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STATUS OF BIGEYE TUNA IN THE EASTERN PACIFIC OCEAN IN 2017 AND OUTLOOK FOR THE FUTURE

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EXECUTIVE SUMMARY

1. The assessment of bigeye tuna in the eastern Pacific Ocean (EPO) in 2017 uses the same model as the previous assessment, and includes new and updated data.
2. The results of this assessment indicate a recovering trend for bigeye in the EPO during 2005-2009, subsequent to IATTC tuna conservation resolutions initiated in 2004. However, although the resolutions have continued since 2009, the rebuilding trend was not sustained during 2010-2013, and the spawning biomass ratio (the ratio of the current spawning biomass to that of the unfished population; SBR) gradually declined to a historically low level of 0.15 at the start of 2013. This decline could be related to the below-average recruitments in 2007 and 2008, and coincides with a series of particularly strong La Niña events. Thereafter, the SBR is estimated to have increased markedly, from 0.15 in 2013 to 0.23 at the start of 2016, due mainly to the strong recruitment in 2012; in the model, the estimate is driven mainly by the recent increase in the catch per unit of effort (CPUE) of the longline fisheries that catch adult bigeye. It should be noted that after several years of recent increases, the SBR is estimated to have decreased to 0.21 at the start of 2017, due mainly to the decrease in the CPUE of the longline fisheries for bigeye from 2016 to 2017.
3. There is uncertainty about recent and future levels of recruitment and biomass. At current levels of fishing mortality, and if effort and catchability continue at recent levels and average recruitment persists, the spawning biomass is predicted to decrease towards a SBR of 0.17. This level of spawning biomass is below that corresponding to the maximum sustainable yield (MSY) (0.21).
4. According to the base case assessment, recent fishing mortality rates (F) are above the level corresponding to MSY (F_{MSY}), whereas recent spawning biomasses (S) are slightly above that level. This is a substantial change from the previous assessment, which estimated recent fishing mortality rates below the level corresponding to MSY ($F < F_{\mathrm{MSY}}$). These interpretations are subject to uncertainty, but do not exceed the limit reference points; however, they are highly sensitive to the assumptions made about the steepness parameter (h) of the stock-recruitment relationship, the weighting assigned to the size-composition data (in particular to the longline size-composition data), the growth curve, and the assumed rates of natural mortality (M) for bigeye, as shown in previous assessments. An investigation of the reasons for the change in fishing mortality relative to F_{MSY} is described in Document SAC-09 INF-A.

5. The following topics should be a priority in future research into the bigeye stock assessment:
   a. Investigation of the causes of model misspecification responsible for the two-regime recruitment pattern in the bigeye assessment.
   b. Formulation of a growth curve that is more representative of the data.
   c. Weighting of the different data sets.
   d. Fishery definitions.
   e. Stock structure. The IATTC staff will also conduct research aimed at improving the spatial structure in the current bigeye stock assessment model, as well as how best to incorporate the available tagging data. In addition, the staff will continue collaborating with the Secretariat of the Pacific Community (SPC) on a Pacific-wide assessment of bigeye. This will incorporate new tagging data in a spatially-structured population dynamics model, which will help to evaluate potential biases resulting from the current approach of conducting separate assessments for the EPO and the Western and Central Pacific Ocean.
   f. Improving the estimates of natural mortality.
   g. Improving the indices of relative abundance used in the assessment.
   h. Modelling temporal variation in purse-seine selectivity.

1. UPDATE ASSESSMENT

This report presents the key results of an update stock assessment of bigeye tuna (*Thunnus obesus*) in the eastern Pacific Ocean (EPO), conducted using an integrated statistical age-structured stock assessment model (Stock Synthesis 3.23b). "Update" stock assessment means that the base case model used in this assessment is the same as that used in the previous full assessment, conducted in 2016 (Document SAC-07-05a), and that only the data used in the model have been updated. The Stock Synthesis assessment model produces an extensive series of model output results and fit diagnostics. These are available for the base case model in html and pdf formats.

Bigeye tuna are distributed across the Pacific Ocean, but the bulk of the catch is made towards the eastern and western ends of the ocean basin. The purse-seine catches of bigeye are substantially lower close to the western boundary of the EPO at 150°W; the longline catches are more continuous, but relatively low between 160°W and 180°. Bigeye are not often caught by purse seiners in the EPO north of 10°N, but a portion of the longline catches of bigeye in the EPO is taken north of that parallel.

The assessment is conducted as if there were a single stock of bigeye in the EPO, with minimal net movement of fish between the EPO and the western and central Pacific Ocean (WCPO). The results are consistent with those of other Pacific-wide analyses of bigeye. However, a large amount of conventional and electronic tagging data has recently become available from the SPC's Pacific Tuna Tagging Programme, which has focused its efforts between 180° and 140°W since 2008. The tag recoveries clearly show that there is extensive longitudinal movement of bigeye across the IATTC's management boundary at 150°W, in particular from west to east. The IATTC staff will continue to collaborate with SPC on research into a Pacific-wide stock assessment model for bigeye. This will incorporate the new tagging data in a spatially-structured population dynamics model, which will help in the ongoing evaluation of potential biases resulting from ignoring exchange of fish across the WCPO-EPO boundary in the current approach of conducting separate assessments for the EPO and WCPO.

