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AN INTERIM MULTI-SPECIES AND MULTI-STOCK MSE FOR TROPICAL TUNAS IN THE EASTERN PACIFIC OCEAN

Mark N. Maunder, Haikun Xu, Carolina Minte-Vera, Rujia Bi and Alexandre Aires-da-Silva

SUMMARY

An *interim* multi-stock management strategy evaluation (MS-MSE) was conducted for tropical tunas in the eastern Pacific Ocean (EPO), where both different species and alternative stock structure hypotheses within a species (for yellowfin) are considered. A fully integrated multi-species, multi-stock MSE was not possible due to time constraints and because multi-stock management objectives have not yet been identified. Therefore, this interim MS-MSE evaluated the least conservative harvest strategy (HS) identified in the bigeye tuna MSE (F30-S20) using the ensemble of models from the yellowfin tuna (separate northeast and southwest stocks) and skipjack tuna risk analyses.

The MS-MSE evaluated fishing mortality relative to target and limit reference points for each stock. A more comprehensive evaluation of the performance of the bigeye tuna harvest strategies is provided in SAC-17-05. The analysis presented here does not explicitly evaluate other performance metrics, such as spawning biomass and catch, although approximate inferences can be made under equilibrium assumptions.

The results indicate that application of the bigeye tuna F30-S20 harvest strategy to manage the tropical tuna fishery as a whole would maintain fishing mortality for both yellowfin stocks and the skipjack stock at or below their respective target reference points and well below their limit reference points. The results further indicate that spawning biomass would remain at or above the corresponding target reference points and well above the limit reference points. Because F30-S20 is the least conservative harvest strategy identified in the bigeye tuna MSE, these conclusions are expected to apply equally, or more strongly, to the other harvest strategies that were evaluated.

Equilibrium yield analyses indicate that skipjack yield could be increased substantially through higher levels of fishing mortality. In contrast, little increase in yellowfin yield is expected through increases in overall fishing mortality, although yield may be increased by reducing fishing mortality on smaller yellowfin while increasing fishing mortality on larger yellowfin.

The results indicate that the current interim management framework can be implemented using a harvest strategy developed through the bigeye tuna MSE. However, the 2026 updated bigeye tuna assessment (SAC-17-03) indicates continued reductions in fishing mortality on juvenile bigeye tuna, such that yellowfin tuna is now estimated to be the stock requiring the most restrictive management measures

under the southwest yellowfin stock-structure hypothesis. Despite this shift, the analyses presented here indicate that application of a bigeye-based harvest strategy would be unlikely to adversely affect the status of the yellowfin or skipjack stocks.

The development of multi-species, multi-stock management objectives, harvest strategies for yellowfin and skipjack tuna, and alternative approaches for managing tropical tunas in the EPO should be a priority before undertaking a fully integrated multi-species, multi-stock MSE.

1. INTRODUCTION

The tropical tuna fishery in the eastern Pacific Ocean (EPO) is a multi-gear, multi-species fishery targeting yellowfin, bigeye and skipjack tuna. The species composition of the catch varies considerably among fishing gears and, in the case of purse-seine fisheries, among set types. Three main purse-seine set types are conducted in the EPO: (1) sets on tuna associated with dolphins (DEL), (2) sets on tuna associated with floating objects (OBJ), and (3) sets on unassociated schools (NOA). These set types have distinct species compositions. DEL sets catch predominantly large yellowfin tuna. OBJ sets catch predominantly skipjack tuna but also substantial quantities of small yellowfin and bigeye tuna. NOA sets catch predominantly skipjack tuna together with substantial quantities of small yellowfin tuna. Consequently, the purse-seine set type used by a vessel strongly influences its contribution to species-specific fishing mortality. In addition, the spatial distribution of fishing effort affects the degree to which fishing mortality is exerted on each tropical tuna species and stock.

A further complication is the potential existence of multiple stocks within a species in the EPO. For example, the current yellowfin tuna assessment considers alternative stock-structure hypotheses, including the possibility of two yellowfin stocks within the EPO (Figure 1). As with different species, different stocks may have different vulnerabilities to fishing gears, purse-seine set types, and the spatial distribution of fishing effort. For simplicity, this report uses the term multi-stock management strategy evaluation (MS-MSE), recognizing that different species can also be viewed as distinct stocks within a broader multi-stock framework.

Management of tropical tuna fisheries in the EPO is implemented through a variety of measures, including seasonal fishery closures, individual vessel thresholds (IVTs), spatial closures, full-retention requirements for tropical tunas, non-retention requirements for certain bycatch species, vessel capacity limits, limits on active echosounder buoys, and longline catch limits for some CPCs. These measures serve different objectives and interact in different ways. Some operate independently, others are complementary, and some are effective only when implemented in combination.

Seasonal closures (closure days) are the primary measure used to control fishing mortality on tropical tunas in the purse-seine fishery. More recently, IVTs for bigeye tuna have been adopted as an additional species-specific measure to reduce fishing mortality on bigeye, particularly in floating-object fisheries. Because the seasonal closure applies regardless of purse-seine set type, it affects fishing mortality on all three tropical tuna species, yellowfin, bigeye and skipjack.

Under the IATTC interim harvest control rule (HCR), management advice is based on stock assessment estimates of fishing mortality (Resolution C-23-06). Specifically, the assessment is used to determine how much the current fishing mortality (F_{cur}, defined as the average over the most recent three years) must change to achieve the fishing mortality associated with maximum sustainable yield (F_{MSY}) for the stock requiring the most restrictive management. Management measures, primarily the purse-seine closure period, are then adjusted accordingly.

Historically, bigeye tuna has been the species of greatest management concern and has therefore largely driven management decisions for tropical tunas in the EPO. Consequently, Management Strategy Evaluation

(MSE) was first undertaken for bigeye tuna (SAC-17-05). This work has now been completed, and several alternative harvest strategies have been evaluated. Three harvest strategies were identified as meeting the proposed management objectives.

These harvest strategies would, on average, reduce the number of closure days and therefore increase fishing mortality on bigeye tuna relative to current levels, while maintaining the stock at the target level. As expected, because the purse-seine closure affects all tropical tuna species, these harvest strategies would also increase fishing mortality on yellowfin and skipjack tuna. Consequently, there is growing interest in conducting MSEs for yellowfin and skipjack tuna and, ultimately, developing a fully integrated multi-species, multi-stock MSE framework capable of evaluating management objectives and harvest strategies across all three tropical tuna species simultaneously.

A full multi-stock MSE is computationally demanding because it requires operating models for all stocks and the coordination of management actions across stocks during each management cycle. It also requires the specification of harvest strategies for all stocks, potentially leading to a large number of combinations of harvest strategies to be evaluated. In addition, management objectives must be defined and agreed upon for each stock. Consequently, the development and evaluation of a full multi-stock MSE is a time-consuming process, both in terms of designing the framework and conducting the simulations, and is therefore unlikely to be completed in the short term.

However, since both yellowfin stock hypotheses and the skipjack stock are currently estimated to be in healthy condition, it may be sufficient to investigate whether application of the bigeye tuna harvest strategy (also termed a Management Procedure; SAC-17 INF-T) would adversely affect the status of either yellowfin stock or the skipjack stock. This question is particularly relevant because, under the southwest yellowfin stock-structure hypothesis, yellowfin tuna is now the stock of greatest management concern, although alternative harvest control rules have only been tested for bigeye tuna. For this MS-MSE, the F30-S20 harvest control rule is evaluated because it is the least conservative of the harvest control rules tested in the bigeye tuna MSE (SAC-17-05). As such, it provides a useful test case for evaluating the potential impacts of applying the bigeye tuna Management Procedure on the other tropical tuna stocks.

This report presents a practical approach for implementing an *interim* multi-species, multi-stock MSE for tropical tunas in the EPO. While not a fully integrated MS-MSE, it provides a reasonable approximation for evaluating whether the harvest strategies identified for bigeye tuna are appropriate for the other tropical tuna stocks under the current management framework. The analysis focuses on the limited management objectives of managing based on bigeye, the single stock of greatest concern, maintaining populations at levels capable of producing maximum sustainable yield (MSY) for all stocks in accordance with the Antigua Convention, and avoiding limit reference points. In addition, equilibrium yield analyses are used to evaluate the potential for increasing catches of yellowfin and skipjack tuna through higher levels of fishing mortality.

2. MANAGEMENT STRATEGY EVALUATION (MSE)

2.1. Management objectives

The management objectives are interpreted based on those identified for bigeye tuna (SAC-17-05), but within the constraints of the bigeye harvest strategy. This assumes that bigeye is the species of most concern. A main objective is to ensure that implementing the bigeye HS does not cause yellowfin or skipjack to become the species of concern. In other words, to follow the Antigua Convention which states: "*maintain or restore the populations of harvested species at levels of abundance which can produce the maximum sustainable yield*".

The closure should reduce as much as possible, while also considering the desire for stability, to increase the catch of yellowfin and skipjack tuna without reducing their respective biomasses below the MSY levels on average or below the limit reference points with more than 10% probability. Similarly, the fishing mortality should not increase above that corresponding to MSY on average and not increase above that corresponding to the limit reference point with more than 10% probability.

As described below, the simplified multi-stock MSE does not simulate biomass into the future and therefore cannot directly evaluate biomass-based objectives. However, when considering averages over time, particularly if considering dynamic biomass reference points (those that take the time series of recruitment into consideration), biomass-based objectives can be well represented by fishing-mortality-based objectives. Therefore, we evaluate fishing mortality rate objectives.

2.2. Performance metrics

The performance metrics are simply the fishing mortality relative to 1) that corresponding to maximum sustainable yield (FMSY), 2) the maximum fishing mortality rate in the bigeye F30-S20 harvest control rule and recommended as a global proxy for MSY (SAC-17-05; F30%), and 3) the limit reference point (the fishing mortality rate corresponding to a spawning biomass of 7.7% of the unfished biomass; FS7.7%).

