**JOINT IATTC AND WCPFC-NC WORKING GROUP MEETING ON THE MANAGEMENT OF PACIFIC BLUEFIN TUNA**
**SEVENTH SESSION (JWG-07)**

ELECTRONIC MEETING
09:00-13:00, Japan Standard Time
12-14 July 2022

# [DRAFT] 2022 Pacific Bluefin Tuna Stock Assessment – Executive Summary

**IATTC-NC-JWG07-2022/IP-01**

**ISC[1] PBFWG**

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

2022 Pacific Bluefin Tuna Stock Assessment

# ISC PBFWG

# EXECUTIVE SUMMARY (***DRAFT***)

## 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 landings records are available dating back to 1804 from coastal Japan and to the early 1900s for U.S. fisheries operating in the EPO. Based on these landing records, PBF catch is estimated to be high from 1929 to 1940, with a peak catch of approximately 47,635 t (36,217 t in the WPO and 11,418 t in the EPO) in 1935; thereafter catches of PBF dropped precipitously due to World War II. PBF catches increased significantly in 1949 as Japanese fishing activities expanded across the North Pacific Ocean. By 1952, a more consistent catch reporting process was adopted by most fishing nations and estimated annual catches of PBF fluctuated widely from 1952 to 2020 (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 2019 and 2020 was 11,557 t and 13,779 t, respectively, including non-member countries of the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC). 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). Catch of PBF has been predominantly composed of juvenile PBF (age 0-2) throughout the assessment period. 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-2010s due to stricter control of juvenile catch (Figures 1 and 3).

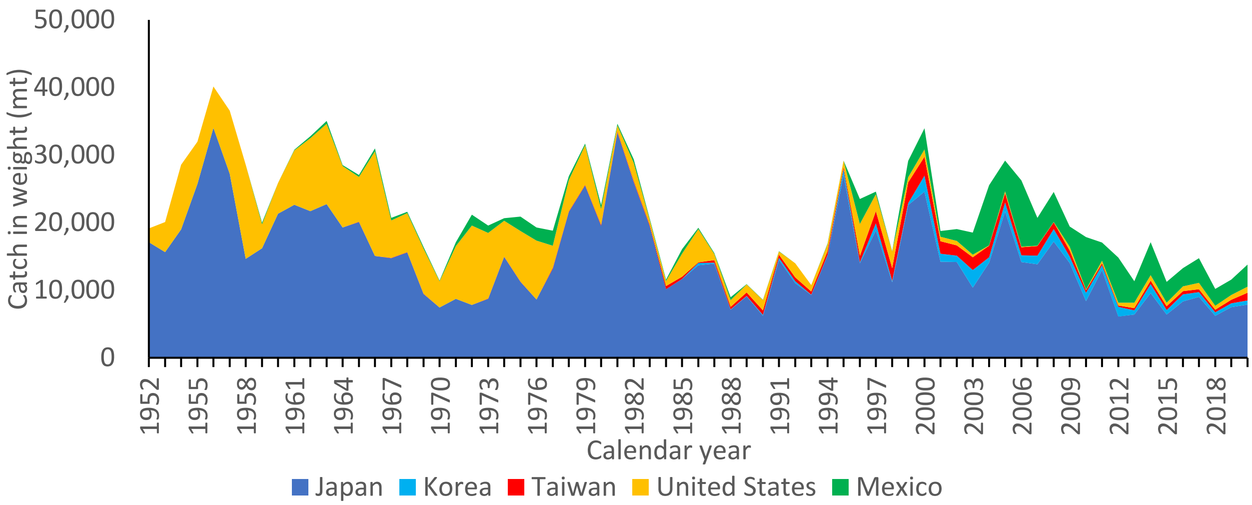



**Figure 1.** Annual catch (ton) of Pacific bluefin tuna (*Thunnus orientalis*) by ISC member countries from 1952 through 2020 (calendar year) based on ISC official statistics.

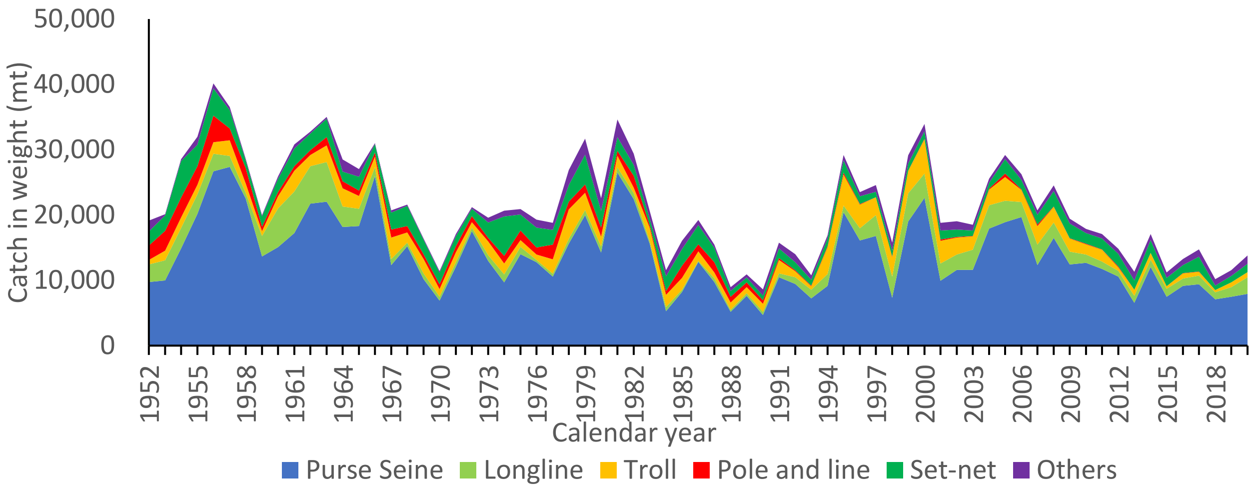



**Figure 2.** Annual catch (ton) of Pacific bluefin tuna (*Thunnus orientalis*) by gear type by ISC member countries from 1952 through 2020 (calendar year) based on ISC official statistics.

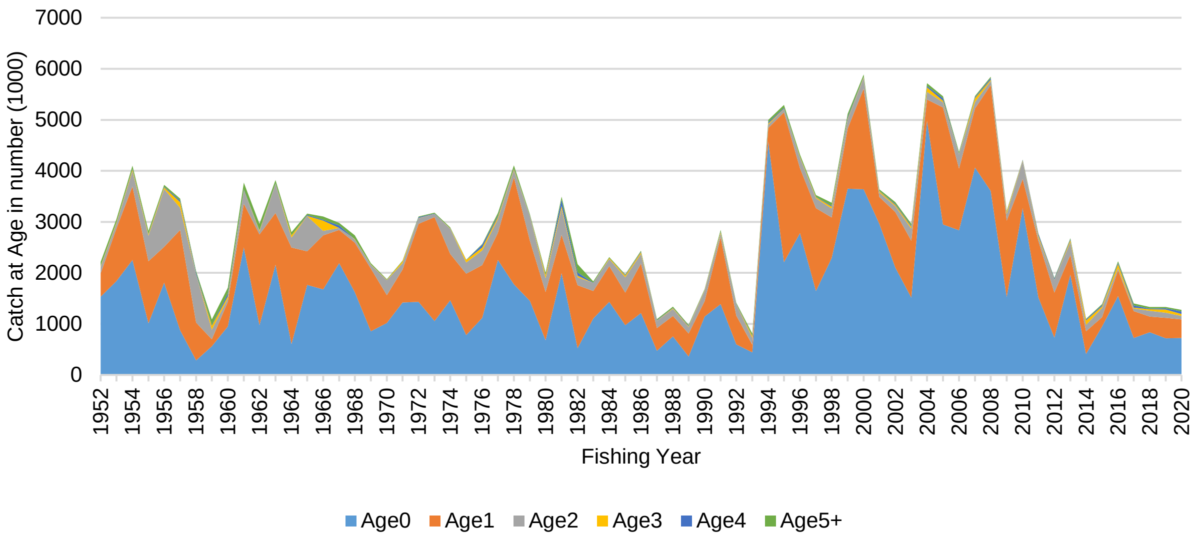



**Figure 3.** Estimated annual catch-at-age (number of fish) of Pacific bluefin tuna (*Thunnus orientalis*) by fishing year by the base-case model (1952-2020).

