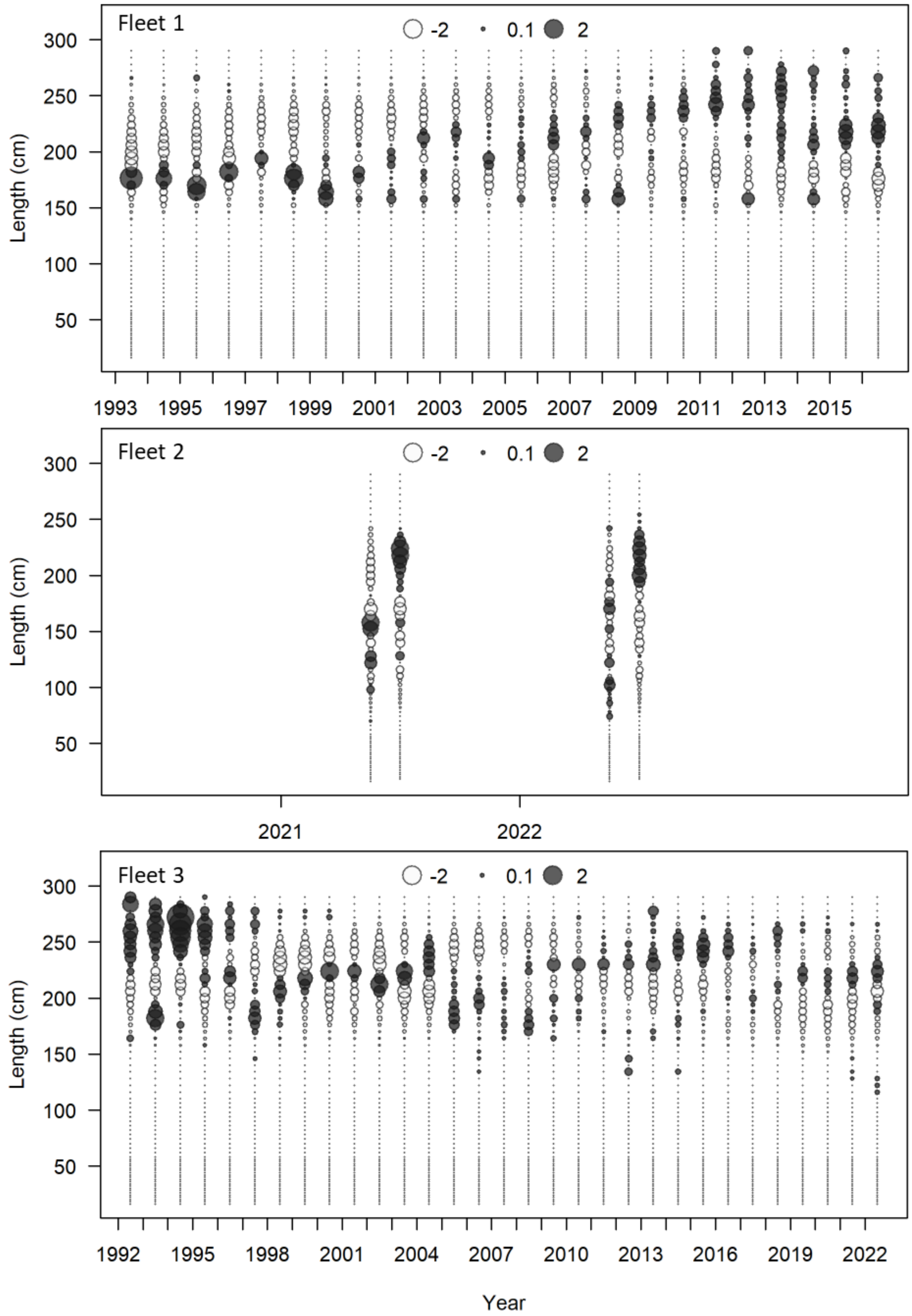


Figure 5-7. Pearson residual plots of model fits to the size composition data of Pacific bluefin tuna *Thunnus orientalis* by fishery. The hollow and filled circles represent observations that are higher and lower than the model predictions, respectively. The areas of the circles are proportional to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

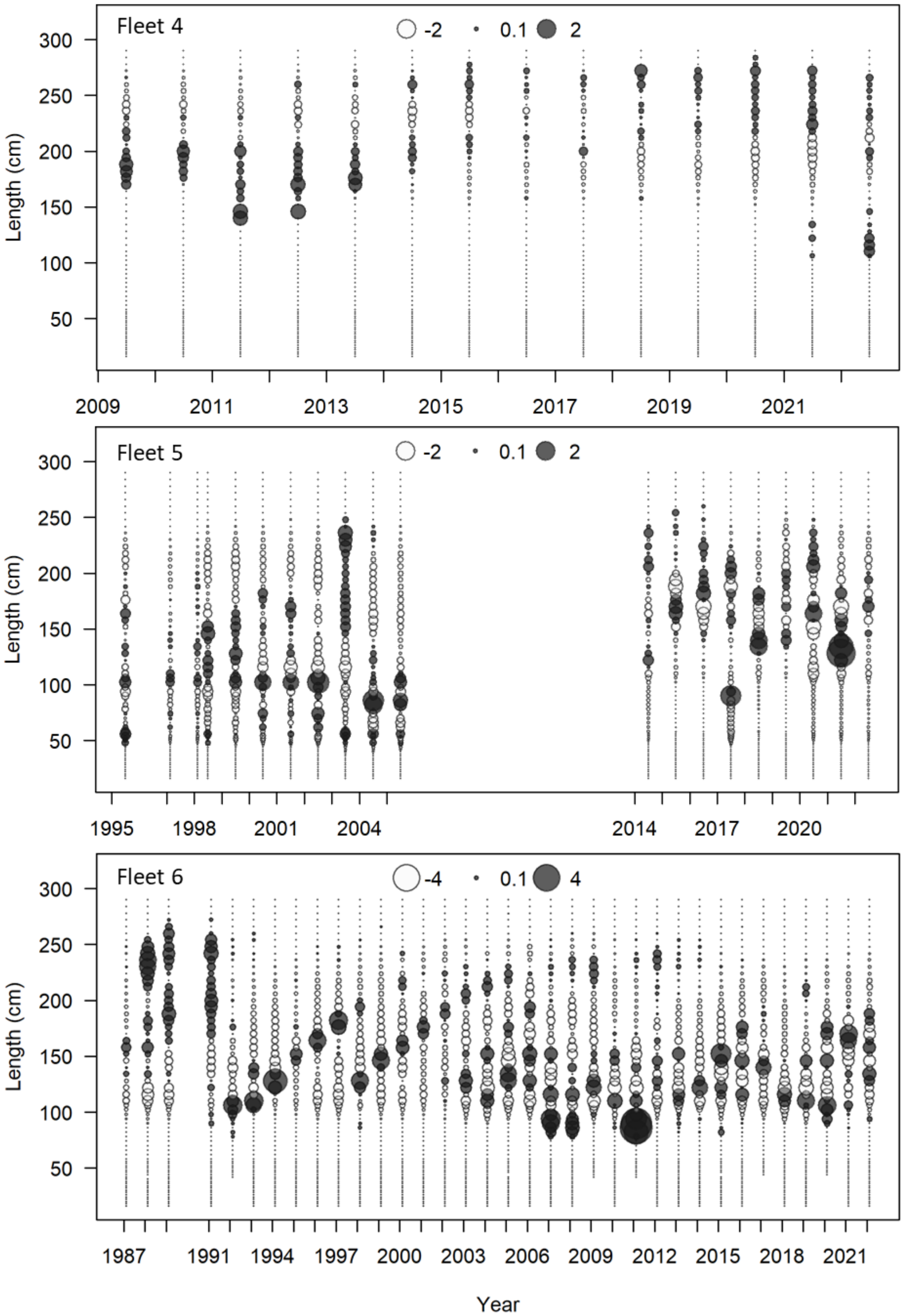
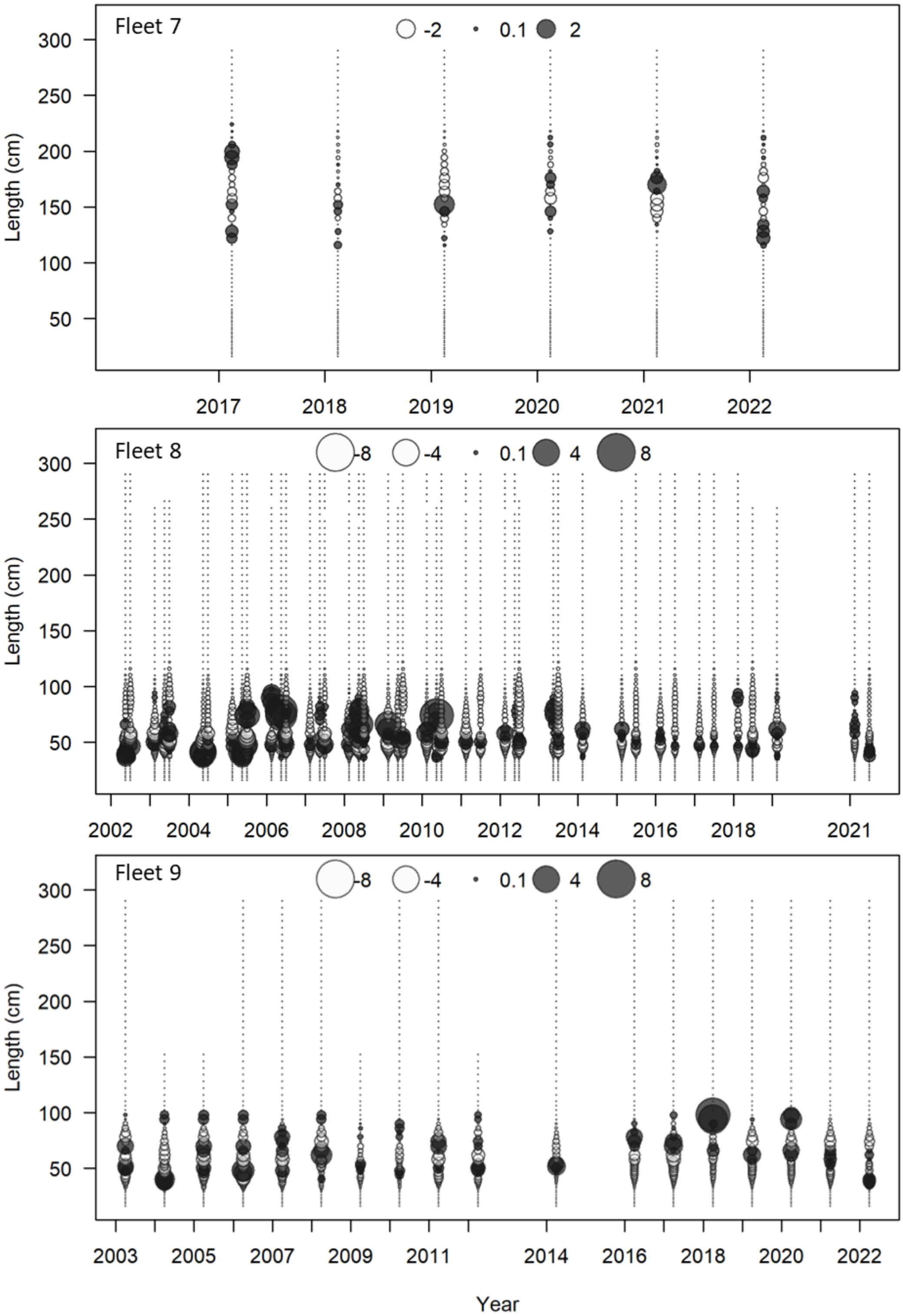


Figure 5-7. Cont.



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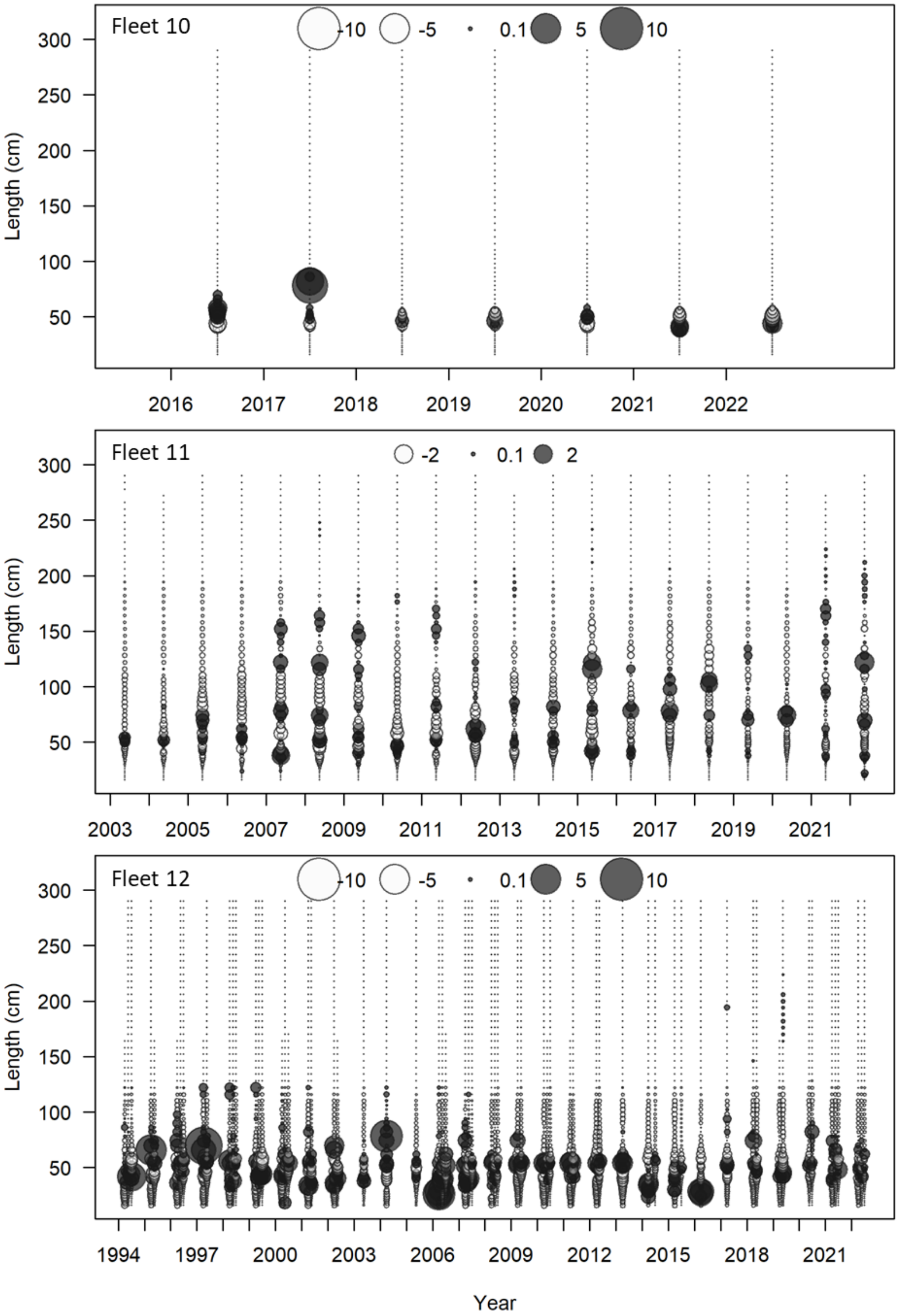


Figure 5-7. Cont.

