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INVESTIGATION OF THE SUBSTANTIAL CHANGE IN THE ESTIMATED *F* MULTIPLIER FOR BIGEYE TUNA IN THE EASTERN PACIFIC OCEAN

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CONTENTS

Executive summary 1
1. Introduction 1
2. Possible sources of interannual change in the *F* multiplier 2
3. Plan to improve the assessment 4
4. Proposed workplan: 5
References 5

EXECUTIVE SUMMARY

The *F* multipliers estimated in the assessments of bigeye and yellowfin tuna in the eastern Pacific Ocean are used as a basis for the IATTC scientific staff's recommendations for management measures, specifically the duration of the seasonal closures. Therefore, they are the most influential management quantities estimated by the stock assessment models. The *F* multiplier for bigeye estimated in the SAC-09 assessment (0.87; SAC-09-05) is substantially lower than that estimated in the SAC-08 assessment (1.15; SAC-08-04a). This is due mainly to the new data for the indices of relative abundance, based on longline CPUE, which resulted in lower estimates of recent biomass. The new length-composition data incorporated in the SAC-09 assessment also contribute to a lower *F* multiplier; additionally, there is substantial uncertainty in the estimates of the *F* multiplier and in the model assumptions. The IATTC staff has developed a comprehensive work plan to address this uncertainty and model misspecification, which will greatly improve the assessment of the bigeye tuna stock.

1. INTRODUCTION

The *F* multipliers[1] estimated in the assessments of bigeye and yellowfin tunas in the eastern Pacific Ocean (EPO) are used as a basis for the IATTC scientific staff's recommendations for management measures, specifically the duration of the seasonal closures. Therefore, they are the most influential management quantities estimated by the stock assessment models.

An *F* multiplier of 1.0 means that the fishery is meeting the management goal of fishing at the level of the maximum sustainable yield ($F_{current} = F_{MSY}$); if it is below 1.0, fishing mortality is excessive ($F_{current} > F_{MSY}$). Multiplying fishing mortality (or effort) by the *F* multiplier will move the fishery towards that goal;

[1] *F* multiplier = F_{MSY} (the fishing mortality that will produce the maximum sustainable yield) divided by $F_{current}$ (the average fishing mortality for the three most recent years).

specifically, the *F* multiplier of 0.87 estimated for bigeye in the SAC-09 assessment means that, for the fishery to reach that goal, the fishing mortality would have to be reduced to 87% of its average level during 2015-2017.

Resolution C-17-02, the management measure for tropical tunas currently in force, states that "In order to evaluate progress towards the objectives of these measures, in each year the IATTC scientific staff will analyze the effects on the stocks of the implementation of these measures, and previous conservation and management measures, and will propose, if necessary, appropriate measures to be applied in future years."

The *F* multiplier of 0.87 for bigeye tuna estimated in the SAC-09 assessment ("SAC-09"; Document SAC-09-05) is 24% lower than the 1.15 estimated in the SAC-08 assessment ("SAC-08"; SAC-08-04a). This substantial and surprising change is the largest inter-annual difference in the *F* multiplier seen in an update assessment[2] since the IATTC scientific staff initiated integrated stock assessments in 2000. Therefore, the staff carefully investigated the reasons for this change before considering the new *F* multiplier as a basis for its management advice, and presents its conclusions in this report.

The report discusses the three components that could have caused the change in the *F* multiplier (the years included in the three-year average, new or updated data in the stock assessment, and different model assumptions), as well as the uncertainty in the stock assessment and in the relationship between fishing mortality and fishing effort. It also outlines the Stock Assessment Program's workplan to improve the stock assessment and management advice.

2. POSSIBLE SOURCES OF INTERANNUAL CHANGE IN THE *F* MULTIPLIER

2.1. Years used to calculate recent fishing mortality

The SAC-08 assessment used 2014-2016 as the "current" years of estimated fishing mortality (*F*) to calculate the *F* multiplier, whereas the SAC-09 assessment used 2015-2017. Therefore, the change in the *F* multiplier could partially be explained if the *F* in 2017 (the year added in the SAC-09 assessment) was higher than the *F* in 2014 (the year removed in the SAC-09 assessment). However, F_{MSY} is also dependent on the age-specific *F* (a function of the proportions of the catch taken by the different fisheries), and therefore will be affected by any differences in the age-specific *F* for 2014 and 2017. There is little difference in the relative age-specific *F* among years, except that the increase in *F* affects mainly the younger fish, which are caught by the purse-seine fishery on floating objects (Figure 1). The SAC-09 estimated *F* for the main ages (quarters 2-7) caught by that fishery in 2017 was around 60-70% higher than in 2014.

The influence of the change in years was investigated by repeating the SAC-08 assessment with the 2017 catches included in the SAC-09 assessment (1). The results were as follows:

		Resulting *F* multiplier based on:	
	Description	2015-2017	2014-2016
	SAC-09 assessment	0.87	0.97
	SAC-08 assessment	N/A	1.15
(1)	SAC-08 + 2017 catch from SAC-09	1.13	1.15

The resulting *F* multiplier based on the 2014-2016 period (1.15; see Table 1) was the same as that estimated in the SAC-08 assessment (SAC-08-04a), as is to be expected since the data used in the model to estimate the parameters did not change. The *F* multiplier based on the 2015-2017 period fell to 1.13,

[2] "Update" stock assessment means that the base case model used in the assessment is the same as that used in the previous full assessment, and that only the data used in the model have been updated.

accounting for 7% of the total decline. This analysis assumes average recruitment in 2017, which may bias the estimate. To further investigate the effect of changing the years, the SAC-09 assessment was also used to estimate the *F* multiplier using the 2014-2016 average; the resulting *F* multiplier (0.97) accounted for 36% of the total decline.