## 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 indices data from 1952 to 2020 fishing years (FY; from July to June of the following year), provided by Members of the ISC, Pacific Bluefin Tuna Working Group (PBFWG) and non-ISC countries obtained through the Secretariat of the Pacific Community (SPC). Life history parameters included a length-at-age relationship from otolith-derived ages and natural mortality estimates from a tag-recapture study and empirical-life history methods. The assessment model is a single-area model and assumes "areas-as-fleets" fishery selectivity. The 2022 base-case model maintained most of the model structure and settings from the previous benchmark assessment in 2020.

A total of 25 fleets were defined for use in the stock assessment model based on country/gear/season/region stratification until the end of the 2020 FY (June 2021). Quarterly observations of catch and size compositions, when available, were used as inputs to the model to describe the removal processes. Annual estimates of standardized CPUE from the Japanese distant water, off-shore and coastal longline, the Taiwanese longline, and the Japanese troll fleets were used as measures of the relative abundance of the population. The CPUE data from Japanese longline (adult index) in 2020 and Japanese troll (recruitment index) after 2016 were not included in the model as these observations may be biased due to the additional management measures implemented 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.

After implementing minor improvements and refinements, the PBFWG found that the 2022 base-case model is consistent with the 2020 assessment results, that it fits the data well and the results are internally consistent among most of the data sources. Based on the model diagnostics, it was concluded that the model captures the production function of PBF well, thus its estimated biomass scale is reliable and the model has good predictability. Based on these observations, the PBFWG concluded that the 2022 assessment model reliably represents the population dynamics and is the best available scientific information for the PBF stock.

## 4. Stock Status and Conservation Information

The base-case model results ,reported by fishing year (FY) unless otherwise specified, show that: (1) spawning stock biomass (SSB) fluctuated throughout the assessment period (1952-2020); (2) the SSB steadily declined from 1996 to 2010; (3) the SSB has increased since 2011 resulting in the 2020 SSB being back to the 1996 level; (4) total biomass after 2011 continued to increase with an increase in young fish, creating the 2$^{nd}$ highest biomass peak in the assessed history in 2020; (5) fishing mortality ($F_{\%SPR}$), which declined to a level producing about 1% of SPR[1] in 2004-2009, returned to a level producing 30.7% of SPR in 2018-2020; and (6) SSB in 2020 was 10.2% of $SSB_{F=0}$, an increase from the 5.6% of $SSB_{F=0}$ estimated for 2018 in the 2020 assessment (2018 was the last year of the 2020 assessment). Based on the model diagnostics, the estimated biomass trend for the last 40 years is considered robust although SSB prior to the 1980s is uncertain due to data limitations. The SSB in 2020 was estimated to be around 65,464 t (Table 1 and Figure 4), which is a 30,000 t increase from 2018 according to the base-case model. An increase of young fish (0-2 years old) biomass was observed in 2016-2020 (Figure 5), likely resulting from low fishing mortality on those fish (Figure 6) and is expected to accelerate the recovery of SSB in the future even further.

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

**Table 1.** Total biomass, spawning stock biomass, recruitment, spawning potential ratio, and depletion ratio ($SSB/SSB_{F=0}$) of Pacific bluefin tuna (*Thunnus orientalis*) estimated by the base-case model, 1952-2020 FY.

| Year | Total Biomass (t) | Spawning Stock Biomass (t) | Recruitment (1,000 fish) | Spawning Potential Ratio | Depletion Ratio |
|---|---|---|---|---|---|
| 1952 | 134,789 | 103,359 | 14,008 | 11.6% | 16.1% |
| 1953 | 136,421 | 97,912 | 20,617 | 12.9% | 15.2% |
| 1954 | 146,892 | 88,019 | 34,911 | 7.9% | 13.7% |
| 1955 | 156,701 | 75,353 | 13,343 | 11.4% | 11.7% |
| 1956 | 176,167 | 67,818 | 33,476 | 15.8% | 10.5% |
| 1957 | 193,973 | 77,053 | 11,635 | 10.8% | 12.0% |
| 1958 | 202,415 | 100,943 | 3,203 | 19.5% | 15.7% |
| 1959 | 209,868 | 136,650 | 7,709 | 23.9% | 21.2% |
| 1960 | 202,700 | 144,704 | 7,554 | 17.3% | 22.5% |
| 1961 | 194,047 | 156,534 | 23,235 | 3.4% | 24.3% |
| 1962 | 177,257 | 141,792 | 10,774 | 10.9% | 22.0% |
| 1963 | 166,291 | 120,933 | 27,842 | 6.6% | 18.8% |
| 1964 | 154,459 | 106,314 | 5,689 | 7.5% | 16.5% |
| 1965 | 142,916 | 93,572 | 10,955 | 3.0% | 14.5% |
| 1966 | 120,164 | 89,589 | 8,556 | 0.1% | 13.9% |
| 1967 | 105,483 | 83,751 | 10,951 | 1.1% | 13.0% |
| 1968 | 91,650 | 77,872 | 14,356 | 1.4% | 12.1% |
| 1969 | 80,731 | 64,561 | 6,450 | 8.6% | 10.0% |
| 1970 | 74,490 | 54,181 | 7,182 | 2.9% | 8.4% |
| 1971 | 66,467 | 47,017 | 12,407 | 1.3% | 7.3% |
| 1972 | 64,098 | 40,725 | 22,890 | 0.3% | 6.3% |
| 1973 | 62,899 | 35,510 | 11,251 | 5.6% | 5.5% |
| 1974 | 65,165 | 28,711 | 13,983 | 6.3% | 4.5% |
| 1975 | 65,978 | 26,420 | 11,223 | 8.9% | 4.1% |
| 1976 | 65,030 | 29,152 | 8,071 | 3.1% | 4.5% |
| 1977 | 74,864 | 35,066 | 25,589 | 3.7% | 5.4% |
| 1978 | 76,566 | 32,974 | 14,317 | 5.0% | 5.1% |
| 1979 | 73,608 | 27,866 | 12,876 | 8.2% | 4.3% |
| 1980 | 72,844 | 29,713 | 6,554 | 6.2% | 4.6% |
| 1981 | 57,749 | 27,591 | 13,360 | 0.3% | 4.3% |
| 1982 | 40,714 | 24,235 | 6,454 | 0.0% | 3.8% |
| 1983 | 33,472 | 14,773 | 10,090 | 6.0% | 2.3% |
| 1984 | 37,662 | 12,895 | 9,063 | 5.3% | 2.0% |
| 1985 | 39,805 | 12,957 | 9,654 | 2.7% | 2.0% |
| 1986 | 34,473 | 15,316 | 7,939 | 1.1% | 2.4% |
| 1987 | 32,080 | 14,105 | 5,980 | 8.2% | 2.2% |
| 1988 | 38,238 | 15,059 | 9,483 | 11.0% | 2.3% |
| 1989 | 42,074 | 14,888 | 4,291 | 14.6% | 2.3% |
| 1990 | 57,971 | 18,994 | 17,436 | 18.4% | 3.0% |
| 1991 | 69,431 | 25,290 | 10,617 | 9.8% | 3.9% |
| 1992 | 76,142 | 32,456 | 3,968 | 14.7% | 5.0% |
| 1993 | 83,395 | 43,890 | 4,430 | 16.8% | 6.8% |
| 1994 | 97,472 | 50,177 | 29,319 | 13.5% | 7.8% |
| 1995 | 93,999 | 62,246 | 16,012 | 5.2% | 9.7% |
| 1996 | 96,300 | 61,563 | 17,964 | 8.8% | 9.6% |
| 1997 | 90,121 | 56,179 | 11,082 | 6.0% | 8.7% |
| 1998 | 95,748 | 55,612 | 16,075 | 4.2% | 8.6% |
| 1999 | 91,805 | 51,374 | 22,755 | 3.4% | 8.0% |
| 2000 | 76,307 | 48,461 | 14,385 | 1.7% | 7.5% |
| 2001 | 77,426 | 46,059 | 17,302 | 9.5% | 7.2% |
| 2002 | 75,311 | 43,899 | 13,541 | 5.7% | 6.8% |
| 2003 | 67,904 | 43,152 | 7,157 | 2.3% | 6.7% |
| 2004 | 65,640 | 35,881 | 27,746 | 1.4% | 5.6% |
| 2005 | 55,074 | 29,159 | 15,118 | 0.7% | 4.5% |
| 2006 | 43,314 | 23,294 | 13,540 | 1.1% | 3.6% |
| 2007 | 42,659 | 18,424 | 22,227 | 0.5% | 2.9% |
| 2008 | 38,290 | 13,716 | 21,072 | 0.6% | 2.1% |
| 2009 | 33,985 | 10,195 | 8,277 | 1.2% | 1.6% |
| 2010 | 36,969 | 9,761 | 17,952 | 2.4% | 1.5% |
| 2011 | 38,817 | 11,183 | 13,526 | 4.9% | 1.7% |
| 2012 | 42,482 | 13,902 | 7,169 | 8.2% | 2.2% |
| 2013 | 52,764 | 16,313 | 13,169 | 5.7% | 2.5% |
| 2014 | 53,075 | 19,185 | 3,641 | 11.1% | 3.0% |
| 2015 | 59,220 | 23,640 | 8,653 | 12.5% | 3.7% |
| 2016 | 69,494 | 30,516 | 16,690 | 12.8% | 4.7% |
| 2017 | 82,681 | 32,538 | 10,895 | 21.9% | 5.1% |
| 2018 | 103,849 | 35,741 | 11,145 | 28.3% | 5.6% |
| 2019 | 129,972 | 45,173 | 11,843 | 28.8% | 7.0% |
| 2020 | 156,517 | 65,464 | 11,316 | 35.1% | 10.2% |
| Median(1952-2020) | 74,864 | 35,881 | 11,635 | 6.2% | 5.6% |
| Average(1952-2020) | 89,353 | 49,845 | 13,390 | 8.3% | 7.7% |

