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Introduction

IOTC aims at maintaining stocks at levels not less than those capable of producing their maximum sustainable yield (MSY). For this, after the 2015 stock assessment of yellowfin, the Commission adopted a rebuilding plan towards improving the overall management of this fishery (Resolution 16-01, superseded by 17-01)[1,2]. The implemented measures include effort limitations and catch reductions for purse seine, gillnet and other gears starting in 2017. In particular, a catch reduction of 15% (relative to 2014) was adopted for purse seine fleets. These measures will be in force until they are reviewed no later than in 2019.

During the 2017 Scientific Committee (SC) meeting[3] it was noted that Alternative Management Measures should be explored to improve the management of yellowfin tuna. This document discusses the potential of one alternative to the management measures currently in force for the purse seine fleets operating in the IOTC area of competence. In brief, we would like the Working Party on Tropical Tunas (WPTT) and SC to discuss the pros and cons of inputs controls (i.e. limiting the duration of the fishing season) in comparison to the output controls (i.e. current catch limits). The main reason for this is that the implementation of the catch limits for yellowfin in 2017 has been problematic. In the case of purse seiners, several problems have been identified. We list these and discuss their effects throughout this document. Some are general consequences of the application of catch based measures to multi-specific fisheries such as the Indian Ocean tropical tunas and some are derived from the dynamics of this fishery and the purse seine gear operations. We review the application of effort-based management in IATTC and WCPFC and add a series of projections to limit the fishing season to comply with the 15% catch reduction under Res 17-01. We also present a brief analysis of the seasonal trends of catch, effort and simulated temporal closures that would allow the rebuilding of yellowfin.

1. Problems associated to the yellowfin catch limits on the purse seine fleets

a. Difficulties in monitoring catch

The first inconvenience of applying catch limits to the purse seine fleet is the difficulty in monitoring yellowfin catch in real time. This is because there is a time lag between landings and the effective sampling of catch. The catch of purse seine generally consists in yellowfin, skipjack and in occasionally bigeye. As it was noted by the IOTC Working Party on Data Collection and Statistics (WPDCS) in 2017[3], it is difficult to monitor yellowfin catches in near real-time (as required by Resolution 17-01) due to the necessary correction required to estimate the species composition of purse seine catch. The problem is that until catch is monitored there is no accurate accounting of the catch of each species and therefore, the catch of yellowfin can only be estimated. This can cause problems of non-compliance if the excess of catch is not detected or to premature closures if catch is overestimated. The difficulties in monitoring catch will also worsen the catch statistics used in tropical tuna fisheries stock assessments. Improving the monitoring of catch is possible but would require the investment of additional human and technical resources. For example, approximately 1.5 fish tanks are sampled by boat and landing for an average number of fish tanks of around 15-20. This means that the current sampling effort (and costs) would need to be increased at least 10-fold to be able to obtain precise estimates of YFT catch from every trip.

b. Catch limits, "choke species" and recruitment variability

The purse seine vessels using Fish Aggregation Devices (FADs) capture the younger ages of yellowfin and, to a lesser extent, bigeye, together with skipjack schools. However, the scientific advice in the form of stock status, reference points and catch projections are provided in a single species basis. Also, catch limits for yellowfin and for skipjack (in 2018) are fixed at stock level with the objective of leading both stocks towards their target reference points. However, in multispecies fisheries it is not possible to apply different levels of fishing effort to two or more species that are vulnerable to the same fishing gear and inhabit the same habitat. Provided that discarding yellowfin is not allowed by Resolution (17-04), when the catch limit for this stock is reached (choke species) but not for skipjack, fleets will stop their fishing operations. In that case, the catch limits for skipjack will not be reached with the associated loss of opportunities for the fishing fleets and other undesirable socioeconomic consequences. The later include loss of food production, shortages to canneries and potentially price increases due to a lower supply at international markets.

This problem is exacerbated in the case of pelagic species like tunas, which are known to present a very variable recruitment. In general, TAC based management requires accurate estimates of stock status, reference points and recruitment equilibrium. Should the biomass and recruitment be underestimated catch limits will be reached sooner than expected and fishing opportunities would be wasted unless the choke species is discarded. On the contrary, if stock biomass is overestimated, when managing with fixed catch limits, biomass will continue to decline as fishing mortality will increase. The projections used to set the catch limits for yellowfin tuna in 2016 reflect the uncertainty associated with the equilibrium recruitment level and its variability. This makes that the years following abnormally large recruitments the catch limits for yellowfin tuna will be reached very soon and therefore the fishing season will be shortened even more, contributing to the direct and indirect losses for the fleets and associated socioeconomic consequences. Also, the years following a large recruitment, the catch limits will be reached applying a lower fishing mortality than the rate that was estimated necessary to allow for stock rebuilding. Should the contrary occur, the years following abnormally low recruitments, the catch limits will not avoid exceeding the fishing mortality estimated to rebuild the stock and will eventually slow down or impede recovery.