2.3. Harvest control rule

The bigeye tuna harvest strategies involve fitting a simplified stock assessment model to data every three years and using the estimated spawning biomass and fishing mortality in a simple harvest control rule that applies a constant fishing mortality above the biomass control point and reduces the fishing mortality below the control point linearly to zero (Figure 2). The fishing mortality is translated into closure days. The change in closure days is limited to 10 days each three-year management cycle except for when the bigeye spawning biomass is below the control point where the closures days can increase by a maximum of 20 days. The alternative bigeye tuna harvest strategies are described in SAC-17-05. Here we assume that the status of the other species does not influence the harvest strategy (i.e., bigeye tuna is the stock of most concern). The closures days from the bigeye MSE can then be used directly to modify the F for the two yellowfin stocks and the skipjack stock.

Given the assumption that bigeye tuna is the species of most concern, we test the least conservative HCR and infer the interpretation of the other HCRs from those results. The least conservative HCR (F30-S20) includes a maximum fishing mortality corresponding to a depletion level of 30% (F30%) and a control point at a depletion level of 20% (S20%; see Figure 2). The rationale for this HCR is presented in SAC-16-06.

2.4. Operating model

The bigeye tuna MSE uses the ensemble of models from the risk analysis (SAC-11-08) for the operating models. These operating models are used to project the population forward in time under alternative harvest strategies. The ensemble of models in the risk analysis represents uncertainty about the knowledge of the population and fishery dynamics and is used to calculate probability statements about the status of the stock. Risk analyses have also been conducted for both yellowfin (SAC-16-03) and skipjack tuna (SAC-16-04). Given time constraints, it is not feasible to use the ensemble of models from the risk analysis to project the populations into the future under alternative harvest strategies. However, the risk analysis does determine the probability of the current fishing mortality exceeding the target and limit reference points. The current fishing mortality is based on the most recent three years in the stock assessment (2021-2023), which includes the 72-day closure for all three years for both yellowfin stocks and the skipjack stock. Since the reduction in days of closure (or more precisely, the increase in days open) is assumed proportional to fishing mortality, the current fishing mortality can simply be adjusted appropriately to determine the distribution of fishing mortality relative to the reference points.

2.5. Implementation

The MS-MSE for tropical tunas in the EPO uses the days of closure calculated from the bigeye tuna MSE to modify the probability distribution of fishing mortalities estimated in the risk analyses for yellowfin and skipjack tuna. The risk analysis estimates the probability distribution of the current fishing mortality relative to reference points across the ensemble of models. The current fishing mortality is defined as the average over the three most recent years in the risk analysis (2021-2023). These probability distributions are simply modified by the ratio of days open, which is a function of days of closure (d). For both yellowfin and skipjack, the current F includes years with a 72 day closure. The bigeye tuna MSE includes random implementation error so that the resulting F is not perfectly proportional to the days the fishery is open. We also include the implementation error (ε) for yellowfin and skipjack and assume it is independent from bigeye tuna.

$$\frac{F}{F_{ref}} = \frac{F_{cur}}{F_{ref}} \frac{365 - d}{365 - 72} e^{\varepsilon}$$

$$\text{Where } \varepsilon \sim N(-0.5\sigma^2, \sigma^2) \text{ and } \sigma = 0.1$$

3. YIELD ANALYSIS

The equilibrium yield curve (catch as a function of fishing mortality relative to the current fishing mortality) and associated spawning biomass curve derived from each operating model for each stock is used to compare the equilibrium yield and biomass from the current fishing mortality to that at FMSY and F30%. This is used to determine whether yield from the two yellowfin tuna and the skipjack tuna stocks could be substantially increased using a multi-species multi-stock harvest strategy with appropriate objectives. How much yield would increase for yellowfin and skipjack depends on the flatness of the yield curve and where the currently fishing mortality is situated on the curve.

4. RESULTS

4.1. Management Strategy Evaluation

Fishing mortality

The MS-MSE estimates that fishing mortality remains at or below the target reference points for both yellowfin stocks (Figures 3–6) and the skipjack stock (Figure 7) throughout the management period. For skipjack, fishing mortality is estimated to remain substantially below the $F_{30\%}$ target reference point, with a very low probability of exceeding that level (Figure 7). Similarly, the northeast (NE) yellowfin stock has a very low probability of exceeding either the F_{MSY} or $F_{30\%}$ target reference points (Figures 3 and 4).

In contrast, the southwest (SW) yellowfin stock has a moderate, although less than 50%, probability of exceeding the *F*MSY and *F30%* target reference points. This probability increases over successive management cycles (Figures 5 and 6). Nevertheless, the estimated probabilities remain below 50%

throughout the management period. The MS-MSE estimates that fishing mortality has a very low probability of exceeding the limit reference points for either yellowfin stock (Figures 8 and 9). Results for skipjack are not presented because there is negligible probability of exceeding the limit reference point.

Spawning biomass

Although spawning biomass projections were not conducted for the two yellowfin stocks or the skipjack stock, likely trends in spawning biomass can be inferred from the fishing mortality results. The target reference points are based on dynamic spawning biomass and therefore generally correspond to fishing mortality reference points, although with some lag and variability due to recruitment fluctuations, particularly for relatively short-lived species such as yellowfin and skipjack tuna.

Given that fishing mortality for skipjack is projected to remain substantially below the F30% target reference point, and recent risk analyses indicate a low probability of spawning biomass falling below S30%, it is likely that skipjack spawning biomass would remain above S30% under application of the bigeye tuna harvest control rule. For yellowfin, particularly under the southwest stock-structure hypothesis, there is a higher probability that fishing mortality will exceed the target reference points. Nevertheless, the projected probabilities remain moderate, indicating that spawning biomass would likely remain at or above the corresponding biomass target reference points.

Similarly, because the probability of fishing mortality exceeding the limit reference points is estimated to be very low for all stocks, the probability of spawning biomass falling below the corresponding biomass limit reference points is also expected to be low. Although biomass limit reference points are based on equilibrium conditions and recruitment variability may influence their evaluation, the bigeye tuna MSE results suggest that recruitment variability is unlikely to alter these conclusions for yellowfin and skipjack tuna.

4.2. Yield analysis

Results from the equilibrium yield analysis indicate that, for most yellowfin models, the yield curve is relatively flat around the current fishing mortality or that current fishing mortality is close to F_{MSY} and $F_{30\%}$. Consequently, equilibrium yield is not expected to increase substantially relative to that associated with current fishing mortality (Figure 10; Table 1).

In contrast, current fishing mortality for skipjack is substantially below the level corresponding to maximum sustainable yield ($S_{30\%}$) and is therefore not located on the flat segment of the yield curve nor close to F_{MSY}. As a result, equilibrium yield could increase substantially if fishing mortality were increased (Figure 11; Table 2). For most models in the ensemble, equilibrium catches of skipjack are estimated to increase by 50% or more relative to those associated with current fishing mortality.

5. DISCUSSION

The MS-MSE indicates that application of the bigeye tuna F30-S20 harvest strategy to manage the tropical tuna fishery as a whole is expected to maintain fishing mortality for both yellowfin tuna stocks and the skipjack tuna stock at or below their respective target reference points and well below their limit reference points. The results further suggest that spawning biomass would remain at or above the corresponding target reference points and well above the limit reference points. Because the F30-S20 harvest strategy is the least conservative of the harvest strategies evaluated in the bigeye tuna MSE, these conclusions are expected to also apply to the other harvest strategies tested (SAC-17-05).

The present analysis evaluates only fishing mortality for yellowfin and skipjack tuna and infers likely performance relative to biomass reference points. The analysis could be extended to evaluate spawning biomass and catch by projecting the operating models from the respective risk analyses forward in time and adjusting fishing mortality in each management cycle according to the bigeye harvest strategy. Such an approach would be substantially less computationally demanding than a full MS-MSE, as it would not require estimation models for all stocks or the evaluation of multiple stock-specific or joint harvest strategies.

This type of analysis would provide useful information on long-term and equilibrium performance metrics. However, caution would be warranted when interpreting short-term performance metrics. The risk analyses for the three tropical tuna species were conducted in different years and therefore use different definitions of the current year. Consequently, differences in current stock status, age structure, and recruitment conditions among the operating models could influence short-term projections.

For this reason, extending the analysis to include spawning biomass and catch projections for yellowfin and skipjack would likely be most informative after the operating models for all three species have been updated using the most recent available data.

The *interim* MS-MSE presented here evaluates a single harvest strategy for bigeye tuna under the assumption that bigeye remains the species used to guide management actions for the tropical tuna fishery. A fully integrated MS-MSE would require harvest strategies for yellowfin and skipjack tuna, allowing all three species to be explicitly considered in management decisions. Development of species-specific or joint harvest strategies would, in turn, require the definition and evaluation of management objectives across all three species and stocks.

The development of management objectives for bigeye tuna has been a lengthy process involving extensive discussion among managers, stakeholders, and scientists. Although several candidate objectives have been identified, they have not yet been finalized. Consequently, the development of multi-species, multi-stock management objectives is also likely to be a substantial undertaking requiring considerable time and consultation.

The results of the yield analysis indicate that equilibrium yield could be increased substantially for skipjack tuna through higher levels of fishing mortality, but not for yellowfin tuna. The finding that current fishing mortality levels for yellowfin produce yields close to MSY is consistent with previous analyses of yellowfin tuna in the EPO (see SAC-17 INF-T). Previous studies have also shown that yellowfin yield could potentially be increased by reducing fishing mortality on small yellowfin in the floating-object and unassociated fisheries while increasing fishing mortality on larger yellowfin in the dolphin-associated fishery (e.g., Maunder 2002).

