USING EFFORT CONTROL MEASURES TO IMPLEMENT CATCH CAPACITY LIMITS IN ICCAT PS FISHERIES

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SUMMARY

Total Allowable Catches (TAC's) have been implemented for numerous stocks by ICCAT. However, in the case of tropical tunas (yellowfin (Thunnus albacares) and bigeye (Thunnus obesus)), catch controls, while intended to ensure that overall fishing mortalities are not exceeded, have failed to maintain catches at the desired level because some ICCAT CPCs have exceed targets on a regular basis or were not covered by the measures. The purpose of this study is to explore how full seasonal closures (over an estimated time-frame), where vessels remain in port, may better assist surface fisheries in achieving the levels of catch reduction sought by the ICCAT. It presents a model based on parameter estimates of individual models to estimate catches by time as a function of available biomass for BET, effort by strata (month), and month-effort interactions to estimate BET catch targets (and associated YFT and SKJ as a result). The implementation of seasonal fishery closures has proved successful at the IATTC, which has been using a control rule based on this principle for over fifteen years with stocks maintained by the target reference level throughout that period. Management systems based on seasonal fishery closures have also proved to be more efficient than those based on TACs, due to the latter leading to underreporting unless extensive monitoring is in place. Some examples of how the control rule may be implemented are provided. A decision support tool is developed based on the data and proposed season closures to implement an overall target catch on Bigeye tuna, one of the stocks managed to a TAC by ICCAT.

KEYWORDS

Catch/effort; Tropical tunas; Season regulations.

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1. Introduction

In recent years, all tuna-Regional Fishery Management Organisations (tRFMO) have adopted a range of management measures to ensure that tropical tuna stocks are maintained at the target sustainable biomass levels. To ensure those levels are maintained, tRFMOs have agreed to carry Management Strategy Evaluation (MSE) and move towards the adoption of Harvest Control Rules (HCR) for their stocks (Hillary et. al. 2015). At present, the Indian Ocean Tuna Commission (IOTC) is the only tRFMO to have formally adopted a Harvest Control Rule (HCR) for its skipjack tuna (SKJ) stock, while other stocks are subject to various interim measures, including TACs, FAD closures, limits on active Fish Aggregating Devices (FADs), limits on support vessels, and limits on fishing capacity for partial or complete coverage of a fleet (subset of fleets in CPC's IOTC SC 2017). However, these measures have not been effective at maintaining the catches of the target stocks at the agreed levels, e.g. (yellowfin tuna (YFT) in IOTC and the former and bigeye tuna (BET) in ICCAT).

In the Atlantic Ocean, the ICCAT adopted Total Allowable Catches (TACs) for yellowfin tuna and bigeye tuna since 2001 (ICCAT REC 00-1) for long line fleets and since 2005 (ICCAT REC 04-1) for the rest of the fleets in a multiannual management plan. However, both those TACs have been consistently breached, with recent catches well above the TAC (ICCAT SCRS 2017). FAD closures have also been evaluated as ineffective, mainly due to relocation of effort to areas outside the closure and catch rates in those areas at similar levels than those attained in the past inside the closure area (SCRS, 2017). The multispecies nature of purse seine fisheries also makes it difficult to obtain catch estimates by species in real time. In addition, the quality of catch estimates may be compromised as a consequence of various potential sources of bias associated with the sampling scheme and/or estimation procedures used by some CPCs (Herrera 2018).

In the eastern Pacific Ocean, the Inter-American Tropical Tuna Commission (IATTC) adopted a control rule that contemplates two closures of the purse seine fishery (IATTC RES C-17-02), with the length of those closures adjusted using a formula that relies on the most recent assessments of the stocks of tropical tunas and potential overall levels of capacity of purse seiners estimated for the following year(s). At the start of each year, purse seine companies have to indicate which of their purse seiners will adhere to the first closure and which to the second (Squires et. al. 2016). In addition, IATTC has implemented a ban on support vessels, FAD limits, a FAD closure and input capacity limits for purse seiners, and TACs for longliners (Squires et. al. 2016).

OPAGAC is currently implementing a Fishery Improvement Project (FIP) and adopted an action plan that includes actions to improve stock status and compliance in all oceans, the former through assisting on the implementation of HCR and the latter through assisting improvements in compliance. Considering that the performance reviews of ICCAT (ICCAT , 2016) and IOTC (IOTC, 2016) have recommended that both organisations improve their management framework for tropical tunas, we would like to explore the effectiveness of alternative management measures, along the lines of those adopted by the IATTC, in improving the management framework of those RFMO.

As for the ICCAT area, the goal is to explore if purse seine fisheries would be better managed through a system similar to the one used by the IATTC, rather than through TACs, which have proved to be ineffective in most oceans. This includes the IATTC , which recently shifted from fishery closures to TACs, to realise, in less than one year, that TACs were ineffective, deciding to revert back to fishery closures (IATTC RES C-17-01 amended by C-17-02).

The main objective of this analysis is to explore to which extent the approach taken by the IATTC can be successfully used to manage tropical tunas at the ICCAT (in terms of efficiency of management, including its monitoring and compliance components) and, if so, provide a control rule that would allow converting from a BET TAC into a number of closure days, including a proposal of suitable time-periods for the closure; this is done bearing in mind not only the BET stock but also potential impacts of the measure on other target stocks (YFT and SKJ) . In addition, the report recommends actions that ICCAT would need to undertake to make implementation of the new system possible.

2. Methods

2.1 Approach

Effort is assumed to be proportional to fishing mortality. Hence, effort closures temporally would have the same net effect as allowable TAC. The reason is simply shown below in eq. 1:

$$qE_t = F_t \quad \text{(eq. 1)}$$

Where *q* is catchability and *E* is the effort in the fishery, and *F*, fishing mortality in the fishery. The assumption essentially is that if we can parse effort by different time periods in a year and close some periods, we would essentially have a net limit of fishing mortality (*F*). Note that, implicitly we assume that q will remain constant through the unit of fishing effort measured (in fishing hours, as reported to ICCAT).

If we have a standardized unit of effort for all fleets, then we could estimate an optimal effort, *Eopt* capacity for the fleet, as a function of optimal fishing mortality, *Fopt* by looking at the following equation

$$E_{opt} = \frac{-ln(1-F_{opt})}{q} \quad \text{(eq. 2)}$$

Essentially, when we have an over capacity fleet, the yield would be less than optimal (**Figure 0**), as discussed in Squires et. al. (2016)

Once effort exceeds optimal capacity, at some assumed *q*, the ability to get a profitable fishery declines substantially. Hence limiting effort would make sense to some effect on a fishery, especially if it operates at levels over its optimal capacity, as indicated in the SCRS report for BET and YFT (ICCAT SCRS 2017).

We stratified effort data by time and area, and assess its relationship to catch assuming a 1-1 relationship with BET catch by year and area (GLM model developed eq. 3). Essentially, if we can limit effort for a portion of days based on the ICCAT dataset, we would estimate a substantial reduction in catch and thereby achieve the reliable target that is determined pre-season.

So, we will try and estimate the following

$$BET_{PSCatch_t} = \alpha + \beta PS_{Effort_t} + \varepsilon \quad \text{(eq.3)}$$

Where *BETPSCatch* is a function of the *PSEffort*. We could look at both log response and normal response. Based on slope values by time-period, we can limit overall effort by area to limit catch. This can be related eventually to PS well capacity and number of trips (fishing hours by month and if needed by area) which could be estimated and controlled for.

2.2 Data sources and preparation

The PS data used was downloaded from the ICCAT website in May 2018 or requested through e-mail. The following datasets were used to build the file for the analysis:

- **T1NC_20171013.zip**: Refers to ICCAT's Task I Data, in MS Excel format, which contains nominal catches of Atlantic tunas and tuna-like fish (including sharks), by year (1950-2016), gear, region and flag [MS Excel; version 10/2017[3]];
- **t2ce_20161114.rar**: Refers to ICCAT's Task II Catch & Effort in Access Data Base (various formats, 1950-2015) [MS Access; version 11/2016[4]];

[3] https://www.iccat.int/Data/t1nc_20171013.zip
[4] https://www.iccat.int/Data/t2ce_20161114.rar

- **cdis50_15_all.csv**: Refers to ICCAT's Task II catch data disaggregated and raised to total landings for the main ICCAT market species, including all three tropical tunas (species, 5x5 degree squares, year (1950-2015), quarter, gear) [CSV format; version 7/2016[5]];
- **effdis_ps_1990_2015.csv**: Refers to ICCAT's Task II Spatio-Temporal estimates of overall Atlantic Fishing Effort for Purse seine fleets (5x5 degree squares, year (1990-2015), quarter, gear) [CSV format; version 7/2016[6]];
- **casYFT1960-14_stdFmt_v1.7z.csv**: Refers to ICCAT's Task II Catch-at-Size file for the yellowfin tuna (YFT), as produced for the assessment of the Atlantic Ocean YFT stock by the ICCAT IN 2016 (various formats, 1960-2014) [CSV format; version YFT assessment 2016[7]];
- **casBET7514_details_v2.7z.csv**: Refers to ICCAT's Task II Catch-at-Size file for the bigeye tuna (BET), as produced for the assessment of the Atlantic Ocean BET stock by the ICCAT in 2015 (various formats, 1975-2014) [CSV format; version BET assessment 2015[8]];
- **casSKJ6913_v1.7z.csv**: Refers to ICCAT's Task II Catch-at-Size file for the skipjack tuna (SKJ), as produced for the assessments of the Atlantic Ocean SKJ stocks by the ICCAT in 2014 (various formats, 1969-2013) [CSV format; version SKJ assessment 2014[9]]

The above data were used to produce two files that contained catch and effort of tropical tunas in the Atlantic Ocean, for the period 1991-2015, with one file containing number of specimens and the other weight, in kilograms. For this all purse seine data were extracted and used to produce:

- **VBA_OUTPUTNO.csv**: file containing catches in number, effort, and number of fish measured according to their maturity stage (immature/mature) and by length class bin, by species, 5 degree square grid, year (1991-2015) and month.
- **VBA_OUTPUTKG.csv**: file containing catches in weight, effort, and the weight of fish measured according to their maturity stage (immature/mature) and by length class bin, in kilograms, by species, 5 degree square grid, year (1991-2015) and month.