A major modeling challenge, recognized in the Pacific-wide bigeye research, is possible misspecification in the model resulting from assuming common growth rates for bigeye across the Pacific, while available studies indicate regional differences. The staff of the SPC recently constructed a Pacific-wide stock assessment model to test the sensitivity of management advice for the WCPO to the assumption that the dynamics of bigeye in the EPO can effectively be ignored when conducting WCPO stock assessments (McKechnie *et al*. 2015). The results indicated that the dynamics of bigeye in the WCPO estimated by the

Pacific-wide model are not substantially different from those estimated by the WCPO-only model, and that it is therefore reasonable to continue to make management recommendations to the Western and Central Pacific Fisheries Commission (WCPFC) on the basis of WCPO regional assessment models. Investigations into the spatial structure of the assessment have indicated that the apparent regime shift in recruitment is likely a consequence of stock-structure misspecification (Document SAC-09-08), and further work on a spatial stock assessment is planned.

The stock assessment requires a substantial amount of information. Data on retained catch, discards, catch per unit of effort (CPUE), and size compositions of the catches from several different fisheries have been analyzed. Several assumptions regarding processes such as growth, recruitment, movement, natural mortality (*M*), and fishing mortality (*F*), have also been made. Catch and CPUE data for the surface fisheries have been updated, and include new data for 2017. New or updated longline catch data were available for China (2016-2017), Japan (2015-2017), Korea (2016-2017), Chinese Taipei (2014-2017), the United States (2015-2016), French Polynesia (2016), Vanuatu (2017) and other nations (2014-2016). Longline catch data for 2017 were available for China, Japan, Chinese Taipei, and Korea from the monthly report statistics. For longline fisheries with no catch data, catches were assumed to be the same as in the previous year. New or updated CPUE data were available for the Japanese longline fleet for 2015-2017. New purse-seine length-frequency data were available for 2017, and data from previous years were updated. New or updated Japanese longline length-frequency data were also available for commercial (2014-2015) and training (2014 and 2016) vessels.

A prominent feature in the time series of estimated bigeye recruitments is that the highest recruitment peaks of 1982-1983 and 1998 coincide with the strongest El Niño events during the historic period of the assessment (Figure 1). There was a period of above-average annual recruitment during 1994-1998, followed by below-average recruitments in 1999 and 2000. Recruitment was above average from 2001 to 2006, and was particularly strong in 2005; this was followed by below-average recruitment in 2007 and average recruitment in 2008. The 2009-2017 period was dominated by above-average recruitments; it was particularly strong in 2012. The most recent estimates (2015-2017) are highly uncertain, and should be regarded with caution, since recently-recruited bigeye are represented in only a few length-frequency data sets, and the length-frequency data are down weighted. Over the range of spawning biomasses estimated by the base case assessment, the abundance of bigeye recruits appears to be unrelated to the spawning potential of adult females at the time of spawning.

During 2005-2008, the spawning biomass ratio (SBR; the ratio of the spawning biomass at that time to that of the unfished stock) gradually increased to 0.24 at the start of 2009, probably due to the combined effect of above-average recruitment during 2001-2006, the IATTC tuna conservation resolutions that started in 2004, and decreased longline fishing effort in the EPO during 2004-2008. However, although the resolutions have continued since 2009, the rebuilding trend was not sustained during 2010-2013, and the SBR gradually declined to a low historic level of 0.15 at the start of 2013 (Figure 2). This decline could be related to the below-average recruitments in 2007-2008, and coincides with a series of particularly strong La Niña events. Thereafter, the SBR is estimated to have increased markedly, from 0.15 in 2013 to 0.23 at the start of 2016; in the model, the estimate is driven mainly by the recent increase in the CPUE of the longline fisheries that catch adult bigeye, which can be attributed to the strong recruitment in 2012. It should be noted that after several years of recent increases, the SBR is estimated to have decreased to 0.21 at the start of 2017, which is due mainly to the decrease in the CPUE of the longline fisheries for bigeye after 2016.

There have been important changes in the amount of fishing mortality (*F)* caused by the fisheries that catch bigeye tuna in the EPO. On average, since 1993 the fishing mortality of bigeye less than about 8 quarters old has increased substantially. For fish more than about 8 quarters old, *F* also increased initially, but then fluctuated around a constant level (Figure 3). The increase in the fishing mortality of the younger fish was caused by the expansion of the purse-seine fisheries that catch tuna in association with fish-aggregating devices (FADs). It is clear that the longline fishery had the greatest impact on the stock prior to 1995, but with the decrease in longline effort and the expansion of the FAD fishery, at present the impact of the purse-seine fishery on the bigeye stock is far greater than that of the longline fishery (Figure 4). Discards of small bigeye by the purse-seine fishery have a small, but detectable, impact on the depletion of the stock.

According to the base case results, at the beginning of 2017 the spawning biomass (S) of bigeye in the EPO was about 2% above the level corresponding to the maximum sustainable yield (S_{MSY}), and the recent catches are estimated to have been about 15% higher than the MSY level. If fishing mortality is proportional to fishing effort, and the current patterns of age-specific selectivity are maintained, the current level of fishing effort is estimated to be about 13% higher than the level of fishing mortality corresponding to MSY (F_{MSY}) (Table 1). This is a substantial change from the previous assessment, which estimated F_{MSY} to be about 15% higher than the current level of fishing effort. However, there is substantial uncertainty in the estimate of the current fishing mortality and in the model assumptions used. An investigation of the cause of this change concluded that it is mainly due to new and updated data in the stock assessment (SAC-09 INF-A).