The results indicate that the current interim management framework can be implemented using a harvest strategy developed through the bigeye tuna MSE. However, the 2026 updated bigeye tuna assessment (SAC-17-03) indicates continued reductions in fishing mortality on juvenile bigeye tuna, such that yellowfin tuna is now estimated to be the stock requiring the most restrictive management measures under the southwest yellowfin stock-structure hypothesis. Despite this shift, the analyses presented here indicate that application of a bigeye-based harvest strategy would be unlikely to adversely affect the status of the yellowfin or skipjack stocks.

Harvest strategies evaluated in MSEs are often simplified representations of the management measures ultimately implemented in fisheries. This is particularly true for tropical tunas in the EPO, which are managed through a combination of measures, including seasonal closures, individual vessel thresholds (IVTs), spatial closures, full-retention requirements for tropical tunas, non-retention requirements for certain bycatch species, vessel capacity limits, limits on active echosounder buoys, and longline catch limits for some CPCs. Despite these measures, vessels retain considerable flexibility in their fishing operations and, consequently, in the species composition of their catches. For example, purse-seine vessels can shift effort between dolphin-associated sets that primarily target yellowfin tuna and floating-object sets that primarily target skipjack tuna.

Furthermore, management based primarily on seasonal closures applied uniformly across purse-seine vessels cannot directly target fishing mortality by stock. In addition, the yield obtained from a stock depends not only on the level of fishing mortality but also on the size composition of the catch, which varies among gears and purse-seine set types. Consequently, effective multi-species, multi-stock management of tropical tunas in the EPO will likely require management approaches that more explicitly account for species composition, stock structure, fishing practices, and fleet behavior.

Therefore, development of multi-species, multi-stock management objectives and consideration of alternative management approaches should precede the implementation of a full MS-MSE. Establishing these objectives and management frameworks in advance would help ensure that a future MS-MSE is designed to address the most relevant management questions and evaluate realistic management options.

6. REFERENCES

Maunder, M.N. 2002. The relationship between fishing methods, fisheries management, and the estimation of MSY. Fish and Fisheries, 3: 251-260.

Table 1. Equilibrium yield for the two yellowfin tuna stocks at the current (average 2021-2023) fishing mortality, F_{MSY}, and $F_{30\%,}$ and the percentage increase in yield for the models in the risk analysis.

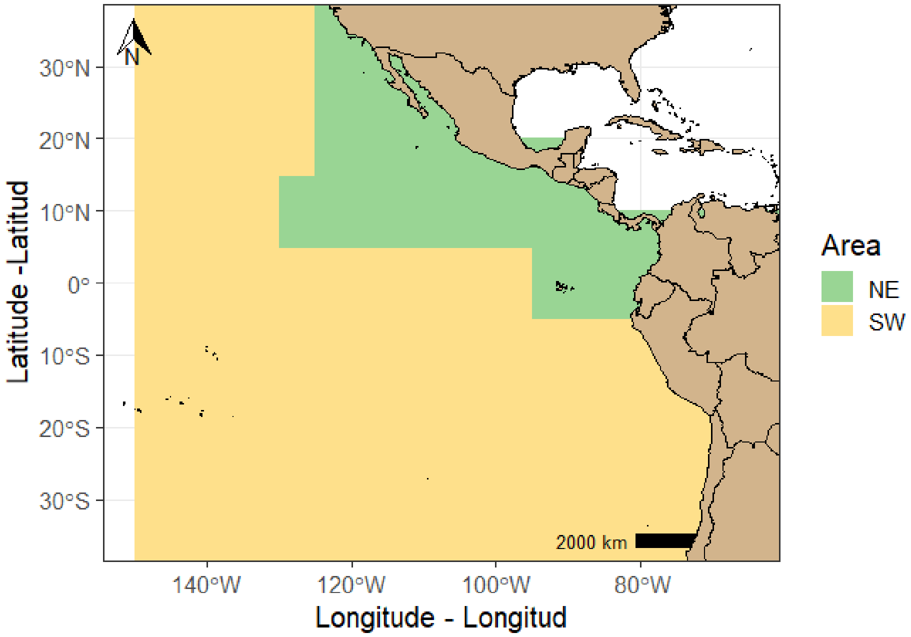
Tabla 1. Rendimiento de equilibrio para las dos poblaciones de atún aleta amarilla en la mortalidad pesquera actual
(promedio 2021-2023), F_{RMS} y F_{30}%, y aumento porcentual en el rendimiento.

Model	Yield_cur	MSY	F_{30}Yield	MSY %increase	*F*30% %increase
SW_base.1	85540	105165	94378	23%	10%
SW_base.0.9	84326	91939	89788	9%	6%
SW_base.0.8	82610	85236	84984	3%	3%
SW_G_high.1	85104	104191	93284	22%	10%
SW_G_high.0.9	83904	90697	88832	8%	6%
SW_G_high.0.8	82164	84359	84182	3%	2%
SW_G_low.1	86182	109901	96488	28%	12%
SW_G_low.0.9	85073	94045	91666	11%	8%
SW_G_low.0.8	83442	86909	86590	4%	4%
SW_M_high.1	93346	176334	137580	89%	47%
SW_M_high.0.9	92807	136300	128653	47%	39%
SW_M_high.0.8	92128	120783	119005	31%	29%
SW_M_low.1	76264	77458	75301	2%	-1%
SW_M_low.0.9	73740	73802	73533	0%	0%
SW_M_low.0.8	69988	72188	72162	3%	3%
SW_q1.1	88266	106113	94162	20%	7%
SW_q1.0.9	86573	91677	89598	6%	3%
SW_q1.0.8	84007	85050	84812	1%	1%
NE_base.1	192558	225846	211645	17%	10%
NE_base.0.9	193660	208267	205337	8%	6%
NE_base.0.8	195194	200206	200014	3%	2%
NE_G_high.1	192350	224667	211054	17%	10%
NE_G_high.0.9	193406	207610	204830	7%	6%
NE_G_high.0.8	194907	199729	199569	2%	2%
NE_G_low.1	192671	226366	211679	17%	10%
NE_G_low.0.9	193816	208410	205370	8%	6%
NE_G_low.0.8	195386	200328	200110	3%	2%
NE_M_high.1	192466	276452	240883	44%	25%
NE_M_high.0.9	193335	236940	229836	23%	19%
NE_M_high.0.8	194514	219736	218593	13%	12%
NE_M_low.1	192158	199509	194496	4%	1%
NE_M_low.0.9	193615	194519	193782	0%	0%
NE_M_low.0.8	195690	196338	196298	0%	0%
NE_q1.1	200450	235602	219620	18%	10%
NE_q1.0.9	200316	215520	211996	8%	6%
NE_q1.0.8	199971	205167	204836	3%	2%

Table 2. Equilibrium yield for skipjack tuna at the current (average 2021-2023) fishing mortality and at F30%, and the percentage increase in yield for the models in the risk analysis.

Tabla 2. Rendimiento de equilibrio para el atún barrilete en la mortalidad por pesca actual (promedio 2021-2023) y en F30%, y aumento porcentual en el rendimiento.

Model	Yield at F_{cur}	Yield at $F_{30\%}$	% increase
Reference	86167	132379	54%
A1-Estimating Linf	86205	132714	54%
A2-Linf = 78 cm	85511	127280	49%
A3-Linf = 88 cm	86296	134280	56%
A4-Estimating Lcv	82446	121836	48%
A5-Lcv = 0.03	87788	136565	56%
A6-Lcv = 0.09	84739	128087	51%
A7-Estimating growth shape parameter	86173	132407	54%
B1-Constant longline selectivity after 78 cm	86205	132674	54%
B2-Constant longline selectivity after 83 cm	86174	132418	54%
B3-Constant longline selectivity after 88 cm	86178	132452	54%
B4-F9 asymptotic selectivity, fixed longline selectivity and no fit for longline size composition	86009	130111	51%
C1-Using the most precise tagging-based absolute index and upweight by ten times	86193	115040	33%
C2-Using four tagging-based absolute indices with low CVs and weight by one	85104	140025	65%
D1-No tagging-based absolute index	85855	147913	72%
D2-No echosounder buoy index	93083	123239	32%
D3-Including longline survey index and size composition	82041	157976	93%
E1-Steepness = 0.75	89886	114725	28%



YFT areas

FIGURE 1. Spatial definitions of the northeast (NE) and southwest (SW) yellowfin tuna stocks.

FIGURA 1. Definiciones espaciales de las poblaciones de atún aleta amarilla del noreste (NE) y suroeste (SO).