These results indicate that the proportion of the reduction explained by the change in the years included in the "current" period is probably somewhere between 7 and 36%. Note that because the change in fishing mortality over these years is larger in the SAC-09 assessment than the SAC-08 assessment (Figure 1), the effects of years used and new and updated data are confounded.

2.2. New and updated data

The SAC-09 assessment included both new and updated data not included in the SAC-08 assessment. The new data included purse-seine catch and length composition (LF) data for 2017, longline catch data for 2017, and longline CPUE data for the last quarter of 2016 (Q4) and the first three quarters of 2017 (the data for the last quarter for 2017 are not used because they are incomplete). The updated data included a variety of catch data for both the purse-seine and longline fisheries, length-composition data for the purse-seine (last quarter of 2016) and longline (2014-2015) fisheries, and longline CPUE data for the first three quarters of 2016. We investigated the effect of including the new data by running the SAC-09 assessment (1) without the new CPUE or composition data; (2) without the new CPUE data; and (3) without the new composition data. The results were as follows:

		Resulting *F* multiplier based on:	
	Description	2015-2017	2014-2016
	SAC-09 assessment	0.87	0.97
	SAC-08 assessment	N/A	1.15
(1)	SAC-09 without 2017 LF or CPUE >= Q4 2016	1.05	1.09
(2)	SAC-09 without CPUE >= Q4 2016	0.96	1.03
(3)	SAC-09 without 2017 LF	0.91	0.99

The new and updated catch data (1) had a moderate impact on the *F* multiplier (the 2014-2016 based *F* multiplier changed from 1.15 to 1.09, for example), while the new CPUE (3) and composition (2) data both greatly reduced the *F* multiplier, with the CPUE having the larger effect. The change in estimates of recent *F* from SAC-08 to SAC-09, and the larger inter-annual changes in the SAC-09 estimates, can be clearly seen in Figure 1. Only the longline CPUE-based indices of relative abundance are used in the assessments, and both show a reduction in CPUE in the new data (Figures 2 and 3). These CPUE data, in combination with the new composition data, resulted in lower estimates of recent spawning biomass and total biomass in the SAC-09 assessment than in the SAC-08 assessment (Figure 4).

2.3. Stock assessment uncertainty

There is substantial uncertainty in the bigeye assessment, caused by both the assumed sampling variation in the data and uncertainty in the model assumptions. The sampling variation is represented by the assumed sample size for the length-composition data and the standard deviations for the longline CPUE-based indices of relative abundance, and is manifested in the parameter estimation uncertainty. Both these assumptions are chosen arbitrarily. The two indices based on longline CPUE are assumed to be the main pieces of information for the assessment model. The sample size for the composition data was greatly reduced to minimize the apparent regime shift in recruitment, which is thought to be a consequence of misspecification of the spatial structure of the model (see SAC-09-08). The uncertainty in the *F* multiplier is illustrated using a likelihood component profile over virgin recruitment (R_0), which defines absolute scale in the model, and presenting management quantities following the approaches of

Maunder and Starr (2001) and Wang *et al*. (2014). The results show that there is considerable uncertainty in the estimated *F* multiplier (Figure 5), with the approximate 95% confidence interval ranging from about 0.69 to 1.2. The CPUE has a much larger influence on the *F* multiplier, which appears to be estimated based on a tradeoff between the CPUE likelihood and the penalty on the quarterly recruitment deviates.

The *F* multiplier is also sensitive to the model assumptions (Figure 6). Typically, stock assessment models show more sensitivity to model assumptions than the parameter uncertainty. The bigeye assessment shows substantial uncertainty to several model assumptions, including the weighting given to the composition data, the steepness of the stock-recruitment relationship, the natural mortality rate (Aires-da-Silva and Maunder 2014; Figure 6), and the asymptotic length (Zhu *et al*. 2016). The *F* multiplier is also likely to be sensitive to the misspecified stock structure that has been identified in the bigeye assessment and is probably the cause of the apparent regime shift in recruitment (SAC-09-08). Other parameters misspecified in the model include the growth curve (Maunder *et al*. 2018), time-varying selectivity for the purse-seine fisheries, and changes in the Japanese longline fishery (*e.g*. changes in targeting and shrinking of the spatial distribution of the effort), whose CPUE is used as a basis for the indices of relative abundance.

The change in the *F* multiplier from SAC-08 to SAC-09 is greater than the growth in capacity of the fleet (Table 2) from 2016 to 2017, and therefore the change cannot be solely due to changes in capacity. Three other factors could be involved: (1) uncertainty in the assessment; (2) CPUE not being proportional to abundance; and (3) fishing mortality not being proportional to fleet capacity. The change appears to be mainly due to the inclusion of the new data, which indicates that the model is misspecified: if the model were correctly specified and the data are informative, such large changes in the *F* multiplier are unlikely. The change in scale of the estimated biomass (Figure 4), which manifests itself in a change in the scale of the *F* multipliers for all years (Figure 7), and is consistent with the large confidence intervals around the biomass (Figure 4) and *F* multiplier (Figure 5) estimates, indicates that the model is very sensitive to new data. The assumption that abundance is proportional to the longline CPUE might be misspecified (*e.g*. due to changes in targeting) and bias the estimates of current abundance, which propagates into the *F* multiplier. Since most bigeye are caught in the floating-object fishery, and there is no real searching effort to find the tuna, it is possible that the catch is not dependent on abundance. Therefore, even when then population declines, the catch remains high, and the fishing mortality increases. However, skipjack tuna makes up the majority of the catch in floating-object sets, and the decision about whether to make a set will be based on the presence of skipjack. In this case, the presence of bigeye at a floating object that is chosen for a set may be related to the total abundance of bigeye and not the decision to make a set; therefore, there could be a relationship between catch and abundance of bigeye. In summary, the relative contributions to the change in the *F* multiplier from SAC-08 to SAC-09 of assessment uncertainty and the variability in the relationship between fleet capacity and fishing mortality are unknown.