In this regard, effort controls are a more flexible way to deal with multispecies fisheries since they can reconciliate conservation objectives of two or more stocks when they are set for the most vulnerable stock, in this case yellowfin. Under an effort control system, it is no longer necessary to estimate the fishable biomass accurately every year, as the level of fishing mortality is restrained directly, irrespective of the continual fluctuations of stock size by controlling the level of fishing effort. Effort will be adjusted periodically and progressively towards meeting the target reference points. As biomass of the most vulnerable species fluctuates following recruitment variability, the catch obtained when applying the effort limits will change proportionally, giving automatic feedback control and allowing for achieving management objectives. Hence, when the stock abundance declines or increases following recruitment variability, the catch will correspondingly decrease or increase. However, for an effort control to be effective, it is important to understand and adequately estimate catchability dynamics of the fishing gears. The IOTC currently has limits on support vessels and FADs, which are the main source for increases of purse seine efficiency.

c. Change from FS to LS fishing

Yellowfin is currently overexploited and undergoing overexploitation due to a combination of overall excessive fishing mortality and catch, abnormally low recruitment estimated for the recent years and the increase in juvenile mortality. From the two type of purse seine operations targeting yellowfin, the free school modality captures adult individuals as opposed to FADs, which mostly catch juveniles. The current system of catch limits is only exacerbating the problem of juvenile catch because it benefits FAD fishing against free school. When a purse seine encounters a free school of yellowfin it is able to catch a large amount of fish, thus quickly contributing to reach their catch limit. Yellowfin and skipjack are not fished simultaneously in yellowfin free schools. Hence, if fishing over free schools of adult yellowfin purse seiners reach their catch limits quickly without catching skipjack, which is undesirable. The consequence of this is that purse seiners may refrain from targeting free schools and increasing their yellowfin juvenile catch from FADs, in order to expand their fishing season to capture skipjack.

In summary, fishing effort limits are restrictions on the intensity of use of the fishing gears. These can include limits to the amount of time vessels are allowed to fish (e.g. limits to fishing seasons), which is relatively easy to enforce through vessel monitoring systems (VMS) and other measures. Also, fishing effort control reduces the need for a real time monitoring of catch which is often difficult and expensive. Effort controls represent a flexible option for achieving management objectives of multispecies fisheries such as Indian Ocean tropical tunas. In addition, the observed seasonal differences in yellowfin and skipjack proportion in FADs can help a more effective distribution of the fishing seasons depending on each stocks' state of exploitation and management objective. Also, seasonal closures can help reducing the pressure on other stocks. It is important to note that in order to determine the effective duration and distribution of the fishing season, it is important to monitor and control any technological improvement that may increase the fleet's fishing power and catchability. It is also essential that capacity limitation measures avoid increasing effort during the fishing season. Failing to account for improvements in technology would cause the fishing mortality to increase over time, which could jeopardize the sustainability of the Indian Ocean tropical tuna stocks.

2. History of TAC vs effort-based management in ICCAT, WCPFC and IATTC

As is in the case of IOTC, the other three tRFMOs that are responsible for the management of tropical tunas have specific measures in place for their stocks: IATTC Resolution C-17-02 *Conservation measures for tropical tunas in the Eastern Pacific Ocean during 2018-2020 and amendment to Resolution C-17-01*, WCPFC CMM-17-01: *Conservation and Management Measure for bigeye, yellowfin and skipjack tuna in the Western and Central Pacific Ocean* and ICCAT Recommendation 16-01: *Recommendation by ICCAT on a Multi-Annual Conservation and Management Program for Tropical Tunas*.

From the above, only ICCAT uses TACs or overall catch limits for all the fleets involved in tropical tuna fisheries. That is the case for Atlantic bigeye and yellowfin that together with Indian Ocean yellowfin and skipjack are the only tropical stocks managed through an overall TAC system. In 2017, both yellowfin and bigeye catch limits established in ICCAT were exceeded. In this way the approach followed in ICCAT and IOTC has not been able to reduce the fishing mortality to recommended levels. IATTC and WCPFC apply output controls (TAC) only for longline fleets targeting bigeye tuna (note that there is a 100% observer coverage on longline fisheries). In the Pacific, purse seine fleets activity is regulated through effort limits such as the days of the fishing season. The IATTC uses an effort based pseudo-HCR to determine the number of days of closure for purse seines required to maintain stocks around their respective Target Reference Point (MSY).

In February 2017 the IATTC attempted to introduce catch limits for bigeye and yellowfin catch from purse seine fleets operating with FADs and an additional catch limit for yellowfin from dolphin associated fisheries. These measures aimed at mitigating the potential impact of the recent increase in capacity on the current status of bigeye and yellowfin stocks. The overall catch limit for 2017 corresponded to the average catch observed during 2013-2015 for both species combined. The attempt to introduce catch limits for the IATTC yellowfin and bigeye fisheries was shortly proven problematic and it had to be amended by a new measure, C-17-02, only 5 months after its entry into force. One of the reasons for this was that, the purse seine fleet fishing on FADs had reached 80% of the total annual catch limit by mid-July, probably due to abnormally large recent recruitments that led to a higher than expected proportion of yellowfin and bigeye in FAD sets. If this measure hadn't been amended, the FAD fishery would have been closed by August or early September, with notable consequences for purse seine fleets. The new measure, adopted in July 2017, eliminated the catch limits and incorporated 10 additional days of purse seine closure which resulted in a total of 72 days of closure.

3. Projections of current catch limits and equivalent effort limits

Very simple projections were carried out using the output of the latest stock assessment of IOTC yellowfin to illustrate the differences between effort-limits and TAC (Figure 1). The yellowfin population was projected forward using the TAC imposed in 2016 (red) and an equivalent reduction of fishing effort (blue). This figure illustrates the impact of recruitment variability in fisheries performance. See for example that with the recent recruitment (2013-2014) is expected to be low which leads to a low catch in the constant catch scenario. Then, following the overall recovery of the stock and a large recruitment in 2015, catch tends to increase without increasing the fishing mortality. The recovery in the short term is very similar in the TAC and effort scenarios and exceeds the SSB_{MSY} reference point before 2020 in both scenarios. The constant effort scenario would allow rebuilding the stock well above SSB_{MSY} and would also allow catches of the purse seine targeted species to increase notably. This is assuming that CPCs do not exceed the TAC but it is not the case.