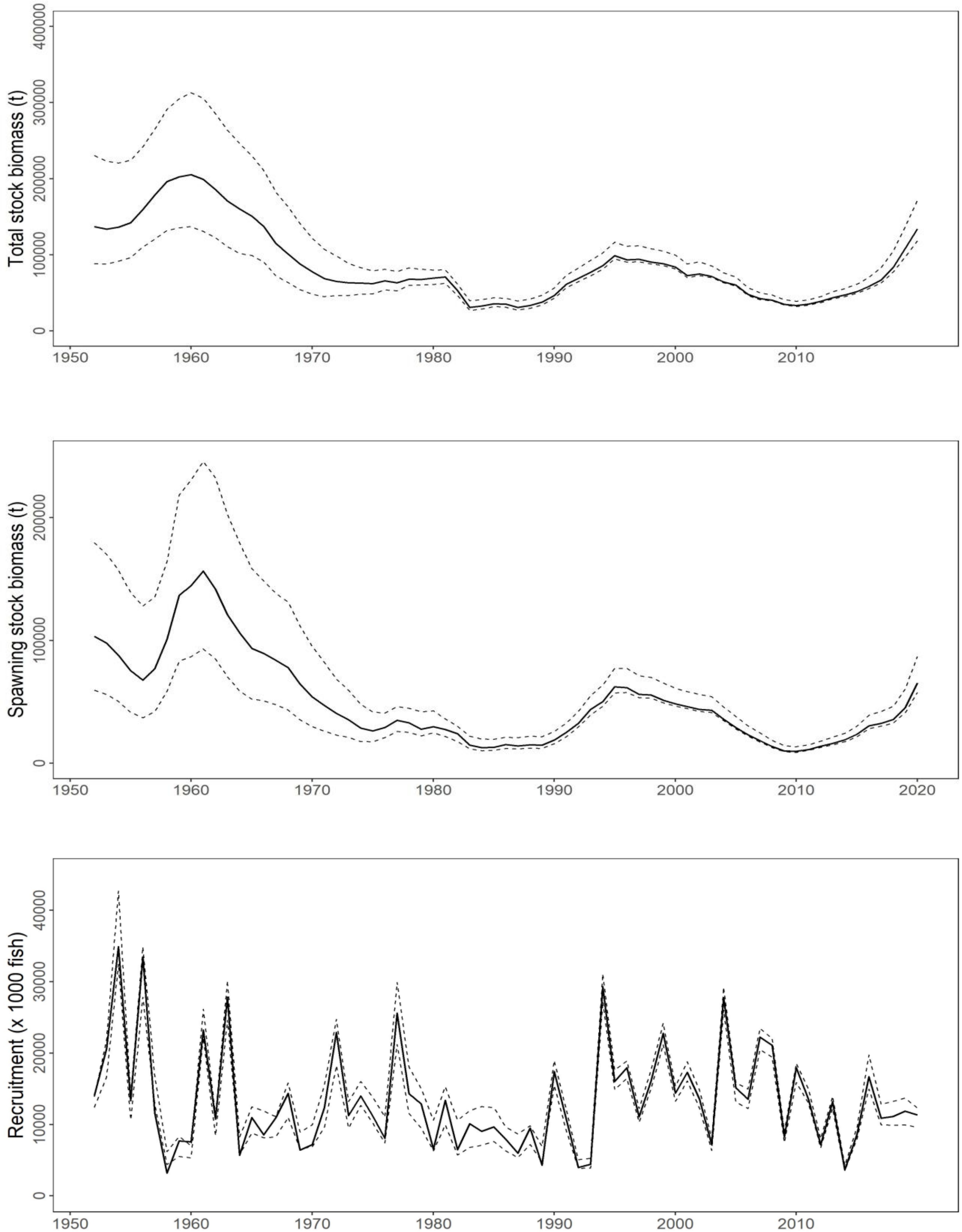



**Figure 4.** Maximum likelihood estimates of total stock biomass (top), spawning stock biomass (middle), and recruitment (bottom) of Pacific bluefin tuna (*Thunnus orientalis*) (1952-2020) estimated from the base-case model. The solid line represents the point estimates and dashed lines

delineate the 90% confidence interval by bootstrapping. Note that the bootstrap confidence interval may not capture the full uncertainty around the recruitment estimates for 2017-2020.

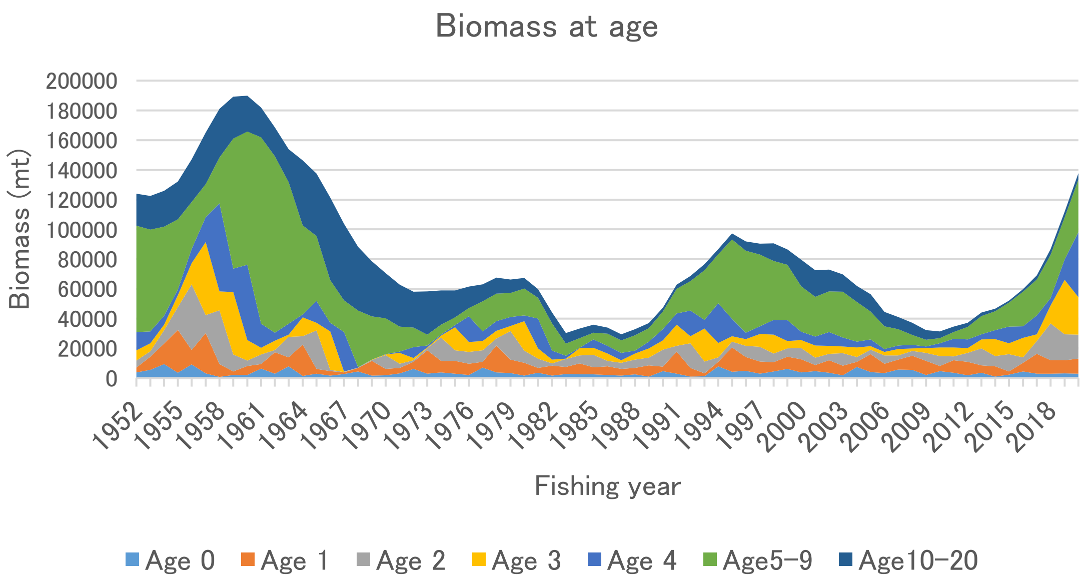



**Figure 5.** Total biomass (tonnes) by age of Pacific bluefin tuna (*Thunnus orientalis*) estimated from the base-case model (1952-2020). Note that the recruitment estimates for 2017-2020 may be more uncertain than in other years.