The *F* multiplier estimated each year for management is subject to the assumptions and data used in that year's assessment, and will differ somewhat from the *F* multipliers estimated by the current model for the same three-year "current" periods (Figure 7). The *F* multipliers estimated using the SAC-08 model were slightly higher than those estimated using the SAC-09 model (Figure 7). In general, both the closure-adjusted capacity[3] and the *F* multipliers from SAC-09 have been moderately stable over time (Figure 7).

3. PLAN TO IMPROVE THE ASSESSMENT

The deficiencies in the bigeye assessment have already been identified (*e.g*. Aires-da-Silva and Maunder 2014). The CAPAM[4] workshop series has identified a suite of good practices for stock assessment

[3] Fleet capacity multiplied by the proportion of the year that the fishery is open; see Table 2

[4] Centre for the Advancement of Population Assessment Methodology

modelling (Maunder *et al*. 2014, 2016, 2017) that should be applied to the bigeye assessment. The current three-year management resolution (C-17-02) expires in 2020, and new management measures will be needed for 2021 and subsequent years. With this in mind, the Stock Assessment Program has developed a comprehensive workplan to improve the bigeye assessment (see below), including some activities that have already been carried out in 2017 and 2018. In addition, several recent research projects are relevant to improving the bigeye assessment: Maunder *et al*. (2018) developed a new growth model that better represents the data available for bigeye tuna; Minte-Vera *et al*. (2017) identified issues with some of the composition data used in the assessment model; Maunder and Piner (2017) outlined a framework for identifying and correcting model misspecification when developing stock assessment models that should be applied to bigeye; and Valero *et al.* (2018) used alternative spatially-structured analyses to investigate the source of misspecification causing the apparent two-regime recruitment pattern for bigeye. Once the workplan is completed, a model that addresses the main deficiencies of the current bigeye assessment will be available for providing the best scientific advice for the next management cycle for tropical tunas in the EPO. Also, stock status indicators, similar to those used for skipjack, will be developed, as an additional check on the status of bigeye.

4. PROPOSED WORKPLAN:

October 2017	CAPAM workshop on recruitment: theory, estimation, and application in fishery stock assessment models	
2017	Collaboration with Japanese scientists on identifying targeting changes	Presentation at SAC-09
February 2018	CAPAM workshop on the development of spatio-temporal models of fishery catch-per-unit-effort data to derive indices of relative abundance	For example, SAC-09-09
2018	Investigation of the relationship between fishing mortality and fleet capacity	CAF-05-04, Project 2
2018	Developing a spatially structured stock assessment for bigeye tuna and other model improvements	CAF-05-04, Project 1
October2018	CAPAM workshop on spatial stock assessment models focusing on bigeye tuna	CAF-05-04, Project 3
January/February 2019	Proposed longline CPUE workshop	See proposal in SAC-09-02
March 2019	Proposed bigeye tuna assessment independent review	See proposal in SAC-09-02
May 2019	Exploratory bigeye tuna assessment	Presentation at SAC-10
January 2020	CAPAM workshop on Natural mortality	
May 2020	Benchmark bigeye tuna assessment	Presentation at SAC-11
July-August 2021	Adopt resolution for new management measures	

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TABLE 1. *F* multipliers for bigeye tuna estimated from various model combinations (see text)
TABLA 1. Multiplicadores de *F* para el atún patudo estimados de distintas combinaciones de modelos (ver texto).

	F multiplier based on - Multiplicador de F basado en	
Description- Descripción	2015-2017	2014-2016
Assessment- Evaluación SAC-09	0.87	0.97
Assessment- Evaluación SAC-08	n/a	1.15
SAC-08 + catch-captura 2017 from-de SAC-09	1.13	1.15
SAC-09 without-sin 2017 LF or CPUE >= Q4 2016	1.05	1.09
SAC-09 without-sin CPUE >= Q4 2016	0.96	1.03
SAC-09 without-sin 2017 LF	0.91	0.99

TABLE 2a. Quantities of interested related to the *F* multiplier for bigeye tuna. SAR: IATTC Stock Assessment Report
TABLA 2a. Cantidades de interés relacionadas con el multiplicador de *F* para el atún patudo. SAR: Informe de Evaluación de Stocks de la CIAT.

SAR	SAC	Assessment type	Year of assessment or data	*F* multiplier						Closure days		Resolution
				Year		Assessment	% change	SAC-09	SAC-08	EPO	*Corralito*	
				First	Last							
SAR	SAC	Tipo de evaluación	Año de evaluación o datos	Multiplicador de *F*						Días de veda		Resolución
				Año		Evaluación	% cambio	SAC-09	SAC-08	OPO	Corralito	
				Primero	Último							
	11	Full-Completa	2020			-				72	31	C-17-02
	10	Exploratory-Exploratoria	2019			-				72	31	C-17-02
	9	Update-Actualizada	2018	2015	2017	0.87	-24	0.87		72	31	C-17-02
18	8	Update-Actualizada	2017	2014	2016	1.15	10	0.97	1.15	72*	31	C-17-02
17	7	Full-Completa	2016	2013	2015	1.05	-8	1.04	1.11	62	31	C-13-01
16	6	Update-Actualizada	2015	2012	2014	1.14	10	0.96	1.01	62	31	C-13-01
15	5	Update-Actualizada	2014	2011	2013	1.04	-1	0.9	0.94	62	31	C-13-01
14	4	Full-Completa	2013	2010	2012	1.05	11	0.81	0.86	62	31	C-11-01
13	3	Update-Actualizada	2012	2009	2011	0.95	2	0.82	0.87	62	31	C-11-01
12	2	Update-Actualizada	2011	2008	2010	0.93	-18	0.87	0.92	62	31	C-11-01
11	1	Full-Completa	2010	2007	2009	1.13	40	0.98	1.03	62	31	C-09-01
10	-	Full-Completa	2009	2006	2008	0.81	-1	1.01	1.06	59	31	C-09-01
9	-	Full-Completa	2008	2005	2007	0.82	6	0.99	1.05	42**	0	
8	-	Full-Completa	2007	2004	2006	0.77	13	0.91	0.96	42	0	C06-02
7	-	Full-Completa	2006	2003	2005	0.68	19	0.9	0.95	42	0	C-04-09
6	-	Full-Completa	2005	2002	2004	0.57	-8	0.82	0.87	42	0	C-04-09
5	-	Full-Completa	2004	2001	2003	0.62	-22	0.83	0.88	42	0	C-04-09
4	-	Full-Completa	2003	2000	2002	0.79	-57	0.85	0.89	31	0	C-03-12
3	-	Full-Completa	2002	1999	2001	1.85	106	1.04	1.1	31	0	C-02-04
2	-	Full-Completa	2001	1998	2000	0.90	-2	1.11	1.17	0§	0	C-01-06, C-01-07
1	-	Full-Completa	2000	1997	1999	0.92		1.14	1.19	0§	0	C-00-02, C-00-03