The number of fish recorded under each length class bin was converted to weight using ICCAT's length-weight equations, as per the ICCAT Manual[10]:

- Yellowfin tuna[11]: $W = 2.153*10^{-5}*FL^{2.976}$ Caverivière (1976)
- Bigeye tuna[12]: $W = 2.396*10^{-5}*FL^{2.9774}$ Parks et al. (1981)
- Skipjack tuna[13]: $W = 7.480*10^{-6}*FL^{3.253}$ Cayré & Laloë (1986)

The amount of fish immature and mature was assigned using ICCAT's length-at-first-maturity for each of ICCAT's tropical tuna stocks, as recorded in the ICCAT Manual:

- Yellowfin tuna[14]: 50% of mature females measuring 108.6 cm (Albaret (1977), Eastern Atlantic);
- Bigeye tuna[15]: 53% mature females measuring 100 cm (Matsumoto and Miyabe (2002), Abidjan). The same authors estimated that 50% mature females measuring 110 cm from samples taken in Dakar. However, data from Abidjan was used as this is the main port of landing of purse seiners in the Atlantic Ocean;

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[5] File downloaded at the time of the assessment
[6] https://www.iccat.int/Data/effdis_ps_1990_2015.csv
[7] File downloaded at the time of the assessment
[8] File downloaded at the time of the assessment
[9] File downloaded at the time of the assessment
[10] https://www.iccat.int/en/iccatmanual.html
[11] https://www.iccat.int/Documents/SCRS/Manual/CH2/2_1_1_YFT_ENG.pdf; Table 2, Page 9
[12] https://www.iccat.int/Documents/SCRS/Manual/CH2/2_1_2_BET_ENG.pdf; Table 2, Page 35
[13] https://www.iccat.int/Documents/SCRS/Manual/CH2/2_1_3_SKJ_ENG.pdf; Table 2, Page 59
[14] https://www.iccat.int/Documents/SCRS/Manual/CH2/2_1_1_YFT_ENG.pdf; Table 3, Page 9
[15] https://www.iccat.int/Documents/SCRS/Manual/CH2/2_1_2_BET_ENG.pdf; Table 3, Page 35

- Skipjack tuna[16]: 50% mature females measuring 45 cm (Hazin et al. (2001), Atlantic). Hazin et al. were chosen among the 4 values available for female maturity, with lengths at first maturity ranging from 42 cm to 51 cm, the one chosen being the most recent study.

The data required a fair amount of processing due to the fact that ICCAT produces datafiles at different points in time and data from the different files may differ as ICCAT's databases are under constant review. The data for the different purse seine fleets were aggregated as follows:

- PS-EU: Purse seine fleets operating under EU flags (France & Spain) or other flags that operate as EU purse seiners (e.g. Curaçao, Guatemala, El Salvador, etc.);
- PS-Ghana: Purse seine vessels flagged in Ghana and vessels flying other flags that operate as the former;
- PS-Other: Purse seine vessels flagged to other countries and that do not usually operate in the core area of the purse seine fishery (e.g. Western Central or South Atlantic, Mediterranean Sea, etc.).

Although the final file contained information for 1991-2015, only data from the EU-PS fleet, for the period 2003-2013 were used for the analysis. This is because the EU-PS fleet reports the highest catches and it is the only fleet for which catch, effort, and size data are fully available. The selection of 2003-13 as time-period was made in order to consider recent years of activity of purse seiners and for the recordset to be complete for all three stocks, considering that the last year in which catch-at-size data is available for the skipjack tuna is 2013.

The final file used for the analysis contained total catches of tropical tunas in kilograms taken by EU and assimilated purse seiners, total effort in fishing hours, total catches of immature BET in kg, total catches of mature BET in kg, total catches of immature YFT in kg, total catches of mature YFT in kg, and total catches of immature SKJ in kg and total catches of mature SKJ in kg, by year, month, and 5 degree square grid.

2.3 Generalized linear models examined

Three basic models were examined that looked at response of BET/SKJ/YFT by main effects. We have control on only two of the main effects in terms of management and focus on those (time and/or area), as such models examined only looked at main effects and interactions of these terms with estimated effort (McCullagh and Nelder 1989). The models examined are the following:

$$SPP_{Catch_t} = \alpha + \sum_{i=1}^{n} \beta_i Y_i + \sum_{s=1}^{12} \beta_s M_s + E_t + B_t + \varepsilon_t \qquad \text{(eq.4)}$$

$$SPP_{Catch_{t,a}} = \alpha + \alpha_1 B_t + \sum_{s=1}^{12} \beta_s M_s + \sum_{a=1}^{67} \beta_a A_a + \alpha_2 E_t + \varepsilon_{t,a} \qquad \text{(eq.5)}$$

Where *SPP* is species (BET, YFT or SKJ), *Y* is a year effect, *M* is month effect, and *B* is the Biomass estimated from the assessment (shown in Figures 7 based on the assessment conducted in 2015). Since Year is confounded with assessment biomass, we chose to use on Biomass as a continuous measure (eq. 5 as it would get rid of 11 degrees of freedom).

Finally, since area controls are not a factor to account for, because the consequences of effort relocation are difficult to assess, we analysed the data based on month and effort only, - i.e. full stop of industrial tuna purse seiners for tropical tunas in the core area of the fishery (eastern and central tropical [and subtropical] fishery).

$$SPP_{Catch_{t,a}} = \alpha + \alpha_1 B_t + \sum_{s=1}^{12} \beta_s M_s + \alpha_2 E_t + \varepsilon_{t,a} \qquad \text{(eq.6)}$$

The final model used month:effort interactions so a variation in slopes for each month could be accounted for (eq. 7). This is eventually the resolution with which they could plan for.

$$SPP_{Catch_{t,a}} = \alpha + \alpha_1 B_t + \sum_{s=1}^{12} \beta_s M_s + \sum_{s=1}^{12} \beta_s M_s E_s + \alpha_2 E_t + \varepsilon_{t,a} \qquad \text{(eq.7)}$$

[16] https://www.iccat.int/Documents/SCRS/Manual/CH2/2_1_3_SKJ_ENG.pdf; Table 3, Page 60

3. Results

3.1 Exploratory data analysis

Since we are interested in overall patterns in the fishery over time, we compiled some simple plots looking at overall catch in numbers for BET between 2003-2013 (aggregated, **Figure 1**) some of effort (**Figures 2, 4**), and catch in weight (aggregated by month over the period) for immature and mature fish separately (**Figure 3**). There may be a positive relationship with effort over the series observed (aggregated, **Figure 6**), and monthly variations in landings between 2003-2013 by area (**Figure 5**). In addition, **Figures 8** and **9** show that there are temporal patterns over the years 2003-2013 which could be used to minimize impacts on yellowfin and skipjack if closures were to occur for certain months.

3.2 Results from Generalized linear models examined

The data were conditioned first on BET and then applied to YFT using large fish as the dependent variable. The aim was to assess loss in catch of large YFT and SKJ on each of the time-periods (months) selected for the closure. A log response model as well as a model for non-linear relationships (log catch related to log effort) were also assessed but both models performed poorly with respect to diagnostics. **Table 1** summaries results using ANOVAs on the 3 models described above.

Diagnostic fits to models 1-3 for BET are shown below (**Figures 10-12**). Final Model 3 with parameter values of the coefficients is shown in **Table 1** (**Figure 13**). Similar parameter values for SKJ and large YFT are shown in **Table 2** as well along with diagnostic fits of model 3 on large YFT (**Figure 14**) and SKJ (**Figure 15**).

3.3 Model developed

Based on the data shown in **Table 3** above a general model was developed based on average effort between 2003 and 2013. The models predictive capability of catches for the EUPS fleet is shown in **Figure 16**. The predictive capability of the model with CV's on overall targets is shown in **Table 4** below. For illustrative purposes two other models are developed with differential closure patterns (all at once) or 2 (multiple closures over the year). Effects of these closures are shown in **Figure 17** and **18** and **Tables 5** and **6** (below).

For example if we wanted to estimate a total catch of 13000 tons for BET with one seasonal closure or 2, it could be implemented with **Table 5** or **Table 6** below resulting in catch distribution pattern shown in **Figure 17** and **18**. Note, that the estimated catch is the measure that controls a portion of the fleet (i.e. EUPS fleet that is the EST TOTAL CATCH that can be explained by the model). If we want to expand it to the observed data, we need to expand what this measure would do to the whole fleet based on the ratio of catch that it represents of the whole fleet, i.e. the expanded total catch (EXP Total Catch). So, the estimated (EST) catch is what is explained by the model, has to then be raised to what the total catch of the EUPS fleet is for that period (on average). Similarly raising factors are applied to YFT and SKJ as well. We can see that the model does well for BET (expansion of only 1.08 on average, but for YFT and SKJ the factors are raised by 1.51 and 1.68 respectively.

4. Discussion

IATTC's system currently uses effort in fishing hours to incorporate increases in fishing capacity. This system could easily be adapted to that as Fishing hours estimated across all fleets, could easily be converted to units of fleet/well capacity times the number of trips to overall well capacity for the fleet for that month. Some work would be needed to account for which fleets are fishing at which month and to incorporate an effort measure that is in units of well capacity. We could then limit the overall well capacity instead of hours to estimate the overall impact using this approach. However, it is important to note that the purse seine fleets operating in the Atlantic and Indian oceans are less heterogeneous than the one operating in the Eastern Pacific Ocean.

Squires et. al. (2016) argue for a case where Effort Rights Based Management has received considerably less conceptual or empirical attention in the literature than transferable catch quota approaches. Rather than having open access, olympic type fisheries, where fishers normally don't get optimal price for their catch, Squires et. al. (2016) argue that effort control type fisheries closely align the private behaviour of fishers with society's desired social–economic–ecological objectives of harvests satisfying a sustainable yield or effort target and sustainable social and economic benefits. Squires et. al. (2016) cover 37 different studies where these approaches have worked and also provided a right to the resource using responsible effort based management measures. Squires et. al. (2016) dispel a number of myths about effort-based fisheries, as discussed below.

Effort controls, in contrast to catch controls, create incentives to increase input use and costs in an attempt to maximize individual vessel catches and revenues. This incentive in turn raises, rather than minimizes, input usage and costs, at least collectively for the fleet. As a fleet becomes more efficient it tends to overfish and catch more with the same input (i.e. effort measure). However, controlling that measure can then keep fleets fishing at sustainable levels (e.g. capacity limitation, FAD limits, etc.). In contrast TAC based measures tend to provide stronger incentives to reduce effort and costs and to increase price. Catch rights thereby increase revenue through improved quality or smoothing out seasonality of production (as there is a limited catch). This was the case with halibut ITQ's (Grafton et al. 2000). However, for tuna fisheries this is far from the case and unless a particular fleet catch is in high demand and not effected by supply from other oceans or sectors (longline, pole-and-line and artisanal which is not the case), so this argument would not work for having a TAC based control rather than an effort-based control.