Historical recruitment estimates have fluctuated since 1952 without an apparent trend (Figure 4). Currently, stock projections assume that future recruitment will fluctuate around the historical (1952-2019 FY) average recruitment level after the initial rebuilding target is reached. No significant autocorrelation was found in recruitment estimates, supporting the use in the projections of recruitment sampled at random from the historical timeseries. In addition, now that SSB has recovered to be larger than the historical median, the PBFWG considers that the assumption that future recruitment will fluctuate within the historical range is reasonable. The recruitment index based on the Japanese troll CPUE has proven to be an informative indicator of recruitment in PBF assessments. However, the present assessment does not use the recruitment index for the recent period (2017-2020) due to a possible change in catchability caused by a change in fishing operations following management intervention as well as operational changes Due to a lack of data to inform trends in recent recruitment, the mean recruitment estimates for 2017-2020 are primarily estimated by the stock-recruitment relationship and are more uncertain than for other years. If recruitment in this period is below average, then the projections would be more pessimistic, while the impact on the current status would be minimal as those cohorts have not grown to contribute to the SSB. The

PBFWG, therefore, investigated the projection results based on a model which includes the recruitment monitoring survey CPUE index for the recent period, which are slightly more pessimistic for recruitment in the terminal years of the assessment than he average recruitment. This analysis provided slightly more pessimistic results as compared to those using the base-case model, but the estimated effects on SSB are not sufficient to necessitate modification of the present management advice based on the base-case model. Note that the PBFWG decided not to include the recruitment monitoring index in the base case assessment as, due to its short duration (2017-2020), the PBFWG was unable to assess its reliability and consistency with other data sources in the model.

Estimated age-specific fishing mortalities (F) on the stock during the periods of 2011-2013 and 2018-2020 compared with 2002-2004 estimates (the reference period for the WCPFC Conservation and Management Measure) are presented in Figure 6. A substantial decrease in estimated F is observed in ages 0-2 in 2018-2020 FY relative to the previous years.

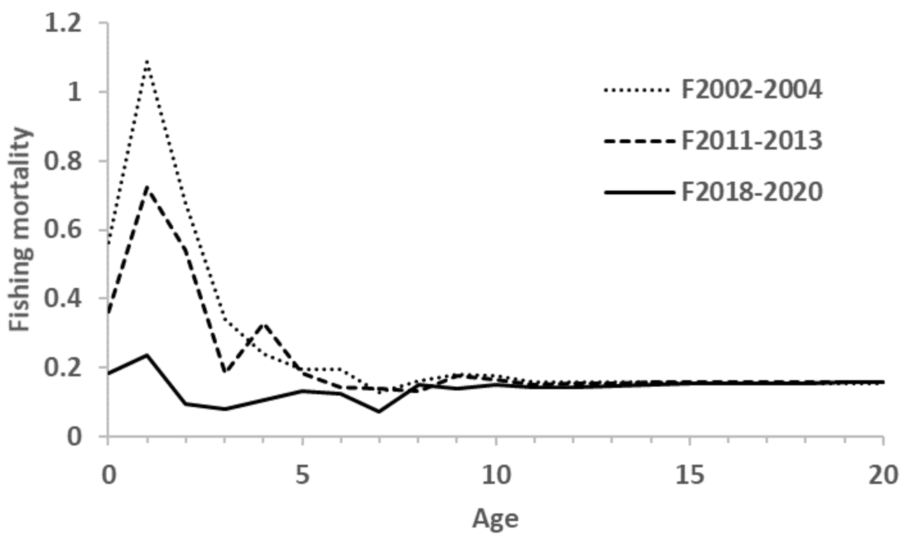



**Figure 6.** Geometric means of annual age-specific fishing mortalities (F) of Pacific bluefin tuna (*Thunnus orientalis*) for 2002-2004 (dotted line), 2011-2013 (broken line), and 2018-2020 (solid line).

The WCPFC and IATTC have adopted an initial rebuilding target (the median SSB estimated for the period from 1952 to 2014) and a second rebuilding target (20%$SSB_{F=0}$ under average recruitment) but did not implement any fishing mortality reference level. The 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 $F_{6.3\%SPR}$ . The Kobe plot shows that the point estimate of the $SSB_{2020}$ was 10.2%$SSB_{F=0}$ (i.e., SSB was approximately 50% of 20%$SSB_{F=0}$) and that the recent (2018-2020) fishing mortality corresponds to $F_{30.7\%SPR}$, reaching the historical lowest level (Table 1 and Figure 7). Although no reference points have been adopted to evaluate the status of PBF, an evaluation of stock status against some common reference points shows that the stock is overfished relative to the biomass-based limit reference points adopted for other species in WCPFC (20%$SSB_{F=0}$), but that the 2018-2020 fishing mortality was lower than the F corresponding to that reference point (20%SPR) ((1-$SPR_{2018\text{-}2020}$)/(1-$SPR_{20\%}$)=0.87 in Table 2). The PBFWG also investigated the impact of the alternative model incorporating the recruitment monitoring index on the estimation of stock status. This model estimated SSB to be 10.7%$SSB_{F=0}$ in 2020 and F 27.9%SPR in 2018-2020. Biomass and SPR estimates from this model do not differ substantively from the base-case model.

**Table 2.** Ratios of the estimated fishing mortalities (Fs and 1-SPRs for 2002-04, 2011-13, and 2018-2020) relative to potential fishing mortality-based reference points, terminal year SSB (t) for each reference period, and depletion ratio **($SSB/SSB_{F=0}$)** for the terminal year of the reference period for Pacific bluefin tuna (*Thunnus orientalis*) from the base-case model**.** $F_{max}$: Fishing mortality (F) that maximizes equilibrium yield per recruit (Y/R). $F_{0.1}$: F at which the slope of the Y/R curve is 10% of the value at its origin. $F_{med}$: F corresponding to the inverse of the median of the observed R/SSB ratio. $F_{xx\%SPR}$: F that produces a given % of the unfished spawning potential (biomass) under equilibrium conditions.

| Reference Period | | | | (1-SPR)/(1-$SPR_{xx\%}$) | | | | Estimated SSB for terminal year of each period (ton) | Depletion rate for terminal year of each period (%) |
|---|---|---|---|---|---|---|---|---|---|
| | Fmax | F0.1 | Fmed | $SPR_{10\%}$ | $SPR_{20\%}$ | $SPR_{30\%}$ | $SPR_{40\%}$ | | |
| 2002-2004 | 1.96 | 2.89 | 1.16 | 1.08 | 1.21 | 1.38 | 1.61 | 35,881 | 5.6% |
| 2011-2013 | 1.54 | 2.27 | 0.87 | 1.04 | 1.17 | 1.34 | 1.56 | 16,313 | 2.5% |
| 2018-2020 | 0.75 | 1.14 | 0.33 | 0.77 | 0.87 | 0.99 | 1.15 | 65,464 | 10.2% |