*: Changed in season-Cambiada durante el año
**: Voluntary closure-Veda voluntaria
§: Catch limits-Límites de captura

TABLE 2b. Quantities of interest, in tons, related to the *F* multiplier for bigeye tuna. "Closure-adjusted capacity" is the fleet capacity multiplied by the proportion of the year that the fishery is open. SSB: spawning biomass.

TABLA 2b. Cantidades de interés, en toneladas, relacionadas con el multiplicador de *F* para el atún patudo. "Capacidad ajustada por veda" es la capacidad de la flota multiplicada por la proporción del año que no es vedada. SSB: biomasa reproductora.

Year of assessment /data	*F* multiplier		Catch (retained + discarded)	SSB SAC-09 (start of year)	Purse-seine vulnerable biomass (start of year)	Purse-seine capacity	Closure-adjusted capacity	% change in closure- adjusted capacity
	Bigeye	Yellowfin						
Año de evaluación/ datos	Multiplicador de *F*		Captura (retenida + descartada)	SSB SAC-09 (principio de año)	Biomasa vulnerable a cerco (principio de año)	Capacidad cerquera	Capacidad ajustada por veda	Cambio porcentual en capacidad ajustada por veda
	Patudo	Aleta amarilla						
2018	0.87	0.99		94,732	86,770			
2017	1.15	1.03	66,381	101,484	88,709	263,018	211,135	-3%
2016	1.05	1.02	57,254	95,132	98,345	261,474	217,059	5%
2015	1.14	1.11	63,090	78,216	115,132	248,428	206,229	8%
2014	1.04	1.21	60,528	71,151	127,579	230,379	191,246	9%
2013	1.05	1.01	49,760	65,898	105,710	212,087	176,061	-3%
2012	0.95	1.15	66,493	74,425	97,521	217,687	180,710	2%
2011	0.93	1.13	57,143	90,940	93,214	213,237	177,016	2%
2010	1.13	1.33	58,316	106,334	79,329	210,025	174,350	-7%
2009	0.81	1.09	77,818	105,937	95,318	224,632	188,322	-5%
2008	0.82	1.13	77,114	98,783	119,827	223,804	198,051	-1%
2007	0.77	0.88	64,340	92,105	126,505	225,359	199,427	0%
2006	0.68	1.02	85,518	88,679	121,435	225,166	199,257	6%
2005	0.57	0.83	69,795	78,411	119,516	212,419	187,976	3%
2004	0.62	1.12	67,045	77,917	112,892	206,473	182,715	-1%
2003	0.79	1.2	55,378	92,184	109,320	202,381	185,193	1%
2002	1.85	1.12	58,370	117,101	103,988	199,870	182,895	-3%
2001	0.90	1.19	61,772	109,537	116,803	189,088	189,088	5%
2000	0.92	NA	100,699	104,273	156,118	180,679	180,679	