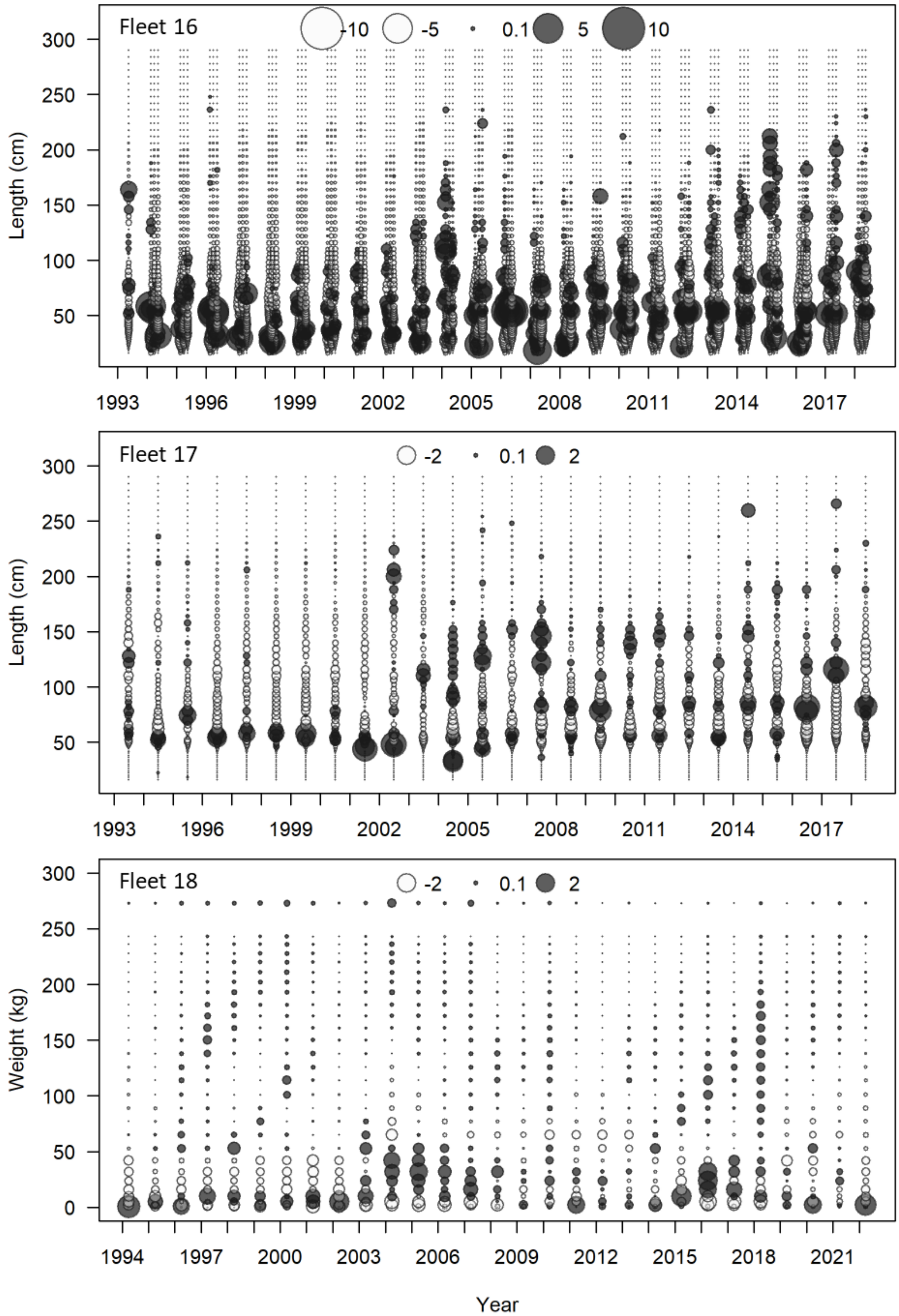
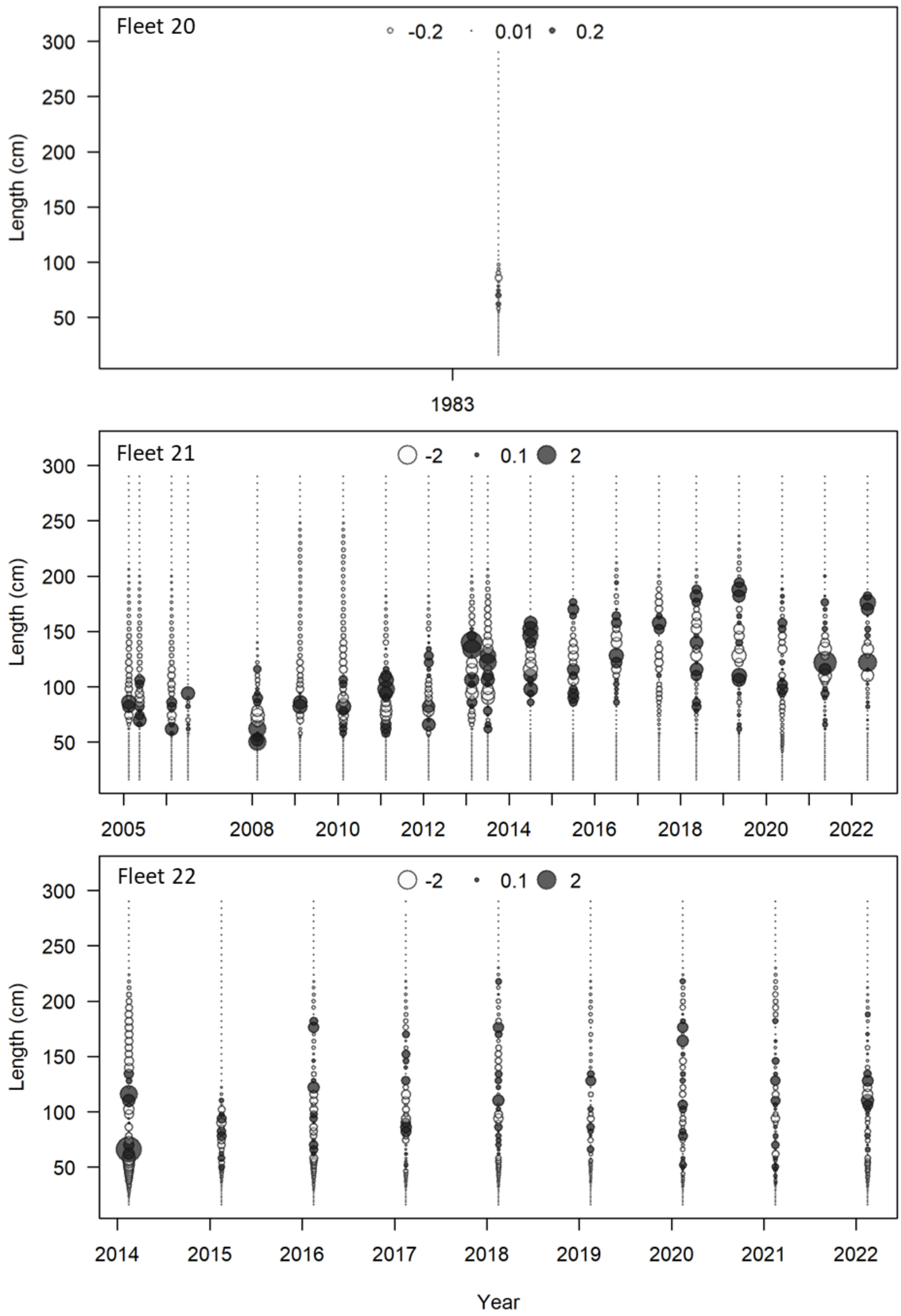


Figure 5-7. Cont.



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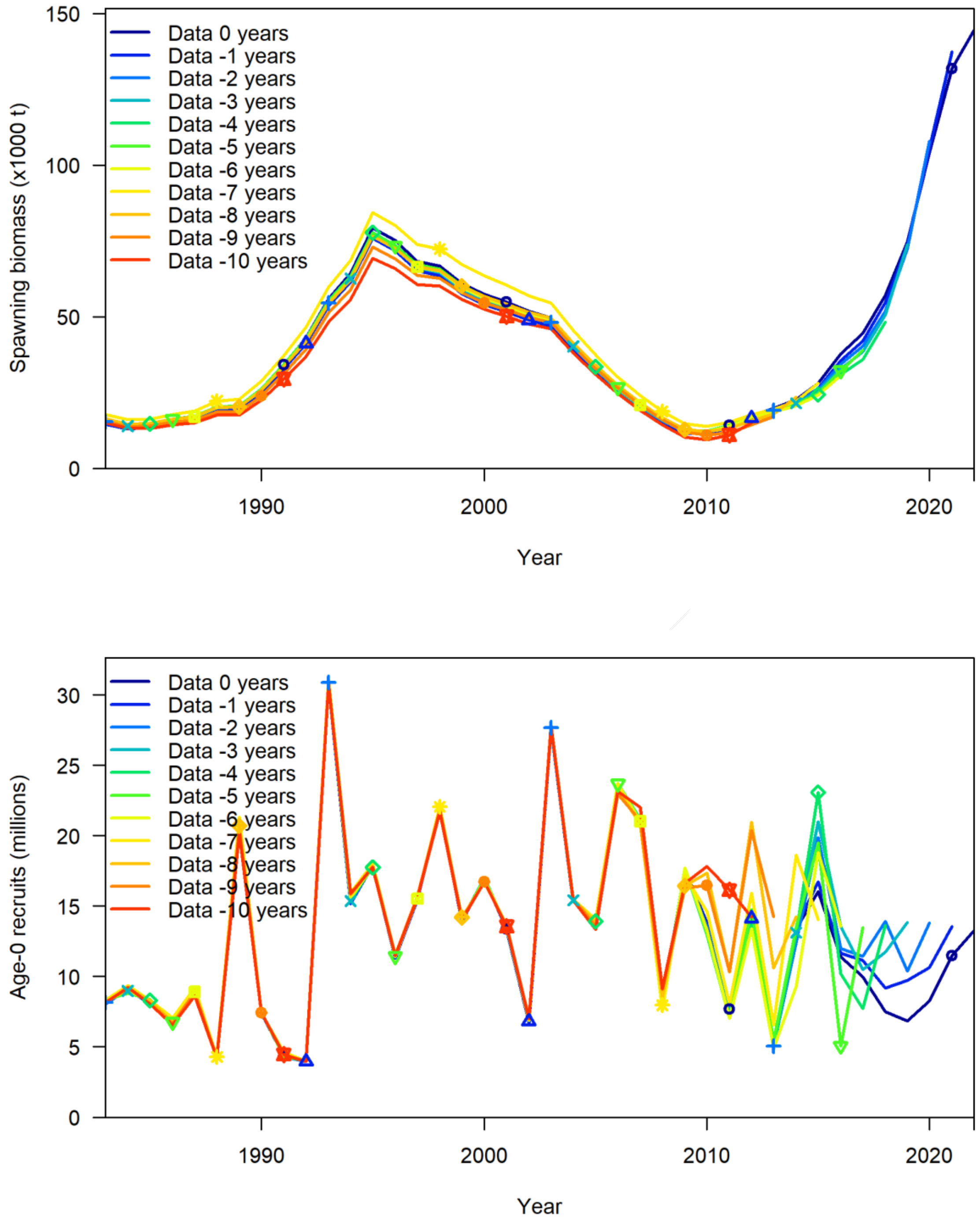


Figure 5-8. Ten-year retrospective analysis of the spawning stock biomass (upper panel) and recruitment (bottom panel) of Pacific bluefin tuna *Thunnus orientalis* from the base-case model.

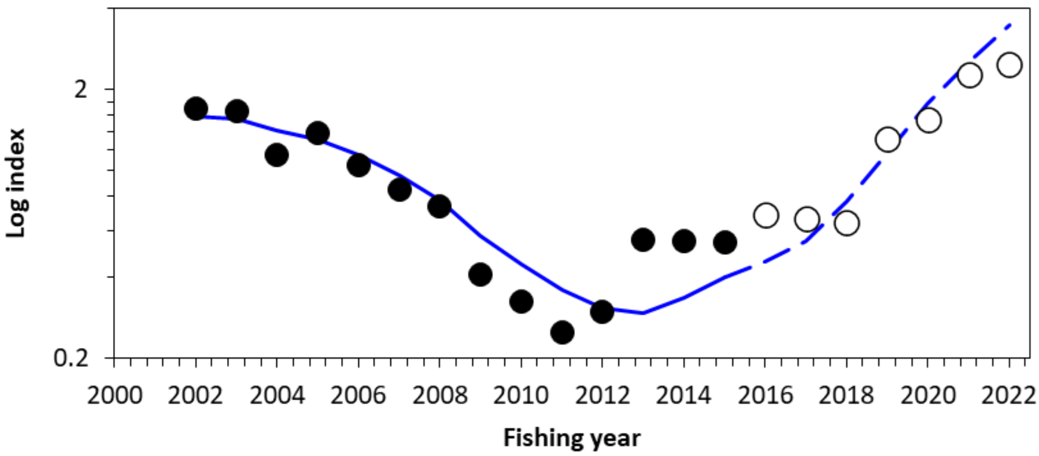


Figure 5-9. Result for hindcasting of the recent 7 years (2016-2022) based on the catch at age. The expected (blue solid line) and predicted (blue dashed lines) Taiwanese longline CPUE index from the age-structured production model, where CPUE observations were removed for the recent 7 years. The solid circles represent the observations used in the model, and open circles represent the missing values.