Other issues such as technological creep will provide incentives for the fleet to maximize catch with better efficiency (the case for PS). However, if we update our analysis with the latest information the relationship would be valid for the latest technology and could be updated every 5 years to give a new measure of effort in line with the recommended TAC. Although that is a serious criticism of effort-based measures to control output from the fisheries, especially if the technological creep increase so that more fish is caught every year that planned with a particular opener (Squire et. al. 2016), IATTC has been implementing such a system for over 15 years and has achieved maintaining the tropical tuna stocks to the target reference points over the entire period (never breaching limit reference points for those stocks).

As for the advantages ascribed to effort controls Squires et. al. (2016) mention that those systems are recommended in the case that catches cannot be estimated properly and/or compliance monitoring is poor. This is, to a different degree depending on the fleet, the case of industrial tuna purse seine fisheries because: catches for some ICCAT CPC are very uncertain (e.g. Ghana, Chassot et al. 2014); catches by species cannot be estimated in near real-time or be estimated by vessel to a known precision (e.g. EU fleet, Herrera 2018); the adoption of TACs has led to gross underreporting of catches by some fleets (e.g. Chinese Taipei longline fleet, ICCAT 2015); the ICCAT has not set any mechanism to independently monitor CPC compliance with the TACs of tropical tunas; the costs of such a mechanism will be extremely high.

4.1 Implementation of closures in the context of the ICCAT

The model presented can be used to assess the time-period and number of fishing days of closure required in order to replace the existing or any future Total Allowable BET Catches recommended by the ICCAT for the industrial tuna purse seine component. Other than the recommended TAC, the following information will be required to estimate the number of closure days for a given year:

1. Number of industrial tuna purse seiners to be in operation, by ICCAT CPC, and the expected total number of days that will be fished by those: The number of tuna seiners can be obtained from the latest national report presented by each CPC, and the total number of fishing days from past reports of vessel numbers and catch-and-effort data by each CPC as part of ICCAT's data requirements (Task 2);

2. Trend in the total number of active support vessels / FADs used by purse seiners, or any other new piece of technology that could contribute to an increase in effective fishing effort directed at the BET stock (i.e. effort creep);

3. Any other management measure ICCAT has implemented in complement to the fishery closure that could contribute to a decrease in effective fishing effort directed at the BET stock (e.g. time-area closure on fishing with FADs).

4. BET Biomass value estimate from the latest stock assessment.

While most of the information covered in 1-4 can be obtained from the ICCAT this does not apply to the numbers of active purse seiners and support vessels that will operate in the future in the ICCAT Convention Area as, at present, ICCAT CPCs not covered by the capacity limitation are not obliged to provide this information in advance to the ICCAT. However, ICCAT could contemplate to make it a requirement for CPC to provide this information, including fish carrying capacity, if this measure is implemented in substitution of the TAC.

4.2 Conclusion

This study shows the potential benefits for ICCAT's management to consider replacing the existing TACs of tropical tunas with fishery closures for its purse seine and pole-and-line components.

There are many possible scenarios of developing solutions to achieve a certain BET target with certain monthly closures. However, we may have conflicting objectives as seen that don't allow the catch to exceed 40K tonnes of large YFT while keeping BET targets low. For instance if we wanted 45K t of large YFT, this would not have been possible using scenario 2. If optimizing to one target the other species may not be maximized as seen above. However, considering the multi-species nature of surface fisheries at the ICCAT and the fact that catch limits exist for both bigeye tuna and yellowfin tuna, it would only be reasonable that the closure adopted seeks a reduction in the catches of both stocks. In addition, the TAC adopted by the IOTC for the yellowfin tuna stock has proved to have a adverse effect on fishing behaviour as it has prompted fishermen to avoid catching adult YFT on free-schools towards fishing on FADs, where YFT, mostly juvenile, only represents a fraction of the total catch. Therefore, there is a potential for effort limits to be more effective in addressing catch limits for multi-species fisheries in which catch limits have been adopted for more than one stock (ICCAT) or those fisheries that operate over its optimum capacity and target stocks that have been assessed to be fully exploited or above such levels, as it is the case of purse seine fisheries in the ICCAT and IOTC areas.

Thus, the choice of closures will be dependent on an iterative discussion between the managers and ship operators as shown in situations presented above. In addition, it is evident in certain months (shoulder seasons March April, and September to November) that catch rates of directed species (large YFT) are lower and closures in those months would benefit BET reductions while not compromising the catches of large yellowfin.

Given the large uncertainties in achieving TACs and the failure shown in IOTC, ICCAT and IATTC to do so, effort controls with large industrial fleets like the PS fleet are considered a better alternative. The ability to do so is entirely dependent on the data and management to implement these closures in an effective manner and has already proved effective in the case of the IATTC.

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Table 1: ANOVAS on models examined

ANOVA: Model 1

Variables	Df	Deviance	Resid. DF	Resid Dev	F	Pr(>F)	Sign.
NULL	3218	3.41E+13					
factor(dat$Year)	12	3.01E+11	3206	3.38E+13	2.9835	0.000368	<0.001
Biomass	0	0.00E+00	3206	3.38E+13			
factor(Month)	11	2.32E+11	3195	3.36E+13	2.5032	0.00392	0.01
FhoursE	1	6.14E+12	3194	2.75E+13	730.3401	<2.2 E-16	<0.001
factor(Flag)	2	6.07E+11	3192	2.68E+13	36.0588	<2.2 E-16	<0.001

ANOVA: Model 2

Variables	Df	Deviance	Resid. DF	Resid Dev	F	Pr(>F)	Sign.
NULL	3218	3.41E+13					
Biomass	1	3.47E+10	3217	3.41E+13	4.466	0.03465	0.05
factor(Month)	11	2.43E+11	3206	3.39E+13	2.8474	0.00102	0.01
factor(Grid)	67	2.66E+12	3139	3.12E+13	5.1082	<2.2 E-16	<0.001
FhoursE	1	6.66E+12	3138	2.45E+13	856.8687	<2.2 E-16	<0.001
factor(Flag)	2	1.73E+11	3136	2.44E+13	11.1187	1.54E-05	<0.001

ANOVA: Model 3

Variables	Df	Deviance	Resid. DF	Resid Dev	F	Pr(>F)	Sign.
NULL	3218	3.41E+13					
Biomass	1	3.47E+10	3217	3.41E+13	4.1086	0.042747	0.05
factor(Month)	11	2.43E+11	3206	3.39E+13	2.6195	0.002503	0.01
FhoursE	1	6.23E+12	3205	2.76E+13	737.3417	<2.2 E-16	0.001
factor(Flag)	2	5.77E+11	3203	2.70E+13	34.1716	2.07E-15	0.001

ANOVA:Model 4

Variables	Df	Deviance	Resid. DF	Resid Dev	F	Pr(>F)	Sign.
NULL	3218	3.41E+13					
Biomass	1	3.47E+10	3217	3.41E+13	4.4064	0.035882	0.05
factor(Month)	11	2.43E+11	3206	3.39E+13	2.8094	0.001186	0.01
FhoursE	1	6.23E+12	3205	2.76E+13	790.7839	<2.2 E-16	0.001
factor(Flag)	2	5.77E+11	3203	2.70E+13	36.6483	<2.2 E-16	0.001
factor(Month):FhoursE	11	1.91E+12	3192	2.51E+13	22.1047	<2.2 E-16	0.001

Table 2: ANOVA for similar model for YFT and SKJ

ANOVA: YFT_Large

Variables	Df	Deviance	Resid. DF	Resid Dev	F	Pr(>F)	Sign.
NULL	3218	2.85E+14					
Biomass	1	5.76E+10	3217	2.85E+14	0.7901	0.374136	NS
factor(Month)	11	2.15E+12	3206	2.83E+14	2.6803	0.001975	0.01
FhoursE	1	3.16E+13	3205	2.51E+14	433.5564	<2.2 E-16	<0.001
factor(Flag)	2	1.17E+12	3203	2.50E+14	8.0096	0.000339	0.001
factor(Month):FhoursE	11	1.72E+13	3192	2.33E+14	21.4948	<2.2 E-16	<0.001

ANOVA:SKJ

Variables	Df	Deviance	Resid. DF	Resid Dev	F	Pr(>F)	Sign.
NULL	3218	5.63E+14					
Biomass	1	1.67E+12	3217	5.62E+14	11.7947	0.000602	0.001
factor(Month)	11	5.82E+12	3206	5.56E+14	3.7448	2.42E-05	0.001
FhoursE	1	7.84E+13	3205	4.77E+14	554.3754	<2.2 E-16	<0.001
factor(Flag)	2	6.04E+12	3203	4.71E+14	21.3646	6.07E-10	<0.001
factor(Month):FhoursE	11	2.01E+13	3192	4.51E+14	12.9034	<2.2 E-16	<0.001

ANOVA: YFT_Small

Variables	Df	Deviance	Resid. DF	Resid Dev	F	Pr(>F)	Sign.
NULL	3218	2.88E+13					
Biomass	1	1.21E+09	3217	2.88E+13	0.1557	0.69316	NS
factor(Month)	11	3.93E+11	3206	2.84E+13	4.6036	5.50E-07	0.001
FhoursE	1	2.05E+12	3205	2.64E+13	264.7475	<2.2 E-16	<0.001
factor(Flag)	2	5.89E+10	3203	2.63E+13	3.7996	0.02248	0.05
factor(Month):FhoursE	11	1.56E+12	3192	2.48E+13	18.2375	<2.2 E-16	<0.001

Table 3: Parameter values for Model 4 for each species.