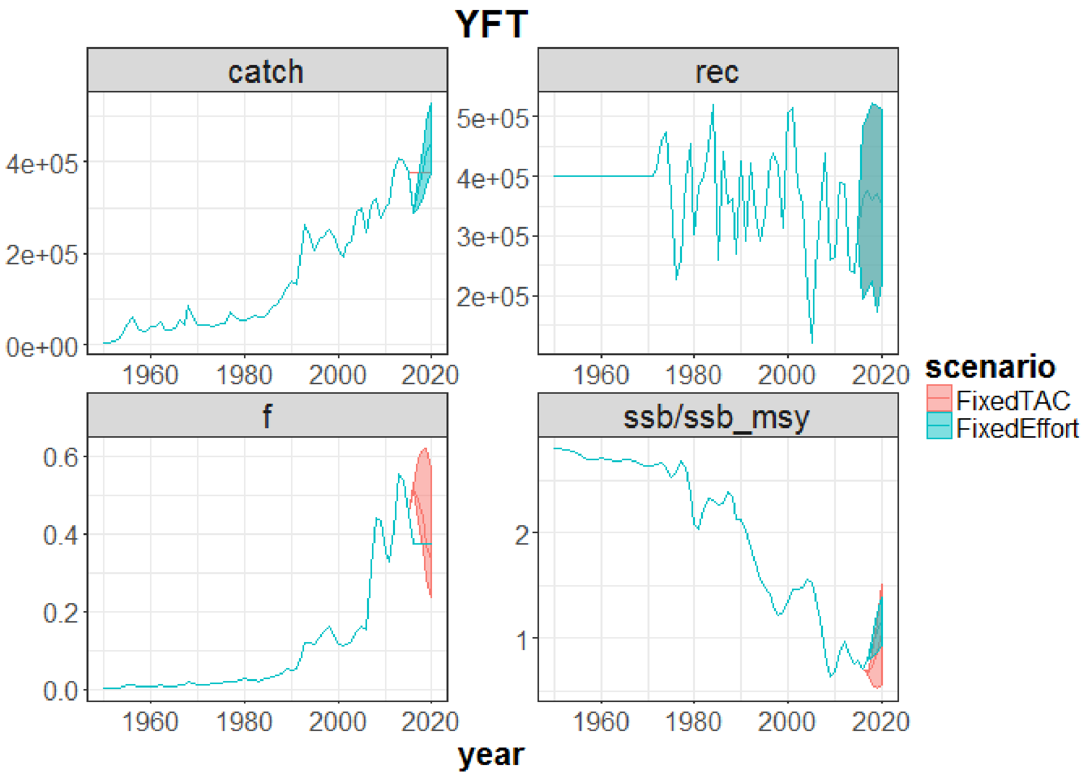

Figure 1.- Catch, recruitment (rec), fishing mortality (f) and relative spawning stock biomass (ssb/ssb_msy) of yellowfin projected using constant catch (red) and constant fishing effort scenarios.

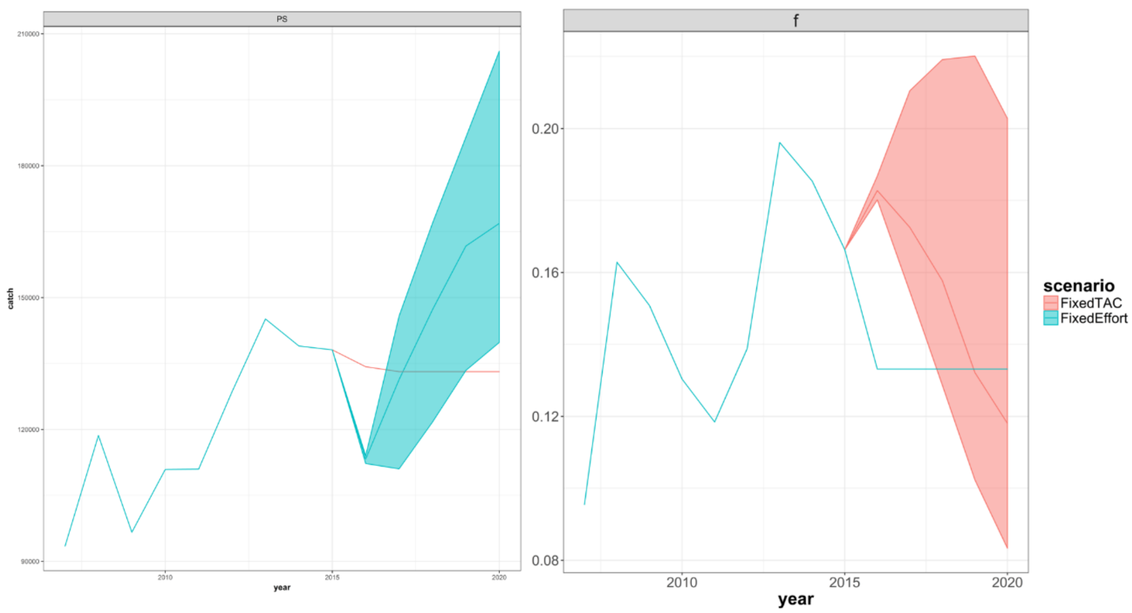

Figure 2.- Purse seine catch of yellowfin and impact of purse seines on yellowfin (f=fishing mortality) projected using constant catch (red) and constant fishing effort (blue) scenarios.