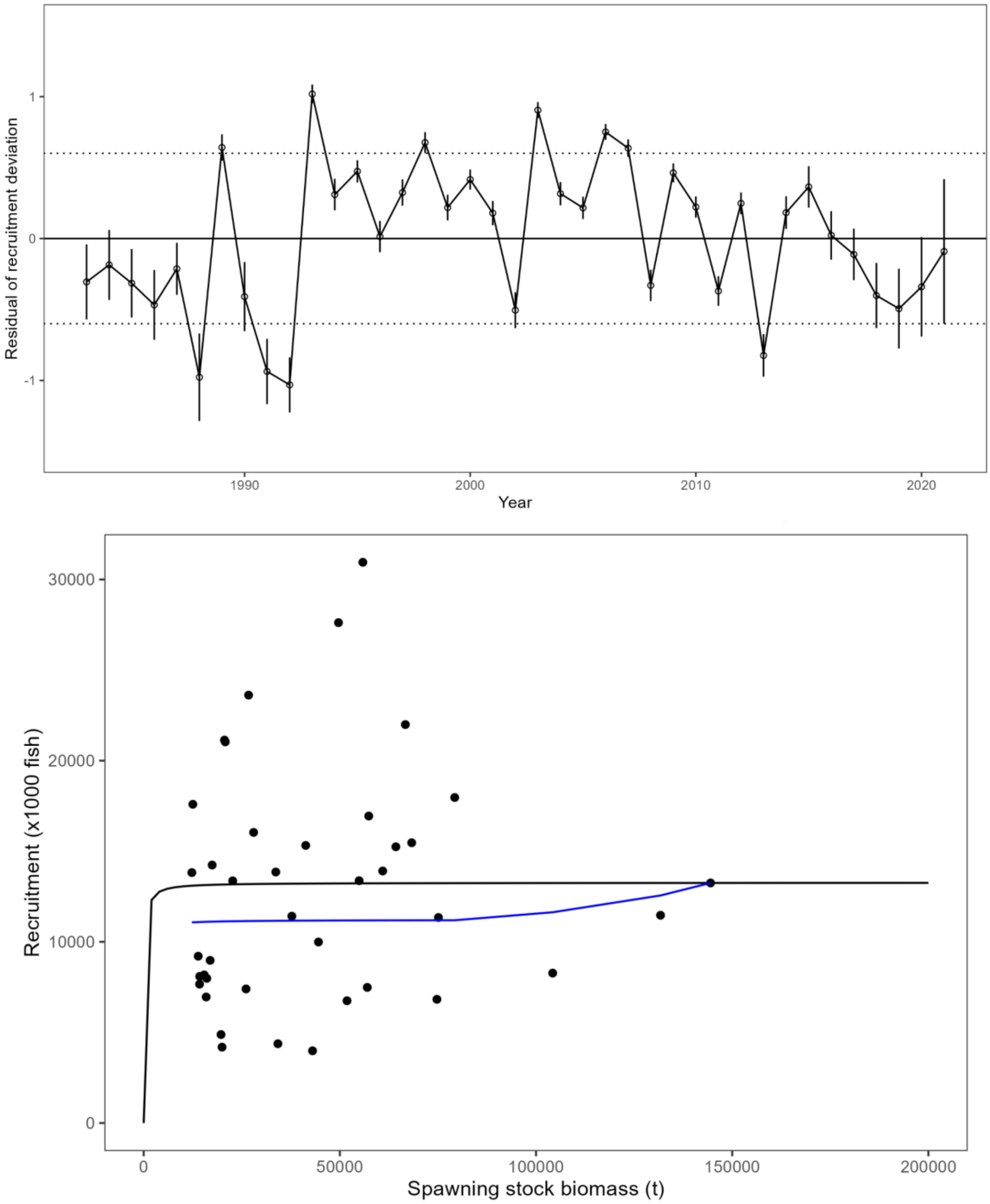


Figure 5-10. Time series of recruitment deviations in log space (upper panel) and the spawning stock-recruitment relationship (lower panel) in the base-case stock assessment model for Pacific bluefin tuna *Thunnus orientalis*. In the upper panel, vertical lines are the 95% CI and horizontal dotted lines indicate σR and -σR. In the lower panel, open circles are the paired estimates of spawning stock biomass and recruitment. The 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 the relationship, respectively.

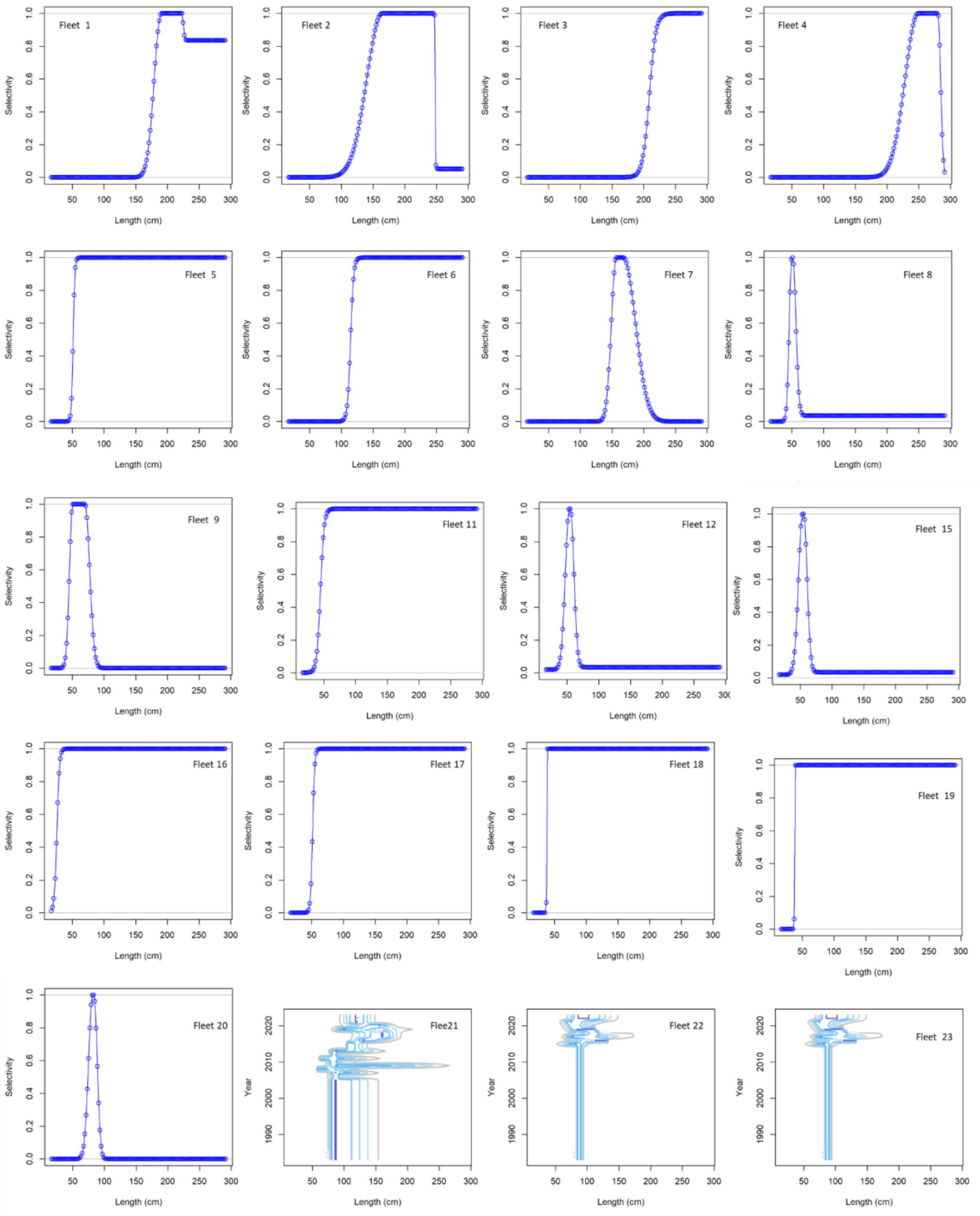


Figure 5-11. Size selectivity for Pacific bluefin tuna *Thunnus orientalis* by fishery from the base case. Fisheries with time-varying selectivity patterns are displayed in contour plots.

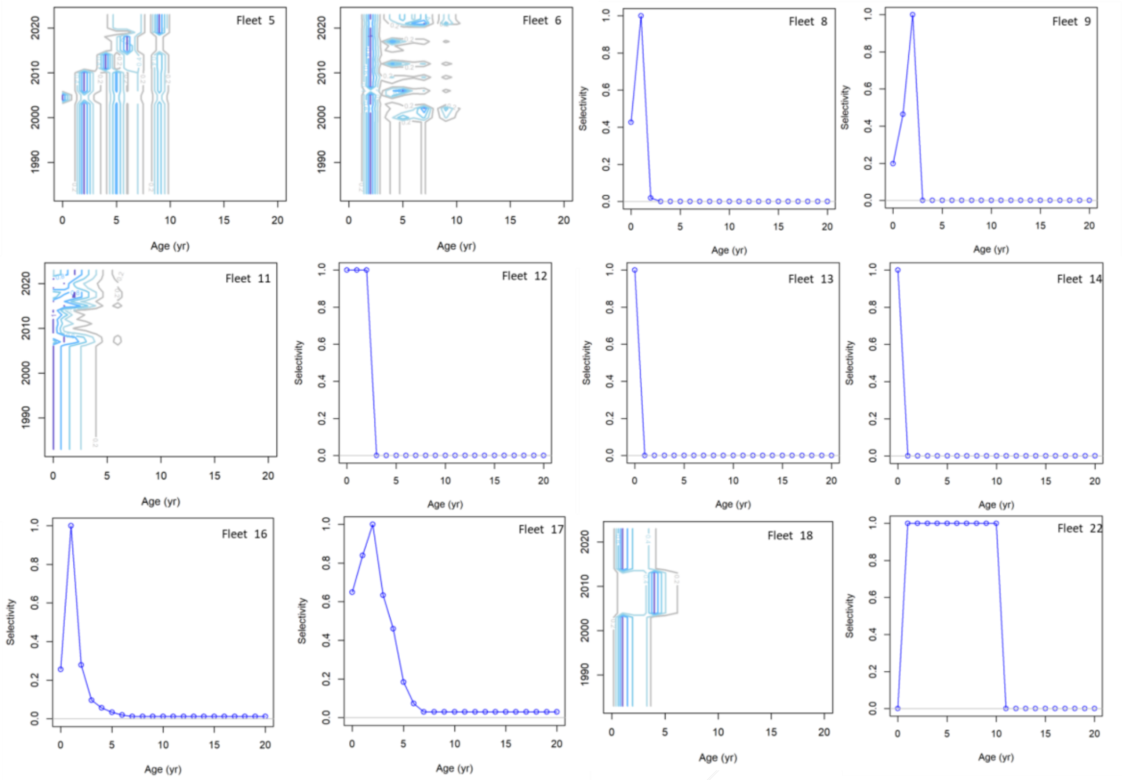


Figure 5-12. Age selectivity for Pacific bluefin tuna *Thunnus orientalis* by fishery from the base case. Fisheries with time-varying selectivity patterns are displayed in contour plots.

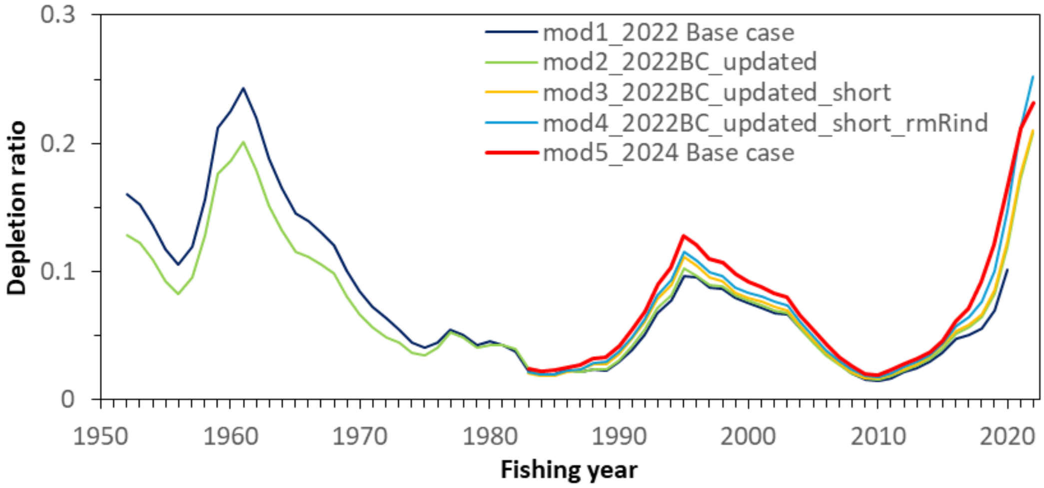


Figure 5-13. Comparison of the trajectory of relative biomass ($SSB/SSB_{F=0}$, depletion ratio) of the assessment models bridging from the 2022 base-case to the 2024 base-case (including the 2022 base-case, 2022 base-case with data-update, 2022 base-case with data-update Short (1983-), and the 2024 base-case model). The 2022 base-case with data-update and 2022 base-case with data-update Short (1983-) almost overlap towards the end. SSB is spawning stock biomass and $SSB_{F=0}$ is the expected SSB under average recruitment conditions without fishing.

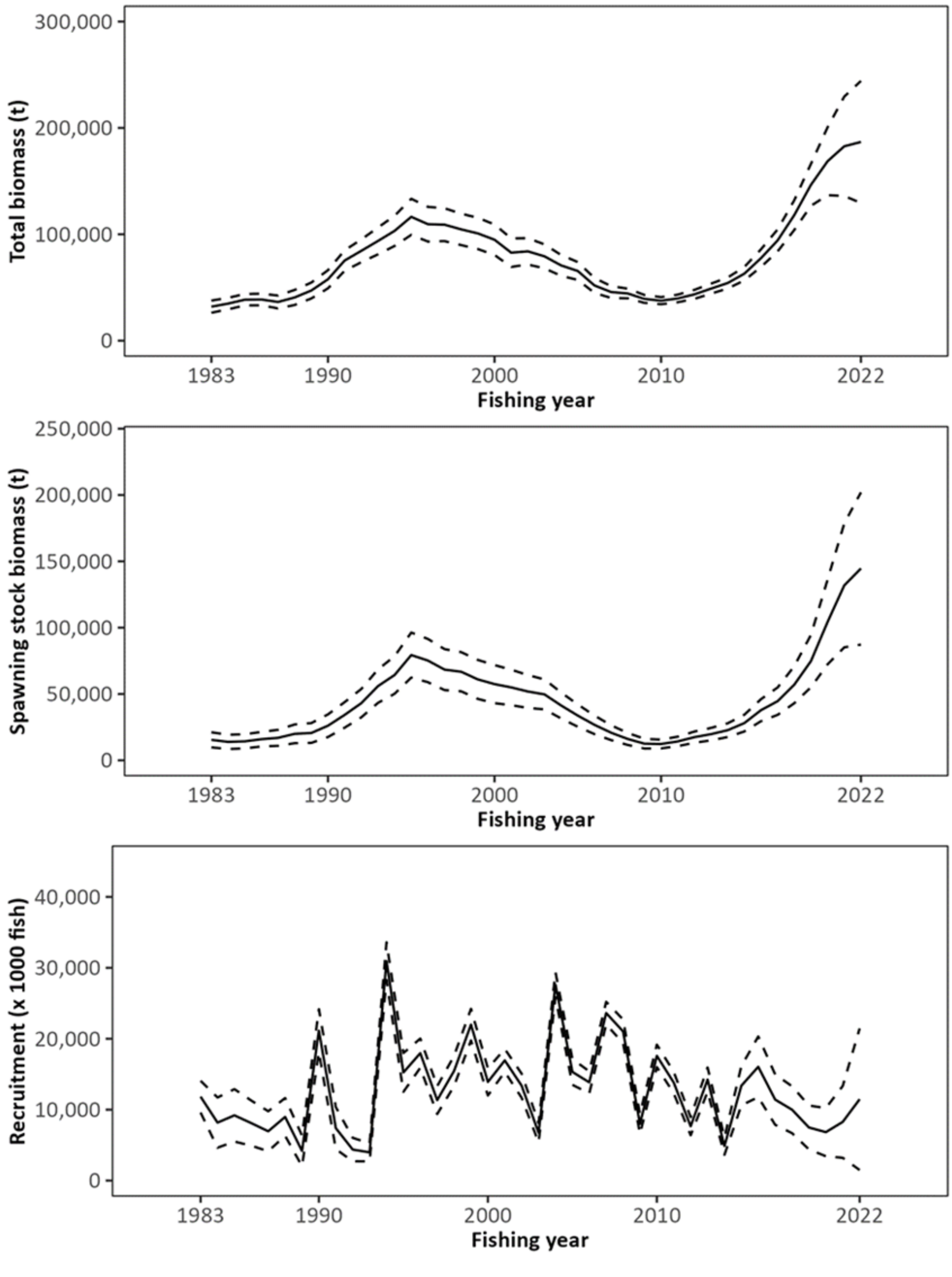


Figure 5-14. Trajectory of total stock biomass (top), spawning stock biomass (middle), and recruitment (bottom) of Pacific bluefin tuna *Thunnus orientalis* (1983-2022) estimated from the base-case model. The solid line is the point estimate, and dashed lines delineate the 90% confidence interval. Note that the recruitment estimates for 2019-2022 are uncertain. The method used to estimate the confidence interval was changed from bootstrapping in the previous assessments to the normal approximation of the Hessian matrix.