Parameters	Estimate BET	Estimate YFT	Estimate SKJ	Estimate YFT Small	Std. Error BET	Std. Error YFT	Std. Error SKJ	Std. Error YFT Small
(Intercept)	39420.00	57840.00	214200.00	2.87E+04	1.62E+04	4.91E+04	6.84E+04	1.60E+04
Biomass	-0.03	-0.10	-0.30	-1.06E-02	3.36E-02	1.02E-01	1.42E-01	3.34E-02
factor(Month)2	-11920.00	-34700.00	10480.00	-3.33E+03	8.95E+03	2.72E+04	3.79E+04	8.88E+03
factor(Month)3	-13810.00	-21320.00	-11500.00	1.08E+04	9.03E+03	2.75E+04	3.82E+04	8.96E+03
factor(Month)4	-10650.00	7479.00	28100.00	9.08E+03	1.04E+04	3.18E+04	4.43E+04	1.04E+04
factor(Month)5	-18500.00	-41030.00	-104300.00	-3.18E+04	1.06E+04	3.22E+04	4.48E+04	1.05E+04
factor(Month)6	-49600.00	-102800.00	-154500.00	-4.33E+04	1.00E+04	3.05E+04	4.25E+04	9.96E+03
factor(Month)7	-18940.00	-38300.00	-143100.00	-4.69E+04	9.39E+03	2.86E+04	3.98E+04	9.32E+03
factor(Month)8	-8887.00	-44660.00	-39630.00	-2.25E+04	9.56E+03	2.91E+04	4.05E+04	9.49E+03
factor(Month)9	3385.00	2788.00	-11230.00	-1.96E+04	9.24E+03	2.81E+04	3.92E+04	9.17E+03
factor(Month)10	15540.00	-4097.00	47290.00	-1.45E+04	8.40E+03	2.56E+04	3.56E+04	8.34E+03
factor(Month)11	15670.00	-2423.00	49440.00	-1.53E+04	8.40E+03	2.56E+04	3.56E+04	8.34E+03
factor(Month)12	-1649.00	-58660.00	62820.00	-2.06E+04	8.47E+03	2.58E+04	3.59E+04	8.41E+03
FhoursE	177.30	416.10	864.30	6.13E+01	2.12E+01	6.46E+01	8.99E+01	2.11E+01
factor(Flag)Ghana	5827.00	3411.00	50650.00	8.49E+03	3.57E+03	1.09E+04	1.51E+04	3.54E+03
factor(Flag)Other	-69720.00	-74380.00	-187900.00	-8.03E+03	1.00E+04	3.05E+04	4.24E+04	9.94E+03
factor(Month)2:FhoursE	-9.73	-30.38	-206.60	5.21E+00	3.07E+01	9.33E+01	1.30E+02	3.04E+01
factor(Month)3:FhoursE	22.47	11.28	-38.94	8.39E+00	3.00E+01	9.14E+01	1.27E+02	2.98E+01
factor(Month)4:FhoursE	-100.80	-334.60	-510.10	-1.59E+01	3.91E+01	1.19E+02	1.66E+02	3.88E+01
factor(Month)5:FhoursE	24.85	19.57	-90.40	8.82E+01	4.24E+01	1.29E+02	1.80E+02	4.21E+01
factor(Month)6:FhoursE	301.70	817.80	420.80	2.11E+02	3.55E+01	1.08E+02	1.51E+02	3.53E+01
factor(Month)7:FhoursE	140.90	299.20	444.80	2.65E+02	2.89E+01	8.79E+01	1.23E+02	2.87E+01
factor(Month)8:FhoursE	23.62	163.60	-377.00	3.49E+01	3.30E+01	1.00E+02	1.40E+02	3.28E+01
factor(Month)9:FhoursE	21.96	-273.60	-369.70	2.80E+01	3.44E+01	1.05E+02	1.46E+02	3.42E+01
factor(Month)10:FhoursE	-107.30	-336.20	-541.80	-8.07E+00	2.74E+01	8.33E+01	1.16E+02	2.72E+01
factor(Month)11:FhoursE	-83.07	-294.20	-445.10	-6.74E+00	2.70E+01	8.22E+01	1.14E+02	2.68E+01
factor(Month)12:FhoursE	47.22	272.80	-363.10	1.19E+01	2.85E+01	8.68E+01	1.21E+02	2.83E+01

Table 4: Catch Estimated with uncertainty based on average effort distribution

Month	Avg Eff	Fishing (on=1)	Biomass (input from BET assessment)	Estimated BET	Estimated Large YFT	Estimated SKJ	Estimated Small YFT	SE (BET)	SE (large YFT)	SE_SKJ	SE (Small YFT)
1	6044	1	400000	1100837	2530905	5317253	395155	157902	480362	668971	156715
2	5947	1	400000	1013870	2275198	4015333	416870	347179	1056162	1470652	344573
3	7045	1	400000	1422843	3005661	5896782	526413	399813	1216247	1694080	396778
4	6275	1	400000	498696	535033	2344480	318908	418433	1273216	1773232	415309
5	6440	1	400000	1312644	2780825	4973333	955783	450083	1369568	1907378	446756
6	5163	1	400000	2452934	6284382	6574606	1385286	332696	1012188	1409387	330184
7	5249	1	400000	1680735	3732778	6822684	1692277	302141	919177	1280391	299856
8	5540	1	400000	1133473	3182927	2753632	535228	339581	1033109	1438631	337017
9	5415	1	400000	1111723	790586	2760851	488892	340252	1034880	1441711	337688
10	5286	1	400000	414861	434389	1845765	291519	294906	897183	1249647	292667
11	4764	1	400000	493882	594445	2140245	269260	267770	814661	1134503	265772
12	5837	1	400000	1338255	3978855	3082212	431241	328590	999721	1392040	326147
			EST TOTAL CATCH (T)	13975	30126	48527	7707				
			EXP TOTAL CATCH (T)	15196	45323	81418	11732				
			cv	0.28	0.40	0.35	0.51				

Table 5: Catch Estimated with uncertainty based on one closure and target of 13000 BET with large YFT near 40000 T.

Month	Avg Eff	Fishing (on=1)	Biomass (input from BET assessment)	Estimated BET	Estimated Large YFT	Estimated SKJ	Estimated Small YFT	SE (BET)	SE (large YFT)	SE_SKJ	SE (Small YFT)
1	6044	1	400000	1100933	2531131	5317722	395188	157913	480397	669019	156726
2	5947	1	400000	1013956	2275396	4015670	416904	347206	1056243	1470765	344599
3	6691	1	400000	1352057	2854224	5604325	501705	381647	1160984	1617104	378749
4	6276	1	400000	498714	535052	2344563	318919	418447	1273259	1773292	415323
5	6441	1	400000	1312769	2781095	4973811	955876	450122	1369688	1907545	446795
6	5312	1	400000	2523983	6467401	6765219	1425622	341115	1037801	1445050	338539
7	5250	1	400000	1681045	3733474	6823958	1692594	302190	919325	1280598	299904
8	5540	1	400000	1133597	3183283	2753932	535287	339614	1033210	1438773	337050
9	0	0	400000	0	0	0	0	0	0	0	0
10	0	0	400000	0	0	0	0	0	0	0	0
11	0	0	400000	0	0	0	0	0	0	0	0
12	5838	1	400000	1338410	3979328	3082556	431291	328624	999825	1392185	326181
			EST TOTAL CATCH (T)	11955	28340	41682	6673				
			EXP TOTAL CATCH (T)	13000	42637	69933	10159				
			cv	0.26	0.33	0.31	0.46				

Table 6: Catch Estimated with uncertainty based on two closures and target of 13000 BET with YFT remaining near 40000 T.

Month	Avg Eff	Fishing (on=1)	Biomass (input from BET assessment)	Estimated BET	Estimated Large YFT	Estimated SKJ	Estimated Small YFT	SE (BET)	SE (large YFT)	SE_SKJ	SE (Small YFT)
1	6532	1	400000	1187402	2734063	5739241	425104	168267	511893	712883	167002
2	0	0	400000	0	0	0	0	0	0	0	0
3	0	0	400000	0	0	0	0	0	0	0	0
4	6798	1	400000	538689	577640	2529649	342684	449956	1369136	1906823	446597
5	6466	1	400000	1317960	2792282	4993684	959716	451757	1374662	1914472	448418
6	5735	1	400000	2726987	6990341	7309858	1540873	365170	1110984	1546951	362412
7	6160	1	400000	1970455	4384057	8014616	1989681	347784	1058028	1473817	345153
8	6470	1	400000	1320271	3721882	3206682	624732	389999	1186493	1652224	387054
9	7000	1	400000	1427493	1016408	3544650	630534	428457	1303140	1815450	425228
10	0	0	400000	0	0	0	0	0	0	0	0
11	0	0	400000	0	0	0	0	0	0	0	0
12	6407	1	400000	1466204	4371442	3367834	472962	356953	1086012	1512193	354299
			EST TOTAL CATCH (T)	11955	26588	38706	6986				
			EXP TOTAL CATCH (T)	13000	40001	64941	10635				
			cv	0.25	0.34	0.32	0.42				

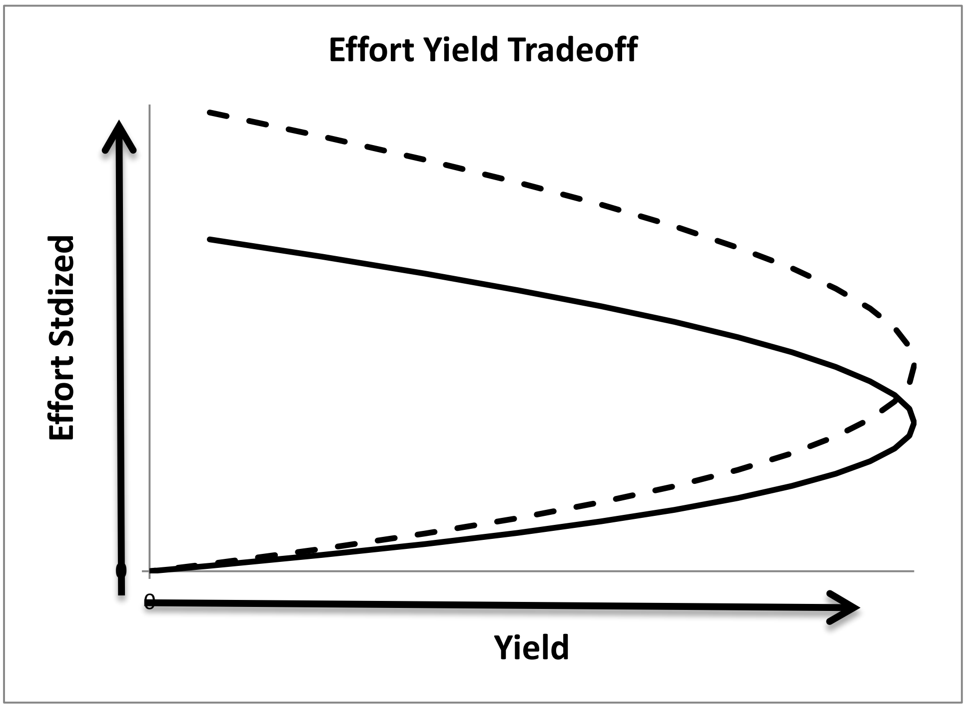

Figure 0: Optimal effort related to yield with different *q*'s.