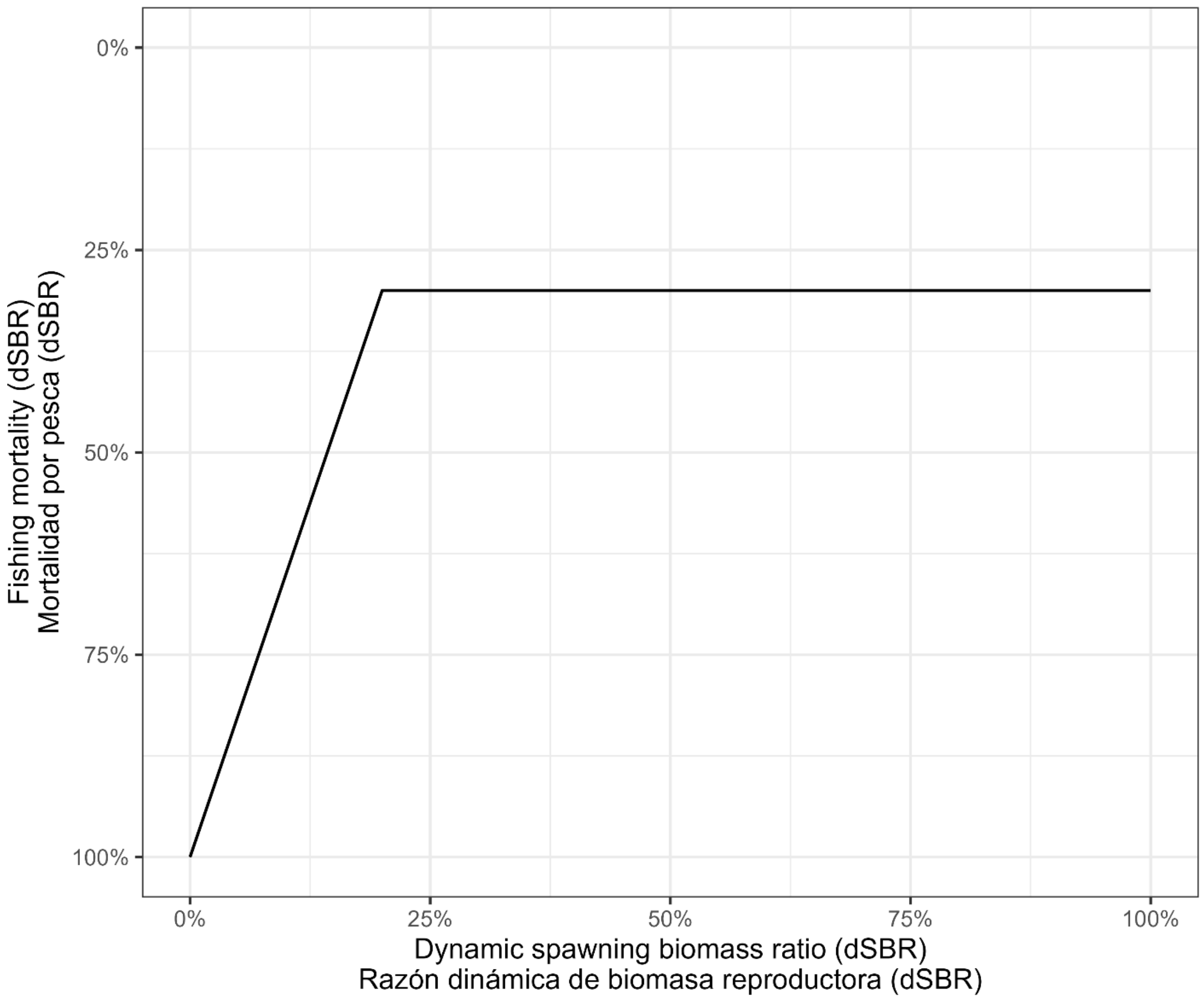


FIGURE 2. The F30-S20 harvest control rule tested in the bigeye tuna MSE (SAC-17-05) and evaluated in the MS-MSE.

FIGURA 2. La regla de control de la extracción F30-S20 se probó en el atún patudo MSE (SAC-17-05) y se evaluó en EEO-ME

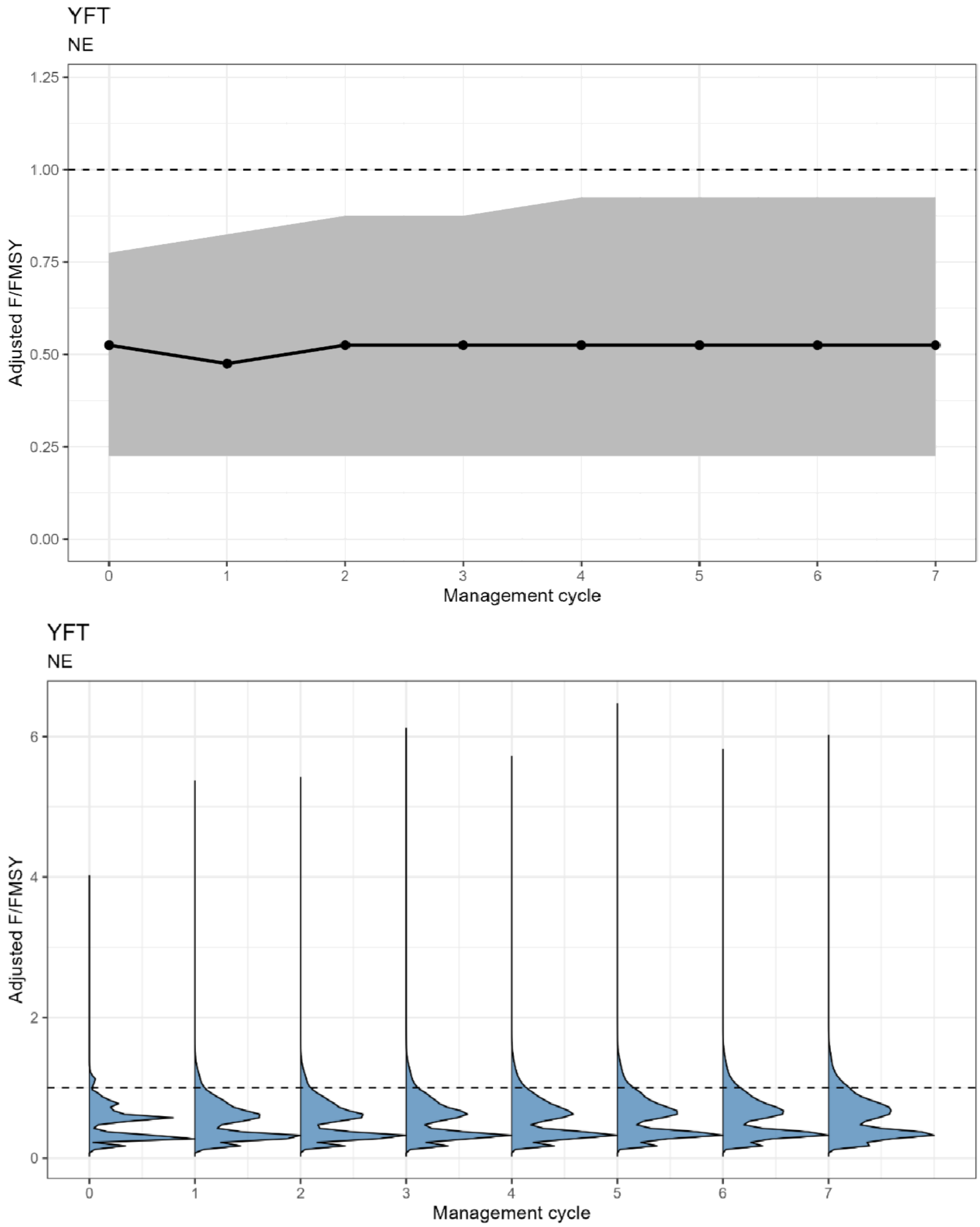


FIGURE 3. Mean and 80% percentiles (top) and distribution (Bottom) of the fishing mortality applied in each management cycle as a ratio of the fishing mortality corresponding to maximum sustainable yield for the northeast EPO yellowfin tuna stock.

FIGURA 3. El promedio y los percentiles del 80% (arriba) y distribución (abajo) de la mortalidad por pesca se aplicaron en cada ciclo de ordenación como una proporción de la mortalidad por pesca correspondiente al rendimiento máximo sostenible de la población de atún aleta amarilla del noreste del OPO

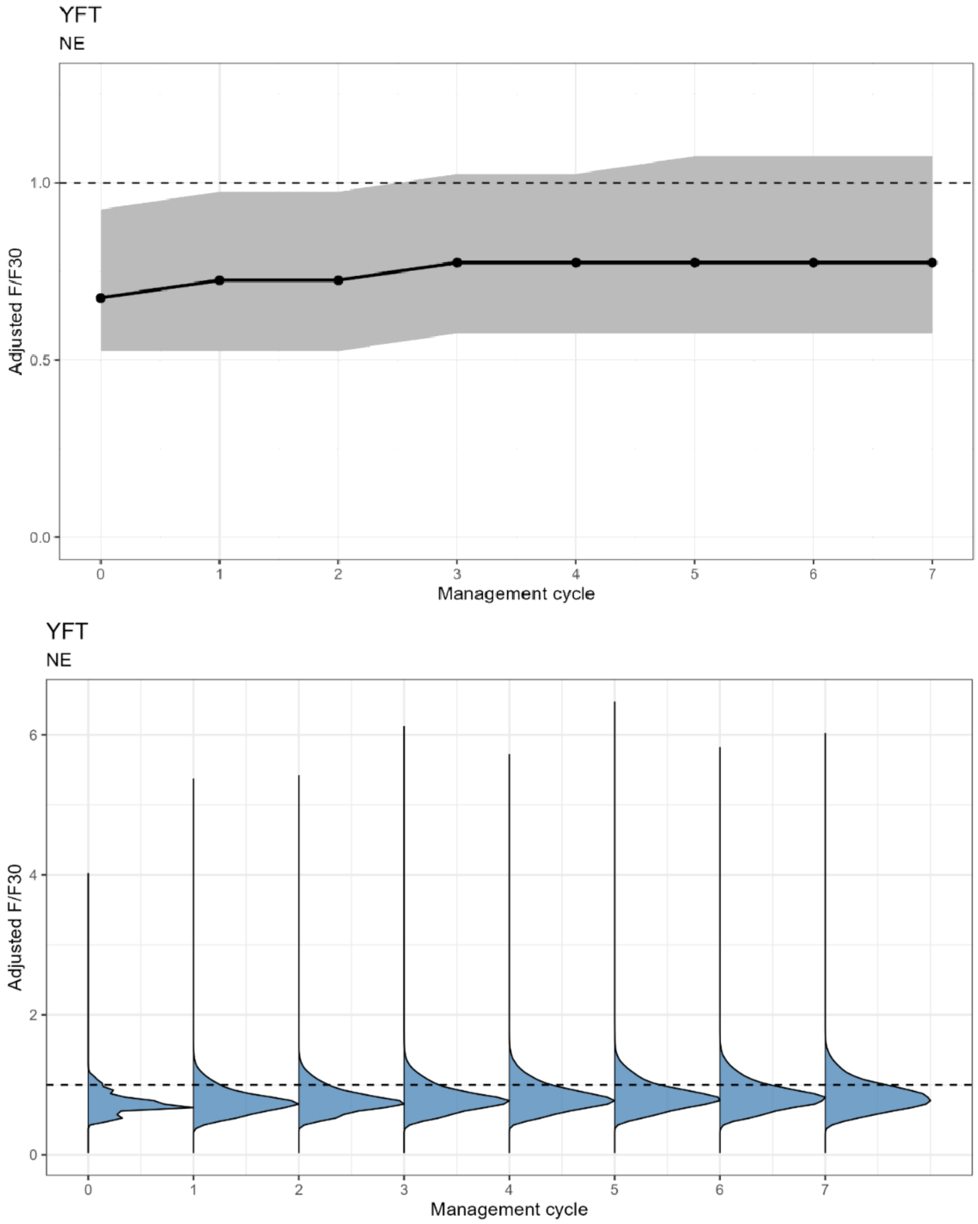


FIGURE 4. Mean and 80% percentiles (top) and distribution (Bottom) of the fishing mortality applied in each management cycle as a ratio of the fishing mortality corresponding to a 30% depletion level for the northeast EPO yellowfin tuna stock.