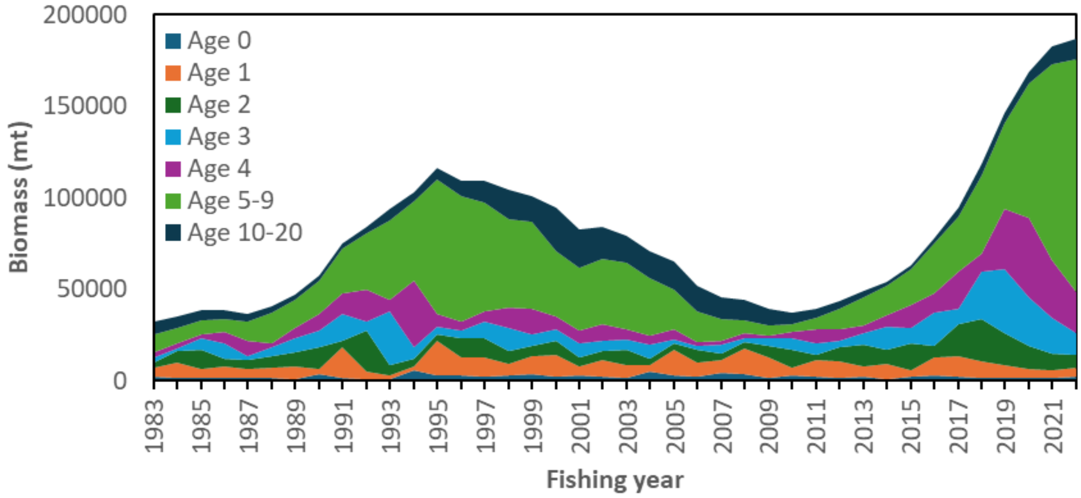


Figure 5-15. Total biomass (tons) by age of Pacific bluefin tuna *Thunnus orientalis* estimated from the base-case model (1983-2022). Note that the recruitment estimates for 2019-2022 are more uncertain than for other years.

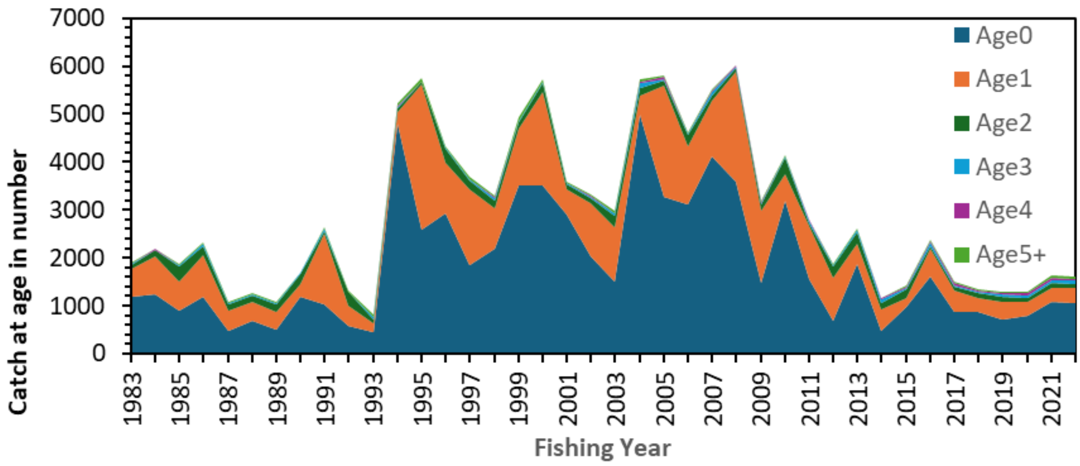


Figure 5-16. Estimated annual catch-at-age (number of fish) of Pacific bluefin tuna *Thunnus orientalis* by fishing year estimated by the base-case model (1983-2022).

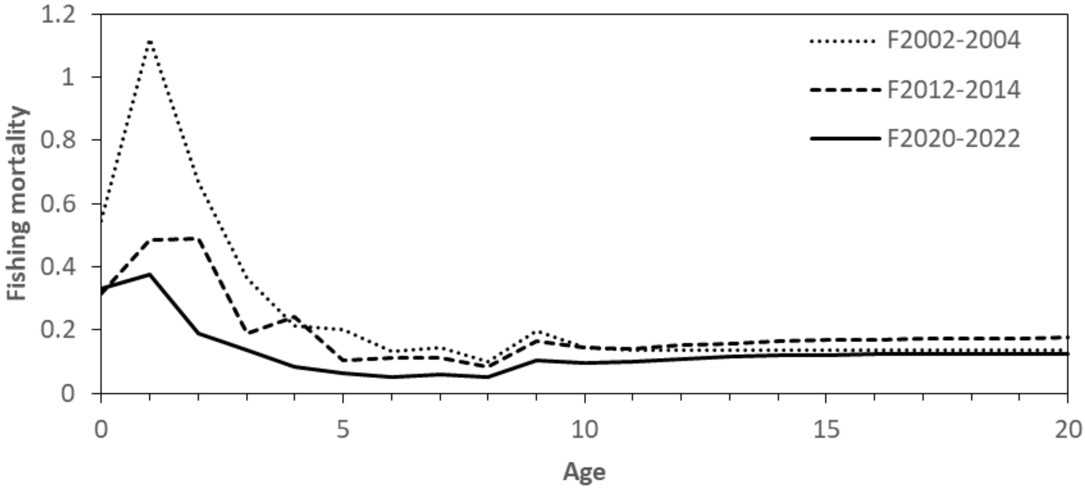


Figure 5-17. Geometric means of annual age-specific fishing mortalities (F) of Pacific bluefin tuna *Thunnus orientalis* for the years 2002-2004 (dotted line), 2012-2014 (dashed line), and 2020-2022 (solid line).

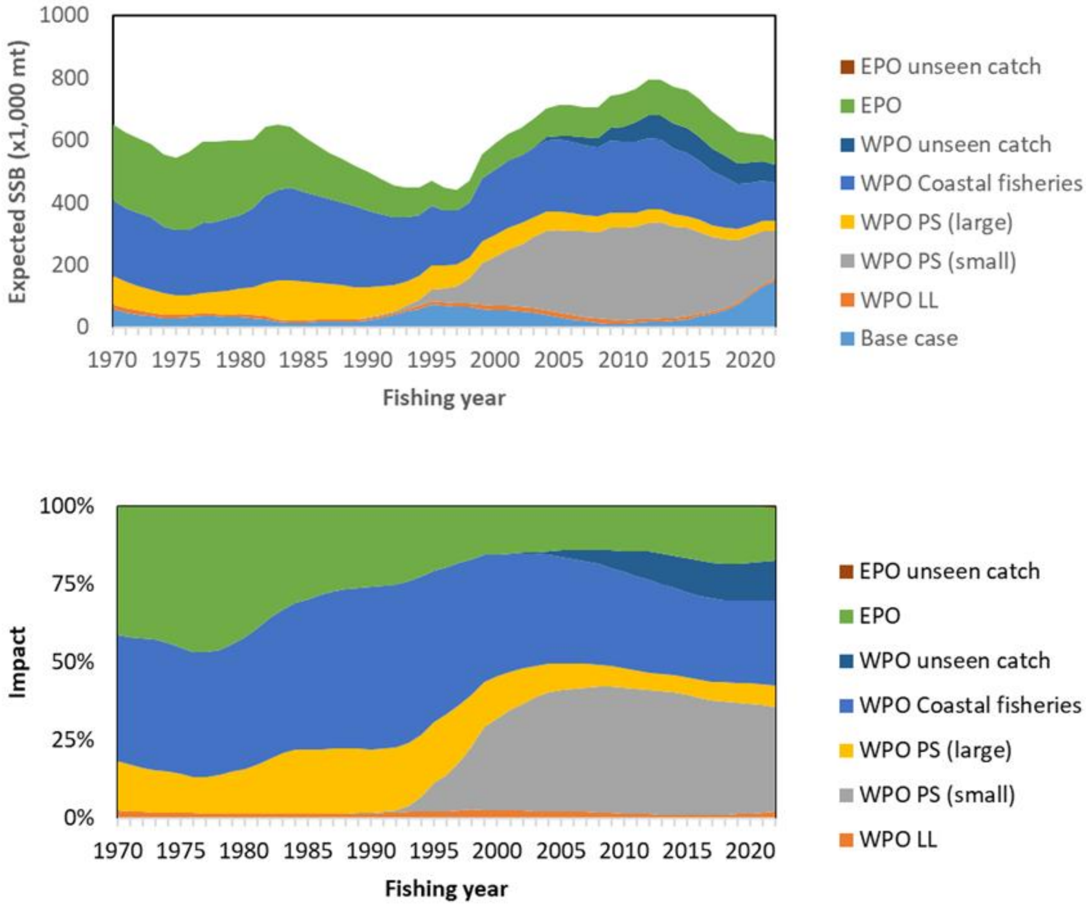


Figure 5-18. The trajectory of the spawning stock biomass of a simulated population of Pacific bluefin tuna *Thunnus orientalis* when zero fishing mortality is assumed, estimated by the base-case long-term model. (top: absolute SSB, bottom: relative SSB). In 2022, the estimated cumulative impact proportion between WPO and EPO fisheries is about 83% and 17%, respectively. Fisheries group definition: WPO longline fisheries: F1-4. WPO purse seine fisheries for large fish: F5-7. WPO purse seine fisheries for small fish: F8-11. WPO coastal fisheries: F12-19. EPO fisheries: F20-23. WPO unaccounted fisheries: F24, 25. EPO unaccounted fisheries: F26. For exact fleet definitions, please see the 2024 PBF stock assessment report. Although larger PBF have been caught by the Korean offshore large-scale purse seine in recent years, this fleet is included in “WPO PS (small)” because of their historical selectivity.

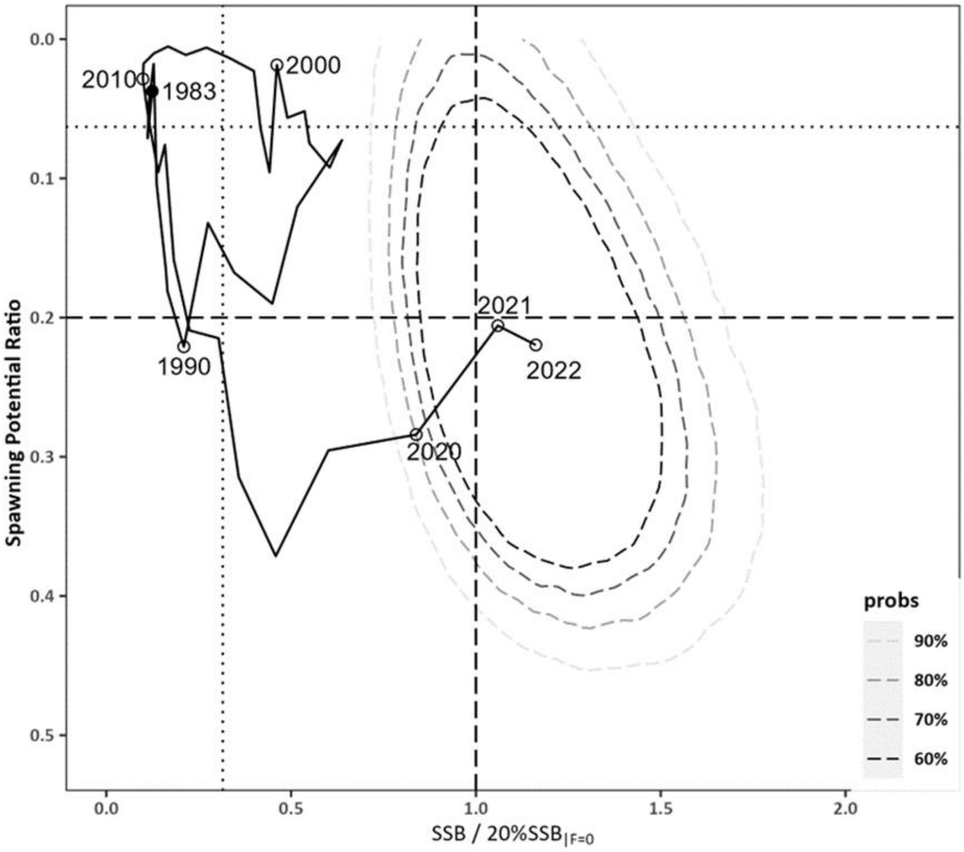
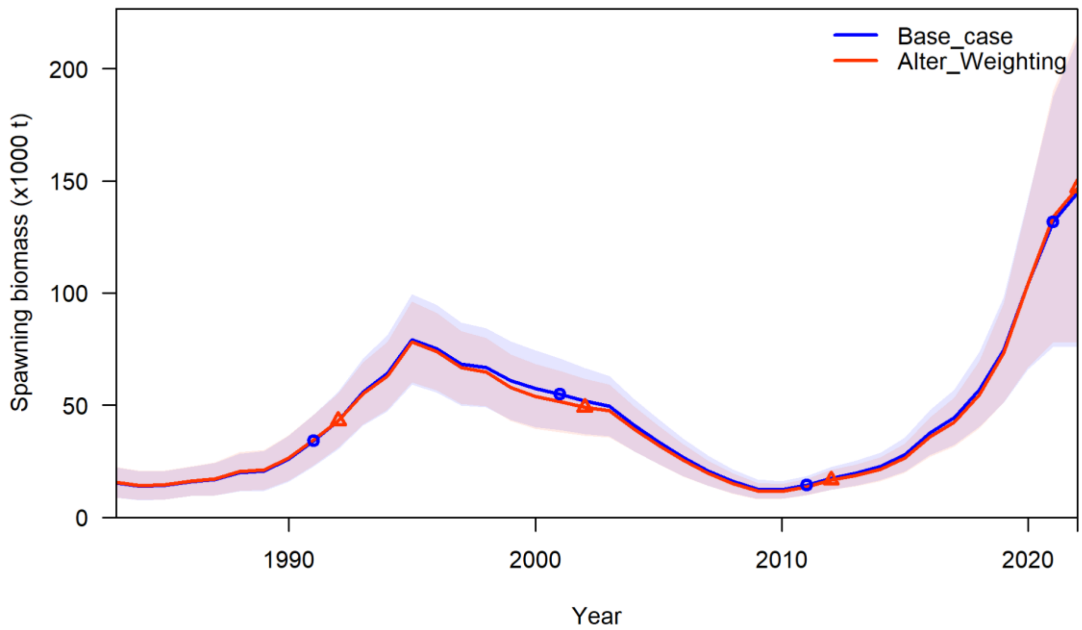


Figure 5-19. Kobe plot for Pacific bluefin tuna *Thunnus orientalis* estimated from the base-case model from 1983 to 2022. The X-axis shows the annual SSB relative to $20\%SSB_{F=0}$ and the Y-axis shows the spawning potential ratio (SPR) as a measure of fishing mortality. Vertical and horizontal dashed lines show $20\%SSB_{F=0}$ (the second biomass rebuilding target) and the corresponding fishing mortality that produces SPR, respectively. Vertical and horizontal dotted lines show the initial biomass rebuilding target ($SSB_{MED} = 6.3\%SSB_{F=0}$) and the corresponding fishing mortality that produces SPR, respectively. SSB_{MED} is calculated as the median of estimated SSB over 1952-2014 from the 2022 assessment. The apparent increase of F in the terminal period is a result of low recruitment in this period. As noted, the recruitment estimates in recent years are more uncertain and this result needs to be interpreted with caution. Contour plots represent 60% to 90% of two probability density distributions in SSB and SPR for 2022. The method used to estimate the confidence interval was changed from bootstrapping in the previous assessments to resampling from the multi-variate log-normal distribution. The probability distribution for the area where SPR is below zero is not shown as such SPR values are not biologically possible.



