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REVIEW OF ALTERNATIVE CONSERVATION MEASURES FOR THE PURSE SEINE FISHERY FOR TROPICAL TUNAS IN THE EPO

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SUMMARY

Tropical tunas in the eastern Pacific Ocean (EPO) are currently managed using temporal closures for purse-seine vessels and catch limits for longline vessels. Other measures such as capacity limits, full retention, active FAD limits, and spatial closures are also in place for some fleet components. Other management options and variations on the currently used measures are possible. This document summarizes the alternative options and the analyses carried out over the past several years with respect to the purse seine fishery for tropical tunas in the EPO.

1. INTRODUCTION

The main tools used over the past decade to manage tropical tunas in the EPO are temporal closures for purse- seine vessels and catch limits for longline vessels. Due to increases in purse-seine vessel capacity, there has been a need to adopt additional conservation measures. In 2017, catch limits were initially put on the purse-seine catch by set type, but were replaced midway through the year by extending the temporal closure by 10 days (C-17-02). Recently, there has been concern about the increasing number of purse seine sets on floating objects (IATTC-94-03, FAD-04-01, IATTC-95-01). This increased number of sets is positively correlated with increasing estimates of fishing mortality (FAD-05 INF-D) and additional precautionary management action has been recommended (SAC-12-08; SAC-12-16). This document summarizes information presented over the past few years on management options; further information can be found in IATTC-90-04d(i), IATTC-90 INF-B, IATTC-90 INF-B Addendum 1, IATTC-91-03a, IATTC-91-03a Addendum 1,, SAC-11 INF-M and other documents (see Table 1). Results from IATTC-90 INF-B are repeated in Appendix 1 for convenience.

There are a range of issues that need to be kept in mind when evaluating alternative conservation measures:

a. There is uncertainty in the estimates of the status of the stocks.
b. The different fisheries and purse-seine set types impact each species to a different degree.
c. The magnitude of the required conservation measures differs among species.
d. The effectiveness of each alternative conservation measure differs among species.
e. The effectiveness of some conservation measures cannot be determined with current knowledge.
f. There is uncertainty in the estimated effectiveness of all the alternative conservation measures, more for some than for others.
g. The effectiveness of the conservation measures can differ from year to year.
h. The effectiveness of the conservation measures can change if the fisheries change their behavior.
i. Some data necessary for the development of fleet-wide management measures may not be available for small[1] purse-seine vessels.
j. Fishing effort (*e.g.* fleet capacity, days fished, number of sets, or number of "active" FADs) is used to control fishing mortality *F* of the purse-seine fisheries; it is assumed that the two are directly proportional. However, this may not be the case.
k. In general, a reduction in catch of juveniles will have a greater benefit in terms of the impact of the fishery on the stock than the same tonnage reduction in the catch of adults.
l. The need for additional conservation measures has partly been driven by the increase in purse-seine capacity, and therefore this is the fishery that needs further controls as opposed to longline.
m. The need for additional conservation measures has partly been driven by the increase in the number of floating-object sets, and therefore this is the set type that is in most need for additional measures.
n. Purse-seine capacity increases are not expected to translate into equal increases in fishing effort by the three set types (*i.e.* dolphin, unassociated, floating-object).
o. IATTC Class 1-3 purse-seine vessels are not covered by the main management measures.
p. More complex and stringent conservation measures could compromise the quality of data collected for compliance monitoring and research use (*e.g.* stock assessments).
q. Management measures may need to be designed to minimize their impact on the quality of data collected for compliance monitoring and research use.

2. REDUCING THE CAPACITY OF THE PURSE-SEINE FLEET

An obvious management measure to adjust for the increased capacity is to reduce the capacity. However, this does not appear to be a possible option as requests for additional capacity continue to be granted. In addition, not all capacity is equal due to factors such as vessel characteristics and fishing modes, technology used, and the skill of the fishing captain. Therefore, reductions in capacity often result in the least efficient vessels leaving the fishery, minimizing the benefit of reducing capacity.

The increase in the capacity of the purse-seine fleet is a major reason for requiring additional days of closure to manage the tropical tuna stocks in the EPO. The effect of the capacity increase has been evaluated at the overall fleet level. The only adjustment for differences in fishing behavior among vessels was for vessels that make a single trip within a year (under the special allowance in paragraph 12 of Resolution C-02-03; CAP-18-03), which are counted as one-quarter of their capacity. A statistically significant, but

[1] Vessels with carrying capacity <363 t.

weak, positive relationship has been detected between fishing mortality and capacity (Maunder and Deriso, 2014). This overall relationship may be weak because the relationship between fishing mortality and capacity depends on a suite of vessel-specific factors, including the number of days fished, the types of sets made, the equipment used (*e.g*. use of a helicopter), and the fishing effectiveness (*e.g.* skipper skill). Some challenges associated with use of these factors to account for their effect on the relationship between fishing mortality and capacity are discussed in the remainder of this section.

The relationship of days fished to capacity varies from year to year, complicating the development of a relationship for use in management. Comparisons of days fished, weighted by capacity, with capacity fishing shows differences in the relative changes among years (IATTC-91-03a, IATTC-91-03a Addendum 1). Moreover, prediction of days fished and capacity for an incomplete year is problematic. Days fished can only be calculated reliably once all the data for the fleet are available, which is several months after the fishing has been conducted; or for near-real time, it must be approximated by days at sea. Currently, only the capacity fishing during a year is predicted for partial years (CAP-18-03) (to provide management advice on the length of the temporal closure). The predictions are, on average, a few percent lower than the actual calculated year-end values (Table 2); however, this corresponds to several additional days of closure.

Associating capacity with set type is problematic because vessels do not make exclusively one type of purse-seine set. The simplest approach to assign capacity to set type would be to assume that vessels with an AIDCP Dolphin Mortality Limit (DML) fish principally on tunas associated with dolphins, and those vessels without a DML fish principally on tunas associated with floating objects. However, not all vessels with DMLs make a large proportion of their sets on dolphins (SAC-10 INF-K), and a large proportion of sets by many vessels are combinations of unassociated sets and dolphin sets, or unassociated sets and floating-object sets. A more detailed analysis of the set type patterns of each vessel is needed to better refine the definition of capacity and how it influences catch by species (SAC-08-06d).