FIGURA 4. La media y los percentiles del 80% (arriba) y la distribución (abajo) de la mortalidad por pesca se aplicaron en cada ciclo de ordenación como una proporción de la mortalidad por pesca correspondiente a un nivel de agotamiento del 30 % para la población de atún aleta amarilla del noreste del OPO.

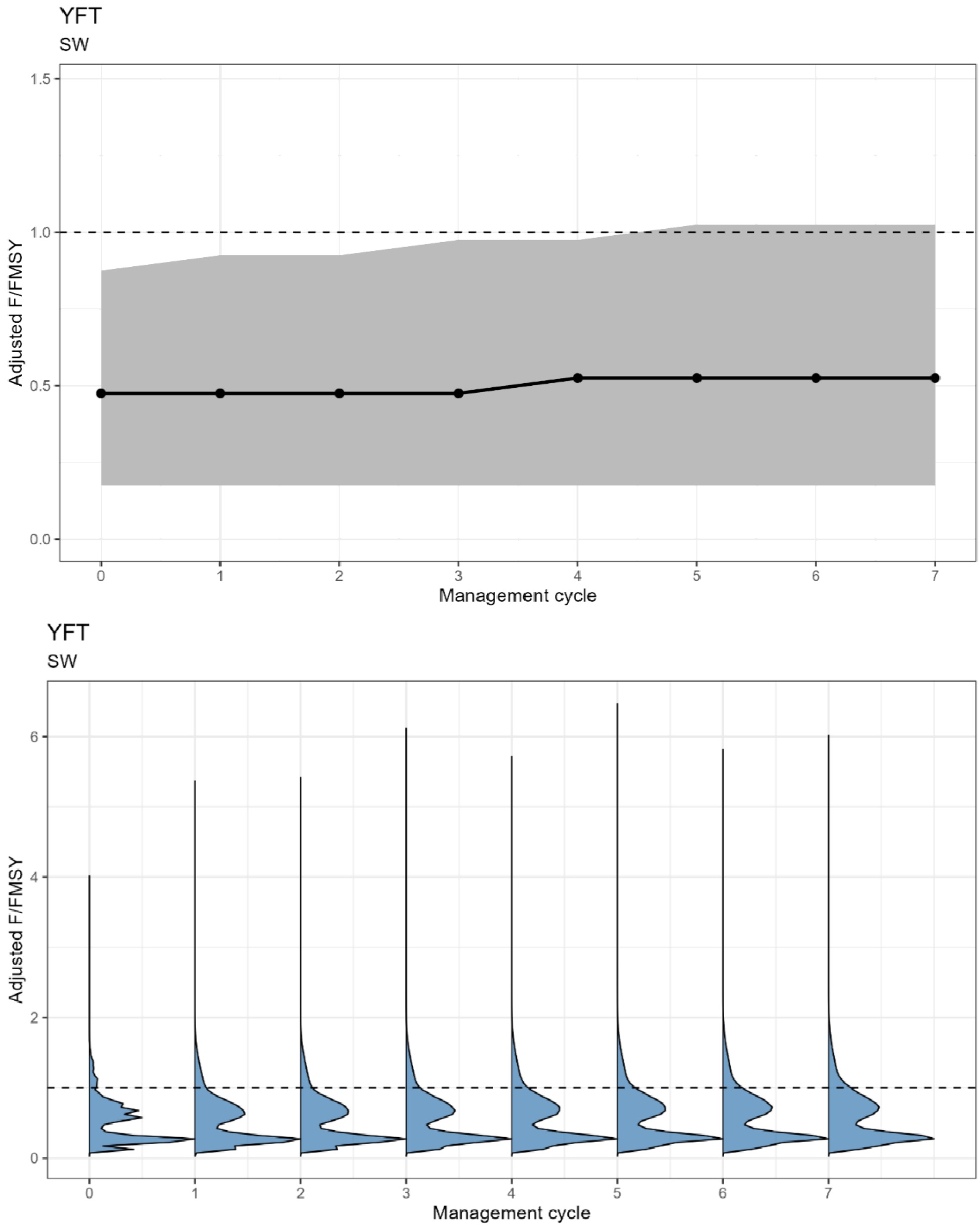


FIGURE 5. Mean and 80% percentiles (top) and distribution (Bottom) of the fishing mortality applied in each management cycle as a ratio of the fishing mortality corresponding to maximum sustainable yield for the southwest EPO yellowfin tuna stock.

FIGURA 5. La media y los percentiles del 80% (arriba) y la distribución (abajo) de la mortalidad por pesca se aplicaron en cada ciclo de ordenación como una proporción de la mortalidad por pesca correspondiente al rendimiento máximo sostenible para la población de atún aleta amarilla del suroeste del OPO.

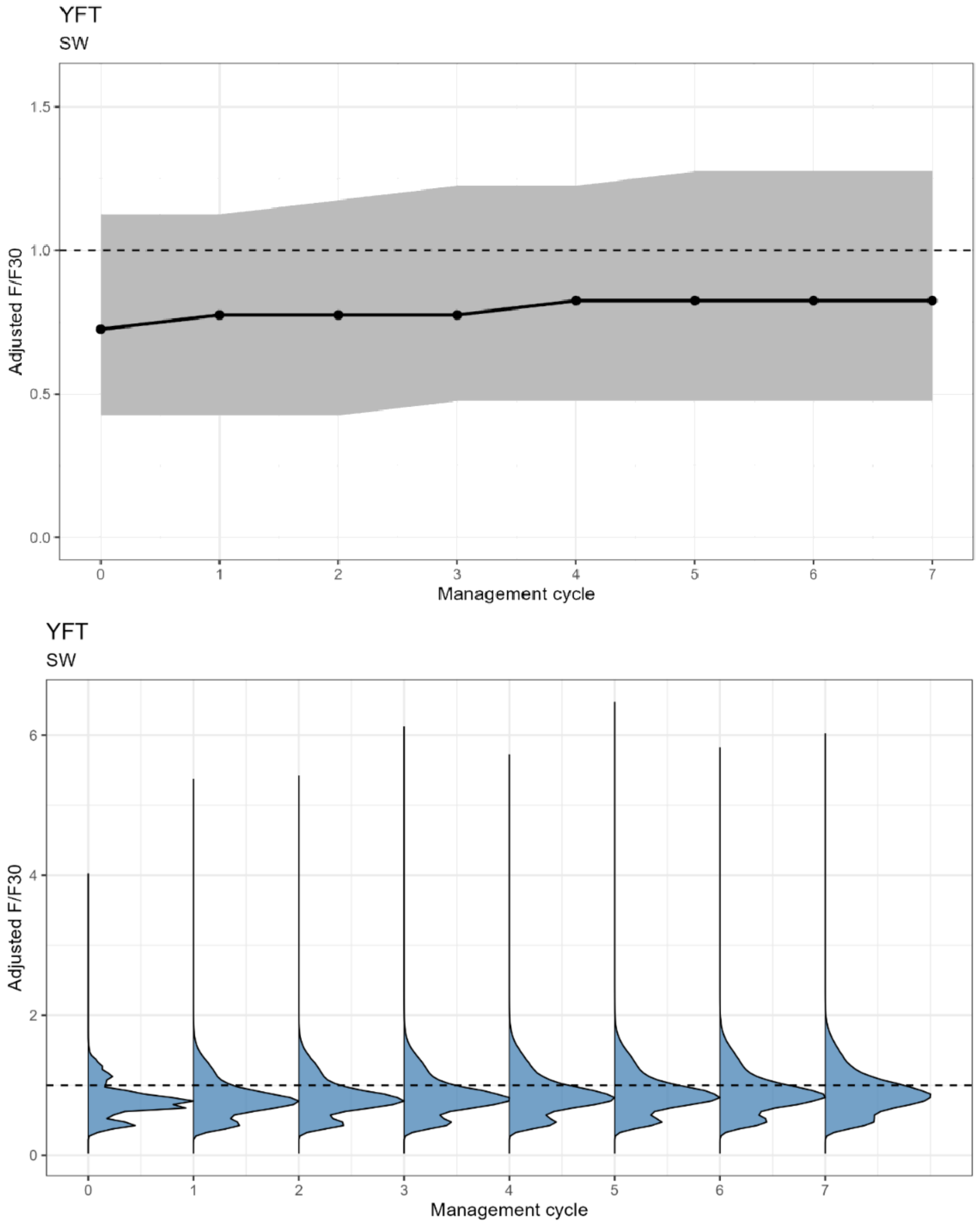


FIGURE 6. Mean and 80% percentiles (top) and distribution (Bottom) of the fishing mortality applied in each management cycle as a ratio of the fishing mortality corresponding to a 30% depletion level for the southwest EPO yellowfin tuna stock.

FIGURA 6. La media y los percentiles del 80% (arriba) y la distribución (abajo) de la mortalidad por pesca se aplicaron en cada ciclo de ordenación como una proporción de la mortalidad por pesca correspondiente a un nivel de agotamiento del 30% para la población de atún aleta amarilla del suroeste del OPO.