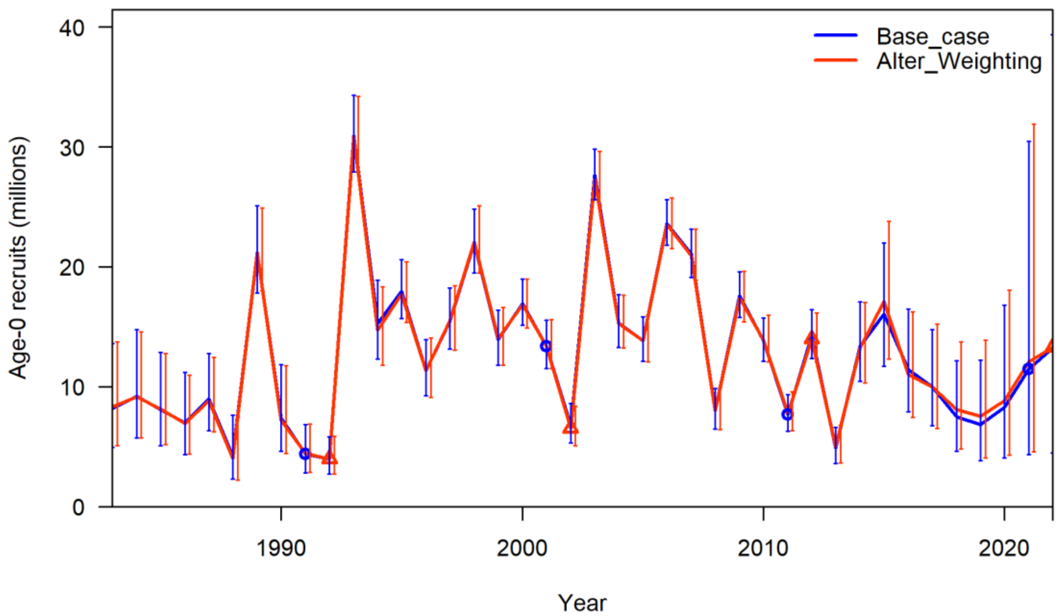


Figure 5-20. Estimated spawning stock biomass (top) and recruitment (bottom) of Pacific bluefin tuna *Thunnus orientalis* for the base-case model and sensitivity analyses using alternative weighting which down-weighted the size composition data of Fleets 2, 5, and 21.

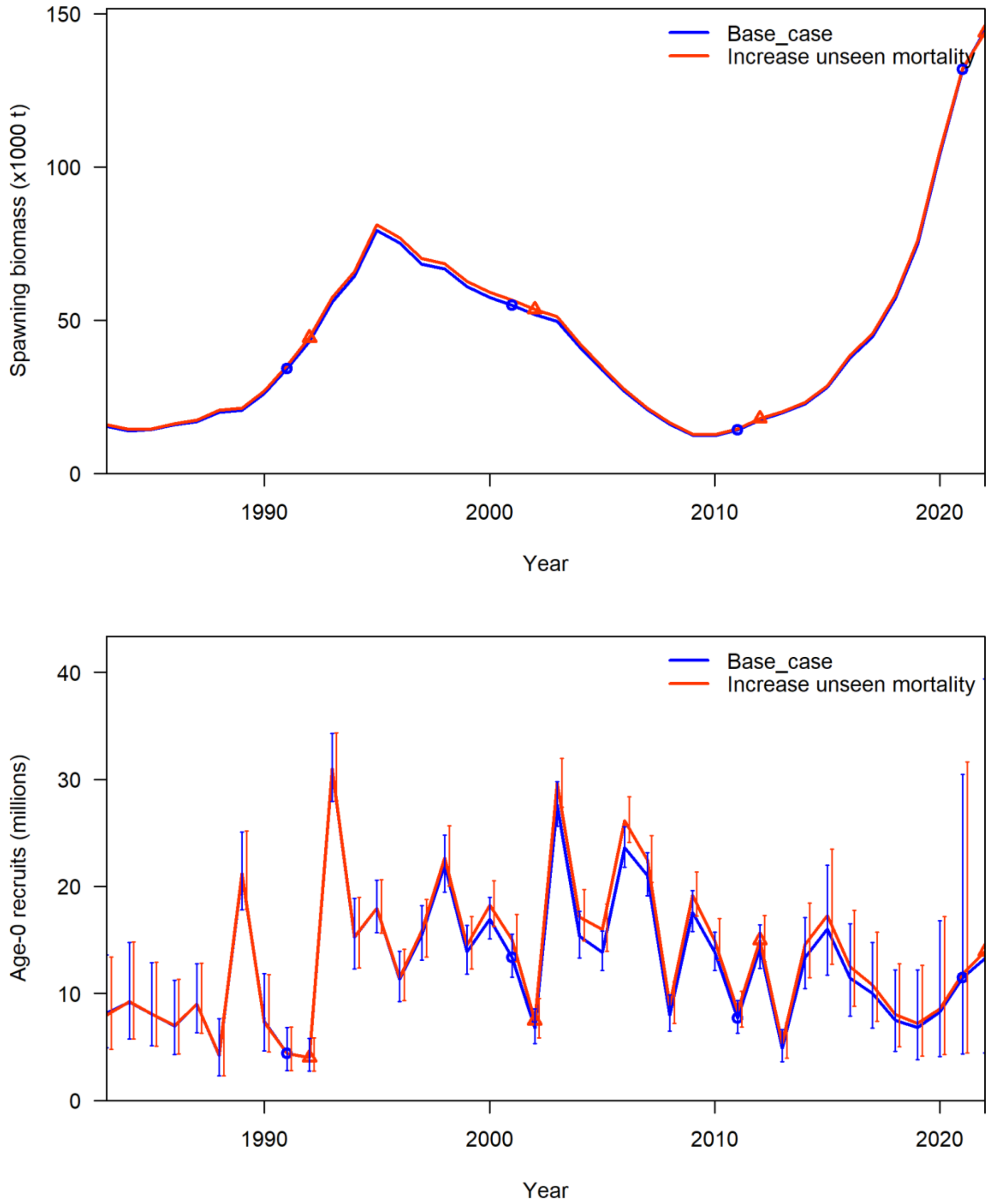
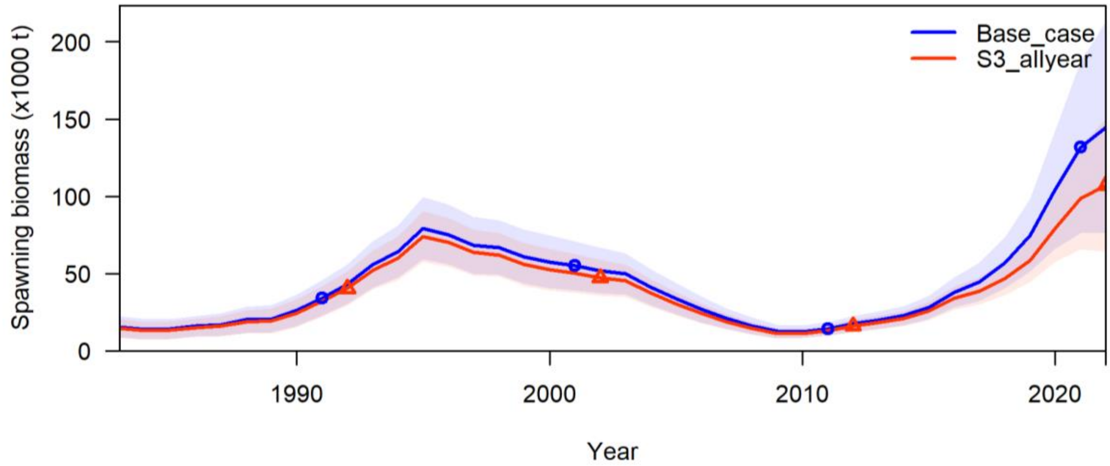
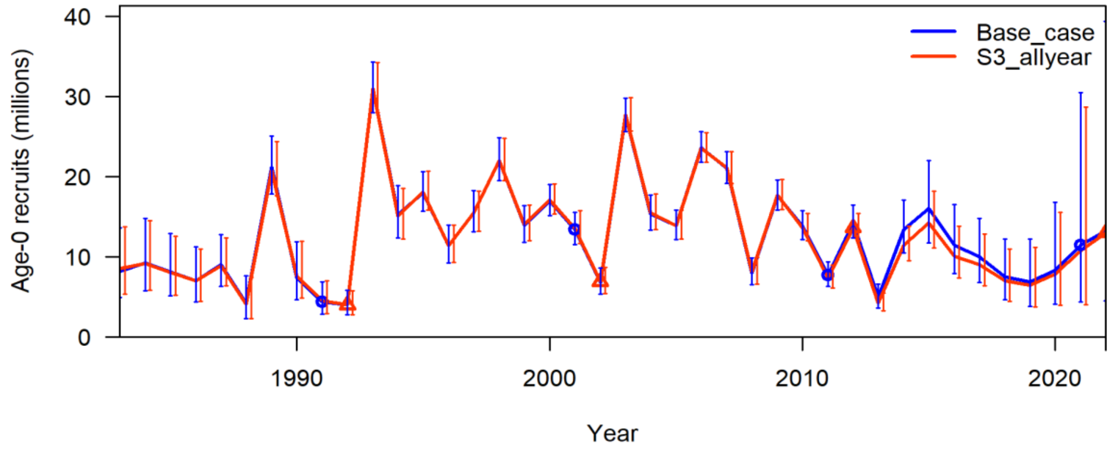


Figure 5-21. Estimated spawning stock biomass (top) and recruitment (bottom) of Pacific bluefin tuna *Thunnus orientalis* for the base-case model and sensitivity analysis assuming unseen catch was double the assumed value.





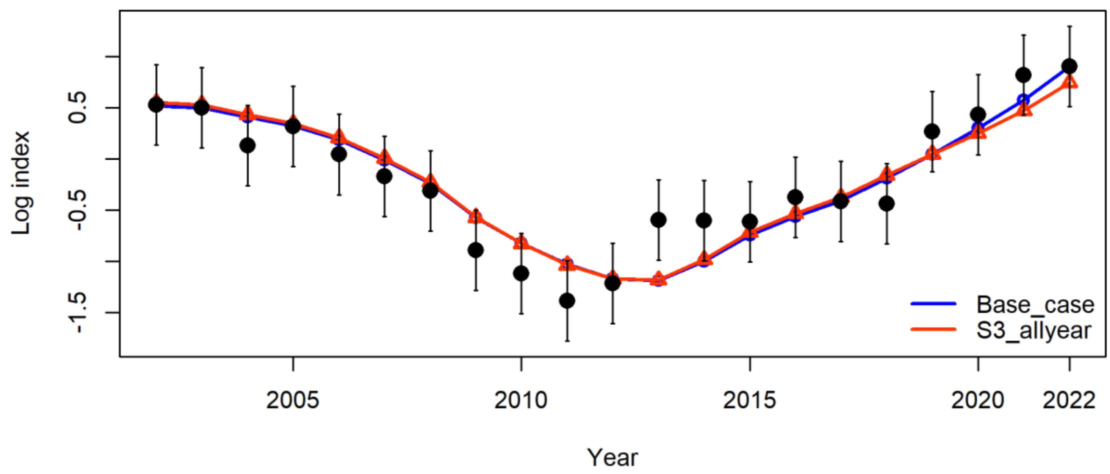


Figure 5-22. Estimated spawning stock biomass (top), recruitment (middle), and predicted and observed Taiwanese longline index (S5) (bottom) for the base-case model of Pacific bluefin tuna *Thunnus orientalis* and a sensitivity analysis including the troll index (S3) for the whole period.