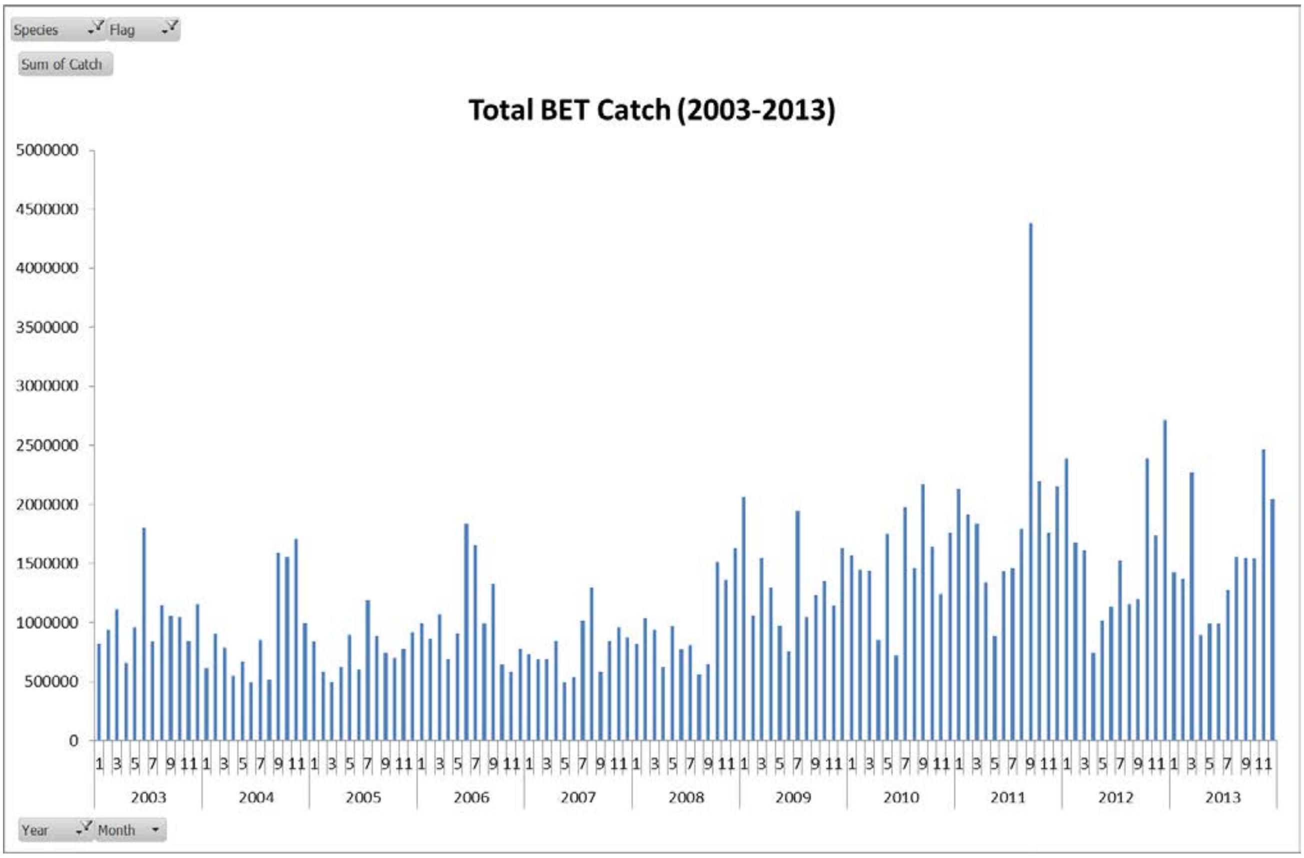

Figure 1: Aggregated Catch in numbers for BET between 2003-2013.

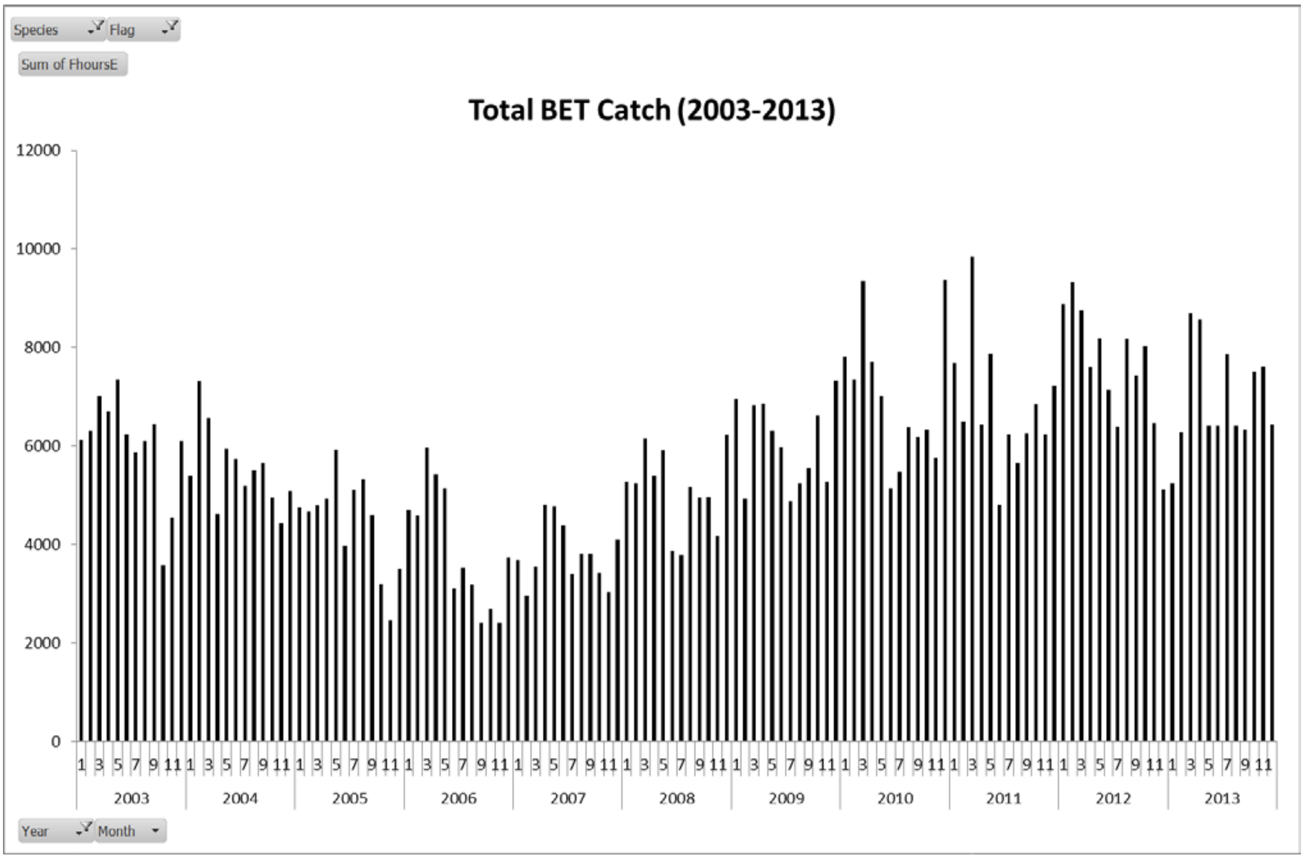

Figure 2: Aggregated effort on BET over the months between 2003 to 2013 (source ICCAT)

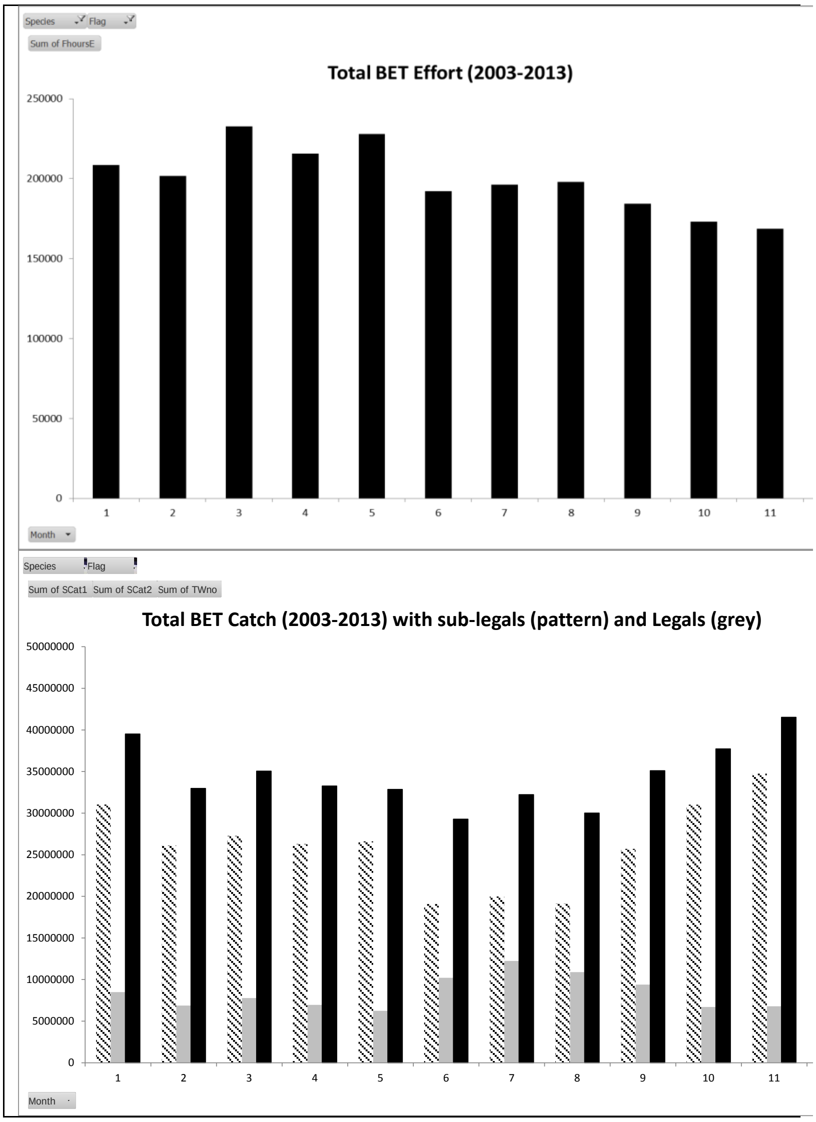

Figure 3: Total BET effort by months (aggregated) and catch by category 1 and 2 (scat 1 are small fish less that l50, and scat2 ae larger fish >l50).