The change in capacity differs by year, DML status, and method of calculation, which makes forecasting capacity changes challenging. For example, results show that capacity increased in 2016 compared to 2015 for Class-6 vessels, with and without DMLs, but not for Class-4 and -5 vessels (IATTC-91-03a, IATTC-91-03a Addendum 1). However, data from Class 1-5 vessels were not used in some analyses because logbook data are not obtained for all trips of such vessels. Note that including these vessels in the analysis would affect only the 'no DML' category, since only Class-6 vessels are allocated DMLs.

3. TEMPORAL CLOSURES

3.1. TEMPORAL CLOSURES FOR THE WHOLE FLEET

Establishing periods of the year during which a fraction of the purse-seine fleet is prohibited entirely from fishing is currently the main management measure used for tropical tunas in the EPO. There are two temporal EPO-wide closures per year, and vessels can choose which closure to observe. The assumptions underlying temporal closures are that fishing mortality is proportional to the number of days fished and the capacity of the fleet (see previous section). The effectiveness of a temporal closure may vary depending on the time of the year that the closure takes place and differs among set types (see IATTC-92 INF-C). Restricting the closure to a single period for all vessels, or mandating a 31-day closure in both of the two current period to be observed by all vessels, did not substantially change the effectiveness of the existing measure (IATTC-90 INF-B).

3.2. TEMPORAL CLOSURES BY SET TYPE

Extending the current closure was considered to control the increase in the number of floating-object (OBJ) sets, but was not recommended due to the need to forecast the number of sets (SAC-11 INF-M).

Moreover, additional days of closure for all vessels would affect the dolphin associated fishery (DEL) and the fishery on unassociated schools (NOA), despite the fact that the current assessment indicates that the yellowfin stock is healthy (SAC-11-07 and SAC-11-08). Closures that are limited to one or more set type might be an option. In 2021, the staff is recommending an extended closure applied to both OBJ and NOA sets, based on the previous year's number of OBJ sets, to overcome these issues (SAC-12-08; SAC-12-16). Using the previous year's number of sets eliminates the need for real-time monitoring, does not require forecasting the number of sets, and allows the use of classification algorithms to check the recorded set type and make appropriate adjustments.

One specific concern as regards FADs in the context of temporal closures is that FADS can be deployed prior to a closure and left at sea to "fish" during the closure, potentially reducing the effectiveness of the closure. A complete stoppage of fishing related to FADs might be achieved by requiring all FADs be removed from the water prior to the start of the closure, but the practicality of such a requirement needs to be taken into consideration.

4. CATCH LIMITS

Catch limits are easy to understand, are used worldwide, and the IATTC has a long history of working with catch limits. Determination of the appropriate catch limit associated with applying the F_{MSY} harvest control rule requires estimation of the stock biomass in the year for which the catch limit is applied. This differs from simply using the maximum sustainable yield (MSY), which is based on the average stock biomass, as a catch limit. The stock assessments project future biomass, but these projections are not used to calculate catch limits. The catch limits used in 2017 were based on average catch in the years used in the stock assessment to calculate the *F* multiplier. The assumption is that, if the *F* multiplier in those years is close to 1, then the catch should be close to the level corresponding to the F_{MSY} harvest control rule. However, this assumes that the stock abundance in the year corresponding to the catch limit is the same as in the years used to calculate the *F* multiplier. Unfortunately, tropical tunas are short-lived, and their abundance fluctuates substantially, so the stock size can also vary substantially from year to year, influencing the appropriate catch levels. This is particularly true for fisheries that catch juvenile tunas (*e.g.* the FAD fishery) and thus involve only a few cohorts, so that variations in recruitment have a substantial impact on the abundance of tuna vulnerable to the fishery.

Catch limits require timely monitoring so that the fishery can be closed or restricted when the limit is reached. The IATTC has an at-sea weekly observer reporting system which could be used to provide a near real-time estimate of the catch. However, catch for some Class 1-5 vessels is not available from the weekly reporting system and would need to be predicted. In addition, while methods to correct species composition are available to adjust the annual catch, producing the best scientific estimates used in the stock assessment, currently no such methodology exists for set-level or trip-level catch data. Thus, the near real-time estimates of catch by species might be biased. In fact, the 2017 catch limits for floating-object sets were based on the combined total catch of bigeye and yellowfin, to reduce the influence of species misidentification. Discards should be included in the catches used to evaluate the catch limits; however, they are not part of the BSE and data are not available on discards by Class 1-5 vessels that did not carry an observer.

The advantage of catch limits is that they are not dependent on fleet or vessel capacity and are therefore not sensitive to the issues of calculating capacity or to changes in capacity. In general, if the capacity increases, the fishery will reach the catch limit earlier, resulting in an increased fishery closure. In addition, if the catch limits are by species, since the main fishing methods (dolphin-associated and floating-object associated) catch different species and ages, they will automatically account for the possibility that an increase in capacity mainly affects a certain set type.

Care needs to be taken in choosing the appropriate data set to calculate the catch limits to ensure that they are consistent with the data used to enforce the catch limit. For example, as noted above, the species composition of the catch used in the stock assessments is based on port-sampling species-composition data, but the weekly report data that could be used for monitoring the catch limits are not adjusted by the species-composition sampling. If there is a bias in the estimates of species composition from observers, logbooks, or canneries, there will be a bias in determining when the limit has been reached. For example, if monitoring of the catch limits is based on the weekly report estimates, which are not adjusted for species composition sampling, it may be appropriate to base the limits on data in the IATTC catch and effort (CAE) database, which are also not adjusted for species composition sampling.

The catch limit could also be adjusted for the *F* multiplier estimated by the assessment to make sure that the limit is equal to the application of the F_{MSY} harvest control rule. If the *F* multiplier is not equal to 1, then this implies that the average catch over the corresponding period does not correspond to application of F_{MSY}. The simplest method would be to assume that the catch should be adjusted in proportion to the *F* multiplier, although this assumption is not strictly correct.