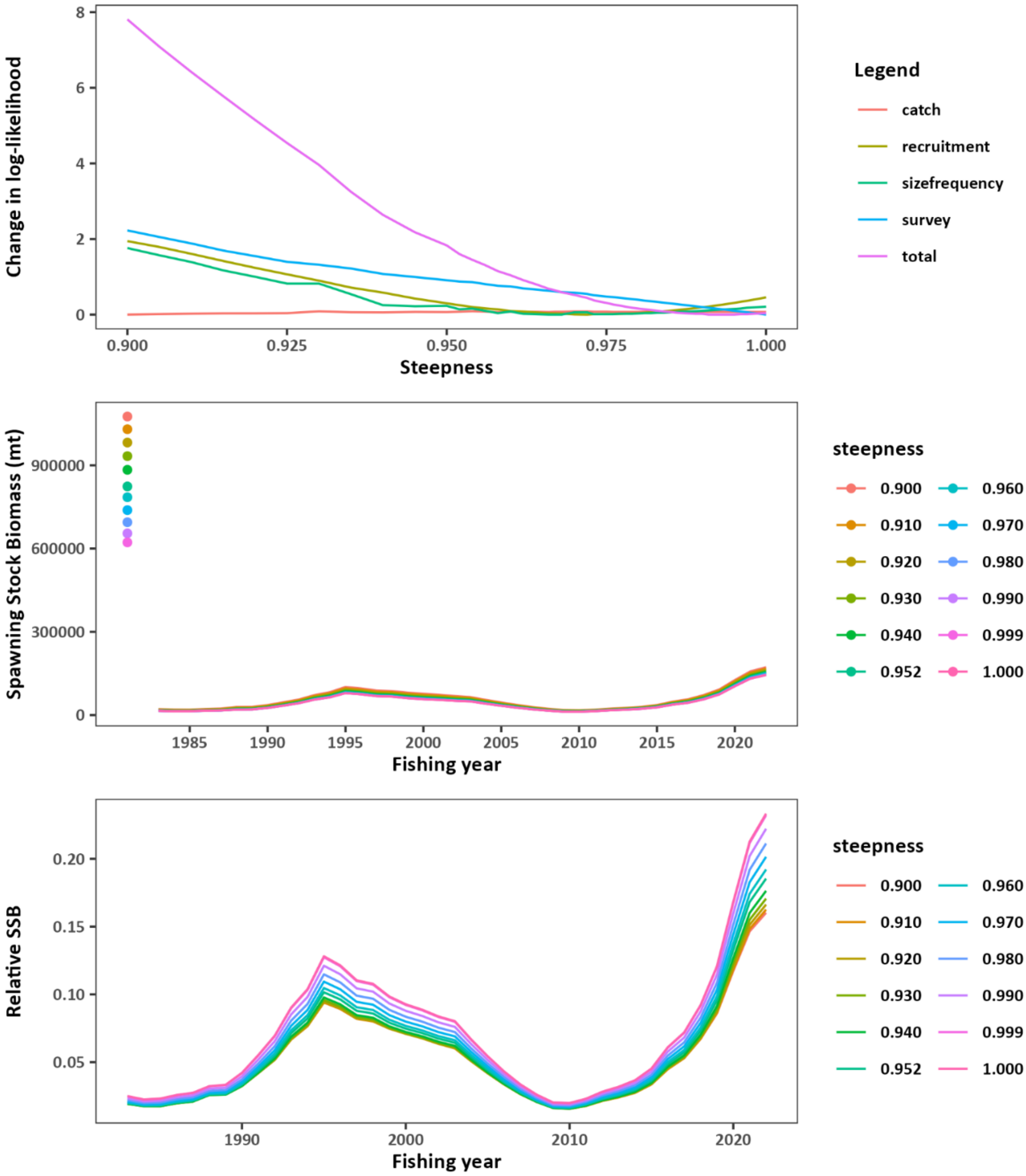
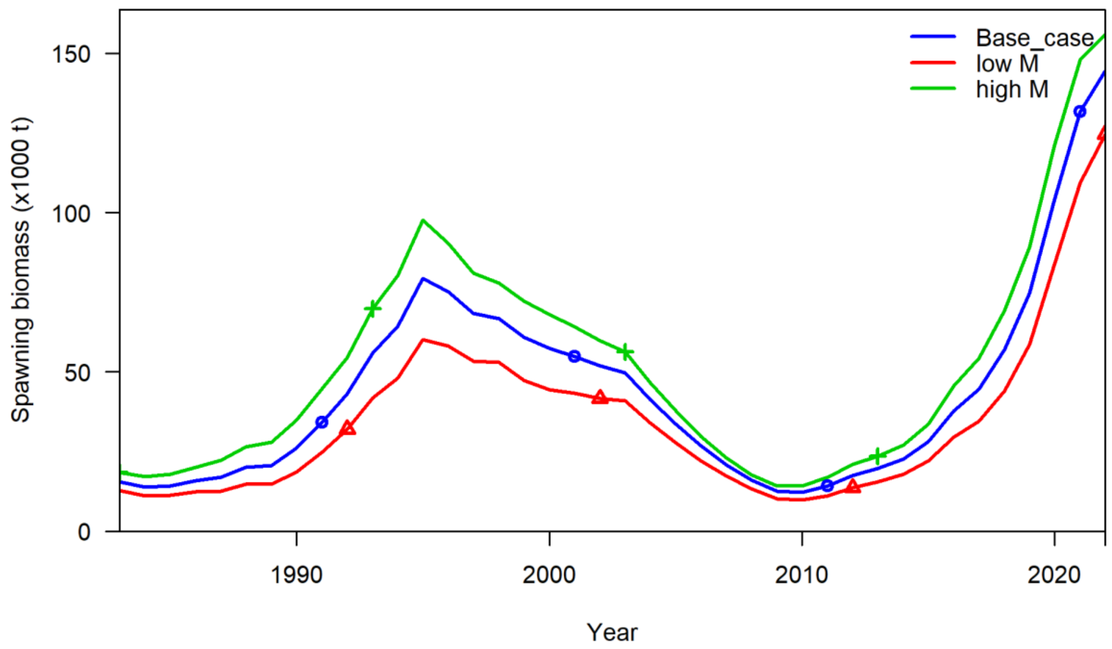


Figure 5-23. (top) Likelihood profile, (middle) spawning stock biomass, and (bottom) relative SSB of Pacific bluefin tuna *Thunnus orientalis* for the base-case model and sensitivity analyses with lower steepness values.



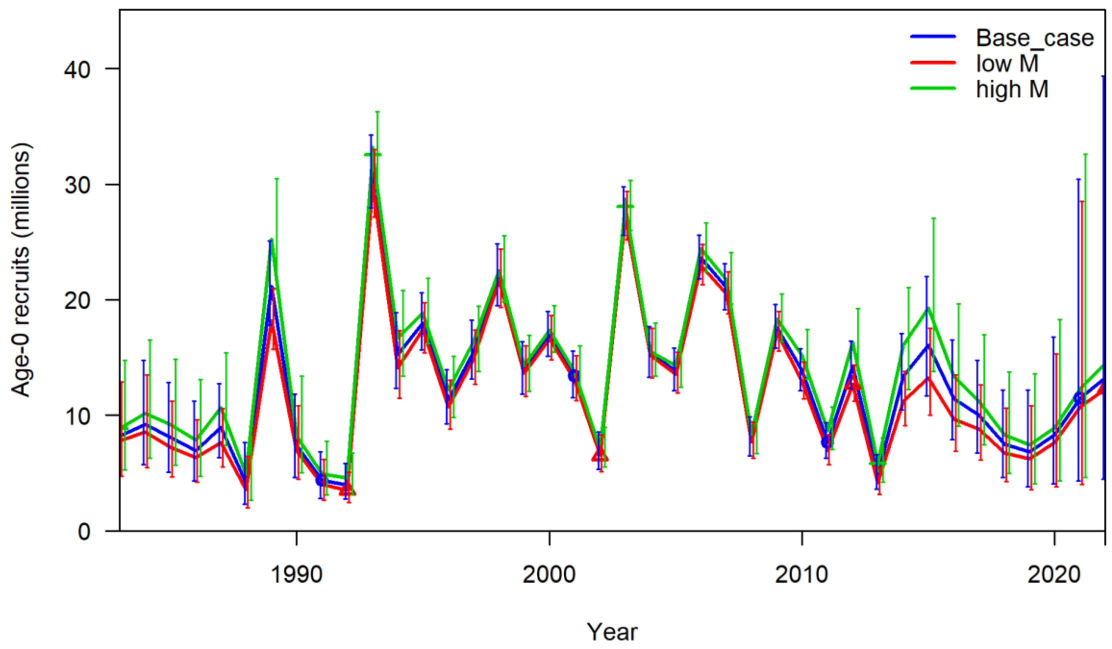
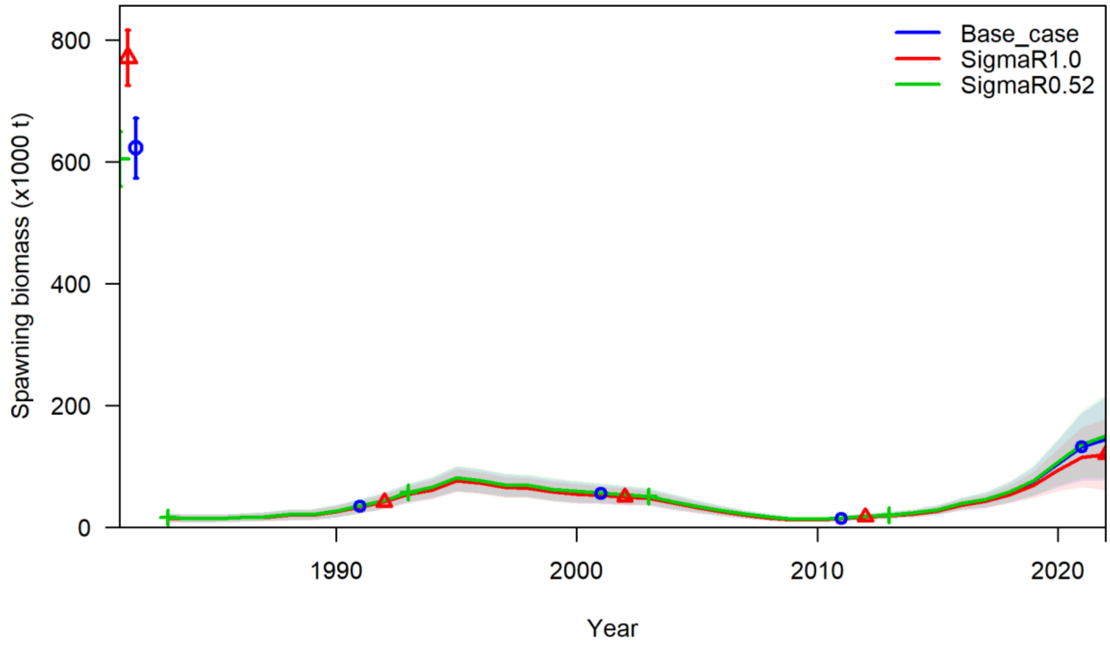


Figure 5-24. Estimated spawning stock biomass (top) and recruitment (bottom) of Pacific bluefin tuna *Thunnus orientalis* for the base-case model and sensitivity analysis with high and low natural mortality for age 2 and older.



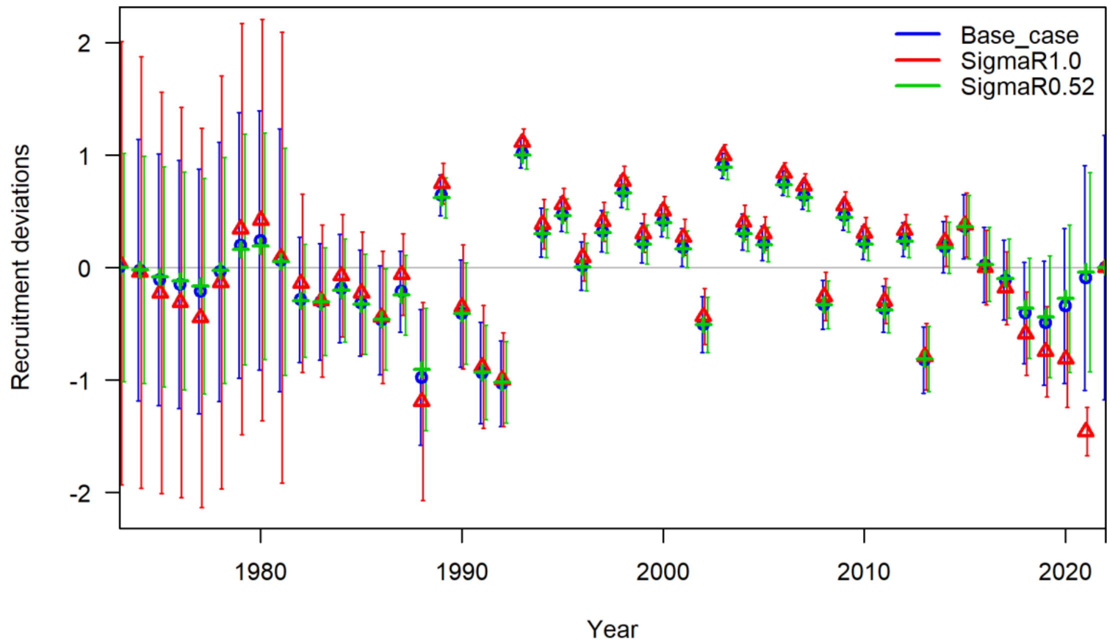


Figure 5-25. Estimated spawning stock biomass (top) and recruitment deviations (bottom) of Pacific bluefin tuna *Thunnus orientalis* for the base-case model and sensitivity analyses with low and high sigmaR.

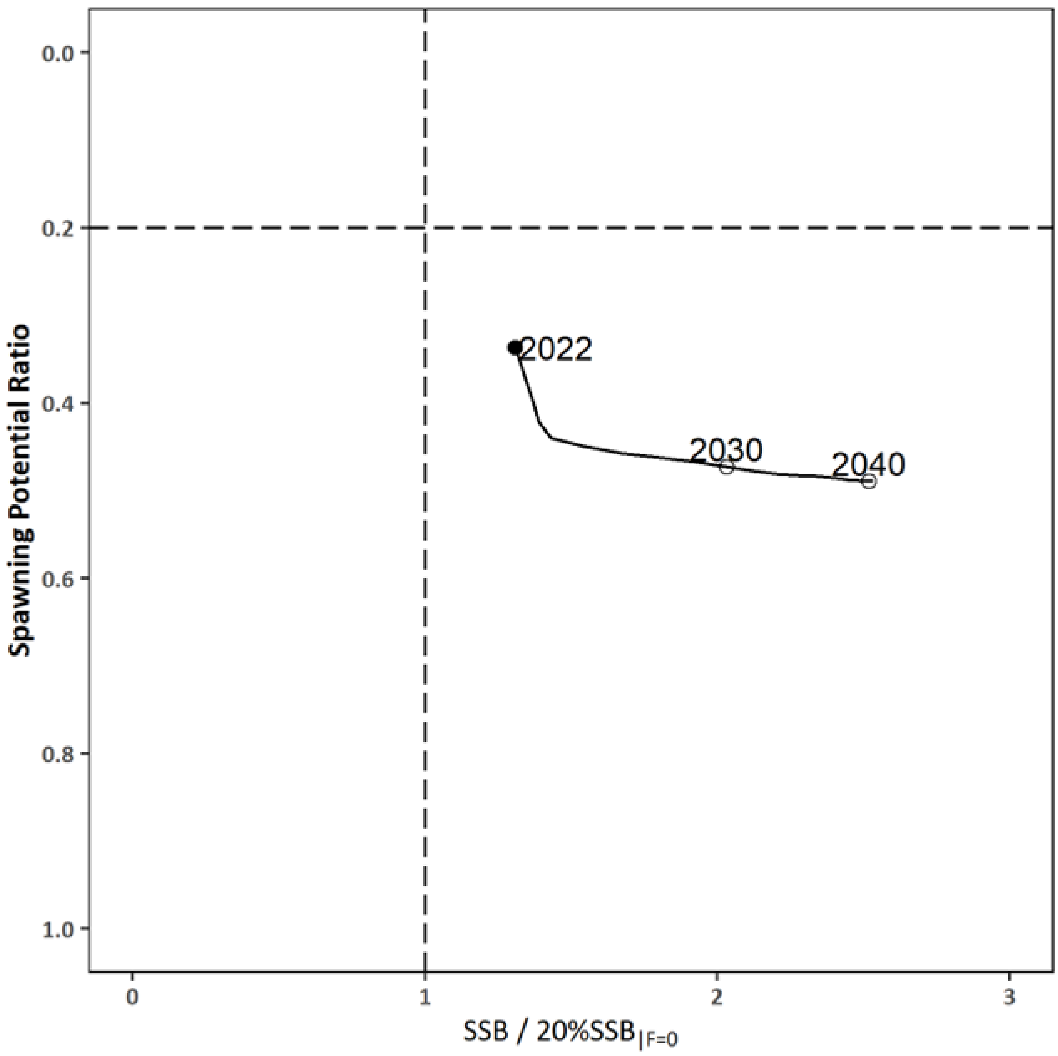


Figure 6-1. “Future Kobe Plot” of projection results for Pacific bluefin tuna *Thunnus orientalis* from Scenario 1 in Table 4-2. Vertical and horizontal dashed lines show 20%SSB$_{F=0}$ (which corresponds to the second biomass rebuilding target) and the corresponding fishing mortality that produces SPR, respectively.