The most recent estimate from the base case assessment indicates that the bigeye stock in the EPO is not overfished (S>S_{MSY}), but that overfishing is taking place (F>F_{MSY}) (Figure 5). The current base case model indicates that the limit reference points of 0.38 S_{MSY} and 1.6 F_{MSY}, which correspond to a 50% reduction in recruitment from its average unexploited level based on a conservative steepness value (h = 0.75) for the Beverton-Holt stock-recruitment relationship, have not been exceeded (Figure 5). These interpretations, however, are subject to uncertainty, as indicated by the approximate confidence intervals around the most recent estimate in the phase plots, which includes F<F_{MSY} and S<S_{MSY}, but they do not exceed the limit reference points. Note that the confidence intervals consider only parameter estimation uncertainty, and do not include uncertainty in fixed parameters or model structure. As illustrated in the previous assessment (SAC-07-05a), the interpretations of stock status are strongly dependent on the assumptions about the steepness parameter (h) of the stock-recruitment relationship, the assumed levels of juvenile and adult natural mortality (M), the growth curve, and the weighting assigned to the size-composition data.

The MSY of bigeye in the EPO could be maximized if the age-specific selectivity pattern were similar to that of the longline fisheries, because they catch larger individuals that are close to the critical weight (the weight at which fish should ideally be caught to maximize yield per recruit). Before the expansion of the FAD fishery that began in 1993, the MSY was greater than the current MSY and the fishing mortality was much less than F_{MSY} (Figure 6).

At current levels of fishing mortality, and if recent levels of effort and catchability continue and average recruitment levels persist, the spawning biomass is predicted to decrease towards a SBR of 0.17, which is below the level corresponding to MSY (Figure 2). It is estimated that catches will be similar in the future at current levels of fishing effort (Figure 7). These simulations are based on the assumption that selectivity and catchability patterns will not change in the future. Changes in targeting practices or increased catchability of bigeye as abundance declines (*e.g.* density-dependent catchability) could result in differences from the outcomes predicted here.

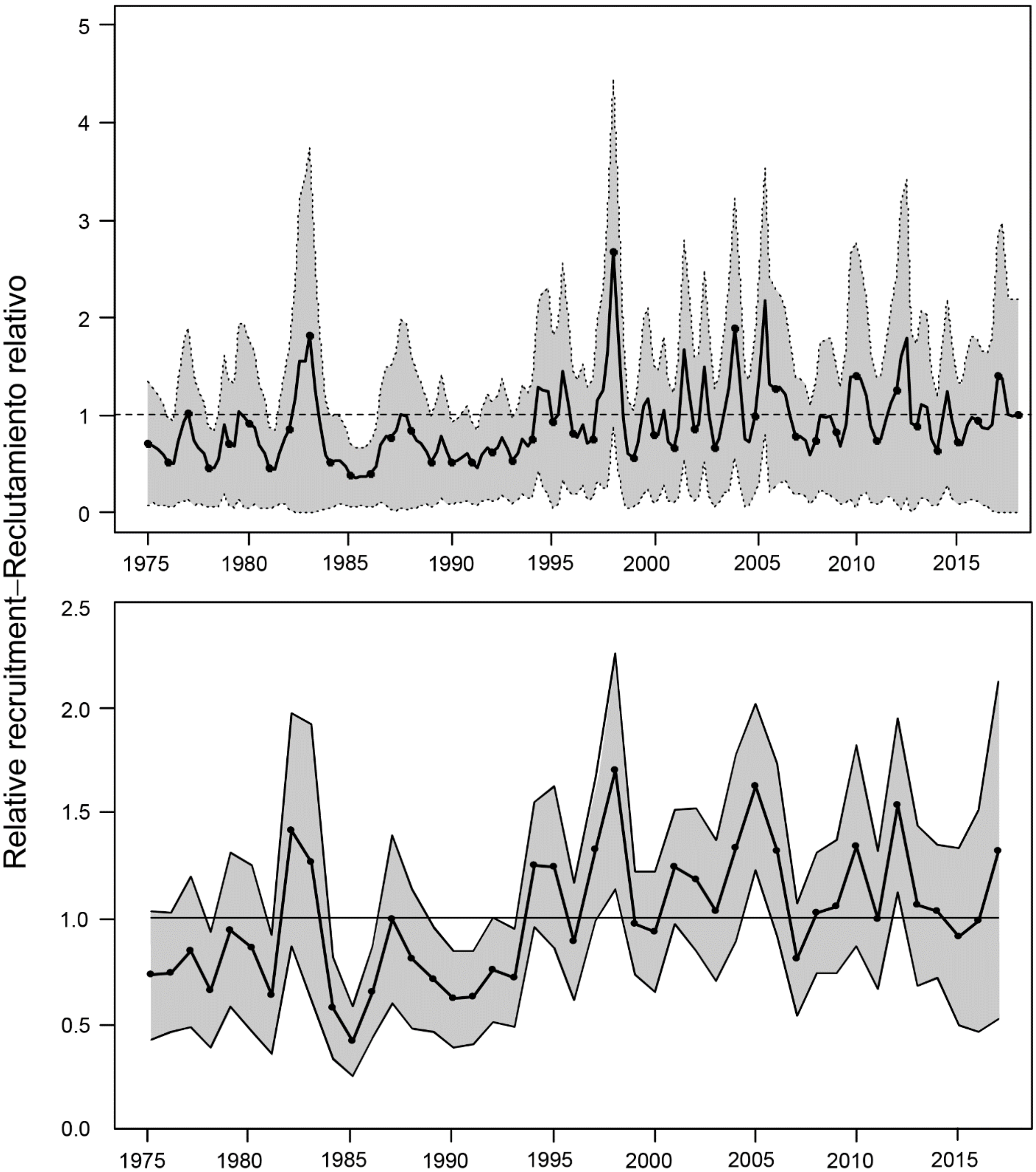

FIGURE 1. Estimated quarterly (top panel) and annual (bottom panel) recruitment of bigeye tuna to the fisheries of the EPO. The estimates are scaled so that the estimate of virgin recruitment is equal to 1.0 (dashed horizontal line). The solid line shows the maximum likelihood estimates (MLE) of recruitment, and the shaded area indicates the approximate 95% intervals around those estimates.