With regards to purse seine fleets, the fixed effort scenario achieves higher catches without jeopardizing the sustainability of the stock (Figure 2). As the stock recovers, in the constant catch scenario, the fishing mortality reduces constantly. However, it is expected that should TAC measures be maintained in the future, these would increase following the recovery of the stock. Note that these projections are made in the assumption that the catchability coefficient of the fleet remains constant throughout the simulation.

4. Analysis of temporal trends of catch and effort and simulation of temporal closures

5. In this section we show a preliminary attempt to establish limits to the fishing season for the purse seine activity to match the required 15 % catch reduction from 2014 levels (2015 for Seychelles) under Res 17-01. This analysis focused on the Seychellois, French and Spanish purse seine fleets. In the period analysed (2000-2016), these fleets have accounted for at least 87% of the total purse seine catch in the IOTC Convention Area. The effort units in the public domain data differ between fleets and years, but is generally consistent for the datasets included in the current analysis. With the exception of the Seychellois fleet in 2016, where effort is only available in fishing days, effort in fishing hours is available for the working dataset. Based on available paired fishing hours/fishing days data, it was assumed that 12 hours of fishing corresponded to one fishing day.
6. The total YFT catch, including FADs and free school, and effort of the three fleets analysed peaked around 2005, and decreased dramatically in the late 2000's due to the piracy issue. The catch of the EU-Spain fleet increased again from 2009 to 2013 and decreased thereafter, while the EU-France and Seychelles fleet catches increased later in the time series. Yellowfin catch rates show similar patterns for the three fleets. It shows important variations between years, which are closely linked to the abundance of juvenile fish, as estimated in the 2015 stock assessment (Langley, 2015), although there seems to be an increase in CPUE from 2009 not related to juvenile fish biomass (Figure 3).

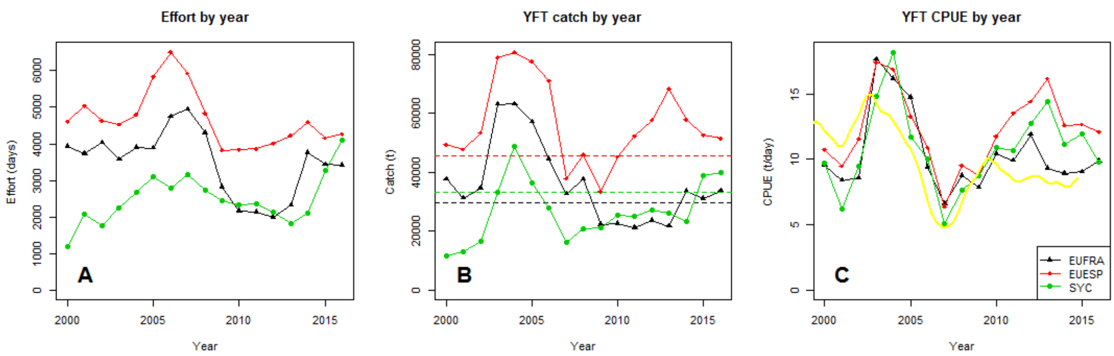

Figure 3.- Temporal trends in catch (FAD+FS) and effort by flag. A.- Effort vs year. B.- Catch vs year. The dashed lines indicate the catch limits assumed for each fleet: 85% of the 2015 catch, as available in the public domain[1], for the Seychellois fleet, and the levels established by the EU regulation for EU-France and EU-Spain[2]. C.- CPUE by year. Solid yellow line: juvenile biomass from the 2015 stock assessment (Langley, 2015).

[1] http://www.iotc.org/documents/nominal-catch-species-and-gear-vessel-flag-reporting-country

[2] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R0127&from=EN

This raise on yellowfin catch from 2009 coincides with a significant increase, almost two-fold, observed in the percentage of yellowfin under FAD sets between 2008 and 2012 (Figure 4A). The ratios YFT to total catch in free school (FS) and FAD sets are similar among fleets, although the percentage of YFT over the total catch is slightly higher for the French fleet, which seems to set more frequently on YFT free schools as compared to the Spanish and Seychelois fleets Fig. 4 B-C).

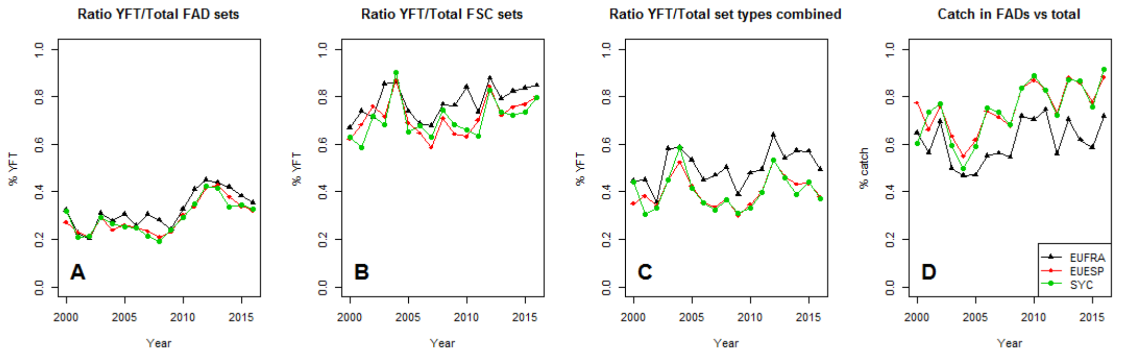

Fig 4.- Yellowfin tuna ratios by association type and percentage of catch in FADs vs total by flag and year. A.- YFT ratio in FAD sets. B.- YFT ratio in FSC sets. C.- YFT ratio for all set types combined. D.- Percentage of total catch in weight in FADs vs total.