4.1. TOTAL CATCH LIMITS

The simplest approach is to put a total catch limit on the whole fleet. A decision needs to be made about how the fishery is closed or restricted when a catch limit is reached. The management action could range from completely closing the fishery for all purse-seine vessels, no matter which species reaches its limit, to banning the catch of a certain species or set type. The current temporal closures are for all purse-seine set types, while the 2017 catch limits were by set type. Anything other than a complete closure for all purse-seine fisheries will redistribute effort from the closed fishing method to the other fishing methods.

There may be spatio-temporal variation in the distribution of each species under a catch quota. Therefore, it is important for the fishing vessels to have information on the current spatial distribution of each species so they can avoid quota species when appropriate (e.g. where the vessel's quota is full). Habitat models have been developed to provide decision-makers and resource-users with near real-time maps of high probability of specific species (*e.g.* bigeye) catches (SAC-10 INF-D). The approach for forecasting on a seasonal timescale can assist end-users in the development of effective catch-based conservation measures.

Total catch limits have several disadvantages. For example, as often happens with catch limits, they could cause a "race to fish", with vessels rushing to catch as much as possible before the limit was reached. Reliability of reporting may also become a problem as the conservation measures become more complicated and stringent. A comprehensive discussion of the advantages and disadvantages of catch limits, as well as a comparison with effort limits can be found in Squires *et al*. (2017).

Appropriate implementation of the catch limits based on the F_{MSY} harvest control rule requires prediction of the stock abundance that is vulnerable to the fishery or some proxy to this quantity. The management measures are currently set, theoretically, in July or August for the following year(s) based on assessments using data from the previous year. This means that the population has to be projected two or more years (depending on if it is a multi-year management measure) into the future to calculate the appropriate catch limit. The uncertainty in these predictions includes parameter estimation uncertainty (as presented in the Kobe plots), model structure uncertainty (as presented in sensitivity analyses and the recently developed risk analysis; SAC-11-08), and future variation in recruitment (as accounted for in the confidence intervals of the projections), and uncertainty in catchability and effort levels. A comprehensive analysis of this uncertainty has not been carried out, but it is likely to be large as indicated by prior unpublished research for yellowfin tuna.

As an alternative to using model predictions of abundance, catch-per-unit-of-effort (CPUE) could be used as a proxy for abundance. This assumes that CPUE is proportional to abundance. This approach is similar to in-season catch increments used previously by the IATTC. However, there are a number of factors that may invalidate this proportionality assumption including the measure of effort used (days fished, number of sets, etc.) and changes in catchability over time. In addition, the CPUE would have to be reasonably current to ensure it represents current abundance. The most up to date CPUE data available would be the catch-per-capacity-fishing data from the weekly reports. The catch limits (CL) for 2022, for example, could be calculated by adjusting the average catch (C) during 2017-2019 by the ratio of the cumulative mid-year CPUE in 2022 to the average mid-year CPUE during 2017-2019. The CPUE is calculated as the cumulative catch in the IATTC weekly report (CWR) at the midpoint of the year divided by the sum of the weekly operative capacity during the first semester of the year (CPUE = CWR/sum(weekly capacity)). Thus:

$$CL_{2022} = [(C_{2017}+C_{2018}+C_{2019})/3]*CPUE_{2022}/[(CPUE_{2017}+CPUE_{2018}+CPUE_{2019})/3]$$

This approach is affected by all the issues associated with defining capacity and how it relates to fishing mortality as described above. Another alternative to using model predictions of abundance would be to use the within-year depletion model for yellowfin tuna (Maunder 2010) to estimate abundance. This approach has not been evaluated for the other species.

4.2. CATCH LIMITS BY SET TYPE

Set type is one of a number of fishery-related characteristics that could be used when setting catch limits to improve the efficacy of the management measure. The 2017 catch limits were set based on set type because the species composition of the catch varies by set type. Dolphin-associated sets catch mainly large yellowfin, while floating-object associated sets catch mainly skipjack, but with significant amounts of juvenile bigeye and yellowfin. Unassociated sets catch a mixture of all three species, but mainly skipjack and yellowfin. The 2017 catch limits were only for floating-object and dolphin associated sets. The limit for floating-object sets was for yellowfin and bigeye combined to reduce the problems with species misidentification. The limit for dolphin-associated sets was only for yellowfin.

Most, if not all, the issues with global catch limits also apply to other types of catch limits, including catch limits by set type. However, monitoring and enforcement may become more complicated as the catch limits are broken down by categories. For example, limits by set type are difficult to enforce because many vessels make multiple types of sets, and their proportion of sets by set type may vary considerably over time. In addition, ambiguity in set type designation may need to be addressed by having a combined limit for floating-object and unassociated sets. Finally, if catch limits are not placed on all set types, as was the case for unassociated sets in the 2017 catch limit measure, effort may be transferred to the limit-free set type(s) after the catch limit(s) for the other set types are reached.

The adoption of catch limits in 2017 highlighted a major disadvantage of the catch limit approach. High catch rates were experienced in 2017 and the catch limit was reached well before the additional equivalent days of closure would have come into effect. This caused the IATTC to conduct a within-year reevaluation of management and the decision was made to revert to extending the days of closure rather than maintaining the catch limits. The higher catch rates were probably caused by higher abundance due to good recruitment entering the fishery, which would have resulted in fishing mortality rates lower than F_{MSY}. However, they could have also been due to increased catchability due to changes in environmental conditions or improved technology, and this would have resulted in fishing mortalities higher than F_{MSY}.

Any evaluation of catch limits by set type needs to take into consideration the proportion of the catch for a particular species by each set type and the size of the fish that are caught. A certain reduction in the catch does not necessarily correspond to the equivalent proportional reduction in the fishing mortality rate applied to the stock. In general, the same tonnage reduction in catch of small fish will have a greater benefit in terms of the impact of the fishery on the stock than would be achieved by a similar reduction in the catch of large fish. For example, the effect on the stock of a reduction in the catch of yellowfin in the floating-object fishery will be 2-3 times greater than the same reduction in catch proportionally spread over all the fisheries that catch yellowfin.

4.3. CATCH LIMITS BY CPC

Catch limits could be set for each CPC. These could be further divided into categories such as set type, vessel, or fishing company.