FIGURA 1. Reclutamiento estimado trimestral (recuadro superior) y anual (recuadro inferior) de atún patudo a las pesquerías del OPO. Se fija la escala de las estimaciones para que la estimación de reclutamiento virgen equivalga a 1.0 (línea de trazos horizontal). La línea sólida indica las estimaciones de verosimilitud máxima (EVM) del reclutamiento, y el área sombreada indica los intervalos de confianza de 95% aproximados de esas estimaciones.

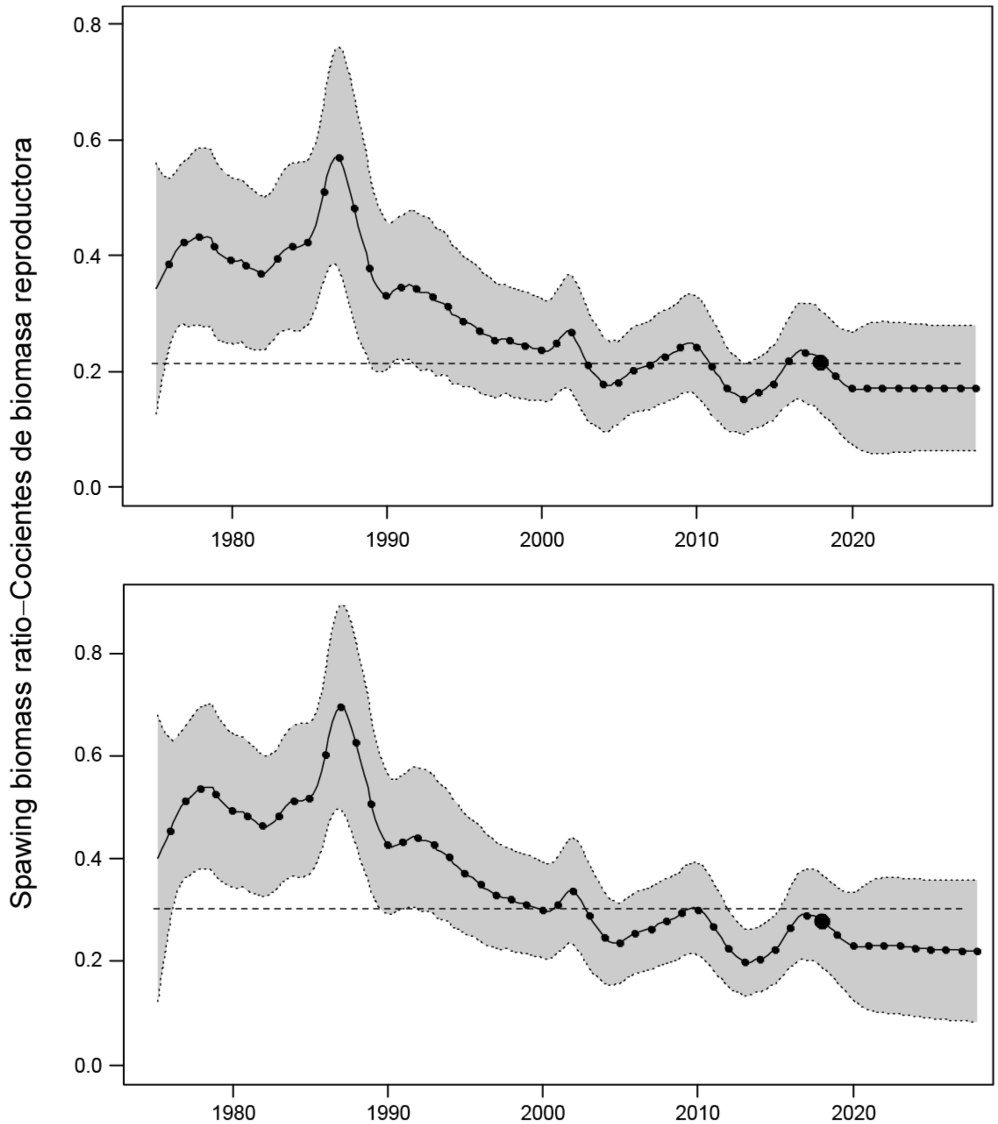

FIGURE 2. Estimated spawning biomass ratios (SBRs) of bigeye tuna in the EPO, including projections for 2018-2028 based on average fishing mortality rates during 2015-2017, from the base case (top panel) and the sensititivty analysis that assumes a stock-recruitment relationship (*h* = 0.75, bottom panel). The dashed horizontal line (at 0.21 and 0.30, respectively) identifies the SBR at MSY. The solid line illustrates the maximum likelihood estimates, and the estimates after 2018 (the large dot) indicate the SBR predicted to occur if fishing mortality rates continue at the average of that observed during 2015-2017, and recruitment is average during the next 10 years. The shaded area indicates the approximate 95-percent confidence intervals around those estimates.

FIGURA 2. Cocientes de biomasa reproductora (SBR) estimados de atún patudo en el OPO, incluyendo proyecciones para 2018-2028 basadas en las tasas medias de mortalidad por pesca durante 2015-2017, del caso base (recuadro superior) y el análisis de sensibilidad que supone una relación población-reclutamiento (*h* = 0.75, recuadro inferior). La línea de trazos horizontal (en 0.21 y 0.30, respectivamente) identifica SBR_{RMS}. La línea sólida ilustra las estimaciones de verosimilitud máxima, y las estimaciones a partir de 2018 (el punto grande) señalan el SBR que se predice occurrirá si las tasas de mortalidad por pesca continúan en el promedio observado durante 2015-2017 y el reclutamiento es promedie durante los 10 años próximos. El área sombreada representa los intervalos de confianza de 95% alrededor de esas estimaciones.