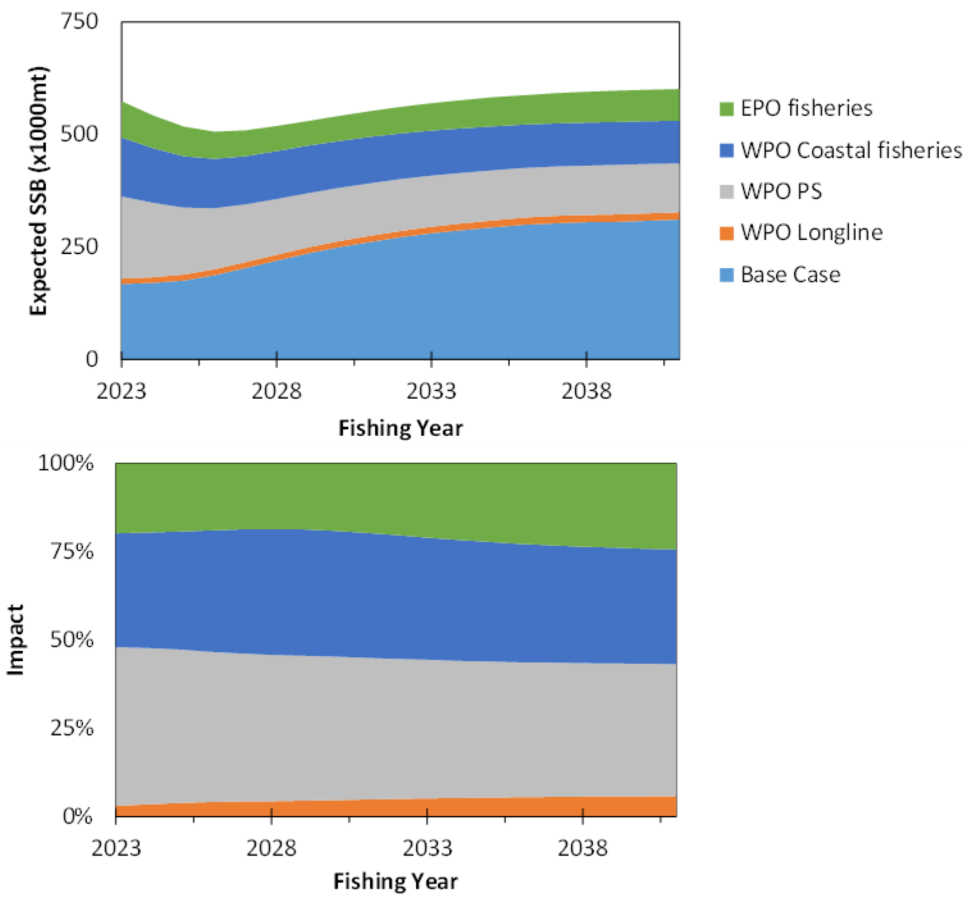


Figure 6-2. “Future impact plot” from projection results for Pacific bluefin tuna *Thunnus orientalis* from Scenario 1 in Table 4-2. The top figure shows absolute biomass and the bottom figure shows relative impacts. The impact is calculated based on the expected increase of SSB in the absence of the respective group of fisheries.

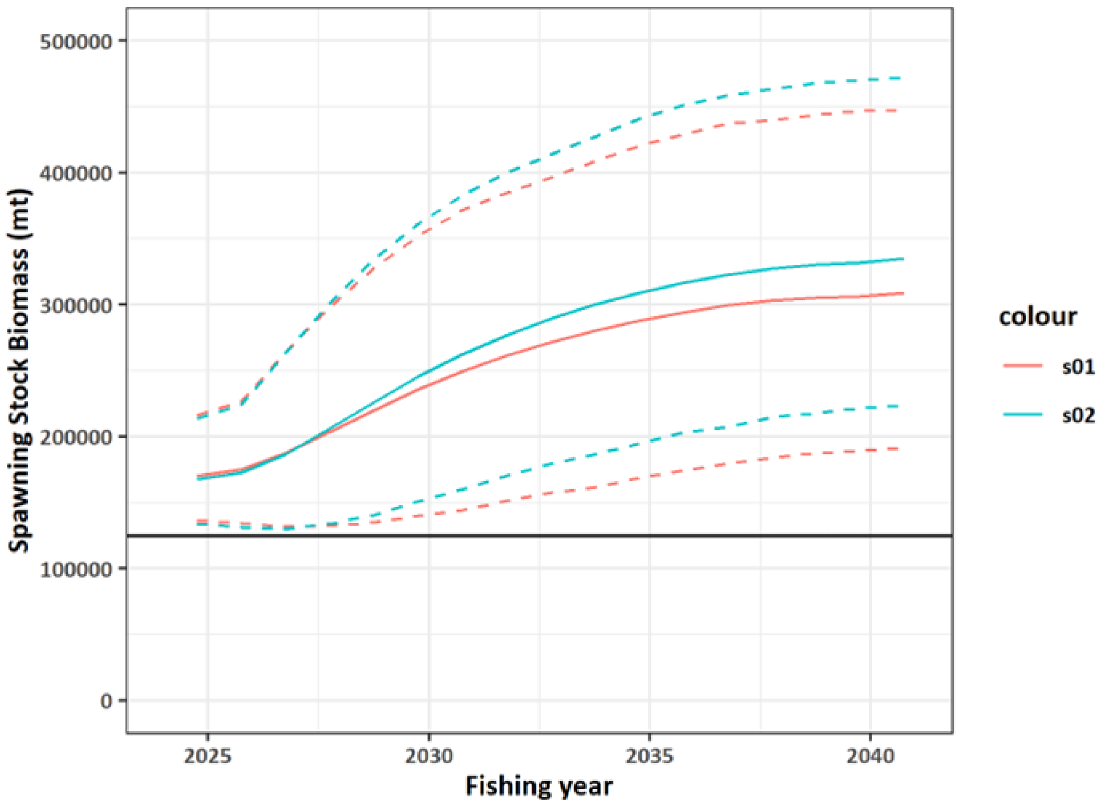


Figure 6-3. Comparisons of various projection results for Pacific bluefin tuna *Thunnus orientalis*. Median of scenarios 1 and 2 (solid lines) and their 90% confidence intervals (dotted lines). The horizontal line represents the second rebuilding target.

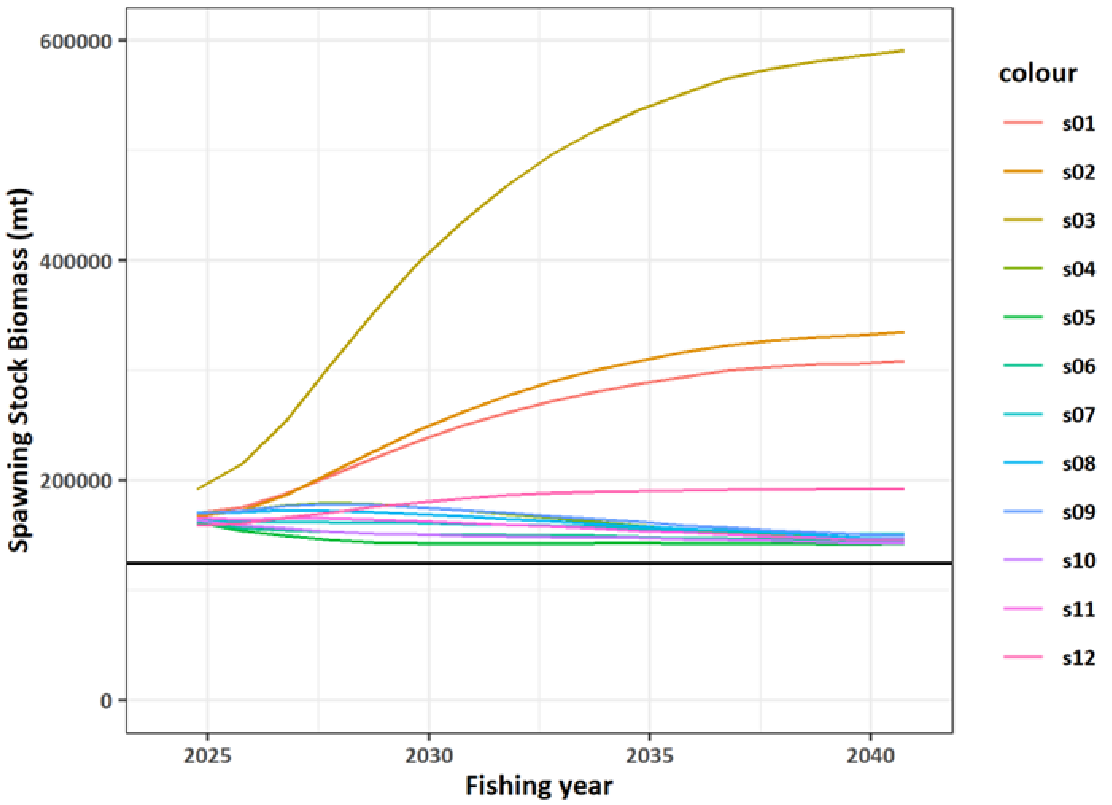


Figure 6-4. Comparisons of various projection results for Pacific bluefin tuna *Thunnus orientalis*. Median of all harvest scenarios examined from Table 4-2. The horizontal line represents the second rebuilding target.

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.

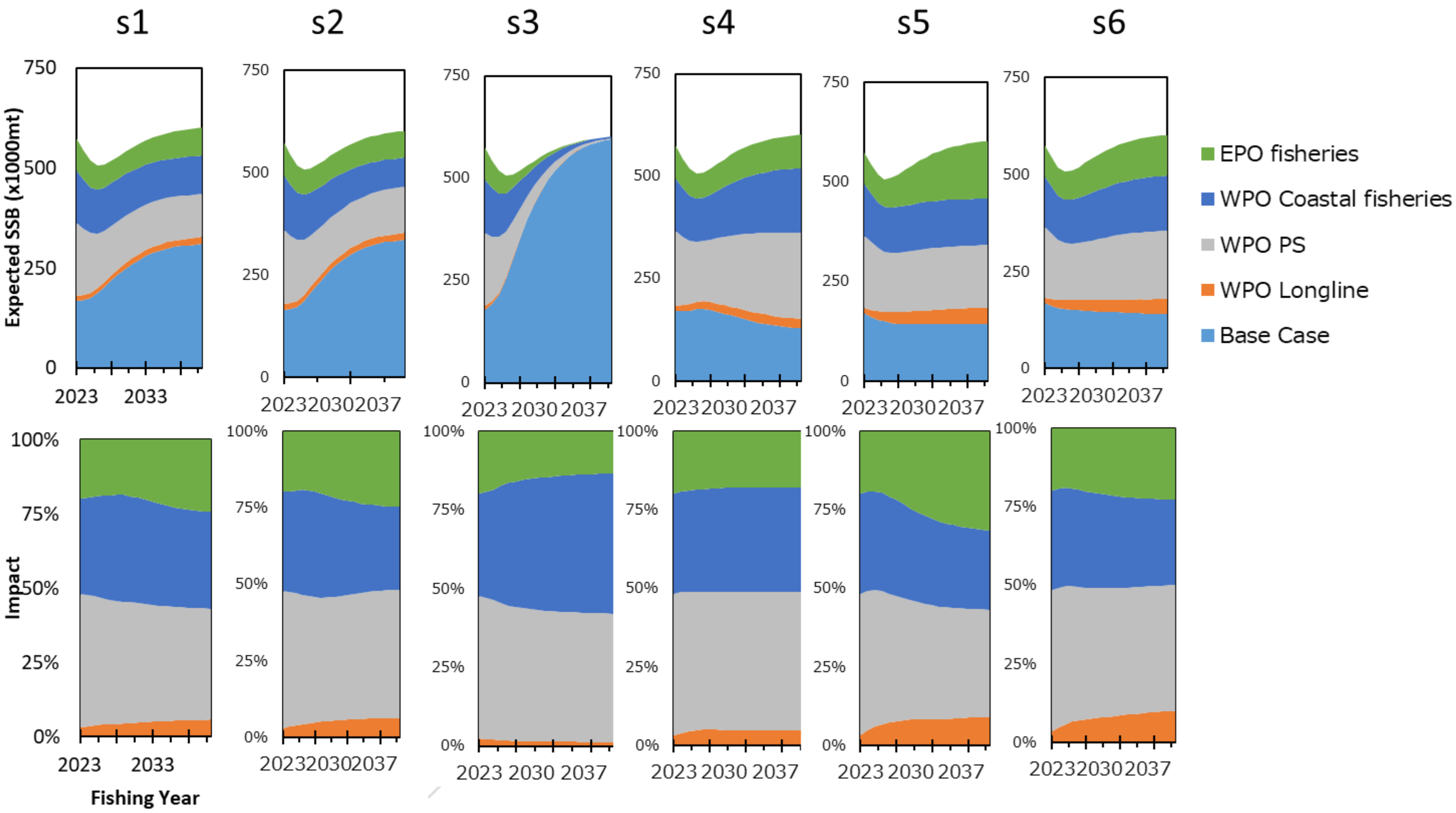


Figure A1-1. Result of impacts by fleets estimated from future projections.