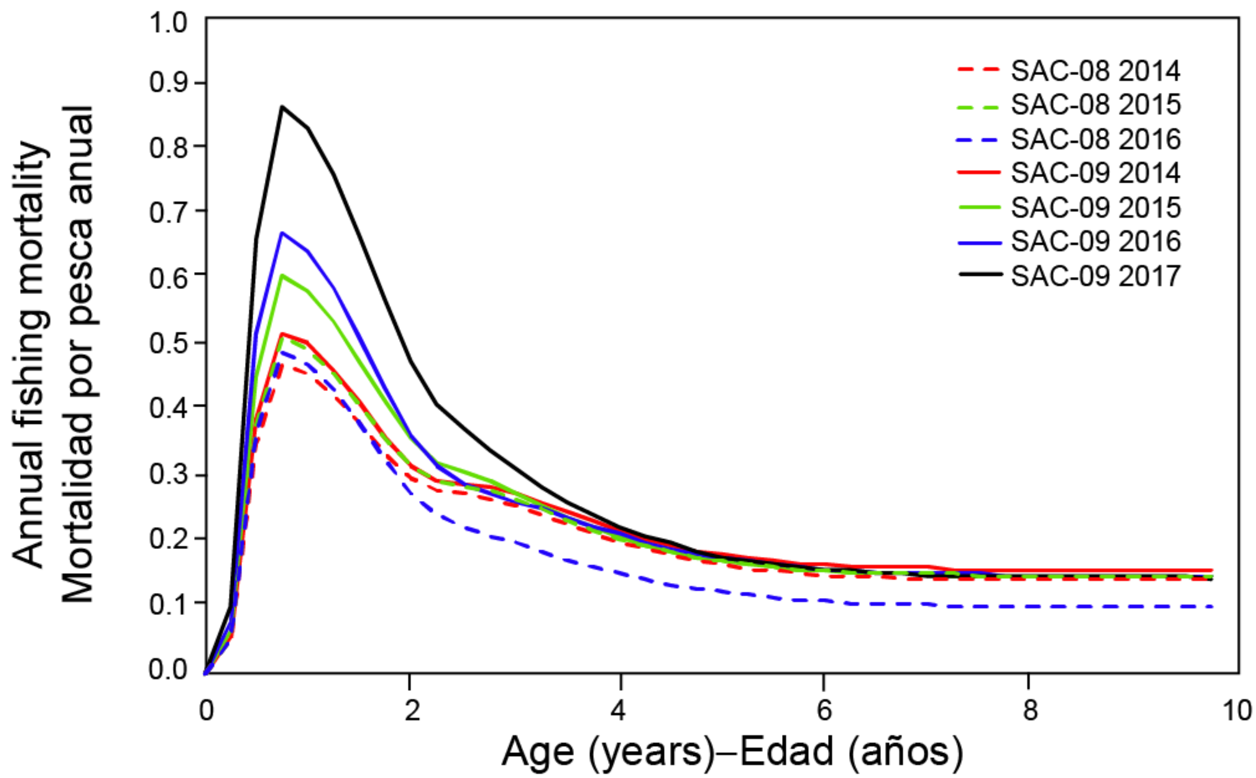


FIGURE 1. SAC-09 estimates of age-specific fishing mortality for the years used in the SAC-08 and SAC-09 estimates of *F* multiplier.

FIGURA 1. Estimaciones de SAC-09 de la mortalidad por pesca por edad correspondiente a los años usados en las estimaciones de SAC-08 y SAC-09 del multiplicador de *F*.

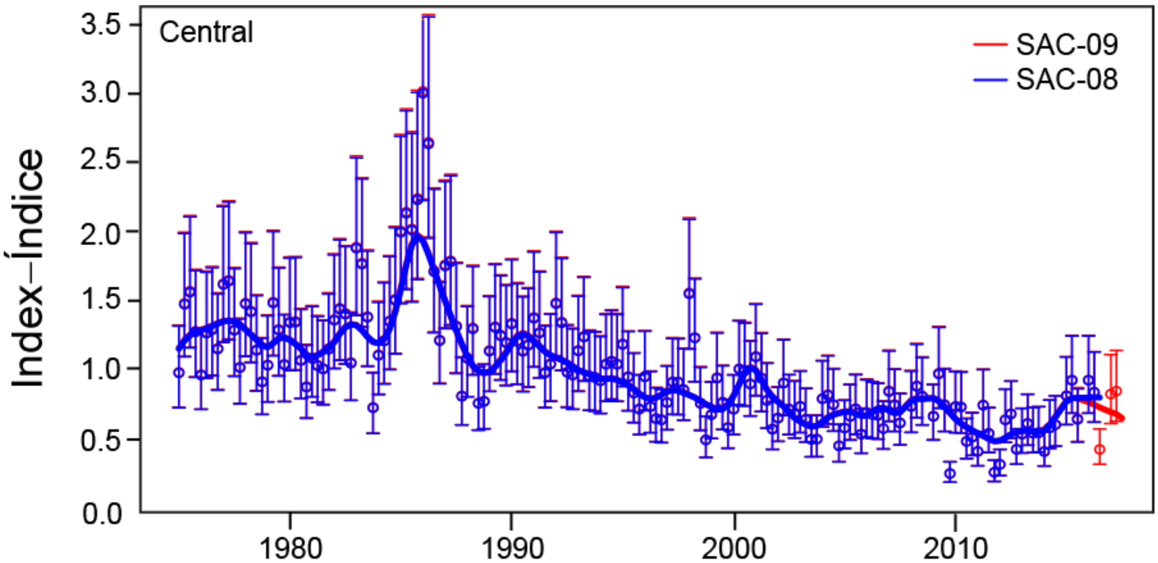


FIGURE 2. Comparison of the standardized longline CPUE for the Central area (dots), and the corresponding assumed 95% confidence interval, used as an index of relative abundance in the SAC-08 and SAC-09 stock assessment models for bigeye tuna. The solid lines represent the expected indices from the two models.

FIGURA 2. Comparación de la CPUE palangrera estandarizada del área Central (puntos), y el intervalo de confianza de 95% supuesto correspondiente, usada como índice de abundancia relativa en los modelos de evaluación de la población de atún patudo SAC-08 y SAC-09. Las líneas sólidas representan los índices esperados de los dos modelos.