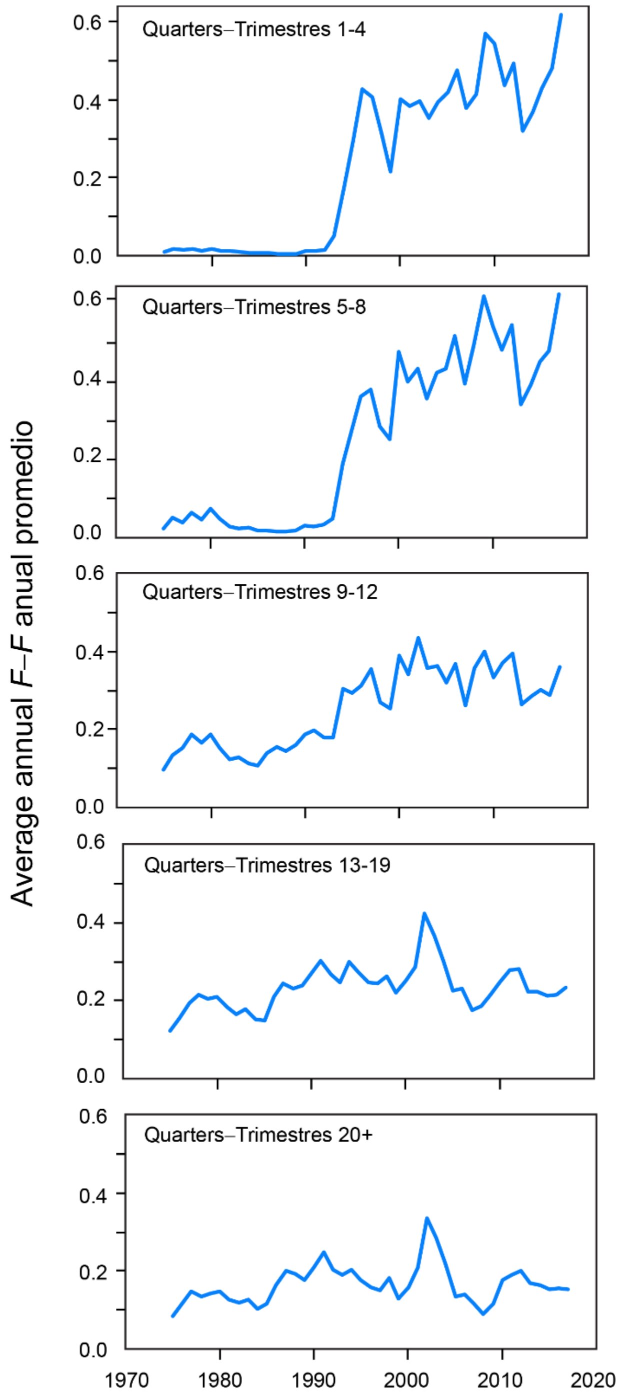

FIGURE 3. Average annual fishing mortality, by all gears, of bigeye tuna recruited to the fisheries of the EPO. Each panel illustrates the average fishing mortality rates that affected the fish within the range of ages, in quarters, indicated in the title of each panel. For example, the trend illustrated in the top panel is an average of the fishing mortalities that affected the fish that were 1-4 quarters old.
FIGURA 3. Mortalidad por pesca anual media, por todas las artes, de atún patudo reclutado a las pesquerías del OPO. Cada recuadro ilustra las tasas medias de mortalidad por pesca que afectaron a los peces de la edad, en trimestres, indicada en el título de cada recuadro. Por ejemplo, la tendencia ilustrada en el recuadro superior es un promedio de las mortalidades por pesca que afectaron a los peces de entre 1 y 4 trimestres de edad.