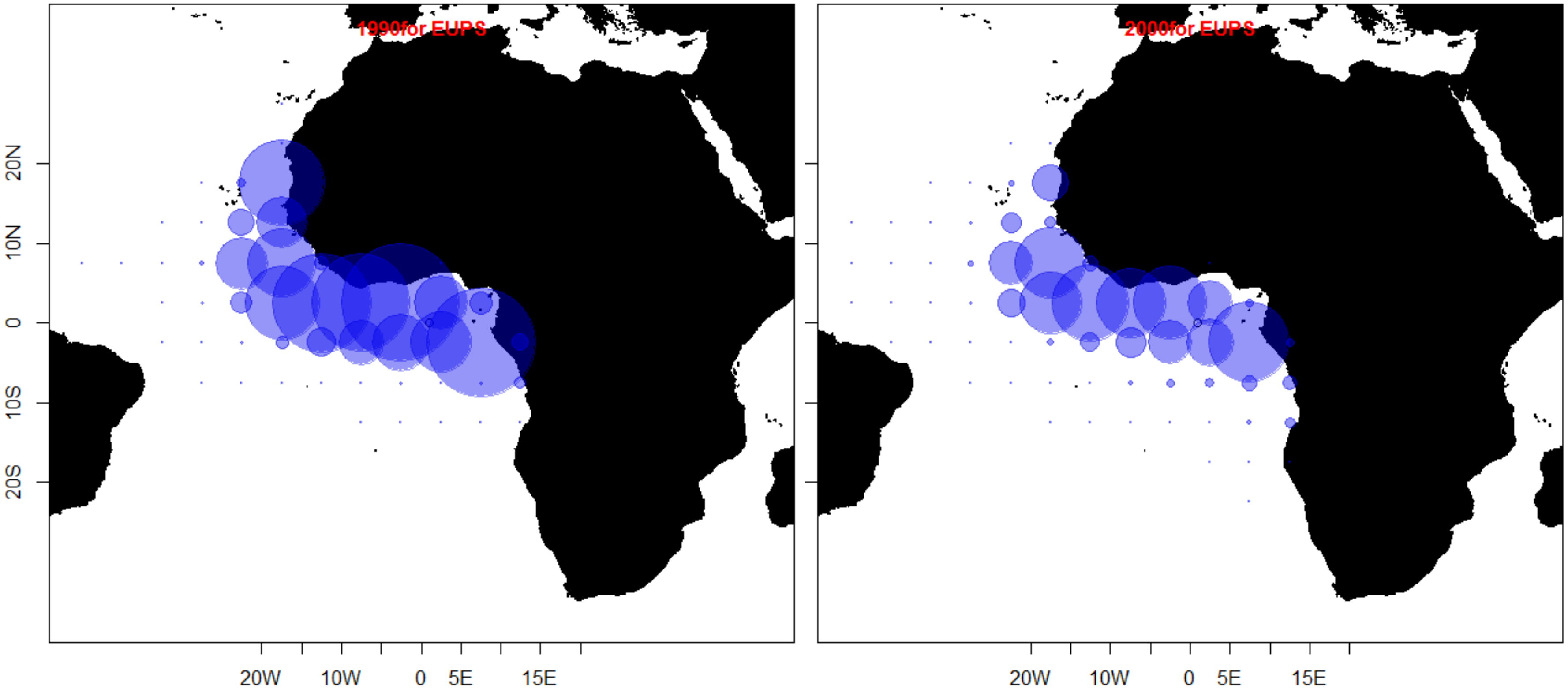

Figure 4: Effort distribution for the PS fleet in the Atlantic by the 1990's and 2000's. Magnitude and spatial extent of the PS fishery has remained the same

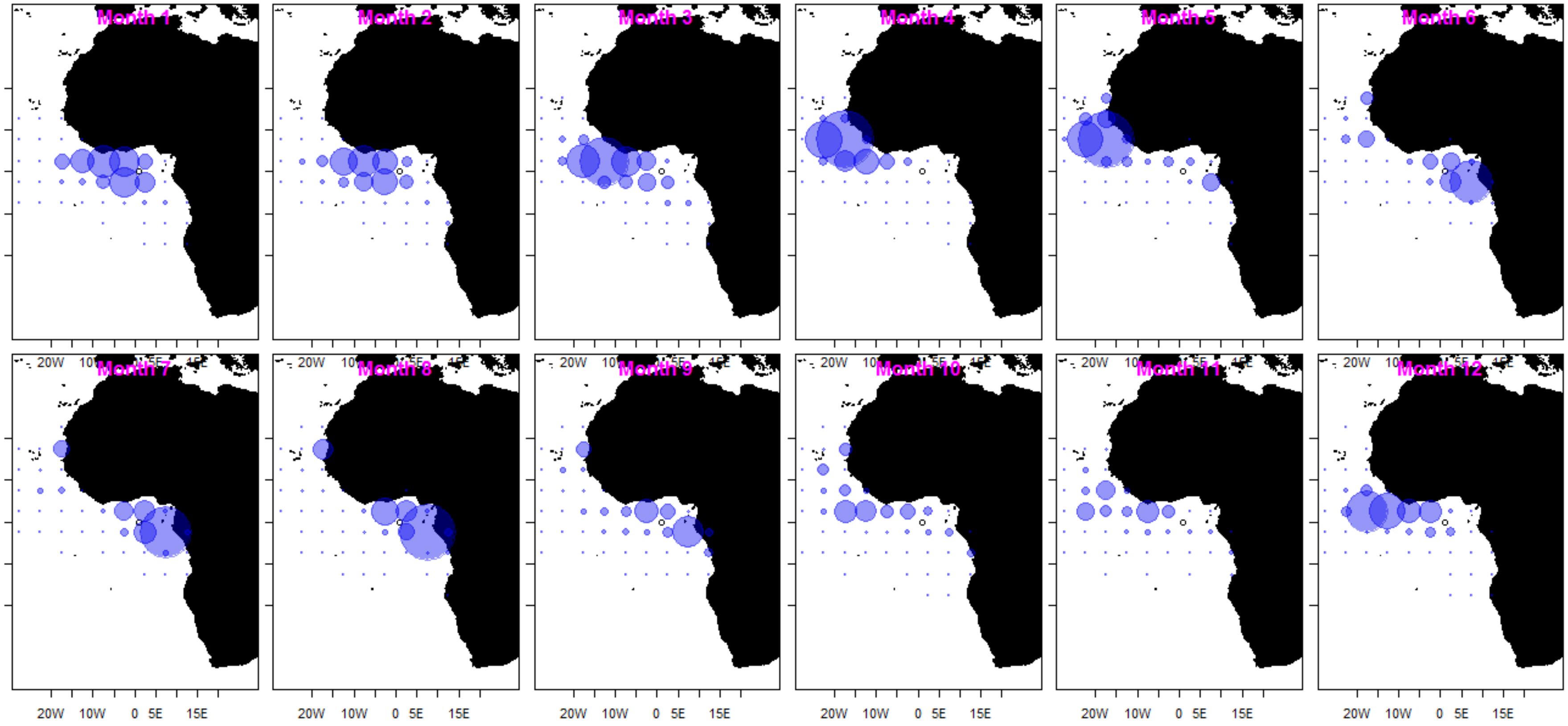

Figure 5: Temporal distribution by month for PS fishery (Month 1=January, Month 12=December on aggregated data over the period 2003-2013)

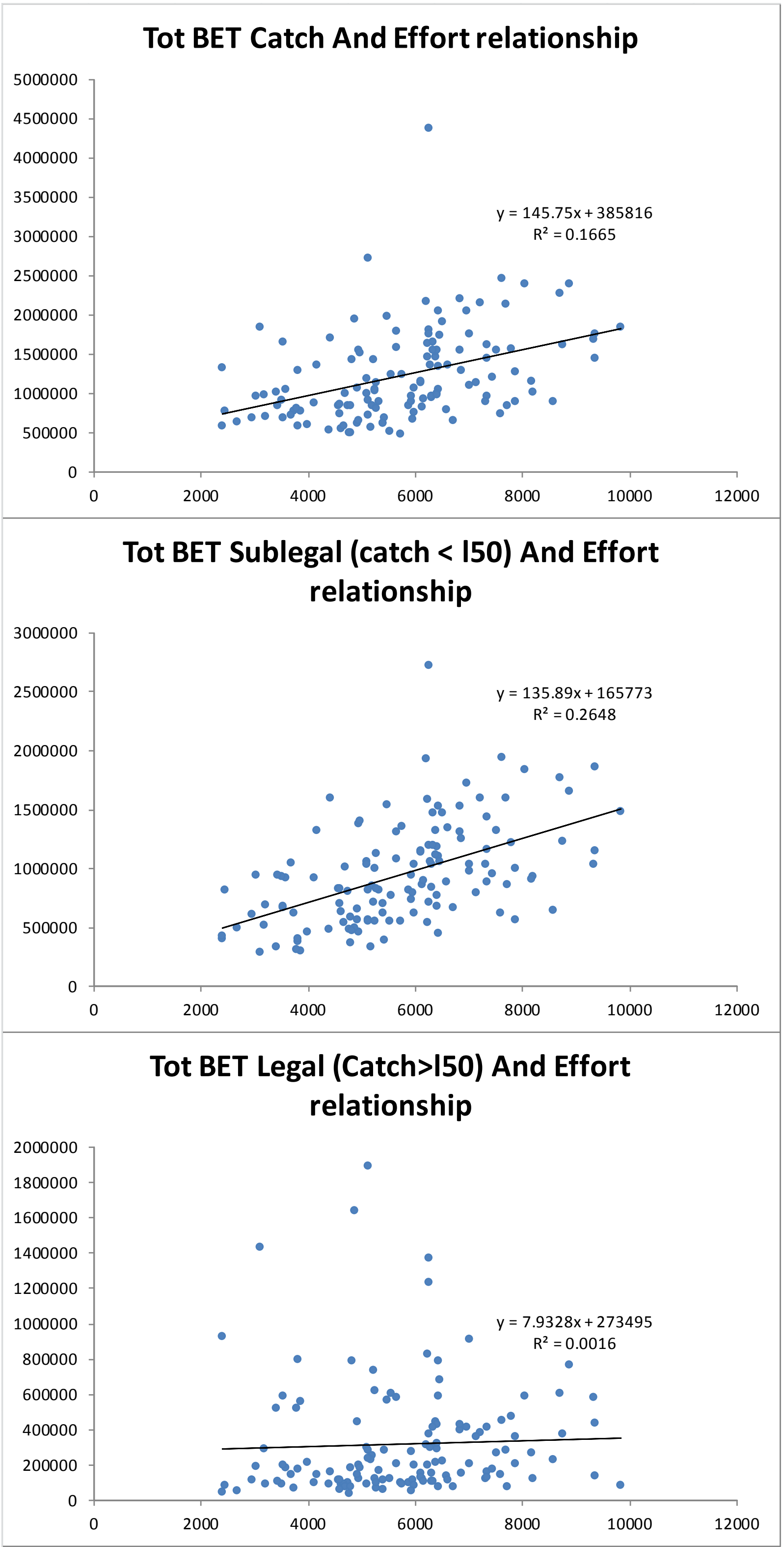

Figure 6: Simple BET relationships (catch in weight in kgs, so divide by 1000 to get catch in weight in tons). Positive significant relationships by size for small and overall fish but not for large fish.