Figures 5A and 5B (Figure 5 is provided for each fleet separately) show the seasonal variability in yellowfin tuna and total tuna catch rates for FAD and Free School (FS) modalities, respectively, in different years. In spite of the high variability between years, some seasonal patterns can be appreciated: Catch rates over FAD sets typically show two peaks, one around January-March and another one in August-November. However, the ratio of yellowfin in the catch on FADs does not seem to follow any clear pattern. Daily catches on free-school sets generally peak around the end of the year and decrease sharply in February-March and shows a second peak around June. These peaks, in the case of free-school sets, are mainly related to catches on adult yellowfin tuna schools (Figure 5B).

A preliminary attempt to analyze seasonal patterns in the yellowfin vs total catch ratio along the year is shown in Figure 5C. These preliminary estimates indicate that a potential reduction in yellowfin catch would produce a lower impact in the catches around the middle of the year (June-July) and in the end/beginning of the year (December-January) (Figure 5C). In these periods, the YFT catch ratio is higher due to the catches of adult yellowfin swimming in free-schools. Hence, closures in these periods would have a lower impact on the total realized catch of the fleet.

The prediction of total catch using the average monthly CPUE values vs the real annual catch is shown in Figure 6D. This figure corroborates previous findings on the interannual variability in CPUE. In years with higher yellowfin abundance, particularly of juvenile fish (e.g., 2004), the realized catch exceeds the one that would be expected on average conditions. On the contrary, in years with lower biomass abundance (e.g., 2007) the realized catch is lower than expected. In this scenario, setting catch rather than effort limits would result in yellowfin acting as a choke species in years with high abundance, and would allow for fishing mortalities higher than expected in those years were abundance is unusually low. A total closure during the month of

January would have resulted in a total catch close to or below the current quota for the Spanish fleet between 2007 and 2011, as well as in 2015 and 2016. In the case of the French fleet, such a closure would have resulted in catches at or below the current limit since 2007. Finally, for the Seychelois fleet, the catch would have been at or below the limit since 2010, with the exception of 2004 and 2016.

The duration of the closures required to achieve the catch limits vary depending on the fleet, year and time of the year. Since 2010, for the Seychelois fleet, closures would have been required only in 2015 and 2016, with a duration ranging between 36 and 93 days, depending on the start date of the closure. In the case of the French fleet, closures would have been required since 2014, and would have ranged between 8 and 68 days, depending on the start date of the closure. For the Spanish fleet, the duration of the closure would vary significantly depending on the year. No closure would have been required in 2010, but in January 2013, a closure of c. 150 days would have been necessary to achieve the yellowfin catch limit. In 2016, the closure duration for Seychelles, France and Spain would have ranged between 48-93 days, 23-73 days and 29-66 days, respectively.

Table I.- Average reduction (expressed as percentage of the total) in the catch of yellowfin (FAD and FS sets and combined), skipjack and total, as a function of the month of closure.

Month	YFT (FADs)	YFT (FS)	YFT (Total)	SKJ	Total catch
January	-5.93	-22.41	-14.29	-5.99	-9.92
February	-6.69	-14.99	-10.9	-6.92	-8.84
March	-8.13	-5.77	-6.93	-9.33	-8.33
April	-6.46	-3.99	-5.21	-7.21	-6.27
May	-4.03	-3.85	-3.94	-5.18	-4.56
June	-4.05	-11.74	-7.96	-3.96	-5.92
July	-8.22	-10.22	-9.23	-6.35	-7.78
August	-11.93	-2.16	-6.97	-11.49	-9.37
September	-14.3	-2.17	-8.14	-13.19	-10.79
October	-14.76	-3.7	-9.15	-16.25	-12.73
November	-9.65	-5.03	-7.31	-8.92	-8.13
December	-5.86	-13.98	-9.98	-5.22	-7.36

On average, the reduction in yellowfin catches exceeds the reduction in total catches in the months where yellowfin catch rates on free-schools peak (December to February and June-July). Therefore, under a catch control scenario, the total yield of the different fleets is less impacted by generally reducing the activity on free-schools.

Figure 6 summarizes the duration of the closure (FAD and total closure scenarios) required to attain the catch limits for the Seychelles, EU-France and EU-Spain combined. Logically, the absolute values vary, due to the fluctuations in total catches by year, which are linked in turn to effort and catchability/abundance oscillations.

Total closures require much shorter duration if implemented at the beginning of the year than FAD closures, and are also less impacting in terms of total catch. However, this is linked to the reduction in catches of adult yellowfin caught on free school sets. The duration of the closure and the reduction in total catch seem to converge for both closure scenarios (total and FAD) around end- August to early-September. In this period the duration of a potential FAD closure, and the associated catch loss, reaches its minimum, and are similar to the duration and catch loss in the event of a total closure. Some years (e.g., 2013 and 2014), YFT catches on FADs also peak at the beginning of the year, and the duration of the closure may show a minimum. However, this peak is less consistent that the one observed in September-October, and does not necessarily minimize the catch loss.