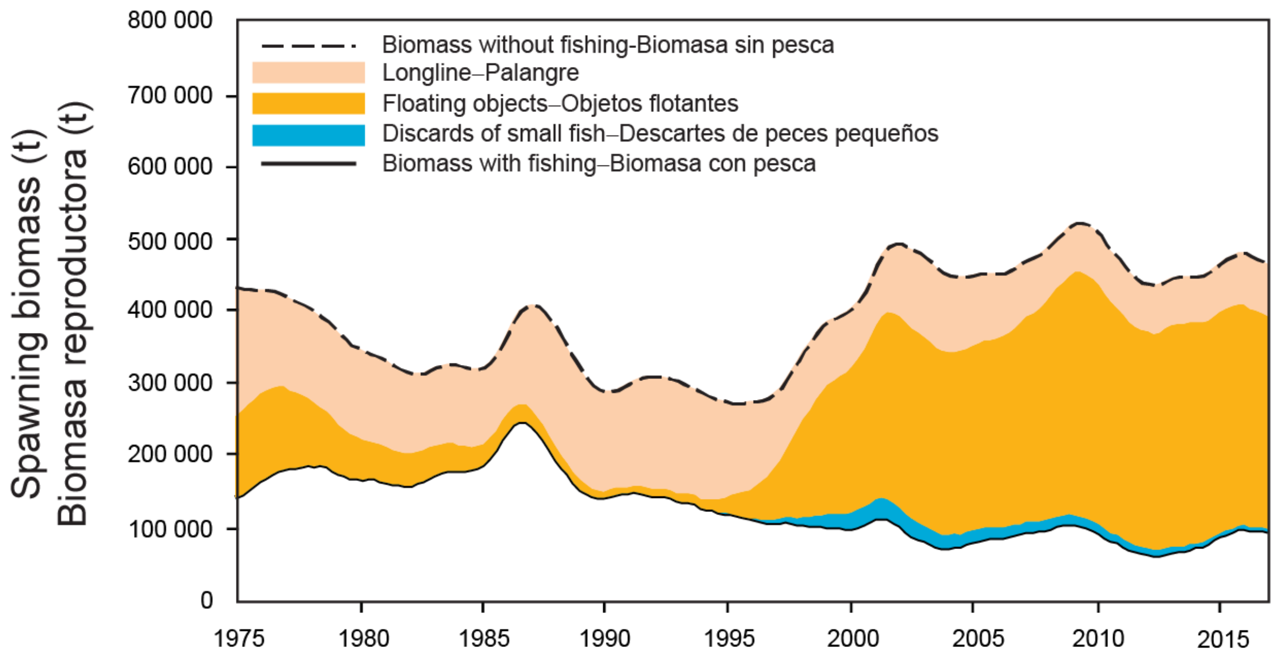

FIGURE 4. Trajectory of the spawning biomass of a simulated population of bigeye tuna that was not exploited (top line) and that predicted by the stock assessment model (bottom line). The shaded areas between the two lines show the portions of the impact attributed to each fishing method. t = metric tons.

FIGURA 4. Trayectoria de la biomasa reproductora de una población simulada de atún patudo no explotada (línea superior) y la que predice el modelo de evaluación (línea inferior). Las áreas sombreadas entre las dos líneas señalan la porción del efecto atribuida a cada método de pesca. t = toneladas métricas.

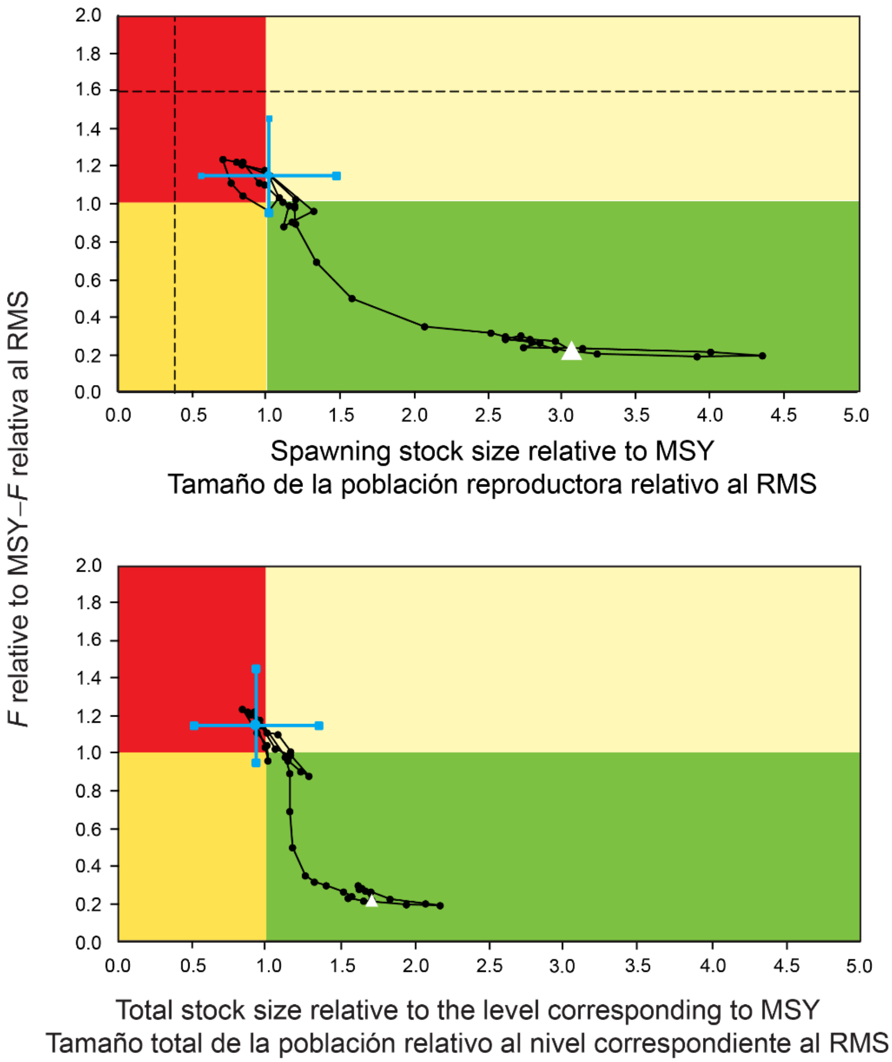

FIGURE 5. Kobe (phase) plot of the time series of estimates of spawning stock size (top panel: spawning biomass; bottom panel: total biomass aged 3+ quarters) and fishing mortality relative to their MSY reference points. The colored panels represent target reference points (S_{MSY} and $F_{MSY;}$ solid lines) and limit reference points (dashed lines) of 0.38 S_{MSY} and 1.6 F_{MSY}, which correspond to a 50% reduction in recruitment from its average unexploited level based on a conservative steepness value (h = 0.75) for the Beverton-Holt stock-recruitment relationship. Each dot is based on the average fishing mortality rate over three years; the large dot indicates the most recent estimate. The squares around the most recent estimate represent its approximate 95% confidence interval. The triangle represents the first estimate (1975).