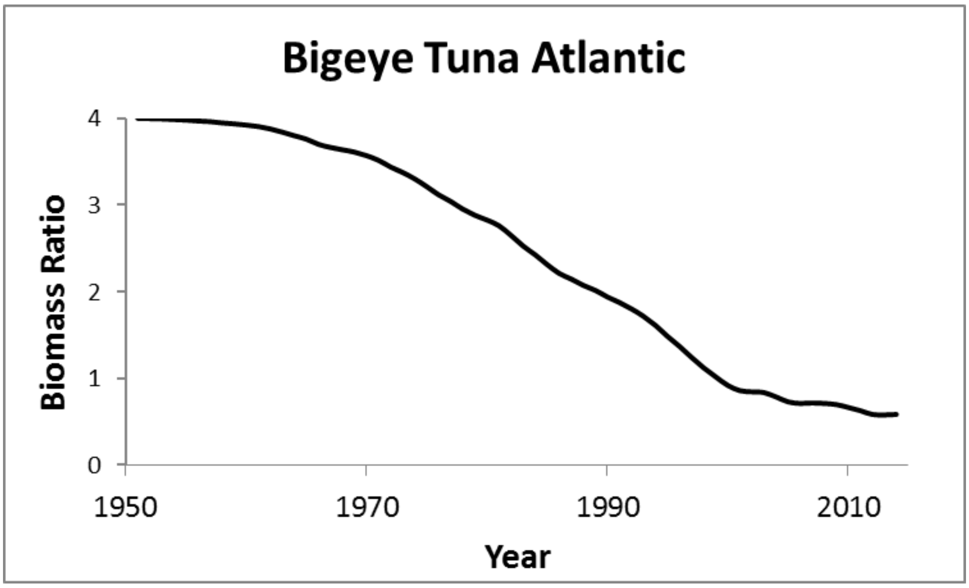

Figure 7: BET scaled abundance trends from last assessment (base run).

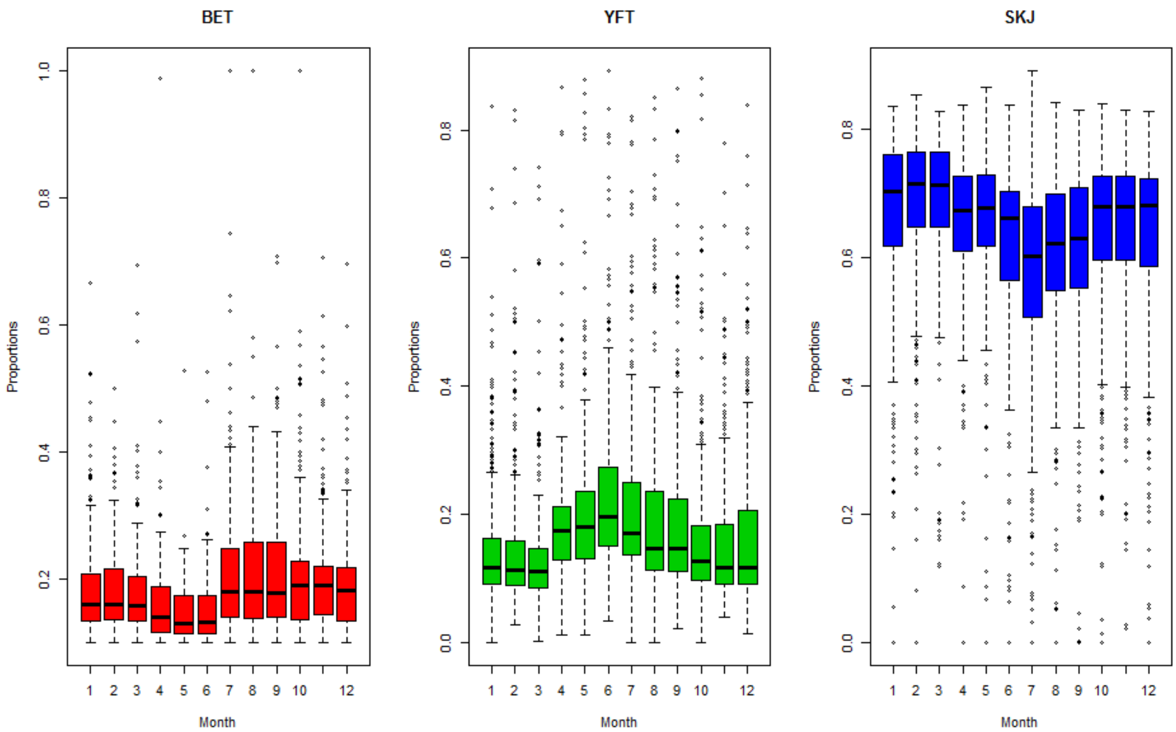

Figure 8: Species proportions by month over 2003-2013 by month.

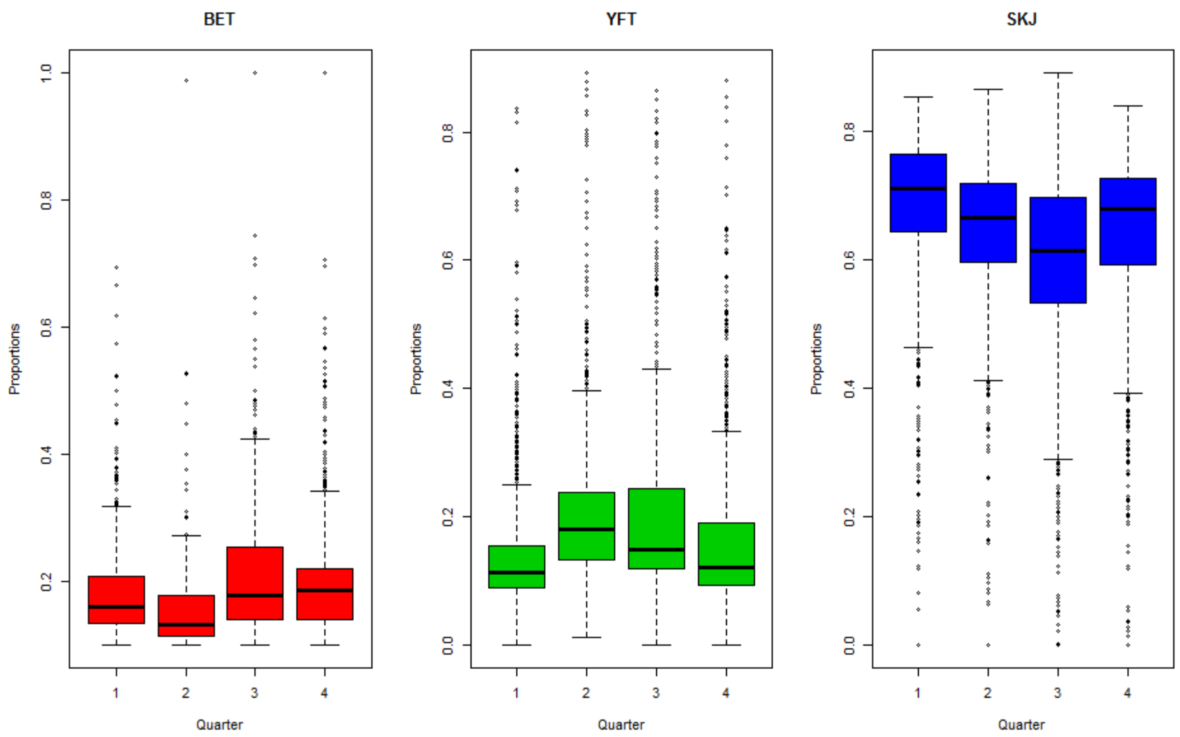

Figure 9: Species proportions by qurter over 2003-2013 by month.