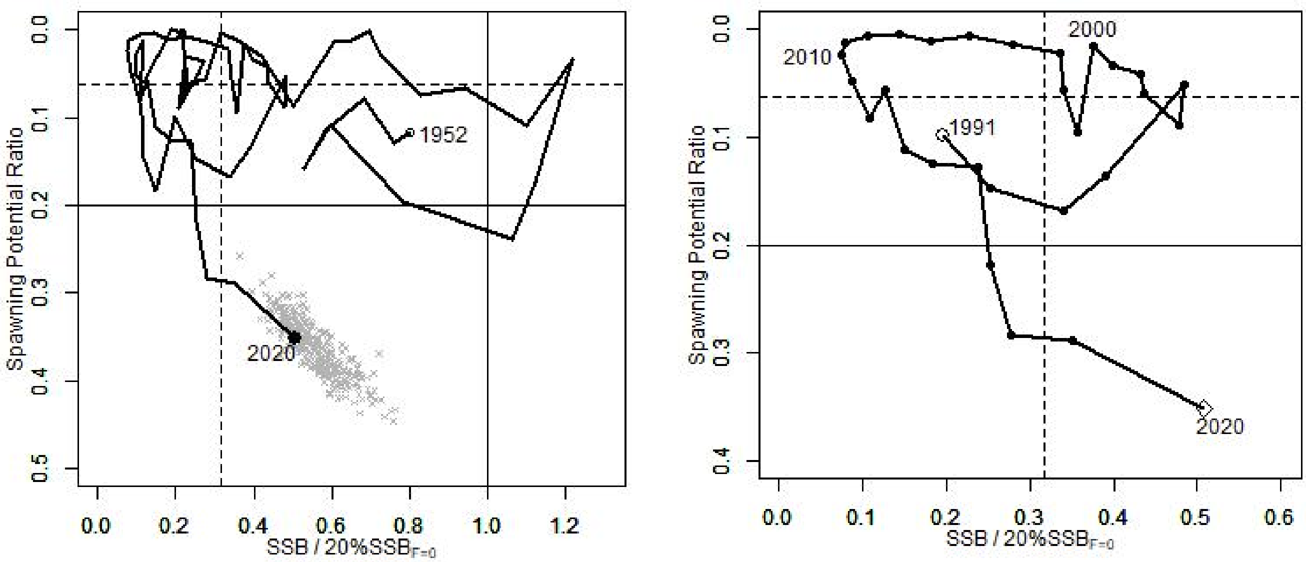
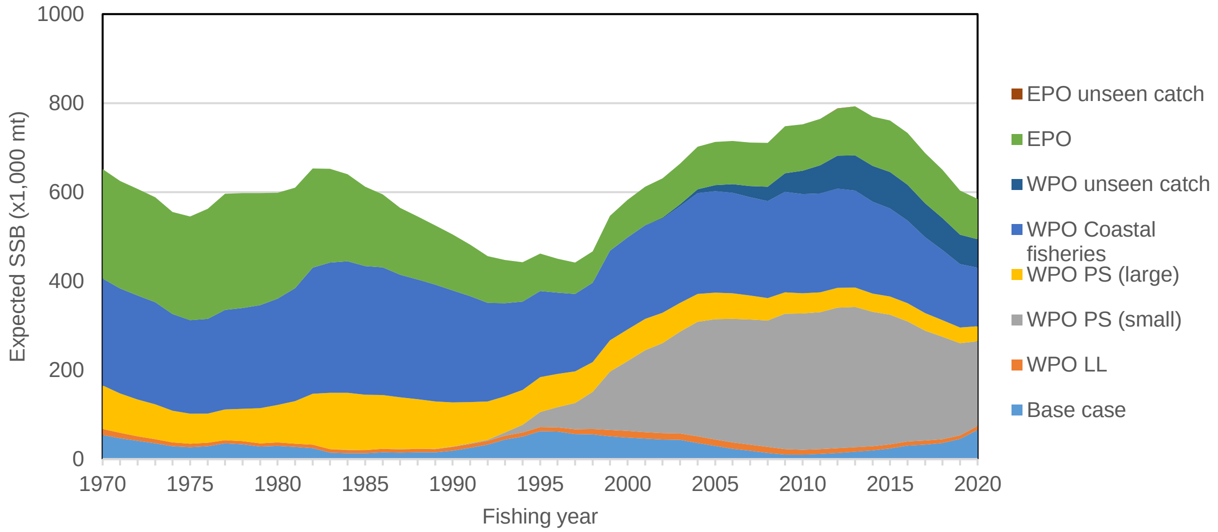



**Figure 7.** Kobe plots for Pacific bluefin tuna (*Thunnus orientalis*) estimated from the base-case model. The X-axis shows the annual SSB relative to $20\%SSB_{F=0}$ and the Y-axis shows the spawning potential ratio (SPR) as a measure of fishing mortality. Vertical and horizontal solid lines in the left figure show $20\%SSB_{F=0}$ (which corresponds to the second biomass rebuilding target) and the corresponding fishing mortality that produces SPR, respectively. Vertical and horizontal broken lines in both figures show the initial biomass rebuilding target ($SSB_{MED}$ = $6.3\%SSB_{F=0}$) and the corresponding fishing mortality that produces SPR, respectively. $SSB_{MED}$ is calculated as the median of estimated SSB in 1952-2014. The left figure shows the historical trajectory, where the open circle indicates the first year of the assessment (1952), the solid circle indicates the last year of the assessment (2020), and grey crosses indicate the uncertainty of estimates in 2020 using bootstrapping. The right figure shows the trajectory of the last 30 years.

Figure 8 depicts the historical impacts of the harvest by fleet on the PBF stock, showing the estimated biomass when fishing mortality from the respective fleets is zero. The impact of the EPO fisheries group was large before the mid-1980s, decreasing significantly thereafter. From the mid-1980s to the late 1990s, the WPO coastal fisheries group has had the greatest impact on the PBF stock. Since the introduction of the WPO purse seine fishery group targeting small fish (ages 0-1), the impact of this group has rapidly increased, and the impact in 2020 was greater than any of the other fishery groups. 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 2020, the estimated cumulative impact proportion between WPO and EPO fisheries is about 83% and 17%, respectively. There is greater uncertainty associated with the dead discards than other fishery impacts because the impact of discarding is not based on observed data (unseen catches in Figure 8).



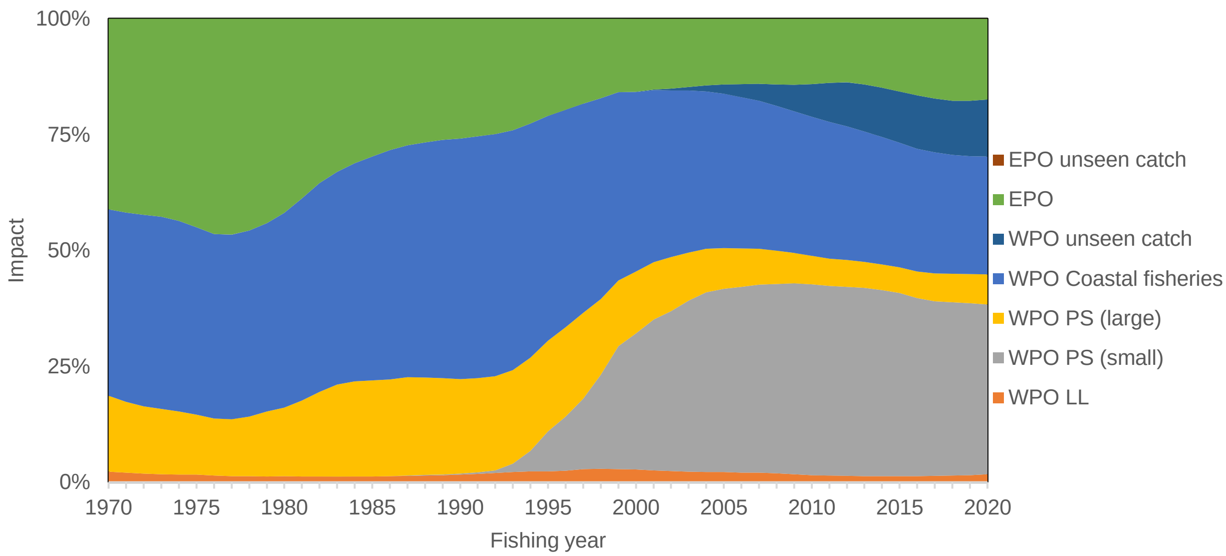




**Figure 8.** The trajectory of the spawning stock biomass of a simulated population of Pacific bluefin tuna (*Thunnus orientalis*) when zero fishing mortality is assumed, estimated by the base-case model. (top: absolute SSB, bottom: relative SSB). In 2020, the estimated cumulative impact proportion between WPO and EPO fisheries is about 83% and 17%, respectively. Fisheries group definition; WPO longline fisheries: F1, F12, F17, F23. WPO purse seine fisheries for small fish: F2, F3, F18, F20. WPO purse seine fisheries for large fish: F4, F5. WPO coastal fisheries: F6-11, F16, F19. EPO fisheries: F13, F14, F15, F24. WPO unaccounted fisheries: F21, 22. EPO unaccounted fisheries: F25. For exact fleet definitions, please see the 2022 PBF stock assessment report.