FIGURA 5. Gráfica de Kobe (fase) de la serie de tiempo de las estimaciones del tamaño de la población reproductora (panel superior: biomasa reproductora; panel inferior: biomasa total de edad 3+ trimestres) y la mortalidad por pesca relativas a sus puntos de referencia de RMS. Los recuadros colorados representan los puntos de referencia objetivo provisionales (S_{RMS} y $F_{RMS;}$ líneas sólidas) y los puntos de referencia límite (líneas de trazos) de 0.38 S_{RMS} y 1.6 F_{RMS}, que corresponden a una reducción de 50% del reclutamiento de su nivel medio no explotado basada en un valor cauteloso (h = 0.75) de la inclinación de la relación población-reclutamiento de Beverton-Holt. Cada punto se basa en la tasa de explotación media de un trienio; el punto grande indica la estimación más reciente. Los cuadros alrededor de la estimación más reciente representan su intervalo de confianza de 95% aproximado. El triángulo representa la primera estimación (1975).

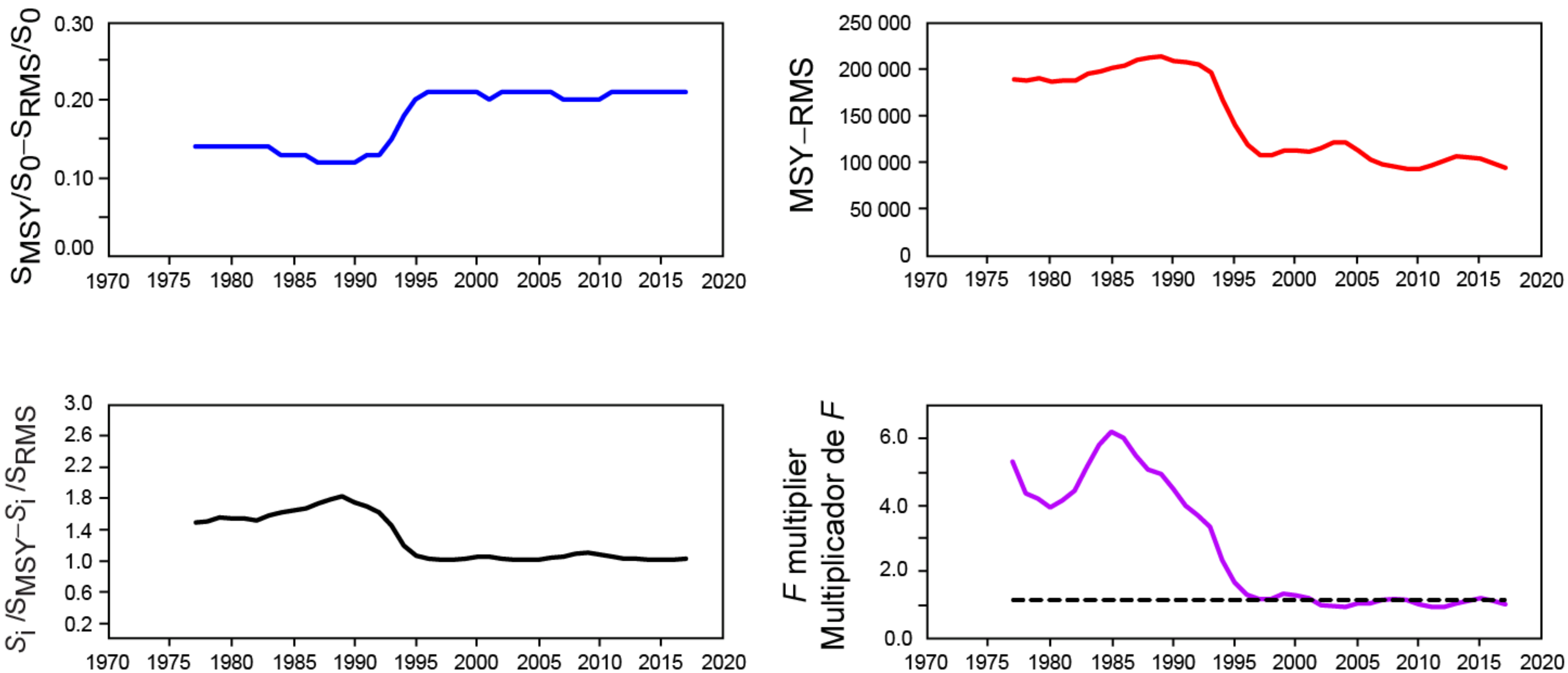

FIGURE 6. Estimates of MSY-related quantities calculated using the average age-specific fishing mortality for each year. (S_i is the spawning biomass at the end of the last year in the assessment.)

FIGURA 6. Estimaciones de cantidades relacionadas con el RMS calculadas usando la mortalidad por pesca media por edad de cada año. (S_i es la biomasa reproductora al fin del último año en la evaluación.