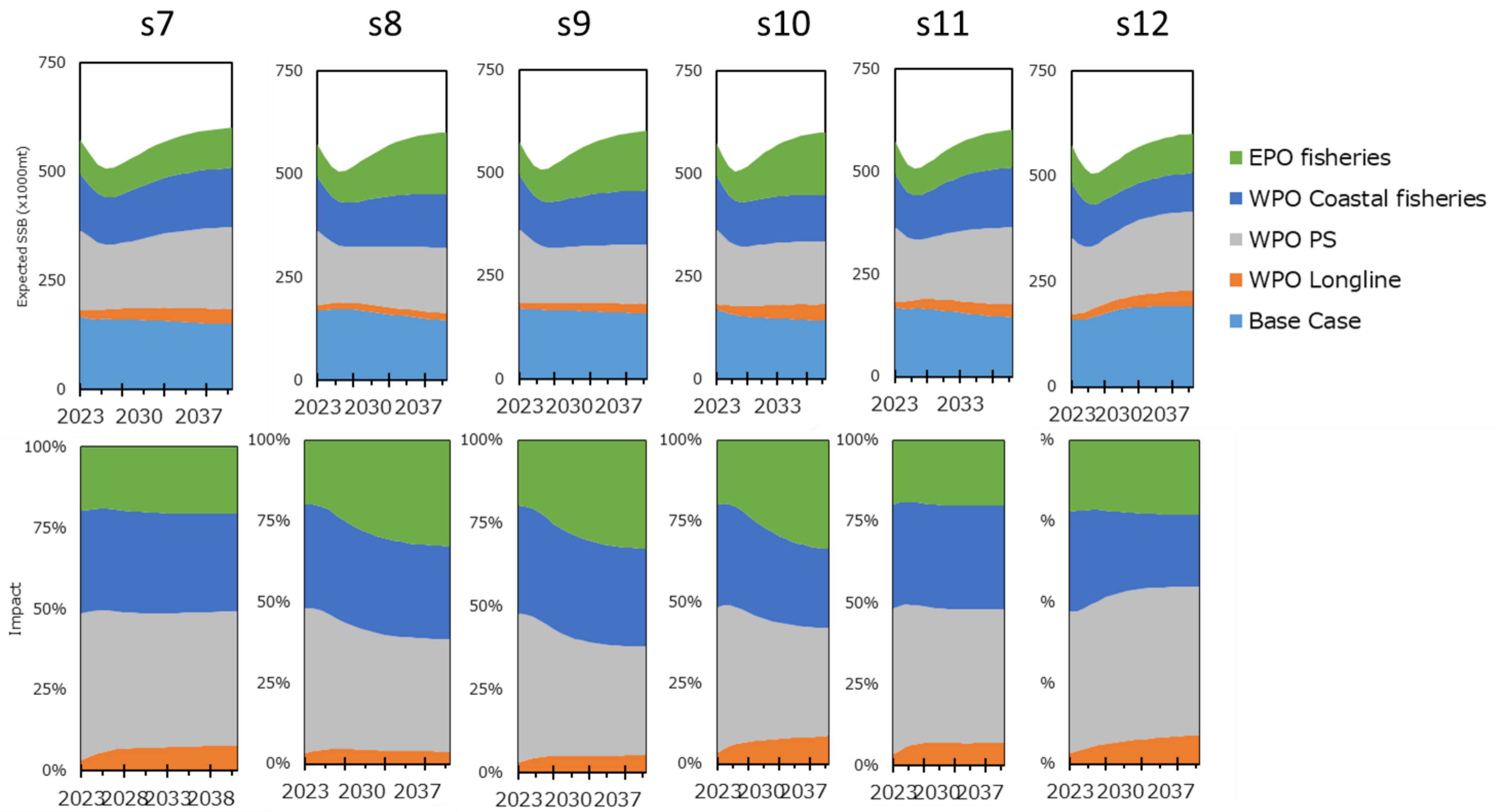


Figure A1-1. Result of impacts by fleets estimated from future projections.

APPENDIX 2

Additional projections conducted by PBFWG in response to the request from the IATTC-WCPFC NC Joint Working Group on PBF Management

The 2024 benchmark stock assessment for Pacific bluefin tuna *Thunnus orientalis* (PBF) was conducted by the ISC PBFWG in March-April 2024. The PBFWG also conducted the future projection to respond to the request from the IATTC-WCPFC NC Joint Working Group on PBF management (JWG) (IATTC-NC JWG08-2023-00 -Annex E) in 2023. All works done by the PBFWG were summarized as a draft stock assessment report and sent to the IATTC Scientific Advisory Committee and the ISC plenary for their review.

In the meantime, the JWG requested several additional harvesting scenarios for the projection to be analyzed by the PBFWG during the 24th ISC plenary meeting (). The ISC instructed the PBFWG to run those requested scenarios. Following projection results prepared by the PBFWG were reviewed and approved by ISC24, which are presented in a similar manner with the original projections.

Table A2-1 shows the harvesting scenarios additionally requested. Table A2-2 and A2-3 show the performance metrics in terms of the SSB level in future and the expected catch in short-term and middle term, respectively. To avoid any confusion, the scenario number was made to be consecutive from the scenarios projected already in the main body of the stock assessment report. For all the additionally examined scenarios, the future SSB were projected to increase throughout the projection period (Fig. A2-1).

Because the 2024 stock assessment report was already finalized well before the ISC plenary meeting, those additionally requested projection was attached to the 2024 assessment report as an appendix.

Table A2-1. Harvest scenarios used in the projection for Pacific bluefin tuna (*Thunnus orientalis*).

Harvesting scenarios											
Reference No	Scenarios				Catch limit in the projection				Specified fishery impact at 2034		Note
	WCPO		EPO		WCPO		EPO				
	Small	Large	Small	Large	Small	Large	Small	Large	WCPO	EPO	
13	Status quo	Status quo +50%	Status quo +50%		4,475	11,664	5,993		-	-	Additional request scenario 1 from JWG.
14	Status quo +5%	Status quo +50%	Status quo +50%		4,711	11,664	5,993		-	-	Additional request scenario 2 from JWG.
15	Status quo +10%	Status quo +50%	Status quo +50%		4,948	11,664	5,993		-	-	Additional request scenario 3 from JWG.
16	Status quo +20%	Status quo +50%	Status quo +50%		5,420	11,664	5,993		-	-	Additional request scenario 4 from JWG.
17	Status quo +5%	Status quo +70%	Status quo +70%		4,711	13,185	6,792		-	-	Additional request scenario 5 from JWG.
18	Status quo +20%	Status quo +100%	Status quo +100%		5,420	15,468	7,990		-	-	Additional request scenario 6 from JWG.

Table A2-2. Future projection scenarios for Pacific bluefin tuna (*Thunnus orientalis*) and their probability of achieving various target levels by various time schedules based on the base-case model.

Harvesting scenarios							Performance indicators								
Reference No	Scenarios				Specified fishery impact at 2034		Median SSB at 2034	Fishery impact ratio of WPO fishery at 2034	Fishery impact ratio of EPO fishery at 2034	Probability of achiving the 2nd rebuilding target at 2041	Risk to breach $SSB_{7.7\%F=0}$ at least once by 2041	Probability of overfishing compared to 20%SSB0 at 2041	Probability of overfishing compared to 25%SSB0 at 2041	Probability of overfishing compared to 30%SSB0 at 2041	Probability of overfishing compared to 40%SSB0 at 2041
	WCPO		EPO												
	Small	Large	Small	Large	WCPO	EPO									
13	Status quo +0%	Status quo +50%	Status quo +50%		-	-	253,119	77%	23%	98%	0%	2%	6%	14%	40%
14	Status quo +5%	Status quo +50%	Status quo +50%		-	-	245,441	78%	22%	97%	0%	3%	8%	17%	45%
15	Status quo +10%	Status quo +50%	Status quo +50%		-	-	237,663	79%	21%	96%	0%	4%	11%	22%	50%
16	Status quo +20%	Status quo +50%	Status quo +50%		-	-	222,182	82%	18%	92%	1%	8%	18%	30%	60%
17	Status quo +5%	Status quo +70%	Status quo +70%		-	-	228,164	78%	22%	94%	1%	6%	14%	25%	55%
18	Status quo +20%	Status quo +100%	Status quo +100%		-	-	178,037	80%	20%	75%	5%	25%	39%	55%	79%

Table A2-3. Expected annual yield for Pacific bluefin tuna (*Thunnus orientalis*) under various harvesting scenarios based on the base-case model.

	Harvesting scenarios								Expected catch							
Reference No	Scenarios				Catch limit in the projection				2029				2034			
	WCPO		EPO		WCPO		EPO		WPO		EPO		WPO		EPO	
	Small	Large	Small	Large	Small	Large	Small	Large	Small	Large	Commercial	Sport	Small	Large	Commercial	Sport
13	Status quo	Status quo +50%	Status quo +50%		4,475	11,664	5,993		4,202	12,030	5,992	1,289	4,193	12,033	5,993	1,400
14	Status quo +5%	Status quo +50%	Status quo +50%		4,711	11,664	5,993		4,423	12,038	5,991	1,264	4,416	12,039	5,993	1,359
15	Status quo +10%	Status quo +50%	Status quo +50%		4,948	11,664	5,993		4,644	12,045	5,990	1,238	4,639	12,045	5,992	1,318
16	Status quo +20%	Status quo +50%	Status quo +50%		5,420	11,664	5,993		5,083	12,062	5,989	1,186	5,086	12,051	5,988	1,237
17	Status quo +5%	Status quo +70%	Status quo +70%		4,711	13,185	6,792		4,435	13,541	6,785	1,222	4,428	13,541	6,789	1,305
18	Status quo +20%	Status quo +100%	Status quo +100%		5,420	15,468	7,990		5,118	15,741	7,926	1,083	5,119	15,635	7,928	1,100

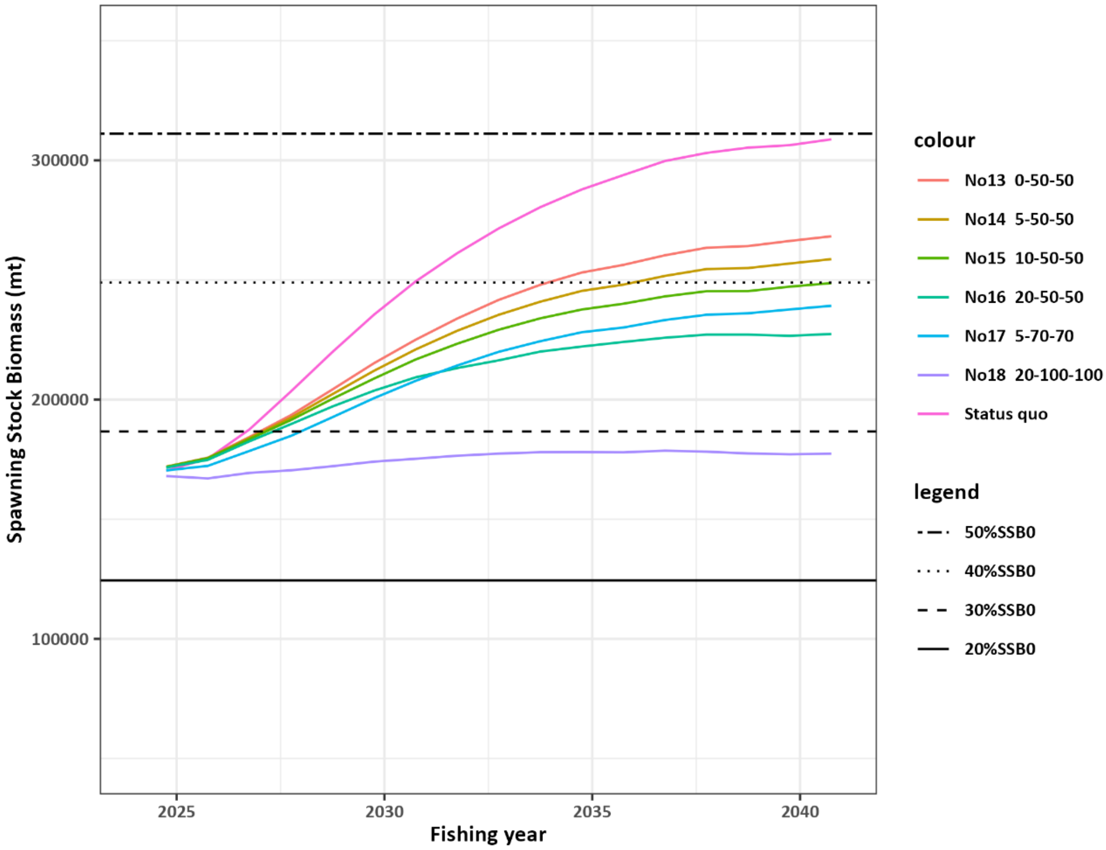


Figure A2-1 Comparisons of various projected median SSB for all harvest scenarios examined for Pacific bluefin tuna (*Thunnus orientalis*) obtained from projection results.

Attachment 2

Joint IATTC/WCPFC Northern Committee
Working Group on Pacific bluefin tuna (JWG)

June 7, 2024

Dear John Holmes, ISC Chair,

We hope this letter finds you well.

It is encouraging to learn from the Pacific Bluefin Tuna Working Group (PBFWG) summary report that the stock achieved the second rebuilding target (20%$SSB_{F=0}$) in 2021, 13 years earlier than originally scheduled in the rebuilding plan. JWG09 will discuss new conservation and management measures for PBF, in accordance with the harvest control rules stipulated in IATTC Resolution C-23-01 and WCPFC HS 2023-02.

JWG08 last year requested the ISC to conduct future projections under several catch increase scenarios and submit the outcomes to JWG09, which are contained in the report of ISC PBFWG. While the catch increase scenarios 4-11 show the maximum levels of catch increase maintaining SSB greater than 20%$SSB_{F=0}$ with a probability of 60%, all these scenarios involve future declines of the stock.

We as JWG Co-Chairs understand that many members are interested in scenarios that allow for increasing or stable SSB and believe that it may be useful to have a few additional scenarios for consideration to aid effective discussion at JWG-09. We would, therefore, respectfully request that the ISC conduct future projections on the following additional scenarios.

Additional scenario 1: WCPO small fish catch limit increase by 0%, WCPO large fish catch limit increase by 50%, and EPO catch limit increase by 50%.

Additional scenario 2: WCPO small fish catch limit increase by 5%, WCPO large fish catch limit increase by 50%, and EPO catch limit increase by 50%.

Additional scenario 3: WCPO small fish catch limit increase by 10%, WCPO large fish catch limit increase by 50%, and EPO catch limit increase by 50%.

Additional scenario 4: WCPO small fish catch limit increase by 20%, WCPO large fish catch limit increase by 50%, and EPO catch limit increase by 50%.

Additional scenario 5: WCPO small fish catch limit increase by 5%, WCPO large fish catch limit increase by 70%, and EPO catch limit increase by 70%.

Additional scenario 6: WCPO small fish catch limit increase by 20%, WCPO large fish catch limit increase by 100%, and EPO catch limit increase by 100%.

We understand that number of scenarios must be minimized but believe that six additional are feasible. We are hopeful that these additional scenarios and projections can be completed by the ISC PBFWG in time for review by the full ISC at your June 19-24, 2024 Plenary meeting.

Please let us know if you have any concerns or questions about this request.
You may reach Co-Chair Miyahara at masamiyafaj1@gmail.com and/or Co-Chair Lowman at dmlowman01@comcast.net

Finally, and importantly, we would assure you that these additional future projections, if presented by the ISC, will be discussed together with other scenarios and will not prejudice the discussion during JWG09.

Sincerely,

Dorothy Lowman and

Masa Miyahara, JWG Co-Chairs

Cc: Shuya Nakatsuka, ISC PBFWG Chair