**Stock Status**

**The PBF spawning stock biomass (SSB) has gradually increased in the last 10 years, and its pace of increase is accelerating. These changes in biomass coincide with a decline in fishing mortality over the last decade. The latest (2020) SSB is estimated to be 10.2% of $SSB_{F=0}$.** 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 overfished relative to the potential biomass-based reference points (20%$SSB_{F=0}$) adopted for other tuna species by the IATTC and WCPFC. On the other hand, SSB reached its initial rebuilding target ($SSB_{MED}$ = 6.3%$SSB_{F=0}$) in 2019, 5 years earlier than originally planned by RFMOs.**
2. **Although no fishing mortality-based reference points have been adopted for PBF by the IATTC and WCPFC, the recent (2018-2020) $F_{\%SPR}$ is estimated to have reduced to a level to produce 30.7%SPR, which is below the level producing 20%SPR.**

**Conservation Advice**

After the steady decline in SSB from 1996 to the historically low level in 2010, the PBF stock has started recovering, with recovery being more rapid in recent years, consistent with the implementation of stringent management measures. The 2020 SSB was above the initial rebuilding target but remains below the second rebuilding target adopted by the WCPFC and IATTC. However, stock recovery is occurring at a faster rate than anticipated by managers when the Harvest Strategy to foster rebuilding were implemented in 2014. The fishing mortality ($F_{\%SPR}$) in 2018-2020 has been reduced to a level producing 30.7%SPR, the lowest observed in the time series.

The PBFWG conducted projections based on the base-case model under several harvest scenarios and time schedules as requested by the RFMOs. The results are shown in Tables 3-5 and Figure 9. Under all examined scenarios the second rebuilding target of WCPFC and IATTC, rebuilding to 20%$SSB_{F=0}$ by 2029 FY (10 years after reaching the initial rebuilding target) with at least 60% probability, is reached, and the risk of SSB falling below the historical lowest SSB at least once in 10 years is negligible. Also, amongst the projection scenarios assessed, Scenario 5 (the conversion of small fish quota to large fish quota at the current conversion factor of 1.47) achieved the second highest SSB when the second rebuilding target was met and after 10 years relative to the old CMM, Scenario 10 (Table 4). The Kobe chart of the projection results shows that PBF SSB will recover to the 2nd rebuilding target due to reduced fishing mortality (Figure 10). In scenarios 6-9 where future impact ratios between WPO and EPO are specified by the RFMOs, the recovery probability or impact ratio was approximated during the search for the appropriate increase levels. More specifically, those scenarios were tuned to achieve the $2^{nd}$ rebuilding target (10 years after achieving the initial rebuilding target) with 60% probability, and as a result, the catch increases are much more aggressive than other scenarios.

The PBFWG evaluated projection results of sensitivity models with lower mortality, larger asymptotic length in the von Bertalanffy growth function, lower steepness, or the recent recruitment monitoring index fit. Though projection results from these lower productivity models are more pessimistic than those from the base-case model, the PBFWG concluded that the current advice is robust to these alternative model assumptions.

The projection results assume that the CMMs are fully implemented and are based on certain biological and other assumptions. For example, these future projection results do not contain assumptions about discard mortality. Although the impact of discards on SSB is small compared to other fisheries (Figure 8), discards should be considered in future harvest scenarios. 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.

A future Kobe chart and impacts by fleets estimated from projections under the current management scheme are provided in Figures 10 and 11, respectively. Because the projections include catch limits, fishing mortality ($F_{x\%SPR}$) is expected to decline, i.e., SPR will increase, as biomass increases. The same information for all harvest scenarios are provided in the main body of the assessment report.

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

| Reference No | Harvesting scenarios | | | | | | |
|---|---|---|---|---|---|---|---|
| | Catch upper limit increments from status quo | | | Catch limit in the projection | | | Note |
| | WCPO | | EPO | WCPO | | EPO | |
| | Small | Large | Commercial | Small | Large | Commercial | |
| 1 | New CMM | | | 4,475 | 7,860 | 3,995 | NC request (paragraph 1; New CMM)<br>WCPFC CMM 2021-02, IATTC Resolution C-21-05 |
| 2 | New CMM | +500 tons | +500 tons | 4,475 | 8,360 | 4,495 | NC request (Paragraph 1, Appendix table 1st line) |
| 3 | 10% increase on the New CMM | | | 4,948 | 8,621 | 4,395 | NC request (Paragraph 1, Appendix table 2nd line) |
| 4 | 20% increase on the New CMM | | | 5,420 | 9,382 | 4,794 | NC request (Paragraph 1, Appendix table 3rd line) |
| 5 | -580 tons | +853 tons | New CMM | 3,895 | 8,713 | 3,995 | NC request (paragraph 3; conversion factor scenario). Transferring 10% (JPN) and 25% (KOR) of small fish catch quota to their largefish catch quota with the defined conversion factor (1.47). |
| 6 | +30% | +30% | +190% | 5,893 | 10,143 | 11,586 | NC request (Achieving 2nd rebuilding target at 10 years after achieving initial rebuilding target in 60 % probability. Fishery impact ratio at rebuilding year is 75:25. Additional quota is assigned proportionally for the WPO fisheries and independently for the EPO commercial fisheries. The balance of additional quota between the WPO and EPO is adjusted to achieve the given fishery impact ratio between them.) |
| 7 | New CMM | +130% | +190% | 4,475 | 17,752 | 11,586 | NC request (Achieving 2nd rebuilding target at 10 years after achieving initial rebuilding target in 60 % probability. Fishery impact ratio at rebuilding year is 75:25. Additional quota is assigned only for the WPO large fish fisheries and EPO commercial fisheries. The balance of additional quota between the WPO and EPO is adjusted to achieve the given fishery impact ratio between them) |
| 8 | +60% | +60% | +90% | 7,310 | 12,425 | 7,591 | NC request (Achieving 2nd rebuilding target at 10 years after achieving initial rebuilding target in 60 % probability. Fishery impact ratio at rebuilding year is 80:20. Additional quota is assigned proportionally for the WPO fisheries and independently for the EPO commercial fisheries. The balance of additional quota between the WPO and EPO is adjusted to achieve the given fishery impact ratio between them.) |
| 9 | New CMM | +230% | +90% | 4,475 | 25,362 | 7,591 | NC request (Achieving 2nd rebuilding target at 10 years after achieving initial rebuilding target in 60 % probability. Fishery impact ratio at rebuilding year is 80:20. Additional quota is assigned only for the WPO large fish fisheries and EPO commercial fisheries. The balance of additional quota between the WPO and EPO is adjusted to achieve the given fishery impact ratio between them) |
| 10 | Old CMM (50% of 2002-04 average level) | Old CMM (2002-04 average level) | Old CMM | 4,475 | 6,841 | 3,300 | Old CMM |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 catch for all fisheries |

* The Reference number of the Scenario is different from those given by the IATTC-WCPFC NC Joint WG meeting.

* Fishing mortality for scenario 1 is specified as the average level of age-specific fishing mortality during 2002-2004, which is the reference years in the WCPFC. Higher levels of the fishing mortality are specified for other scenarios to fulfill their quota in those projections.