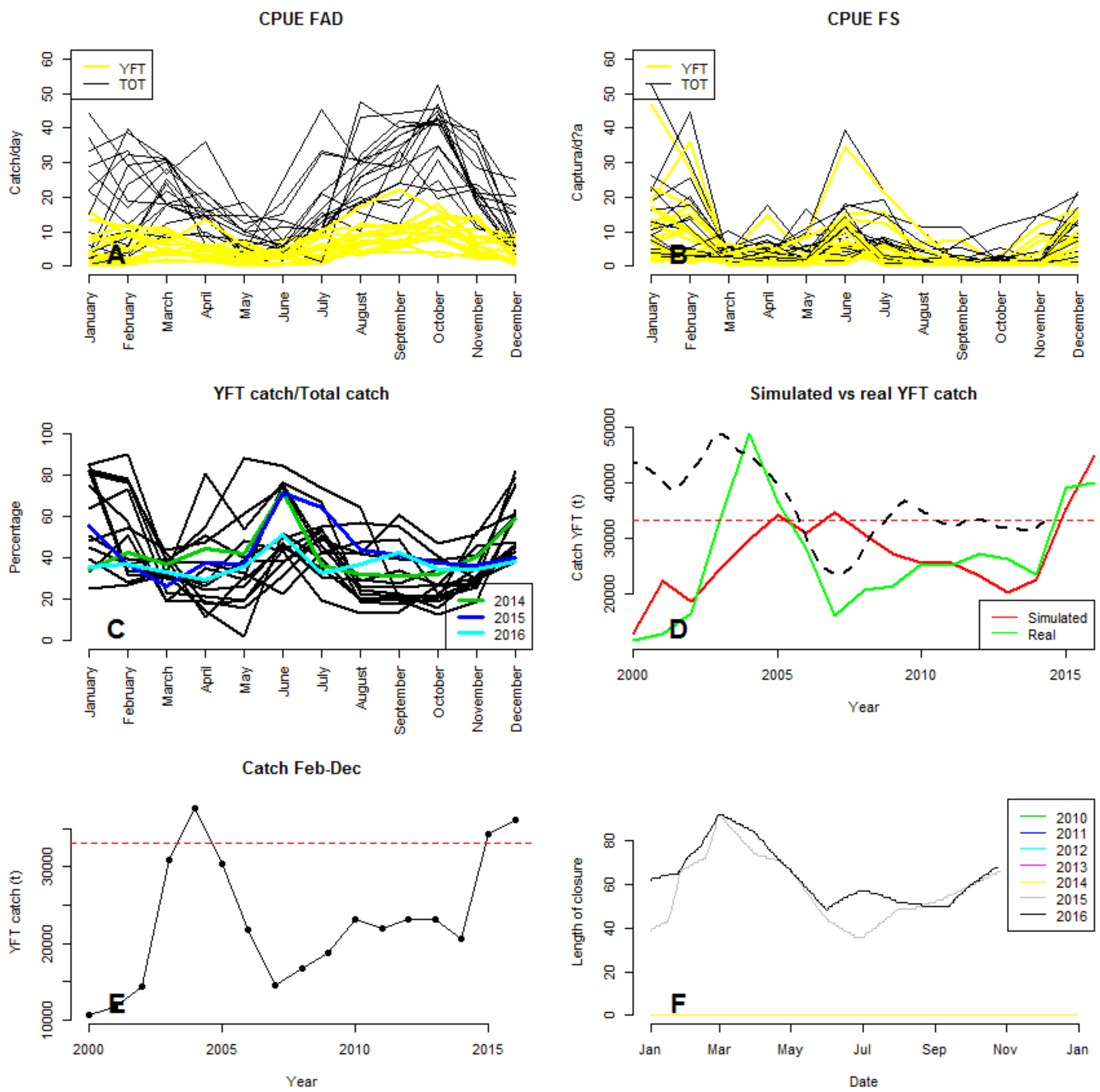

Fig. 5. SYC.- Analysis of catch and effort temporal trends in the Seychelois tropical purse seine fishery. A- CPUE (YFT and total catch per day) in FAD sets; B- CPUE (YFT and total catch per day) in free school sets; C- YFT catch vs total catch; D- Real YFT catch by year vs simulated catch using average monthly CPUEs and real effort exerted. The dashed black line illustrates the juvenile biomass as estimated in the 2015 stock assessment; E- Total catches from February to December by year. The dashed red line indicates 85% of the 2014 YFT catch for the Seychelois purse seine fleet[3]; F- Length of the closure needed to achieve a final YFT yearly catch of 19943 t as a function of the start date of the closure.

[3] http://www.iotc.org/documents/nominal-catch-species-and-gear-vessel-flag-reporting-country