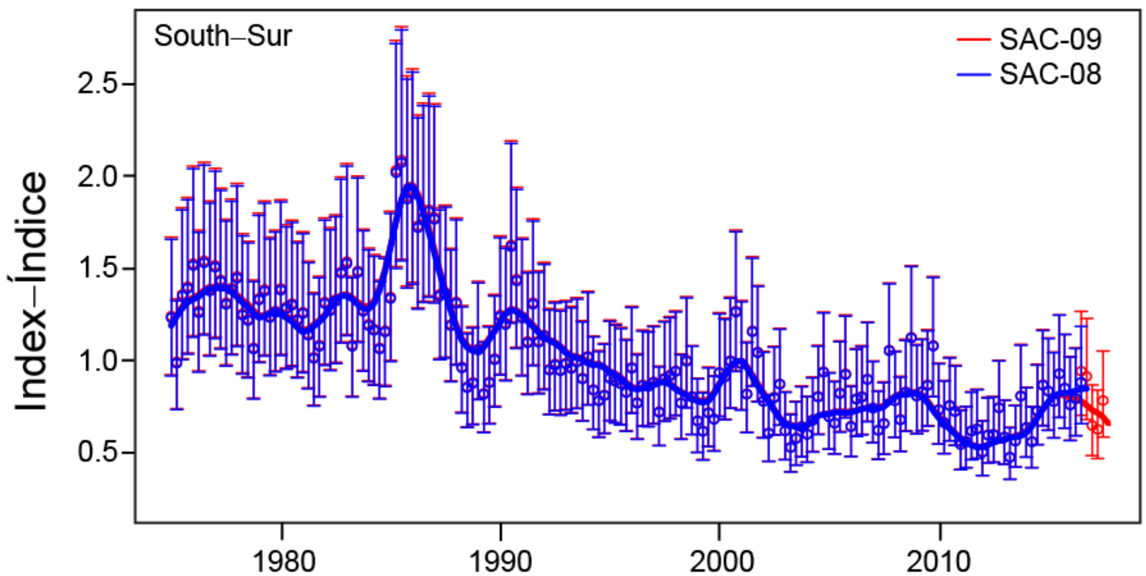
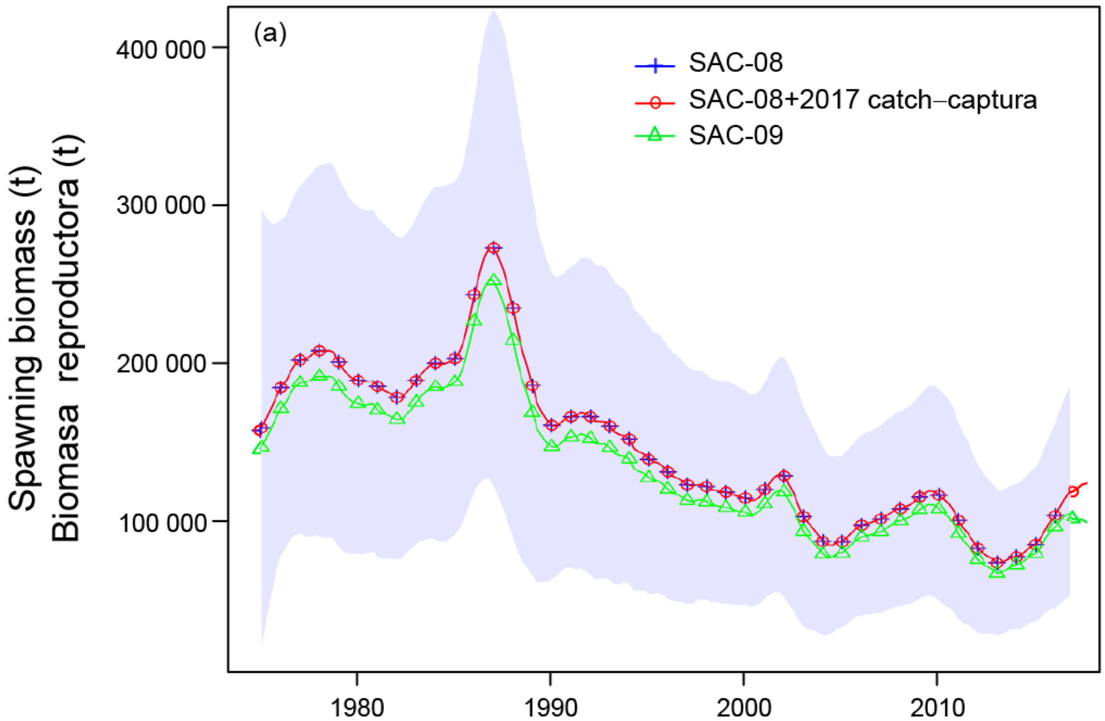


FIGURE 3. Comparison of the standardized longline CPUE for the Southern area (dots), and the corresponding assumed 95% confidence interval, used as an index of relative abundance in the SAC-08 and SAC-09 stock assessment models for bigeye tuna. The solid lines represent the expected indices from the two models.

FIGURA 3. Comparación de la CPUE palangrera estandarizada del área del Sur (puntos), y el intervalo de confianza de 95% supuesto correspondiente, usada como índice de abundancia relativa en los modelos de evaluación de la población de atún patudo SAC-08 y SAC-09. Las líneas sólidas representan los índices esperados de los dos modelos.



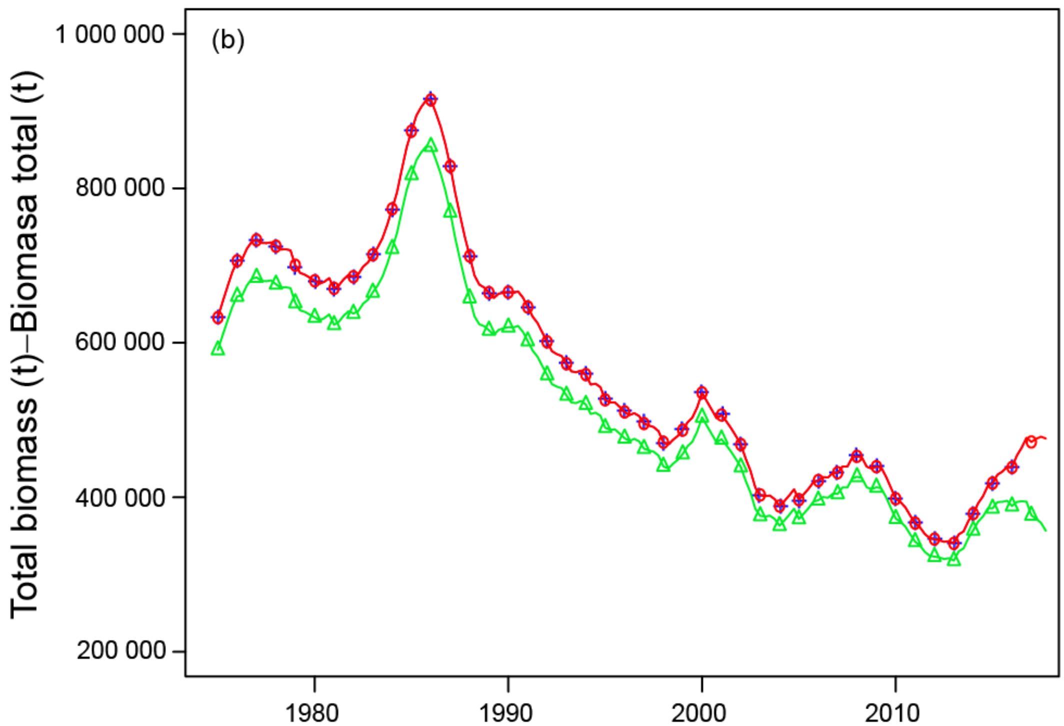


FIGURE 4. Estimates of spawning biomass (top) and total biomass (bottom) from SAC-08, SAC-09, and SAC-08 plus the 2017 catch from SAC-09.