* The Japanese unilateral measure (transferring 250 mt of catch upper limit from that for small PBF to that for large PBF during 2020-2034) is reflected in the projections.

**Table 4. Future projection scenarios for Pacific bluefin tuna (*Thunnus orientalis*) and their results on the base-case model. 2nd rebuilding target is 20%$SSB_{F=0}$. $SSB_{loss}$ is the lowest SSB observed.**

| Harvesting scenarios | | | | | Peformance indicators | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Reference No | WCPO | | EPO | | The fishing year expected to achive the 2nd rebuilding target with >60% probability | Risk to breach $SSB_{loss}$ at least once by 2030 | Probability of achiving the 2nd rebuilding target at 10 years after achieving initial rebuilding target [2029] | Median SSB at 10 years after achieving initial rebuilding target [2029] | Median SSB at 2034 | Fishery impact ratio of WPO fishery at 10 years after achieving the initial rebuilding target [2029] | Fishery impact ratio of EPO fishery at 10 years after achieving the initial rebuilding target [2029] |
| | Small | Large | Small | Large | | | | | | | |
| 1 | New CMM | | | | 2023 | 0% | 98.8% | 262,795 | 307,336 | 81.1% | 18.9% |
| 2 | New CMM | 500 tons increase on the New CMM | 500 tons increase on the New CMM | | 2023 | 0% | 98.2% | 256,170 | 298,867 | 80.3% | 19.7% |
| 3 | 10% increase on the New CMM | | | | 2023 | 0% | 96.9% | 245,333 | 280,687 | 82.3% | 17.7% |
| 4 | 20% increase on the New CMM | | | | 2023 | 0% | 94.0% | 227,183 | 253,598 | 83.4% | 16.6% |
| 5 | -580 tons | +853 tons | New CMM | | 2023 | 0% | 99.3% | 269,289 | 319,863 | 80.2% | 19.8% |
| 6 | +30% | +30% | +190% | | 2023 | 0% | 64.1% | 154,417 | 150,121 | 75.5% | 24.5% |
| 7 | New CMM | +130% | +190% | | 2029 | 0% | 60.0% | 147,931 | 157,963 | 75.2% | 24.8% |
| 8 | +60% | +60% | +90% | | 2023 | 0% | 61.3% | 147,275 | 135,698 | 80.6% | 19.4% |
| 9 | New CMM | +230% | +90% | | 2030 | 0% | 58.6% | 145,058 | 160,473 | 78.3% | 21.7% |
| 10 | Old CMM (50% of 2002-04 average level) | Old CMM (2002-04 average level) | Old CMM | | 2023 | 0% | 99.4% | 272,845 | 320,885 | 82.1% | 17.9% |
| 11 | 0 | 0 | 0 | | 2022 | 0% | 100.0% | 478,465 | 578,729 | 83.0% | 17.0% |

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

* Recruitment is resampled from historical values.

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

| Reference No | Harvesting scenarios | | | | | | Future expected catch | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Catch upper limit increments from status quo | | | Catch upper limit in the projection | | | 2024 | | | | 2034 | | | |
| | WCPO | | EPO | WCPO | | EPO | WCPO | | EPO | | WCPO | | EPO | |
| | Small | Large | Commercial | Small | Large | Commercial | Small | Large | Commercial | Sport | Small | Large | Commercial | Sport |
| 1 | New CMM | | | 4,475 | 7,860 | 3,995 | 4,496 | 7,884 | 4,008 | 1,228 | 4,497 | 7,922 | 4,012 | 1,540 |
| 2 | New CMM | 500 tons increase on the New CMM | 500 tons increase on the New CMM | 4,475 | 8,360 | 4,495 | 4,496 | 8,366 | 4,506 | 1,216 | 4,496 | 8,419 | 4,510 | 1,513 |
| 3 | 10% increase on the New CMM | | | 4,948 | 8,621 | 4,395 | 4,965 | 8,610 | 4,404 | 1,189 | 4,965 | 8,674 | 4,407 | 1,430 |
| 4 | 20% increase on the New CMM | | | 5,420 | 9,382 | 4,794 | 5,434 | 9,307 | 4,801 | 1,150 | 5,435 | 9,413 | 4,802 | 1,318 |
| 5 | -580 tons | +853 tons | New CMM | 3,895 | 8,713 | 3,995 | 3,916 | 8,749 | 4,009 | 1,250 | 3,917 | 8,787 | 4,013 | 1,616 |
| 6 | +30% | +30% | +190% | 5,893 | 10,143 | 11,586 | 5,892 | 10,181 | 11,521 | 996 | 5,889 | 10,018 | 11,247 | 924 |
| 7 | New CMM | +130% | +190% | 4,475 | 17,752 | 11,586 | 4,492 | 17,733 | 11,552 | 1,012 | 4,491 | 17,144 | 11,486 | 1,079 |
| 8 | +60% | +60% | +90% | 7,310 | 12,425 | 7,591 | 7,240 | 12,502 | 7,594 | 979 | 7,211 | 12,073 | 7,512 | 841 |
| 9 | New CMM | +230% | +90% | 4,475 | 25,362 | 7,591 | 4,494 | 23,864 | 7,601 | 1,030 | 4,493 | 24,055 | 7,597 | 1,160 |
| 10 | Old CMM (50% of 2002-04 average level) | Old CMM (2002-04 average level) | Old CMM | 4,475 | 6,841 | 3,300 | 4,497 | 6,866 | 3,317 | 1,243 | 4,497 | 6,888 | 3,319 | 1,580 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