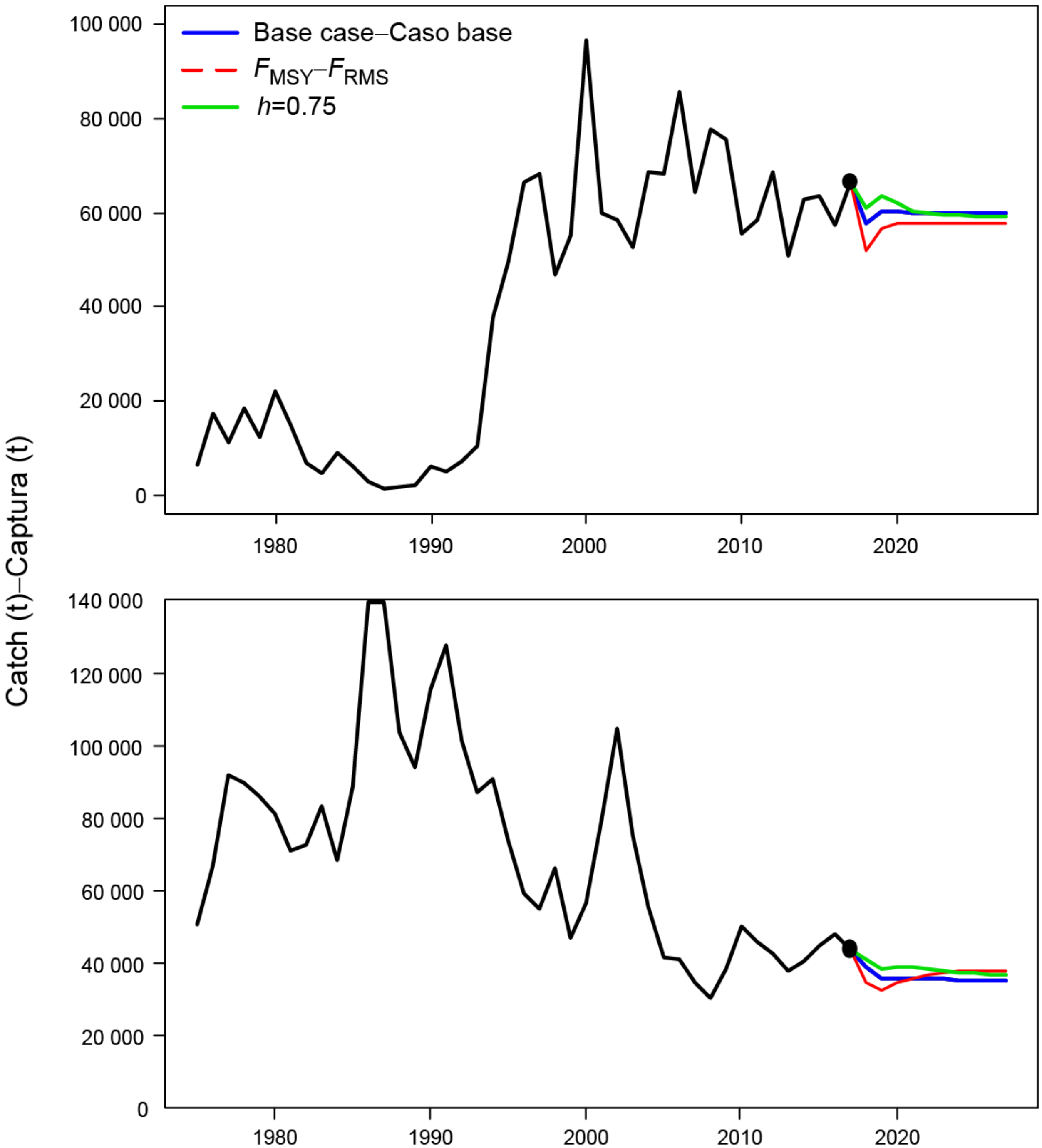

FIGURE 7. Historic and projected annual catches of bigeye tuna over a period of 10 years by surface (top panel) and longline (bottom panel), based on fishing mortality rates during 2015-2017. Projected catches are compared between the base case, the analysis assuming F_{MSY}, and the analysis in which a stock-recruitment relationship (h = 0.75) was used. t = metric tons.

FIGURA 7. Capturas anuales históricas y proyectadas de atún patudo durante un decenio por las pesquerías de superficie (recuadro superior) y de palangre (recuadro inferior), basadas en las tasas de mortalidad por pesca durante 2015-2017. Se comparan las capturas proyectadas entre el caso base, el análisis que supone F_{RMS}, y el análisis en el que se usa una relación población-reclutamiento (h = 0.75). t = toneladas.

TABLE 1. Estimates of the MSY and its associated quantities for bigeye tuna for different assumptions on steepness (*h*). All analyses are based on average fishing mortality during 2015-2017. B_{recent} and B_{MSY} are defined as the biomass of fish 3+ quarters old (in metric tons) at the beginning of 2018 and at MSY, respectively. S_{recent} and S_{MSY} are in metric tons. C_{recent} is the estimated total catch in 2017. The *F* multiplier indicates how many times effort would have to be effectively increased to achieve the MSY in relation to the average fishing mortality during 2015-2017.

TABLA 1. Estimaciones del RMS y sus cantidades asociadas para el atún patudo correspondientes a distintos supuestos de la inclinación (*h*). Todos los análisis se basan en la mortalidad por pesca promedio de 2015-2017. Se definen B_{recent} y B_{RMS} como la biomasa de peces de 3+ trimestres de edad (en toneladas) al principio de 2018 y en RMS, respectivamente. Se expresan S_{recent} y S_{MSY} en toneladas. C_{recent} es la captura total estimada en 2016. El multiplicador de *F* indica cuántas veces se tendría que incrementar el esfuerzo para lograr el RMS en relación con la mortalidad por pesca media durante 2015-2017.

	Base case-Caso base	***h* = 0.75**
MSY-RMS	95,491	97,766
B_{MSY}- B_{RMS}	371,078	718,860
S_{MSY}- S_{RMS}	93,329	200,723
B_{MSY}/B_0- B_{RMS}/B_0	0.26	0.33
S_{MSY}/S_0- S_{RMS}/S_0	0.21	0.30
C_{recent}/MSY- C_{recent}/RMS	1.15	1.13
B_{recent}/B_{MSY}- B_{recent}/B_{RMS}	0.91	0.85
S_{recent}/S_{MSY}-S_{recent}/S_{RMS}	1.02	0.92
F multiplier-Multiplicador de *F*	0.87	0.80