FIGURA 4. Estimaciones de la biomasa reproductora (arriba) y biomasa total (abajo) de los modelos de evaluación SAC-08 y SAC-09, y SAC-08 más la captura de 2017 de SAC-09.

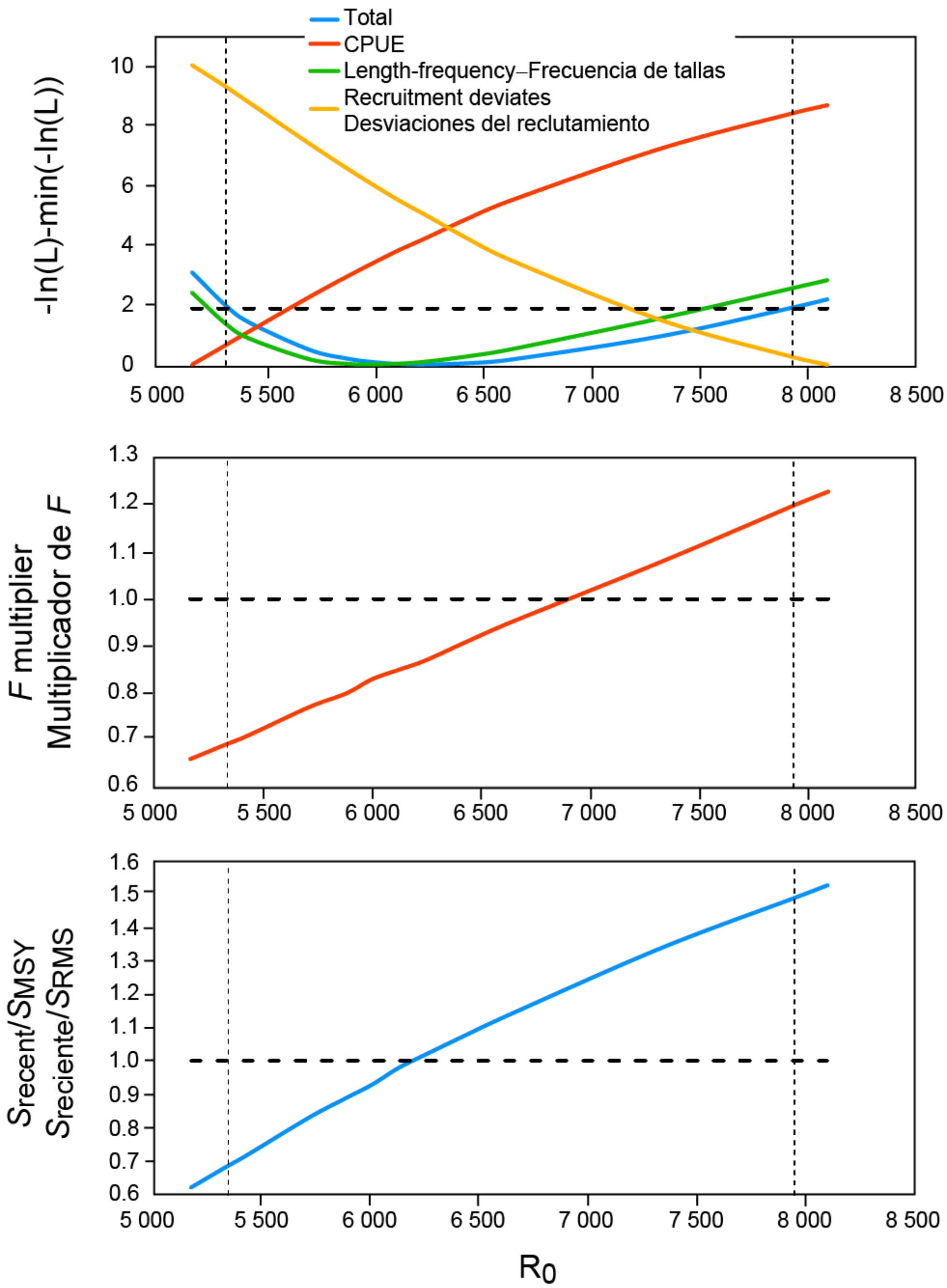


FIGURE 5. Likelihood component profiles and management quantities for different levels of virgin recruitment (*R*0). The horizontal dashed line in the top panel indicates the likelihood value associated with a 95% confidence interval, which is represented by the vertical dashed lines.

FIGURA 5. Perfiles de los componentes de verosimilitud y cantidades de ordenación correspondientes a distintos niveles de reclutamiento virgen (*R*0). La línea de trazos horizontal en el panel superior indica el valor de la verosimilitud asociada a un intervalo de confianza de 95%, representado por las líneas de trazos verticales.