4.4. CATCH LIMITS BASED ON CATCHES IN EXCLUSIVE ECONOMIC ZONES AND THE HIGH SEAS

Catch limits could be set for each of the exclusive economic zones (EEZs) in the EPO, with an additional one for the high seas. Fishing could continue in any EEZ, or on the high seas, until each limit was reached. Such a system was evaluated in Document IATTC-90 INF-B for the 1 February – 30 June period, a time period with no other conservation measures in place (Appendix 1).

4.5. INDIVIDUAL VESSEL CATCH LIMITS

Catch limits could be set for each individual vessel to give more flexibility to each vessel and promote the development of techniques to avoid species that are more vulnerable (*e.g.* bigeye in the floating-object fishery). The limits could be based on catch history or fishing capacity. Setting the limits on fishing capacity could be based on one of two scenarios that may occur when individual set limits are implemented. The first scenario assumes that when a limit is given to a vessel it will change its behavior to catch that limit even if historically it did not catch that much fish. The disadvantage of this approach is that some vessels may have limits much lower than their historical catch and if the other vessels are unable or unwilling to change their fishing strategy, the combined limit will be set too low. The second scenario assumes that vessels will fish in the same way as they did in the past so that they will not catch their limit if their historical catch was low. This approach will allow higher catch limits for all vessels and mainly restrict only those vessels that historically caught a large amount of tuna, but if vessels that historically caught little of that species are able to change their fishing strategy to catch more, the catch will be much higher than desired. In general, this method is not appropriate for the main target species (*e.g.* yellowfin tuna in the dolphin associated fishery) because it assumes that vessels that did not catch their individual vessel limit (IVL) in the past do not catch it in the future, even though in actuality it is likely that vessels will try to maximize their target catch relative to the IVL. An alternative option would be to distribute the catch limits among vessels based on a mixture of historical catch and fishing capacity, or another criterion.

IVLs have most, if not all, the issues related to global catch limits. For example, the limits should be based on the current stock abundance. The IVLs could be set as a proportion of the global limit so that they could be automatically adjusted every year using the approaches described for the global limits.

One benefit of the IVL system is that, if implemented appropriately, vessels that historically caught large amounts of bigeye and yellowfin tuna relative to their capacity will have to reduce their catches the most. To prevent the IVL system from resulting in higher catch due to changes in fishing behavior, it could be combined with an overall catch limit, which could be by country or simply a total fleet limit. Care needs to be taken when choosing the vessels that will be allocated IVLs, if allocation is based on their combined yellowfin and bigeye catch, because some vessels with large historical yellowfin catches could switch to catching more bigeye or vise-versa.

IVLs to reduce the catch of bigeye tuna in the EPO purse-seine fishery have been discussed previously. Documents SAC-04-11 and IATTC-82 INF-A discuss the numerous logistical issues that have to be addressed before implementing IVLs (*e.g.* transferability of limits, switching set types, enforcement, monitoring, and species identification). Examples of the IVLs, their calculation, and further details are provided in Documents IATTC-90 INF-B Addendum 1, IATTC-91-03a, and IATTC-91-03a Addendum 1.

5. SPATIAL CLOSURES

Spatial closures can be used to target conservation of certain species or a component of a stock (*e.g.* juveniles), if there are differences in the spatial distribution among species or components of the stock. The effectiveness of the closure will depend on the location and the timing of the closure. Annual variations in the spatial distribution of the stocks will cause the effectiveness of the closure to change over time. Evaluation of the benefit of spatial closures requires assumptions about the spatial redistribution of the effort outside the closure. These assumptions are often difficult or impossible to validate, which adds uncertainty to the estimated effectiveness of a spatial closure. The redistribution of effort is also complicated by the possibility of vessels changing their fishing behavior. Spatial closures are often only effective for one or a few species, and may increase the catch of bycatch species or reduce the catch of other target species. An advantage of spatial closures over temporal closures is that they allow the fishery to operate throughout the year. However, due to spatial fidelity of some species they could result in local depletion.

The IATTC currently includes a spatial closure in its management of tropical tunas. This closure, which was designed to reduce the catch of juvenile bigeye and yellowfin, affects an area known as the "*corralito*" (96°-110°W between 4°N and 3°S) from 29 September to 29 October, and is estimated to be equivalent, in terms of bigeye conservation, to closing the whole EPO to purse-seine fishing for approximately 3 days. The effect on yellowfin tuna is much less since most of the yellowfin catch is taken outside this area. Document IATTC-90 INF-B Addendum 1 presented several analyses, based on data for 2012-2015, to evaluate the impact of closing a spatial extension of the *corralito* for an additional 1 to 5 months during February-June (a time period when no other conservation measures are in place). For this analysis, the northern and southern boundaries of the extended *corralito* were set at 5°N and 5°S, respectively, and the western boundary was moved westward, from 110°W to 150°W, in 5° increments. The equivalent days of closure for bigeye increases linearly as the western boundary moves west, but the magnitude differs among months. May and June reached about 12 equivalent days at 150°W, and a closure from February to June out to 110°W was found to be equivalent to about 11 days. Thus, it was concluded that the *corralito* closure would have to be extended both westward and for more than one month to achieve substantial reductions in catch. At the time of the analysis, an additional 17 days of EPO-wide closure were required, which was found to be equivalent to, for example, closures during February-April out to 145°W, February-June out to 120°W, March-May out to 130°W, or May-June out to 135°W.

Monitoring compliance of spatial closures would be improved with the adoption of a procedure for accessing all data from the obligatory Vessel Monitoring System (VMS) for all vessels. Absent VMS data, spatial closures could not be independently monitored for Class 1-5 vessels, and for Class-6 vessels, monitoring would have to be done with observer data.

In summary, spatial closures in the western part of the EPO were estimated to be effective for reducing bigeye tuna catch, but generally have to be large and/or for a long time period to provide the desired impact. The spatial closures evaluated in previous work, even those considered specifically for yellowfin management, did not reduce the yellowfin catch to any substantial degree (see SAC-07-07e, IATTC-90 INF-B, IATTC-90 INF-B Addendum 1). Appendix A of document IATTC-90 INF-B presents the size distributions of the catch by 5-degree square, and can be used to evaluate qualitatively the size of the tuna caught in a spatial closure if the size of the fish is a consideration for evaluating management measures. The use of Dynamic Ocean Management to shape adaptive seasonal closures might improve the effectiveness of spatial closures (*e.g*. SAC-10 INF-D).