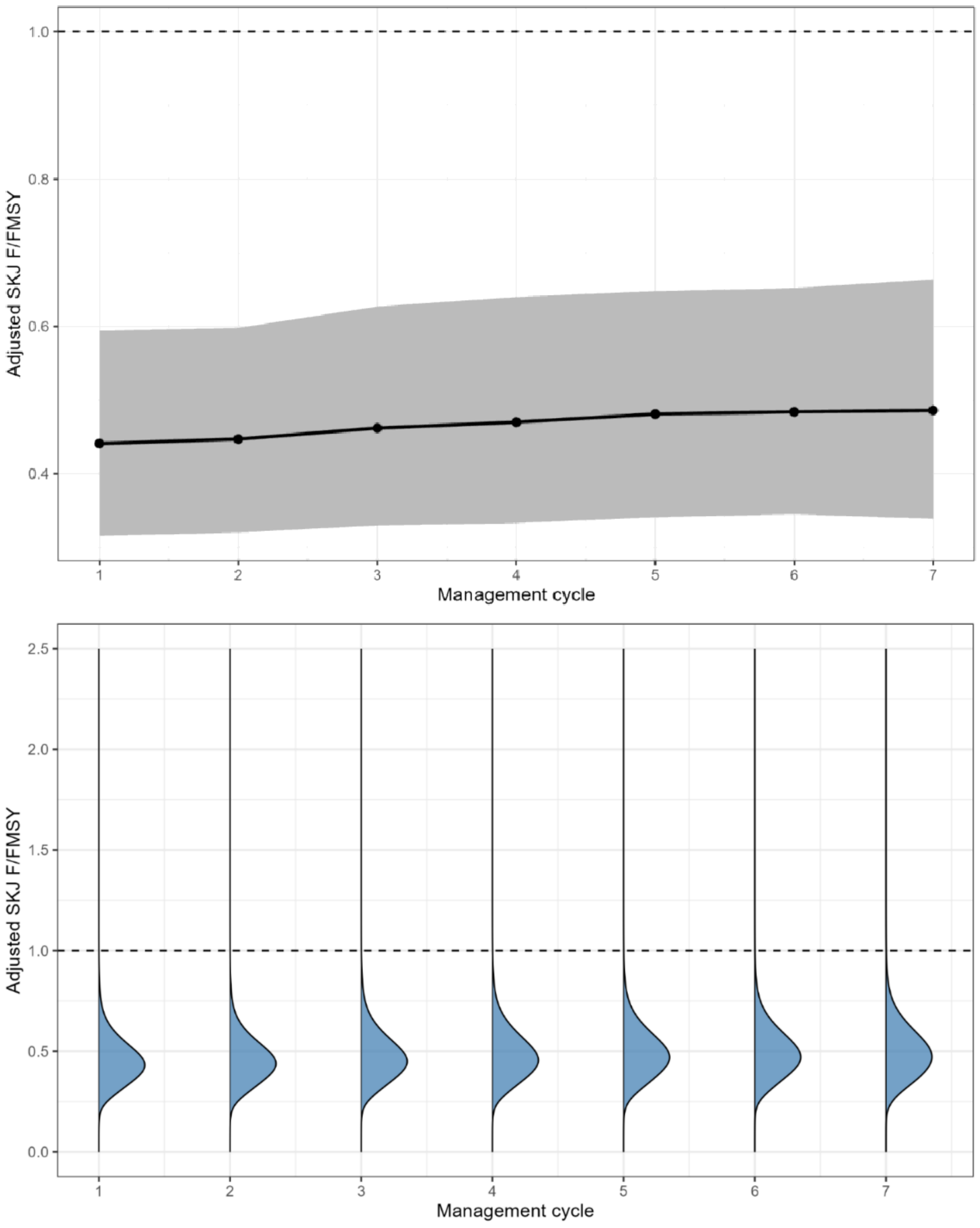


FIGURE 7. Mean and 80% percentiles (top) and distribution (Bottom) of the fishing mortality applied in each management cycle as a ratio of the fishing mortality corresponding to a 30% depletion level for the EPO skipjack tuna stock.

FIGURA 7. La media y los percentiles del 80% (arriba) y la distribución (abajo) de la mortalidad por pesca se aplicaron en cada ciclo de ordenación como una proporción de la mortalidad por pesca correspondiente a un nivel de agotamiento del 30 % para la población de atún barrilete del OPO.

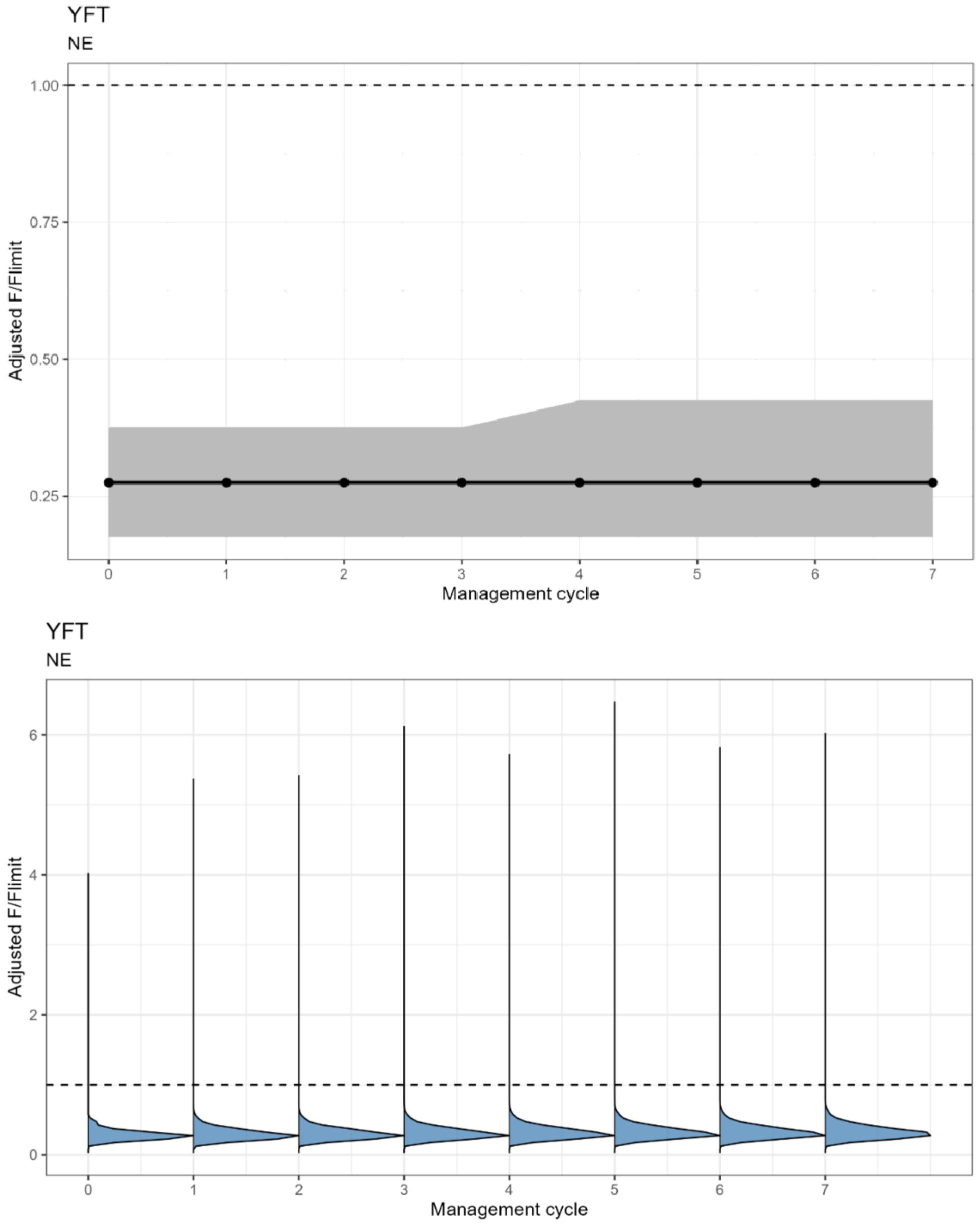


FIGURE 8. Mean and 80% percentiles (top) and distribution (Bottom) of the fishing mortality applied in each management cycle as a ratio of the fishing mortality corresponding to the limit reference point (FS7.7%) for the northeast EPO yellowfin tuna stock.

FIGURA 8. La media y los percentiles del 80% (arriba) y la distribución (abajo) de la mortalidad por pesca se aplicaron en cada ciclo de ordenación como una proporción de la mortalidad por pesca correspondiente al punto de referencia límite (FS7,7%) para la población de atún de aleta amarilla del noreste del OPO.