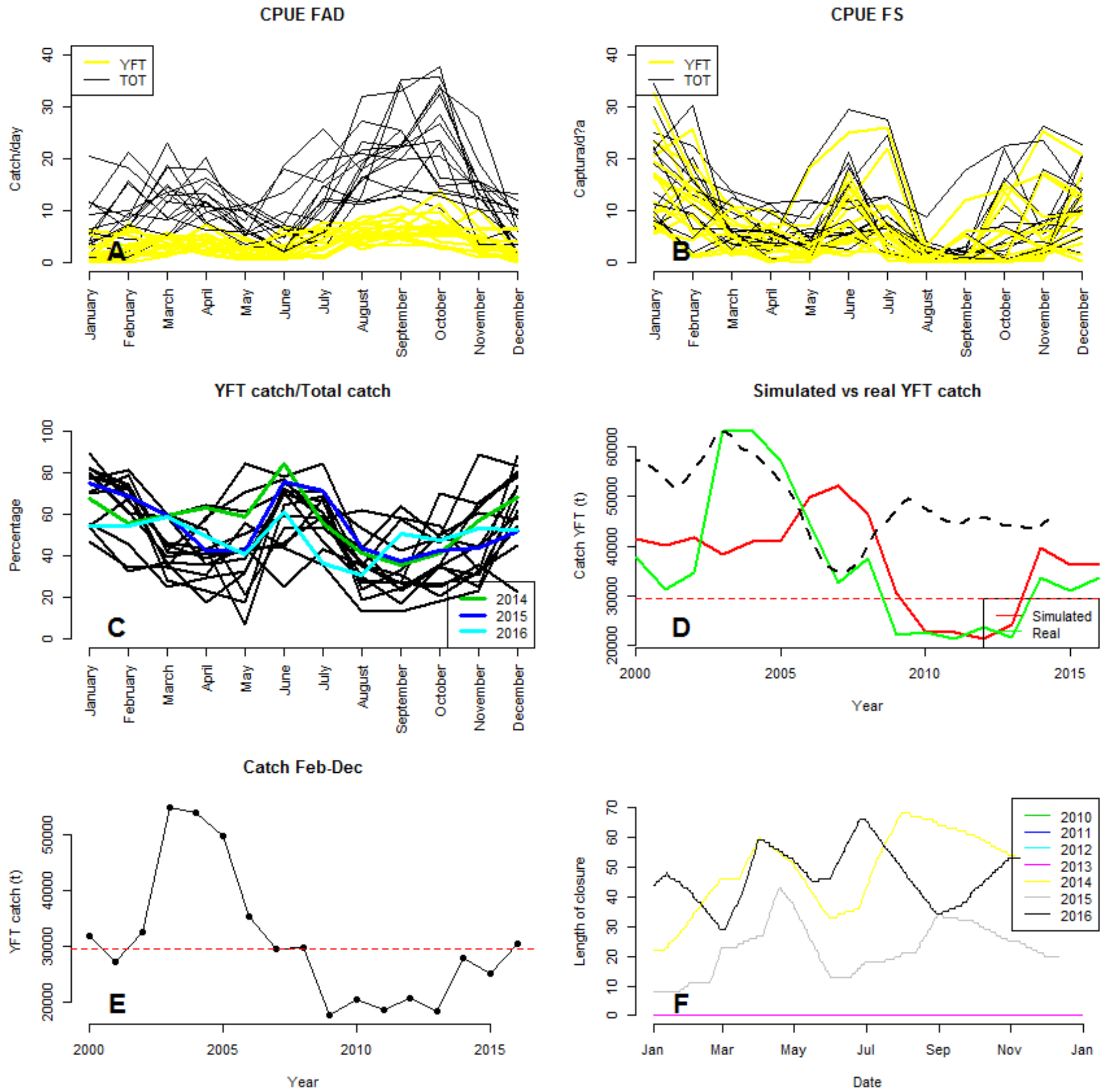

Fig. 5. EUFRA.- Analysis of catch and effort temporal trends in the French tropical purse seine fishery. A- CPUE (YFT and total catch per day) in FAD sets; B- CPUE (YFT and total catch per day) in free school sets; C- YFT catch vs total catch; D- Real YFT catch by year vs simulated catch using average monthly CPUEs and real effort exerted. The dashed black line illustrates the juvenile biomass as estimated in the 2015 stock assessment; E- Total catches from February to December by year. The dashed red line indicates the catch limit established by the EU for the French fleet[4]; F- Length of the closure needed to achieve a final YFT yearly catch of 29501 t as a function of the start date of the closure.