6. FAD-RELATED LIMITS

The technology now present in the floating-object fishery, and the nearly exclusive use of FADs in that fishery (as opposed to natural floating objects), has transferred searching effort from vessels to FADs.

FADs can be equipped with echo-sounders and satellite communication equipment, so that the approximate biomass of fish at a FAD can be determined without the vessel visiting the FAD. This equipment also provides fishers with the location history of each FAD, which may provide an indication of its propensity to have associated tuna taking into consideration remote sensing environmental data using fishers' expertise and experience. This means that the vessel may use information about the distance to a FAD, its drift history, and a proxy of overall biomass at the FAD to determine which FAD(s) should be fished on any given day. This implies that the more FADs that are deployed, the more "searching" is done by the FADs, potentially leading to higher catch rates and/or a greater number of sets. Therefore, limiting FAD availability by, for instance, reducing the number of FADs deployed or limiting the daily number of active FADs allowed for each vessel, might reduce tuna catches. Information on the total number of FADs at sea is not available, so research has been based on the number of FAD deployments recorded by at-sea observers on Class-6 vessels and the active-buoy data reported by vessels under Resolution C-17-02.

Purse-seine vessels in the EPO use different fishing strategies, which complicates development of FAD-related management measures. Fishing strategies can be grouped into the following categories: 1) a tendency to make dolphin sets versus floating-object and unassociated sets; and, among vessels making floating-object sets, 2) a tendency to make floating-objects sets on the vessel's own FADs *versus* 3) on objects found drifting and/or on FADs of unknown origin (SAC-08-06d; FAD-05 INF-A). Vessels fishing primarily on their own FADs tend to fish further offshore and make a greater number of FAD deployments. Based on analysis of 2012-2015 observer data, it was found that the overall relationship between number of FAD deployments and number of floating object sets is characterized by an increasing, nonlinear relationship that begins to asymptote at several hundred deployments (SAC-08-06d). However, this nonlinear relationship differs between those vessels fishing primarily on their own FADs and those vessels making a greater proportion of their sets on other types of floating objects. A weak but statistically-significant increasing relationship was identified during 2012-2015 between standardized catch-per-set and the number of FAD deployments per vessel for Class-6 vessels that set primarily on FADs they deployed themselves, in two of the four years; an increasing relationship was also observed in the other two years, but it was not statistically significant (Lennert-Cody et al. 2018). These results are consistent with the hypothesis that vessels may benefit from larger numbers of FAD deployments because they can try to optimize their catch rates, even if the number of sets they make does not necessarily increase with deployments. However, there is a great deal of variability around the annual relationships, and it is not known whether these results would be applicable to other vessels that make a much greater proportion of their sets on FADs encountered by chance.

There are a number of possible options to limit FAD-related fishing activity, and several of these have been reviewed recently in detail (SAC-11 INF-M). Broadly speaking, limits could be considered for buoy purchases, number of FADs carried on the vessel, daily number of active FADs, number of FAD deployments, number of FAD retrievals, a ratio between FAD deployments and FAD retrievals, or number of FADs a vessel has in the water at any given time. Alternatively, the number of FADs a vessel may deploy, or the daily number of active FADs per vessel, could be linked to the vessel's well volume. However, with the available data it is very difficult to evaluate how effective these measures would be in reducing fishing mortality. Although limiting total FADs at sea would be preferable to limiting active FADs or FAD deployments, the number of FADs at sea, as well as their effects on the catch rates, are currently unknown, and cannot be estimated accurately with the data available to the staff (SAC-11 INF-M). Based on analysis of observer data, the number of FAD deployments by Class-6 vessels varies widely, and as noted above, there is no simple relationship between the number of FAD deployments and the number of floating-object sets made (IATTC-90 INF-B Addendum 1; SAC-08-06d). Limiting FAD deployments has not been recommended because the number of FADs at sea would depend on recoveries and monitoring deployments is difficult (see SAC-11 INF-M for more details). Additional information that needs to be obtained in order to better evaluate the effect of FAD-related limits is outlined in Document FAD-03 INF-A.

The current limits on FAD-related activity are on the number of active FADs. These limits were informed with data on the number of FAD deployments because at the time Resolution C-17-02 was drafted, no data were available on the actual number of active FADs. If the goal is to reduce fishing mortality, these limits likely need to be much lower. In fact, it was estimated that to reduce the number of floating-object sets by 13%, a 30% reduction in active FAD limits was needed (FAD-04-01). However, the relationship between the maximum number of active FADs and number of floating object sets per vessel is highly uncertain. Further limiting the number of active FADs was recommended in combination with floating object set limits to stop the increase in the number of floating object sets (SAC-11 INF-M). As described in SAC-11 INF-M, individual vessel limits on active FADs, based on historic usage, would likely be the most effective means of maintaining the "*status quo*" in terms of active FAD usage. However, the definition and use of active FADs is complicated, and would likely reduce the effectiveness of active FAD limits (FAD-03 INF-A). Additional data reporting and improved reporting are needed to address these shortcomings (SAC-11 INF-M).

7. LIMITING THE NUMBER OF SETS

Limiting the number of sets could also be used to limit fishing mortality. However, since a set is only made once tuna have been found, limiting the number of sets may be more like a catch limit than an effort limit. For example, if the abundance of fish under a FAD is independent of the total stock size (*i.e.* if school size does not change with stock size and only a single school associates with a FAD), then catch will be proportional to the number of FAD sets. However, if the number of tuna under a FAD increases proportionally with stock size, then the number of sets will act like a more traditional measure of effort, and catch will be proportional to both the number of sets and the stock size. It is not clear where the relationship lies between these two extremes. Recent increases in the number of floating-object sets (see SAC-10 INF-K for a breakdown of the increase by fishing strategy) indicates that there is an economic benefit of making more sets, and limiting the number of sets may be needed to ensure fishing mortality does not increase. A positive relationship between number of floating-object sets and fishing mortality has been found in the EPO (FAD-05 INF-D).