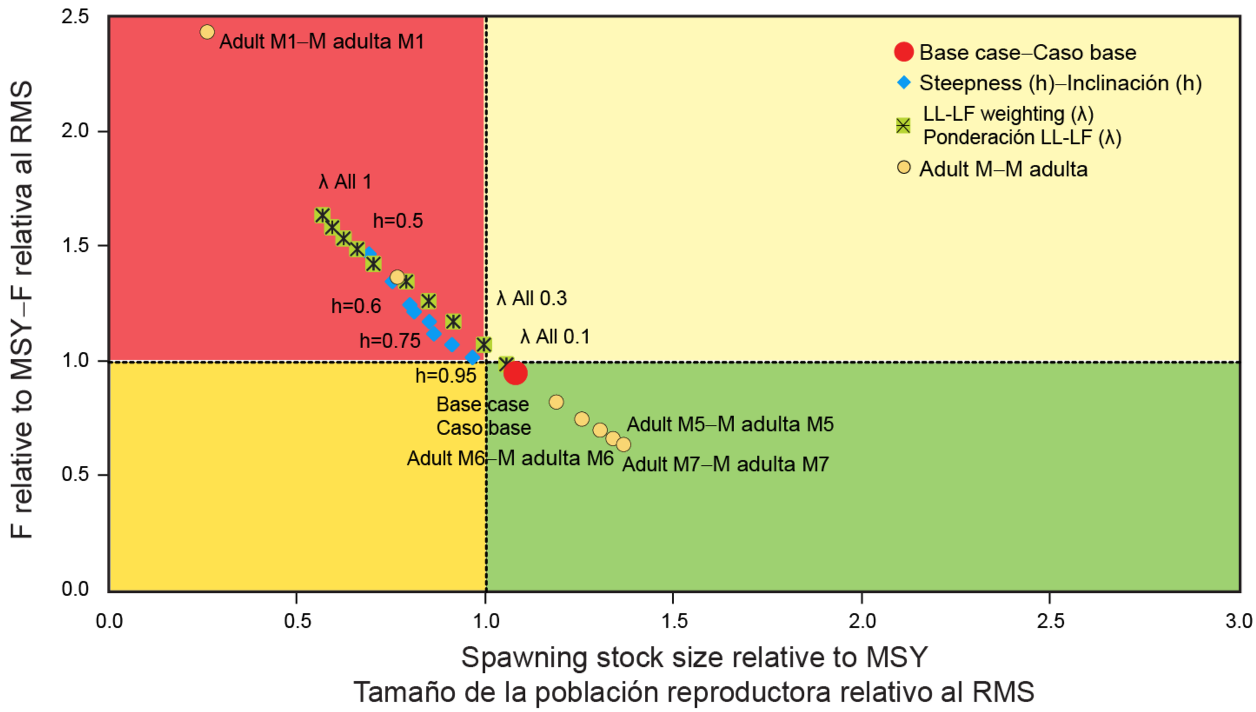


FIGURE 6. Phase plot of the most recent estimate of spawning biomass stock size and fishing mortality relative to their MSY reference points. Each point is based on the average fishing mortality rate over the most recent three years. (From Aires-da-Silva and Maunder 2014)

FIGURA 6. Gráfica de fase de la estimación más reciente del tamaño de la biomasa reproductora y la mortalidad por pesca en relación con sus puntos de referencia de RMS. Cada punto se basa en la tasa de explotación media del trienio más reciente. (De Aires-da-Silva and Maunder 2014)

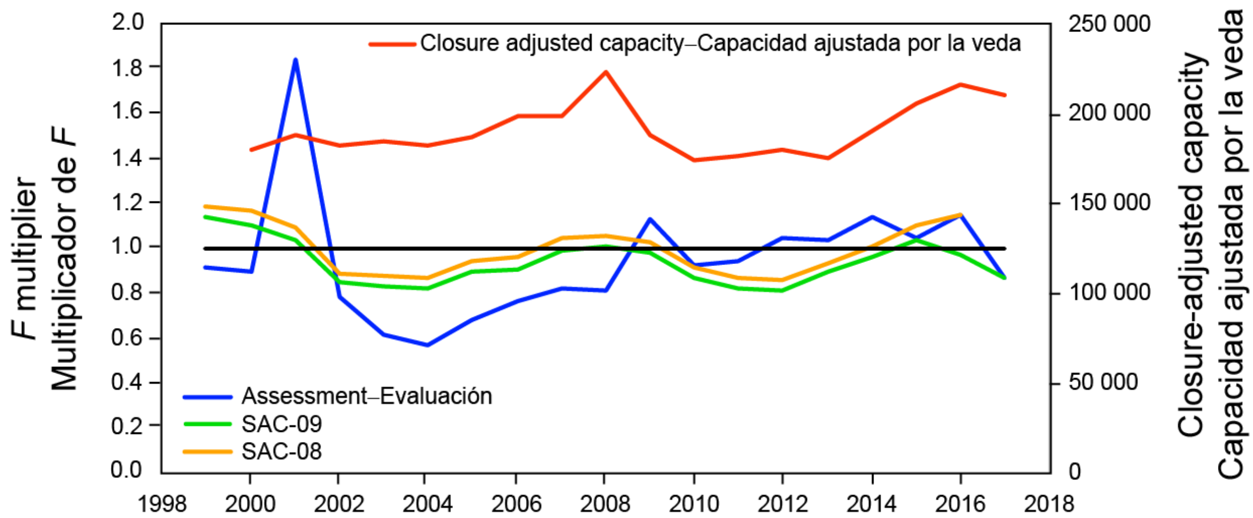


FIGURE 7. Comparison of three *F* multipliers series (SAC-08, SAC-09, and from that year's assessment) to the closure-adjusted capacity (fleet capacity multiplied by the proportion of the year the fishery is open), 1999-2017. The horizontal line at 1.0 represents the management objective of fishing at MSY ($F = F_{MSY}$).
FIGURA 7. Comparación de tres series de multiplicadores de *F* (SAC-08, SAC-09, y de la estimación del año correspondiente) con la capacidad ajustada por la veda (capacidad de la flota multiplicada por la proporción del año que no es vedada). La línea horizontal en 1.0 representa el objetivo de ordenación de pescar al nivel de RMS ($F = F_{RMS}$).