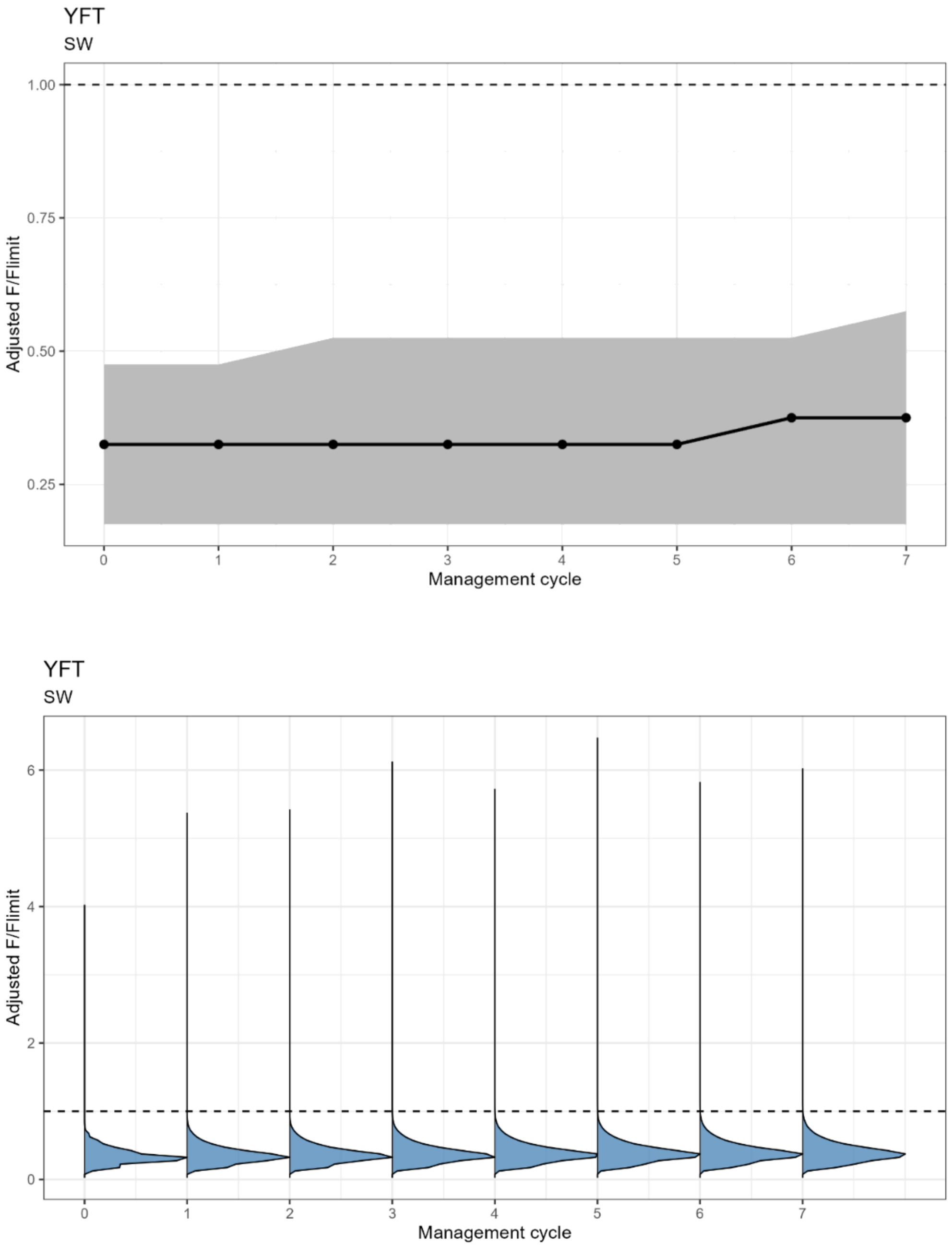


FIGURE 9. Mean and 80% percentiles (top) and distribution (Bottom) of the fishing mortality applied in each management cycle as a ratio of the fishing mortality corresponding to the limit reference point (FS7.7%) for the southwest EPO yellowfin tuna stock.

FIGURA 9. La media y los percentiles del 80% (arriba) y la distribución (abajo) de la mortalidad por pesca se aplicaron en cada ciclo de ordenación como una proporción de la mortalidad por pesca correspondiente al punto de referencia límite (FS7,7%) para la población de atún de aleta amarilla del suroeste del OPO.

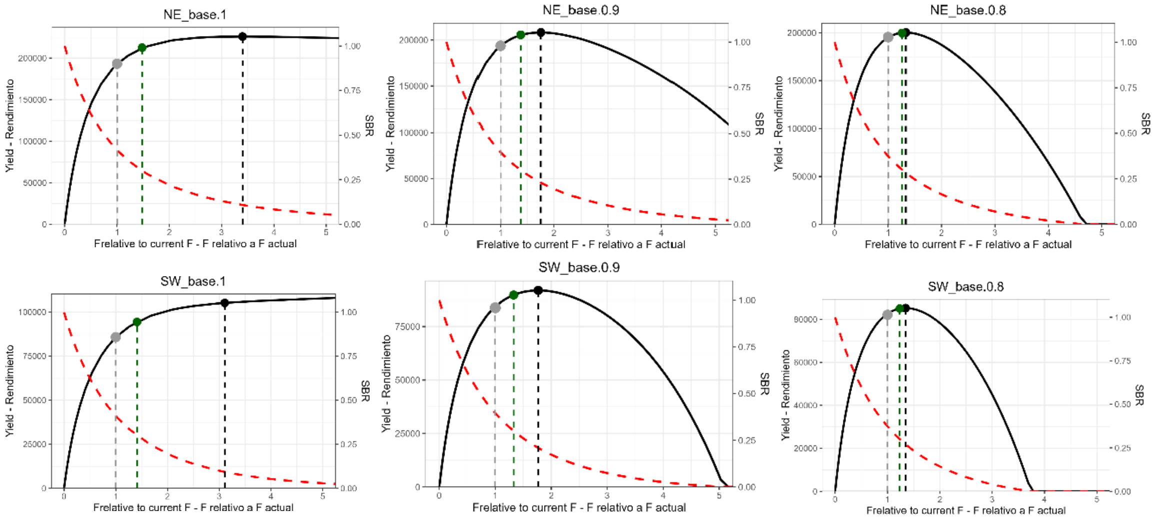
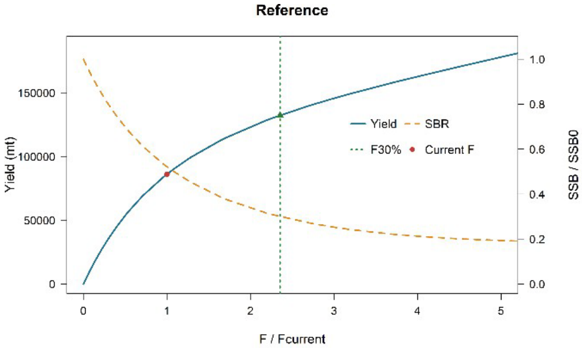
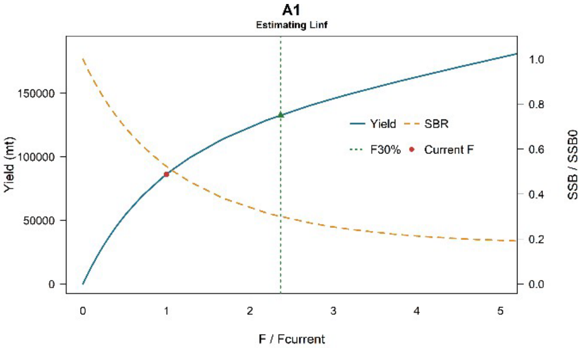
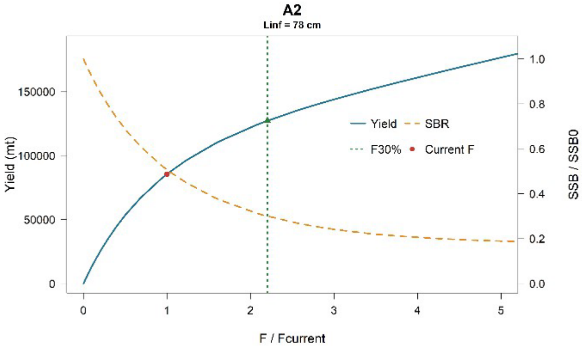


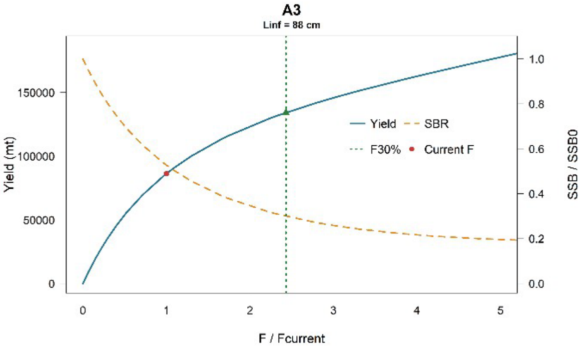
FIGURE 10. Yield and spawning biomass as a function of fishing mortality relative to the current (average 2021-2023) fishing mortality for the two yellowfin tuna stock from the reference model with different values of the Beverton-Holt stock-recruitment steepness. The vertical dashed lines represent the current fishing mortality (left), the fishing mortality corresponding to F30% (middle), and the fishing mortality corresponding to FMSY.

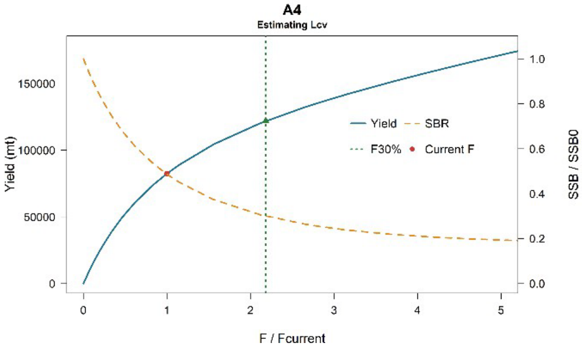
FIGURA 10. El rendimiento y la biomasa reproductora en función de la mortalidad por pesca y en relación con la mortalidad por pesca actual (promedio 2021-2023) para las dos poblaciones de atunes aleta amarilla procedentes de la pendiente del reclutamiento de las poblaciones del modelo Beverton-Holt. Las líneas verticales discontinuas representan la mortalidad por pesca actual (izquierda), la mortalidad por pesca correspondiente al 30 % F30% (medio) y la mortalidad por pesca correspondiente al FRMS.