Limiting the number of floating-object sets in association with limits on active FADs was recommended by the staff to stop the increase in the number of floating object sets (SAC-11 INF-M). The rationale was that this measure directly limits the effort and therefore fishing mortality. If allocation was desirable, it could be done in several ways, including by country or individual vessels. Monitoring could be an issue for Class 1-5 vessels because they generally do not carry observers. Data screening algorithms could be used to monitor compliance, but this would not be in real-time and may require increased port sampling. A detailed discussion of the advantages and disadvantages of set limits can be found in SAC-11 INF-M.

7.1. LIMITING NUMBER OF OBJ SETS PER DAY

It has been hypothesized that the increase in number of OBJ sets may be due to making more sets in a day. Historically, a single OBJ set was made in the morning when the tuna were aggregated around the FAD. So, if more OBJ sets were made in a day this could increase the number of OBJ sets. Reducing the number of sets to one per day could be a way to limit the number of OBJ sets. However, SAC-07-07f(ii) showed that the number of days fished has also increased and therefore the number of sets per day has not changed, nor has the average time of day of a set. Further information is needed to evaluate this option such as the percentage of sets that are not the first in the day and the species composition and catch volume of those sets.

8. FURTHER CONSIDERATIONS WHEN SELECTING MANAGEMENT MEASURES

8.1. SIZE OF FISH CAUGHT

The impact on the fishing mortality of a given tonnage of fish caught is dependent on the size of the fish. In general, because a ton of small fish contains more animals than a ton of large fish, catching a ton of small fish has a larger impact on the fishing mortality. However, fishing mortality is different for different ages and therefore there is no simple measure of fishing mortality. In addition, if the size of the fish caught changes, so does the definition of F_{MSY}. The best way to evaluate the impact of changing the size of the fish caught is through the fishery impact plots, which describe the impact of fishing on the spawning biomass and take both the total catch and the age structure of the catch into account.

8.2. CONSIDERING UNCERTAINTY

There is a large amount of uncertainty in the development of management advice and this should be taken into consideration. Under the precautionary approach to fisheries management, accounting for uncertainty results in more stringent management measures. There is uncertainty in the estimate of the *F* multiplier from the stock assessment due to parameter uncertainty from the model estimation and from model structure uncertainty. There is uncertainty in how capacity is measured and associated with prediction of the capacity for the current year. The relationships between capacity, number of floating object sets, and fishing mortality are also uncertain, which adds to the uncertainty, since increases in capacity are used to adjust the *F* multiplier and increases in the number of floating object sets have prompted additional management recommendations. Catchability also varies temporally, so that for a given capacity level and seasonal closure period, a different fishing mortality might result.

The current bigeye and yellowfin assessments are based on a risk analysis that takes model uncertainty into consideration (SAC-11-08). The bigeye risk analysis produced a bimodal risk curve with a set of pessimistic models and a set of optimistic models, which increases the amount of uncertainty. The number of floating object sets has also been steadily increasing. Therefore, additional precautionary measures have been recommended for tropical tuna management in the EPO (SAC-12-08).

8.3. CLASS 1-4 PURSE-SEINE VESSELS

Class 1-3 purse-seine vessels account for only about 1.1% and 1.4%, and Class-4 vessels about 2.9% and 3.7%, of the total catch of yellowfin and bigeye, respectively, in the IATTC CAE (catch and effort) database (IATTC-91-03a). Class-4 vessels are currently allowed to make one trip of up to 30 days' duration during the closure, so only about half of their potential catches during the closure would be affected by the closure. Fully including Class 1-4 vessels in the current 72-day seasonal closure would reduce catch only by about 0.4% and 0.6% for yellowfin and bigeye, respectively, equivalent to 1 and 2 days of total EPO closure. However, small vessels do catch small yellowfin, so the reduction in yellowfin catch would consist of small tuna, and fishery impact studies suggest that the effect of this is 2-3 times greater than that of a reduction in catches of large tuna. Therefore, for yellowfin the reduction might be equivalent to about 2-3 days of total EPO closure.

9. DISCUSSION

The effectiveness, in terms of reducing catches of yellowfin and bigeye, of any of these management options varies (Table 3), and consequently the duration of the closure and the impact on the skipjack catch also vary. None of the options evaluated previously, except capacity reduction, temporal closures, and catch limits, led to substantial reductions in yellowfin catch, although some spatial closures that include the western part of the EPO appear to be effective for bigeye. Many of the options have different effects on the different species, which is a consequence of the different spatial distribution and species-specific vulnerability of the three purse-seine set types. Dolphin-associated sets catch predominantly yellowfin, while floating-object sets catch predominantly skipjack, but also a large proportion of the bigeye catch. Therefore, options may have to be combined to produce the desired management effect for all species.

Recently, the staff reviewed the advantages and disadvantages of several options to stop the increase in the number of floating object sets, as well as potential solutions to mitigate or compensate the associated disadvantages (SAC-11 INF-M). The staff weighed the management benefits against data and infrastructure shortcomings, which led it to conclude that a limit on floating-object sets for all purse-seine vessels, combined with individual-vessel daily active FAD limits, would be the best option for maintaining the *status quo* and thus preventing an increase in fishing mortality within a management cycle. Previously, a set limit was recommended on the combined floating-object and unassociated sets (IATTC-94-03) to counter the possibility of set misidentification and that the yellowfin assessment indicated that yellowfin, which are caught in the unassociated sets, status was a potential concern. However, this measure was not adopted because of the potential for a race to fish and the potential to switch from unassociated sets to floating object sets (SAC-11 INF-M). For Class 1-5 vessels, the increase in the number of floating object sets appears to be due to a switch from unassociated sets to floating-object sets, not to an increase in number of trips or vessels making floating-object sets (SAC-10 INF-K), indicating that there is a potential for this to continue. This combined set type limit is no longer supported by the staff because 1) yellowfin stock status is no longer a concern (SAC-11-07); (2) the possibility of exceeding existing OBJ set limits under a combined set limit is problematic; and (3) the staff recently developed a data verification algorithm to identify misreported set types in the observer data, and will develop similar algorithms for the logbook data (SAC-12-08). Instead, the staff is recommending an extended closure of both OBJ and NOA sets based on the previous year's number of OBJ sets (SAC-12-08). Using the previous year's number of sets eliminates the need for real-time monitoring, does not require forecasting the number of sets, and allows the use of classification algorithms to check the recorded set type and make appropriate adjustments.