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R0127&from=EN

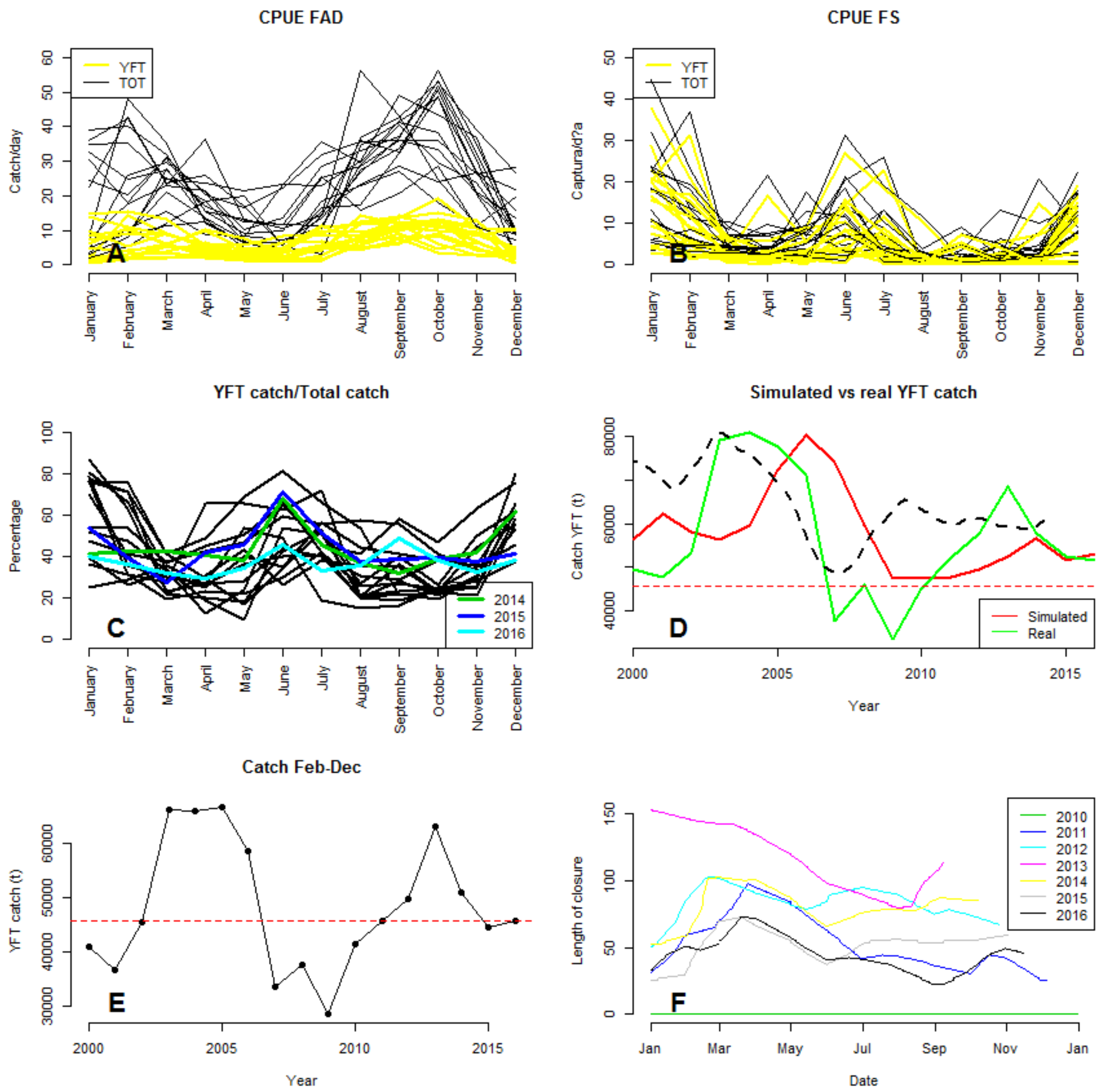

Fig. 5. EUSPA.- Analysis of catch and effort temporal trends in the Spanish tropical purse seine fishery. A- CPUE (YFT and total catch per day) in FAD sets; B- CPUE (YFT and total catch per day) in free school sets; C- YFT catch vs total catch; D- Real YFT catch by year vs simulated catch using average monthly CPUEs and real effort exerted. The dashed black line illustrates the juvenile biomass as estimated in the 2015 stock assessment; E- Total catches from February to December by year. The dashed red line indicates the catch limit established by the EU for the Spanish fleet[5]; F- Length of the closure needed to achieve a final YFT yearly catch of 45682 t as a function of the start date of the closure.

[5] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R0127&from=EN

Fig. 6.- Duration of the closure (FAD and total closures) required to achieve a 15% reduction of the 2014 levels for Seychelles, EU-France and EU-Spain fleets, as well as an estimation of the catch loss, estimated as percentage in weight..

The current analysis is preliminary, aimed at showing the potential issues linked to the establishment of catch limits and the possibility for exploring equivalent effort based measures. The establishment of catch limits are likely to disincentivize fishing on adult yellowfin tuna on free schools, since it will result in the catch limit being reached sooner in the year and in the cessation of the fishing activity (i.e., yellowfin tuna is acting as a 'choke' species). Moreover, catch limits can be reached sooner whenever there are pulses in recruitment. In this regard, those years with high juvenile yellowfin tuna abundance, vessels will have to stop fishing earlier, with evident negative impacts in the profitability of the fishery. On the contrary, those years with low fish abundance, vessels will be allowed to continue fishing for longer periods, and fishing mortality would be higher than desired.

An additional problem of establishing catch limits for the purse seine fishery is that, due to the misidentification of the three main tropical tuna species, catches need to be corrected based on sampling data, and this is generally not possible in near-real time. This can ultimately result in loss of fishing opportunities or noncompliance issues. On the other hand, catch limits may have the potential benefit of controlling fishing mortality when it varies due to catchability oscillations, but this benefit is possibly comparatively minor, especially if the focus is placed in the reduction of juvenile fishing mortality.

According to the current analysis, a closure beginning in August-September would mainly focus on the juvenile component of the fishery, have the shorter duration and the lower impact over the total tuna catch to comply with the 15% reduction of catches from 2014 levels (2015 reference year for Seychelles). In terms of catch loss and closure duration, there does not seem to be significant differences between FAD and total closures, something important to consider when considering the enforcement of management measures. Naturally, a potential effort-based measure should also take into account the total level of effort exerted throughout the year to cater for changes in capacity, effort creep, etc.

Finally, it must be stressed that, in order to explore precise effort limits to manage the purse seine fishery in the IOTC, the current exercise should be undertaken in the framework of the stock assessment process regularly carried out in this RFMO (ideally in a management strategy evaluation framework). This will allow projecting biomass trends in different management scenarios, and take into account different sources of error.

1 IOTC. Report of the 20th Session of the Indian Ocean Tuna Commission. La Reunion, 23–27 May 2016. IOTC–2016–S20–R[E]: 165pp. (2016).

2 IOTC. Report of the 21st Session of the Indian Ocean Tuna Commission. Yogyakarta, Indonesia, 22–26 May 2017. (2017).

3 IOTC. Report of the 20th Session of the IOTC Scientific Committee. Seychelles, 30 November-4 December., (2017).