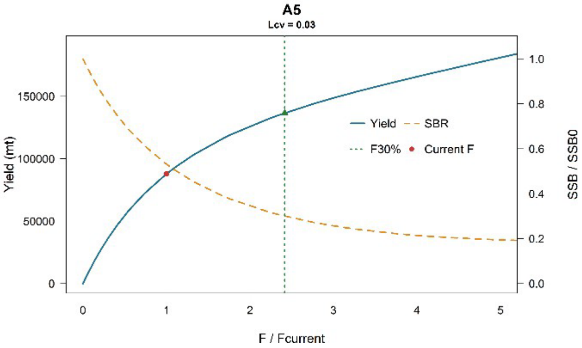

Reference
Yield (mt)
SSB / SSB0
F / Fcurrent
Yield
SBR
F30%
Current F
0
50000
100000
150000
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5


A1
Estimating Linf
Yield (mt)
SSB / SSB0
F / Fcurrent
Yield
SBR
F30%
Current F
0
50000
100000
150000
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5


A2
Linf = 78 cm
Yield (mt)
SSB / SSB0
F / Fcurrent
Yield
SBR
F30%
Current F
0
50000
100000
150000
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5

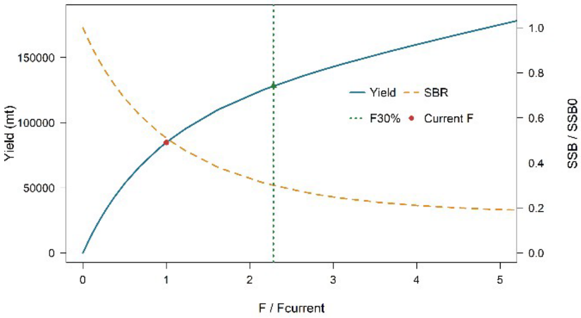

A3
Linf = 88 cm
Yield (mt)
SSB / SSB0
F / Fcurrent
Yield
SBR
F30%
Current F
0
50000
100000
150000
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5


A4
Estimating Lcv
Yield (mt)
SSB / SSB0
F / Fcurrent
Yield
SBR
F30%
Current F
0
50000
100000
150000
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5


A5
Lcv = 0.03
Yield (mt)
SSB / SSB0
F / Fcurrent
Yield
SBR
F30%
Current F
0
50000
100000
150000
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5

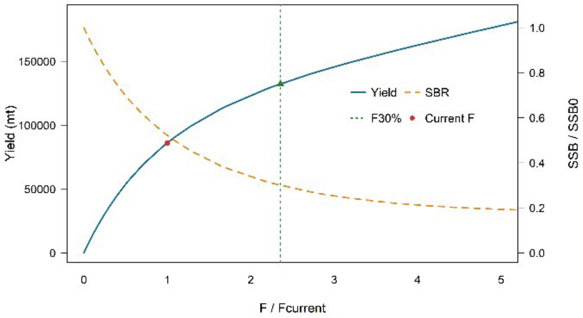
A6

Lcv = 0.09



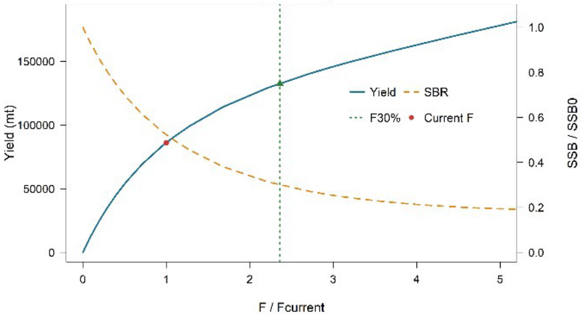
A7

Estimating growth shape parameter



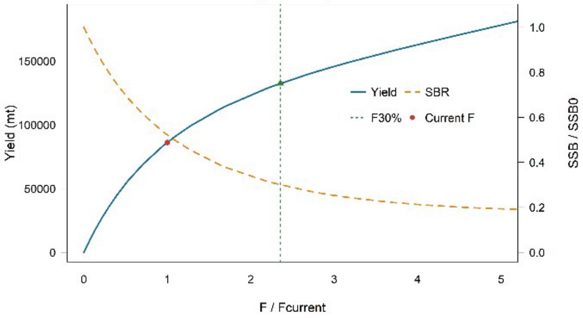
B1

Constant longline selectivity after 78 cm



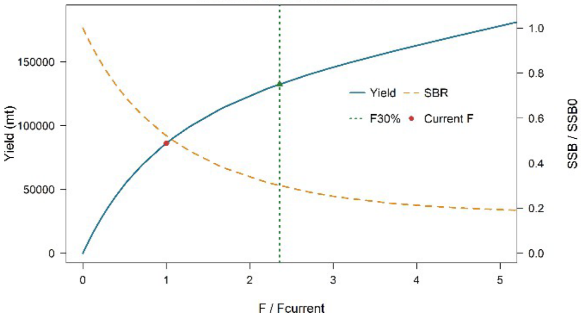
B2

Constant longline selectivity after 83 cm



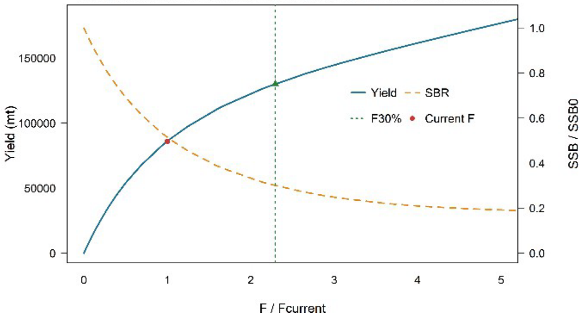
B3

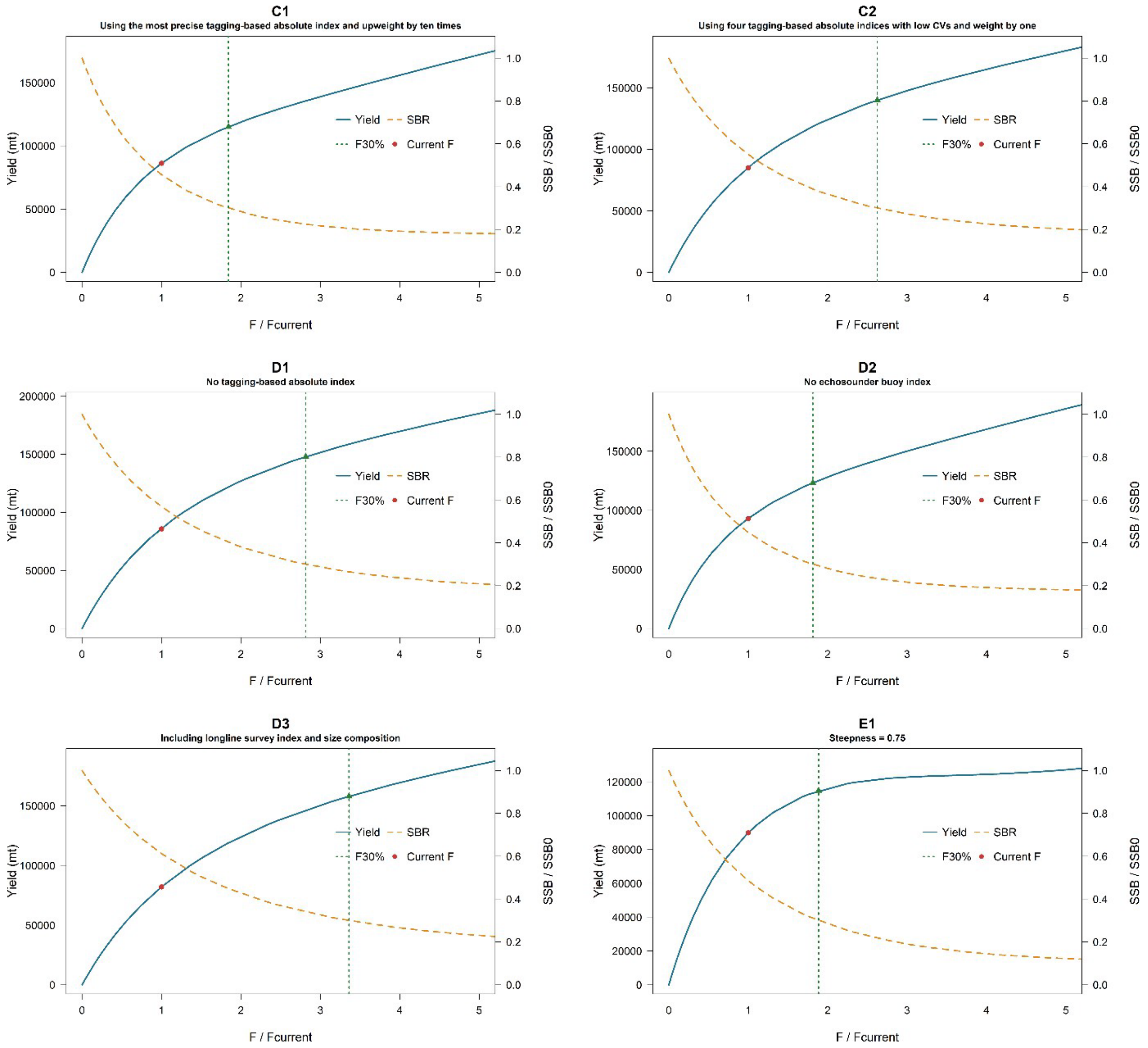
Constant longline selectivity after 88 cm



B4

F9 asymptotic selectivity, fixed longline selectivity and no fit for longline size composition




C1 Using the most precise tagging-based absolute index and upweight by ten times

C2 Using four tagging-based absolute indices with low CVs and weight by one

D1 No tagging-based absolute index

D2 No echosounder buoy index

D3 Including longline survey index and size composition

E1 Steepness = 0.75

FIGURE 11. Yield and spawning biomass as a function of fishing mortality relative to the current (average 2021-2023) fishing mortality for skipjack tuna from the models used in the risk analysis. The vertical dashed line is F30%.

FIGURA 11. Rendimiento y biomasa reproductora en función de la mortalidad por pesca y en relación con la mortalidad por pesca actual (media 2021-2023) para el atún barrilete, según los modelos utilizados en el análisis de riesgo. La línea vertical discontinua es F30%.