Historically, spatial closures have sometimes reduced the amount of small yellowfin or bigeye caught without necessarily reducing the total catch. Determining the impact of spatial closures on F_{MSY} would require taking the size of the fish in the catch into consideration, using the stock assessment model, and has been outside the scope of previous analyses. In general, when small fish are caught, the exploitation rate for a given tonnage of catch is higher due to the larger number of fish that are caught. However, F_{MSY} will also change, and the results will also be sensitive to the assumptions about natural mortality at different ages. Therefore, it is difficult to evaluate the impact of management measures that are intended to alter the size of the fish caught.

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Squires, D., Maunder, M. N., Allen, R., *et al*. 2017. Effort rights-based management. Fish and Fisheries, 18: 440-465.

TABLE 1. Documents relevant to the general topic of management options for the tuna fisheries in the EPO.
TABLA 1. Documentos relevantes para el tema general de opciones de ordenación para las pesquerías atuneras en el OPO.

-	Plan for the Regional Management of Fishing Capacity	2005
PROP CAP-12 A-1	Draft resolution on freeze and reduction of purse seine capacity	2011
CAP-12 PROP B-1	Towards a new capacity management plan in the EPO	2011
CAP-11-04	Review of the Plan for the Regional Management of Fishing Capacity	2011
SAC-04-11	Individual-vessel limits for purse-seine vessels that fish on fish-aggregating devices (FADs)	2013
SAC-04 INF-B	Fishing capacity and efficient fleet configuration for the tuna purse-seine fishery in the EPO: an economic approach	2013
SAC-04 INF-D	Management options: total allowable catch (TAC) scheme	2013
PROP IATTC-85 H-1	Resolution on capacity management applicable to all fleet segments	2013
PROP IATTC-85 H-2	Draft resolution on management of fishing capacity	2013
CAP-14 INF-A	A road map towards a capacity management plan in the EPO	2013
CAP-WS-04A	Target capacity for the tuna fleet in the EPO	2014
SAC-07-07e	Preliminary evaluation of several options for reducing bigeye tuna catch: spatial closures and gear restrictions	2016
IATTC-90-04d(i)	Options for measures for the conservation of tunas in the EPO, 2016	2016
IATTC-90 INF-B	Alternative management measures for tropical tunas in the EPO	2016
IATTC-90 INF-B Addendum 1	Alternative management measures for tropical tunas in the EPO	2016
IATTC-91-03a	Evaluation of tuna conservation proposals	2017
IATTC-91-03a Addendum 1	Evaluation of tuna conservation proposals	2017
IATTC-92 INF-C	Potential effects on tuna stocks of alternative management schemes	2017
SAC-08-06d	A preliminary analysis of the relationship between the number of FAD deployments and the number of FAD sets for the EPO purse-seine fishery	2017
Squires *et al.* (2017)	Comparison of catch- and effort-based limits	2017
IATTC-93 INF-A	Responses to requests for data and analyses	2018
FAD-04-01	Adjusting current FAD limits to meet 2019 staff recommendations for tropical tuna management in the eastern Pacific Ocean	2019
SAC-10-10	Relationship between the characteristics of purse-seine vessels and fishing mortality (Project J.2.a): Progress report	2019
SAC-10 INF-D	Developing alternative conservation measures for bigeye tuna in the eastern Pacific Ocean: A dynamic ocean management approach	2019

SAC-10 INF-K	Causes of the increase in floating-object sets in the eastern Pacific Ocean in recent years: An analysis (Revised)	2019
IATTC-94-03	Staff recommendations for management and data collection, 2019	2019
SAC-11 INF-M	Managing the floating-object fishery for tropical tunas in the EPO: Supporting information for the precautionary additional measures recommended by the staff	2020
SAC-12-08	Managing the floating-object fishery for tropical tunas in the EPO: Additional precautionary measures recommended by the staff	2021
FAD-05 INF-D	The relationship between fishing mortality and the number of floating object sets for bigeye tuna in the eastern Pacific Ocean	2021

TABLE 2. Comparison of estimated and actual (based on full-year data) operating capacity.
TABLA 2. Comparación de la capacidad operativa estimada y real (basada en datos de año completo).

Year	Date	Report	Capacity (m^3)		Estimation error (estimated/actual)
			Estimated	Actual	
2012	8 May	IATTC-83-05c	214,422	217,687	0.99
2013	7 April	IATTC-85-03d	214,979	212,087	1.01
2014	2 May	IATTC-87-03d	215,608	230,379	0.94
2015	19 April	IATTC-89-04d	236,089	248,428	0.95
2016	17 April	IATTC-90-04d (REV)	255,972	261,474	0.98
2017	30 April	SAC-08-11	263,283	263,018	1.00
2018	25 March	IATTC-93-04	260,289	263,666	0.99
2019	NA			265,085	
2020	NA			239,687	

TABLE 3. Summary of advantages and disadvantages of the different management options.
TABLA 3. Resumen de las ventajas y desventajas de las diferentes opciones de ordenación.

Option	Description	Management		Monitoring	
		Advantages	Disadvantages	Advantages	Disadvantages
Fleet capacity					
Total	Limit on total fleet capacity.	Limit and duration of fishing season both known in advance. Provides flexibility for industry with respect to operational aspects. Provides less variability and uncertainty for industry. Does not encourage "race to fish."	Relationship to effort and *F* not well known. May unnecessarily limit fishing on some species. Can switch set type and species composition of catch.	Easy to assess compliance. Can be monitored in real-time.	Multiple definitions of capacity possible (operative, active, total, capacity days, *etc*.)
Set type	Limit on fleet capacity by set type.	Allows more control of effort by species.	Individual vessels can make multiple types of sets.		Potential falsification of set type. Cannot be monitored in real-time for most Class 1-5 vessels.
Temporal closures					
	Close entire EPO to fishing for a period of time.	Already accepted and in use. Limit and duration of fishing season both known in advance. Provides flexibility for industry with respect to operational aspects. Provides less variability and uncertainty for industry. Does not encourage "race to fish."	May unnecessarily limit fishing on some species. To apply to all purse-seine fleet components, all at-sea FADs would need to be retrieved prior to closure.	Easy to assess compliance.	Without FAD marking, impossible to know if all FADs retrieved prior to closure.