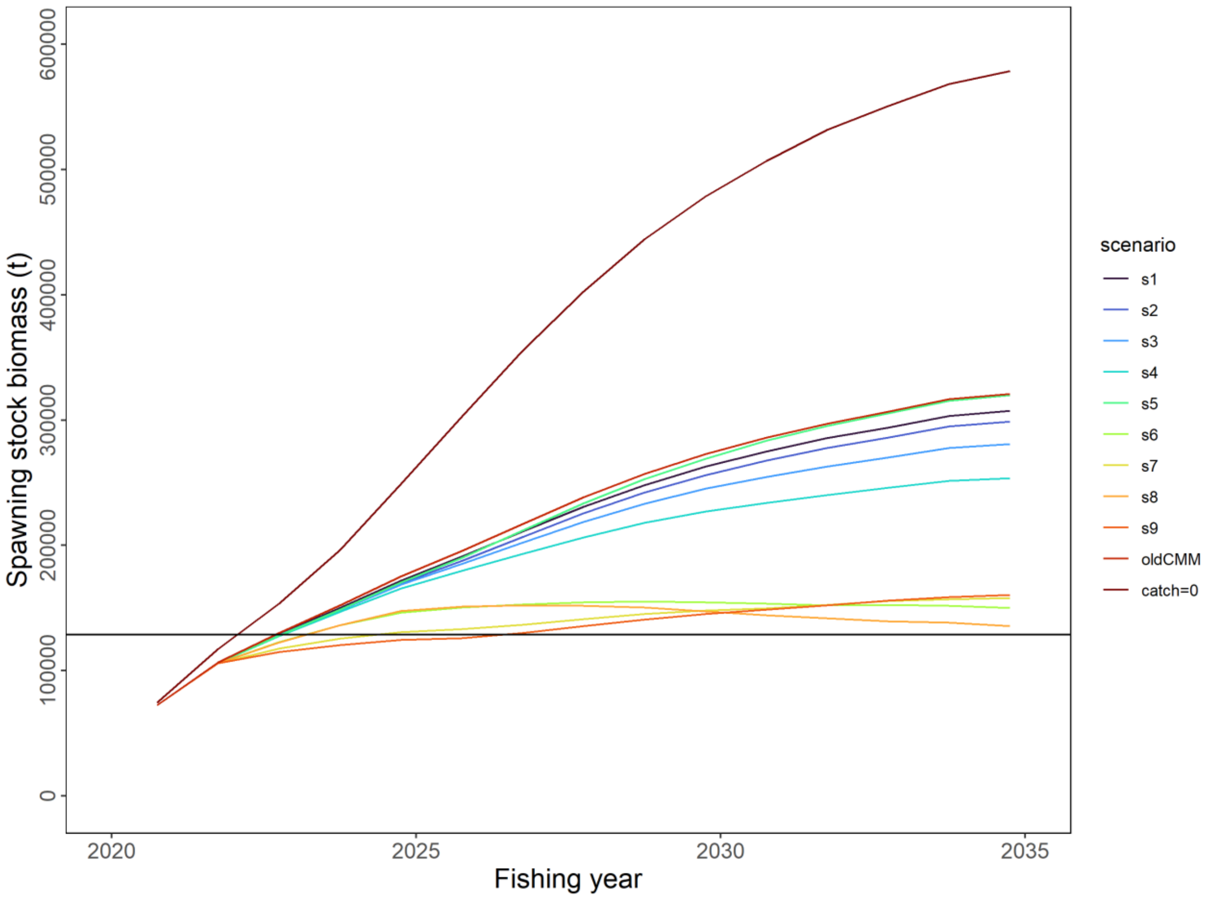


**Figure 9**. Comparisons of various projected median SSB for all harvest scenarios examined for Pacific bluefin tuna (*Thunnus orientalis*) obtained from projection results. The black horizontal solid line shows the second rebuilding target for this species (20%$SSB_{F=0}$).

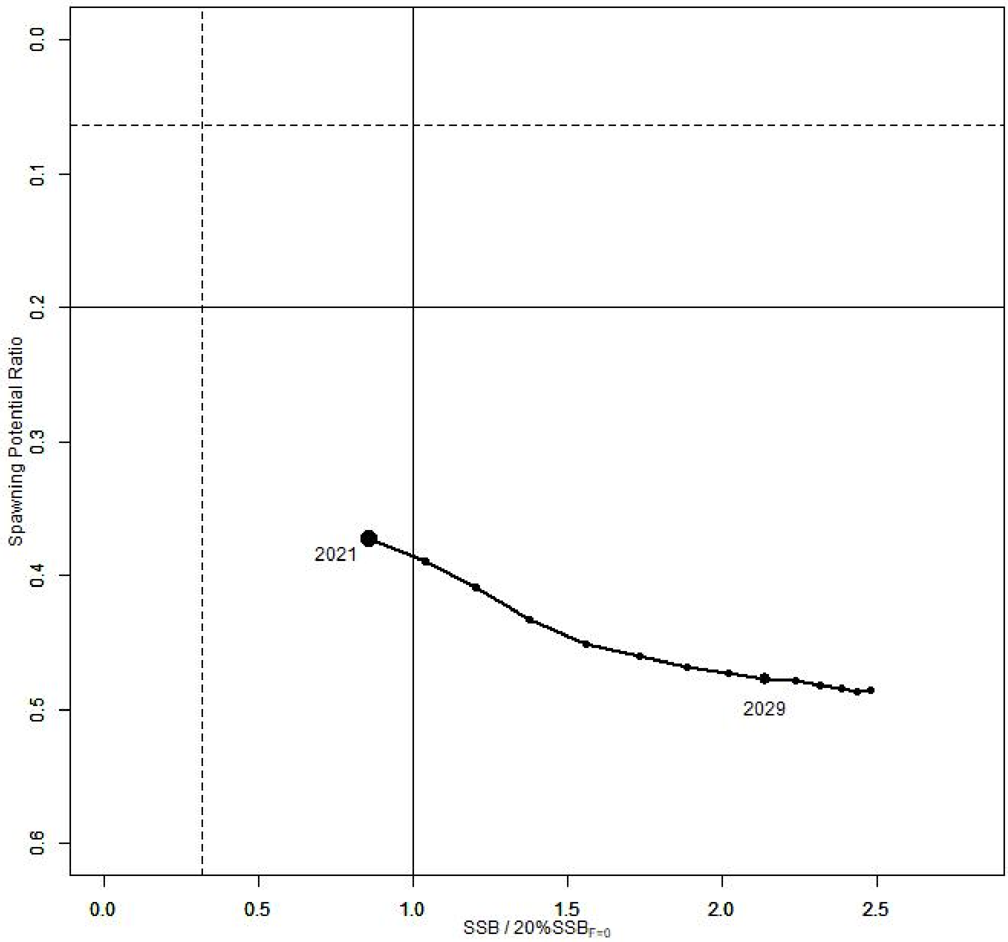


**Figure 10**. "Future Kobe Plot" based on the median estimates of SSB and SPR from the projections for Pacific bluefin tuna (*Thunnus orientalis*) from Scenario 1 from Table 3.

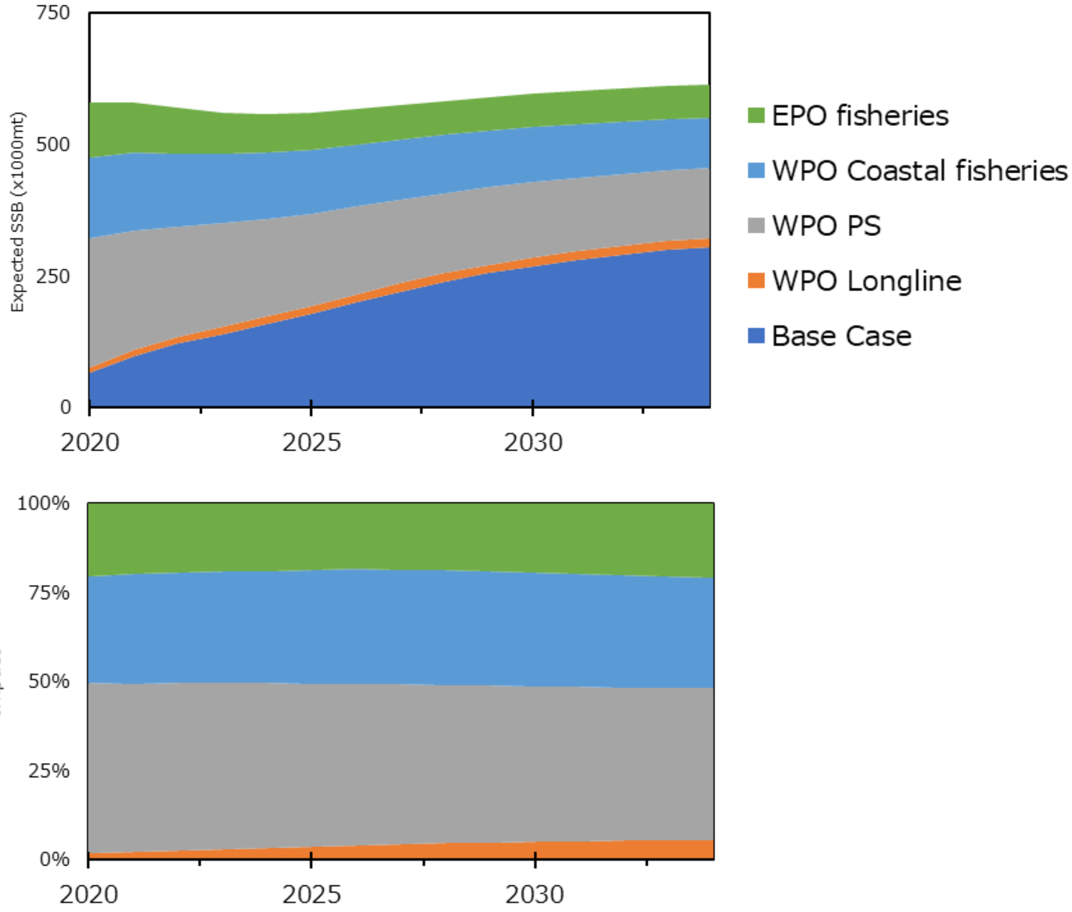


**Figure 11**. "Future impact plot" from projection results for Pacific bluefin tuna (*Thunnus orientalis*) from Scenario 1 of Table 3. The top figure shows absolute biomass and the bottom figure shows relative impacts. The impact is calculated based on the expected increase of SSB in the absence of the respective group of fisheries.