Catch limits					
Total	Limit on total fleet catch by species.	Allows limits to be aligned with stock status.	Tried and abandoned. Needs accurate estimates and forecasts of abundance.	Can be monitored in near real-time for Class-6 vessels.	Species composition data available for near real-time monitoring may be biased. Real-time monitoring for Class 1-5 vessels not presently possible.
Set type	Limits on species catch by set type .	Can target size composition more precisely than total catch and total species limits.	Species composition and age of catch varies by set type.	Can be monitored in near real-time for Class-6 vessels.	Species composition data available for near real-time monitoring may be biased. Real-time monitoring for Class 1-5 vessels not presently possible. May lead to falsification of set type.
CPC	Limits on species catch by CPC.				
EEZ/high-seas	Limits on species catch by EPO region.				
Individual vessel limits	Limits on species catch by vessel.	Allows limits to be aligned with stock status. Encourages individual vessel responsibility for management.	Multiple rules possible for assigning vessel limits.		Species composition data available for near real-time monitoring may be biased. Real-time monitoring for Class 1-5 vessels not presently possible.
Spatial closures					
	Temporal closure of a region within EPO.	Already accepted and in use, but on a very limited scale. Can be designed for particular species.	Effort reallocation adds uncertainty to effectiveness. Variability of effectiveness among years.	Potentially easy to monitor, if VMS data provided. Near real-time monitoring possible.	Without VMS data, may promote falsification of fishing location data.
FAD limits					
Active FADs	Limit number of active FADs per vessel.	Already accepted and in use. Targets effective effort in the floating-object fishery	Relationship between active FADs and *F* not well known. Not enough data to	Active FAD data is required to be reported.	Data currently provided under C-17-02 not adequate to monitor compliance. Activation and deactivation

		more directly.	evaluate management benefit. Definition of "active" (C-17-02) may not include all FADs at sea. Vessels can share FADs.		of FADs may be an issue. Data non-reporting is a current issue.
FAD deployments	Limit number of FAD deployments per vessel.	Targets effective effort in the floating-object fishery more directly. Mitigates the issue of FAD deactivation.	Number of FADs at sea dependent on recoveries. Relationship between deployments and *F* not well known. No deployment data for most Class 1-5 vessels.	Data collected on Form 9/2016 and by observers would allow compliance monitoring.	Submission of Form 9/2016 data has not yet reached 100%. Difficult to monitor deployments.
Set limits					
	Limit number of sets by set type.	Targets species and size composition more precisely. More directly related to catch than FAD limits.	Species and size composition of catch varies by set type. Relationship between number of sets and *F* not well known. May cause a race to fish if a global limit is set.	Easy to monitor in near real-time for Class-6 vessels.	Real-time monitoring not possible for Class 1-5 vessels. May encourage falsification of set type.

Appendix 1. Results of alternative management measures (IATTC-90 INF-B)

TABLE A.1. Proportional change in catch resulting from various spatial and temporal closures.
TABLA A.1. Proporción de reducción de captura para vedas espaciales y temporales.

Management measure	Proportional catch reduction		
	YFT	BET	SKJ
Eliminate second closure period	1.00	0.99	1.02
Eliminate first closure period	1.01	1.02	0.99
Reduce length of both closure periods to 31 days each	Not evaluated	Not evaluated	Not evaluated
Eliminate the capacity exemption in paragraphs 1 and 4 of Resolution C-13-01	Not evaluated	Not evaluated	Not evaluated
Extend the duration of the *corralito* closure	1.01	0.96	1.01
Closure of 5°S to the equator, 95°W-110°W	1.00	0.97	1.01
Closure of 5°S-5°N, 120°W-150°W	0.99	0.93	0.99
Closure south of 15°S	1.00	1.00	0.95
Spatial closure between the coast of Mexico and 125°W north of 23°N	1.01	1.00	1.01
Spatial closure between the coast of South America and 85°W from 5°N to 5°S	1.00	1.03	1.01
Close Guatemalan EEZ	Not evaluated	Not evaluated	Not evaluated
Close all EEZs	1.00	1.17	0.99
Close high seas	1.00	0.66	1.03

TABLE A.2. Equivalent days of closure for each of the conservation measures. The capacity reduction and catch limit proposals are assumed to produce the required equivalent days of closure to compensate for the increased capacity.

TABLA A.2. Días de veda equivalentes para cada una de las medidas de conservación. Se supone que las opciones de reducción de capacidad y límites de captura producen los días de veda equivalentes para compensar el aumento de capacidad.

Management measure	**Equivalent days**		
	YFT	**BET**	**SKJ**
25,000 m^3 capacity reduction	25	25	
Catch limits for bigeye (57,900 t) and yellowfin (232,800 t)	25	25	
In-season adjusted catch limits for bigeye and yellowfin	25	25	
Eliminate second closure period	0	2	-6
Eliminate first closure period	-2	-4	3
Reduce length of both closure periods to 31 days each	≈ -2 to 0	≈ -4 to 2	≈ -6 to 3
Eliminate the capacity exemption in paragraphs 1 and 4 of Resolution C-13-01	Not evaluated	Not evaluated	Not evaluated
Extend the duration of the *corralito* closure	-2	11	-2
Closure of 5°S to the equator, 95°W-110°W	-1	8	-2
Closure of 5°S-5°N, 120°W-150°W	3	20	2
Closure south of 15°S	-1	1	15
Closure between the coast of Mexico and 125°W north of 23°N	-2	0	-2
Closure between the coast of South America and 85°W from 5°N to 5°S	0	-10	-4
Close Guatemalan EEZ	Not evaluated	Not evaluated	Not evaluated
Close all EEZs	0	-49	2
Close high seas	1	97	-9
Ban FADs in the ocean during the closure	Not evaluated	Not evaluated	Not evaluated