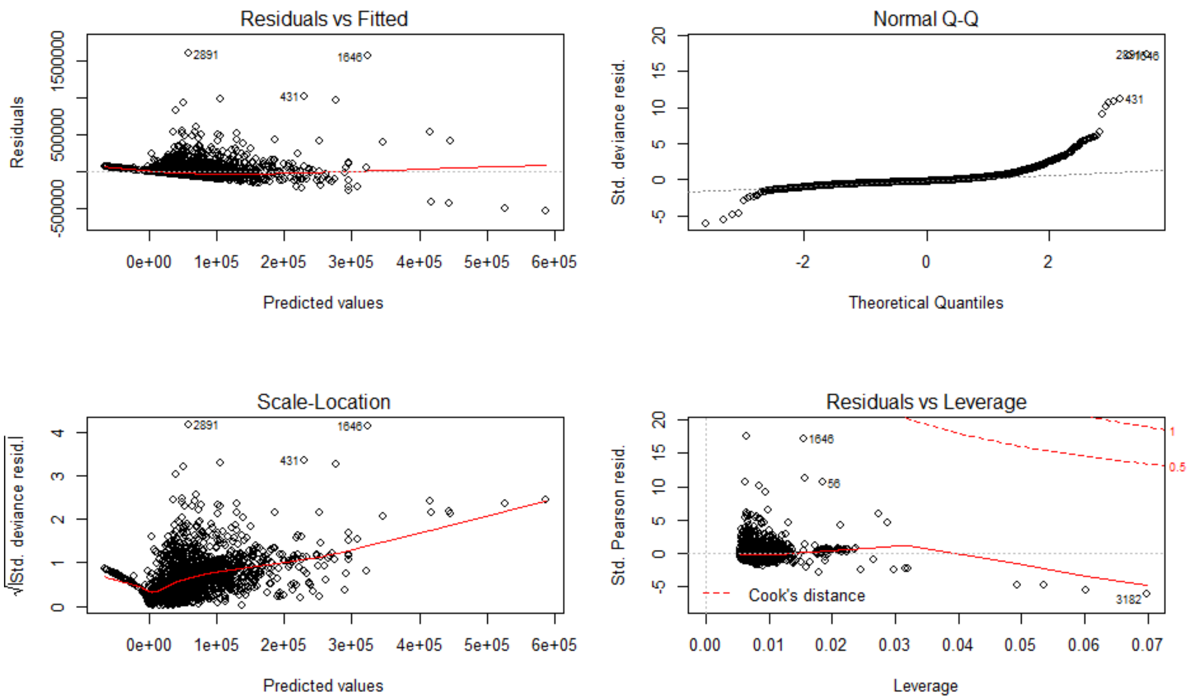

Figure 10: Residual diagnostics for model 1

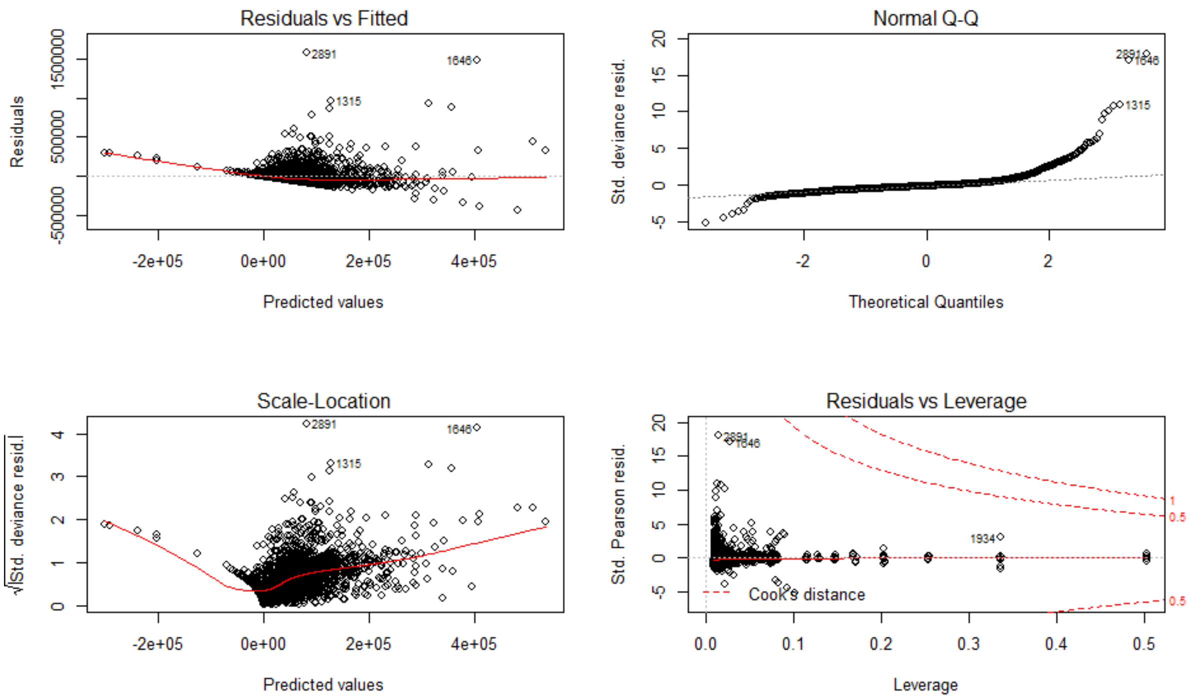

Figure 11: Residual diagnostic for model 2

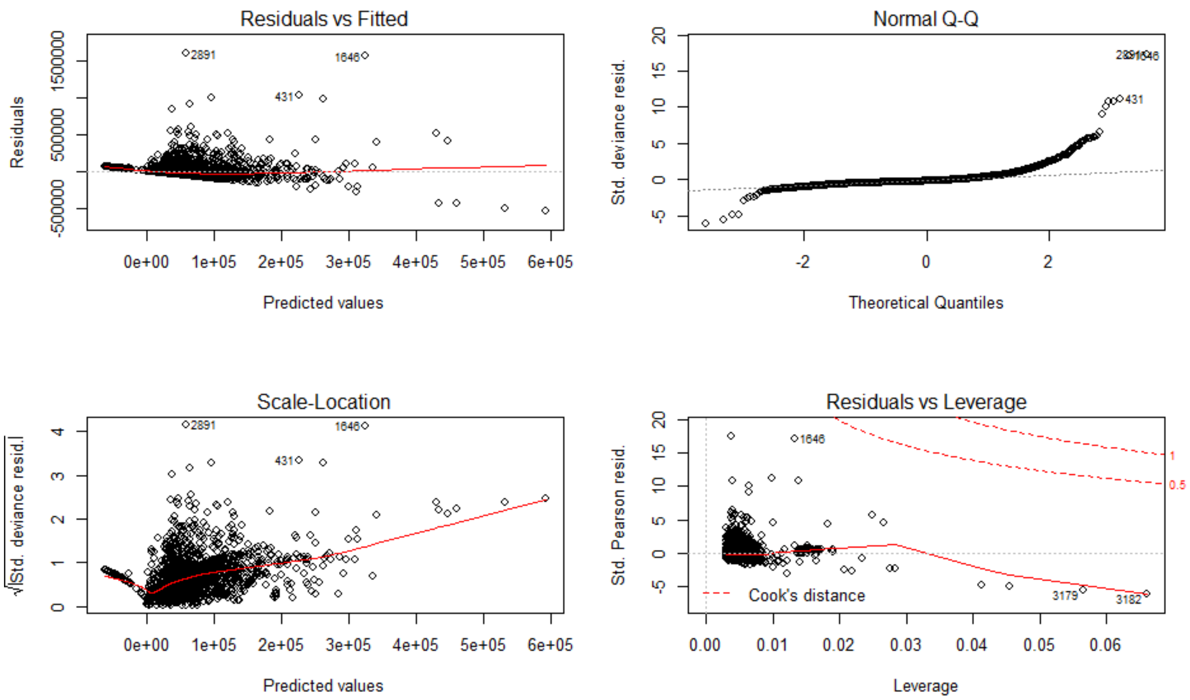

Figure 12: Residual diagnostics for model 3

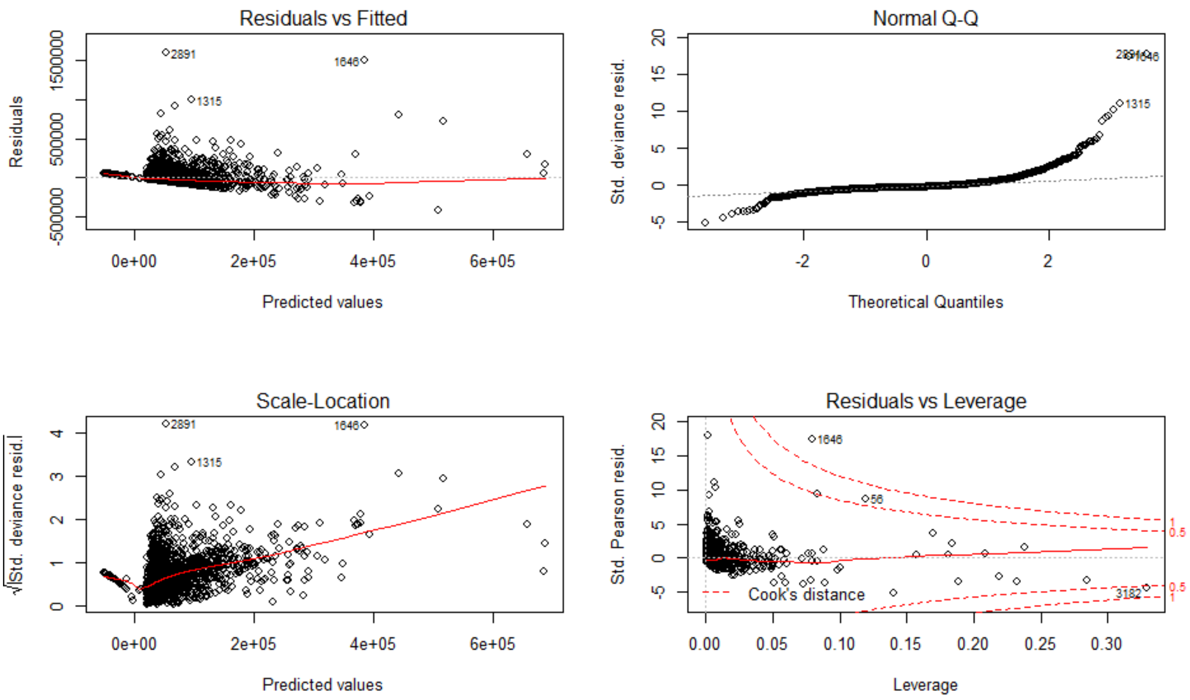

Figure 13: Residual diagnostics for Model on BET- FINAL MODEL.

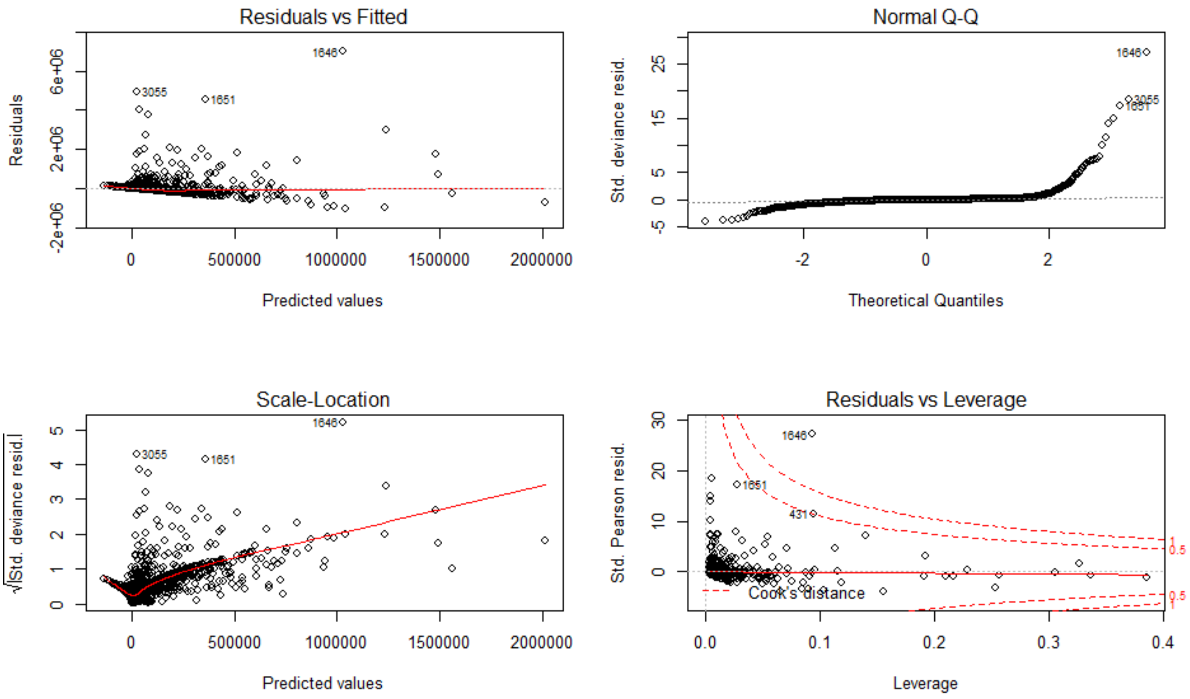

Figure 14: Residual diagnostic for Model on YFT

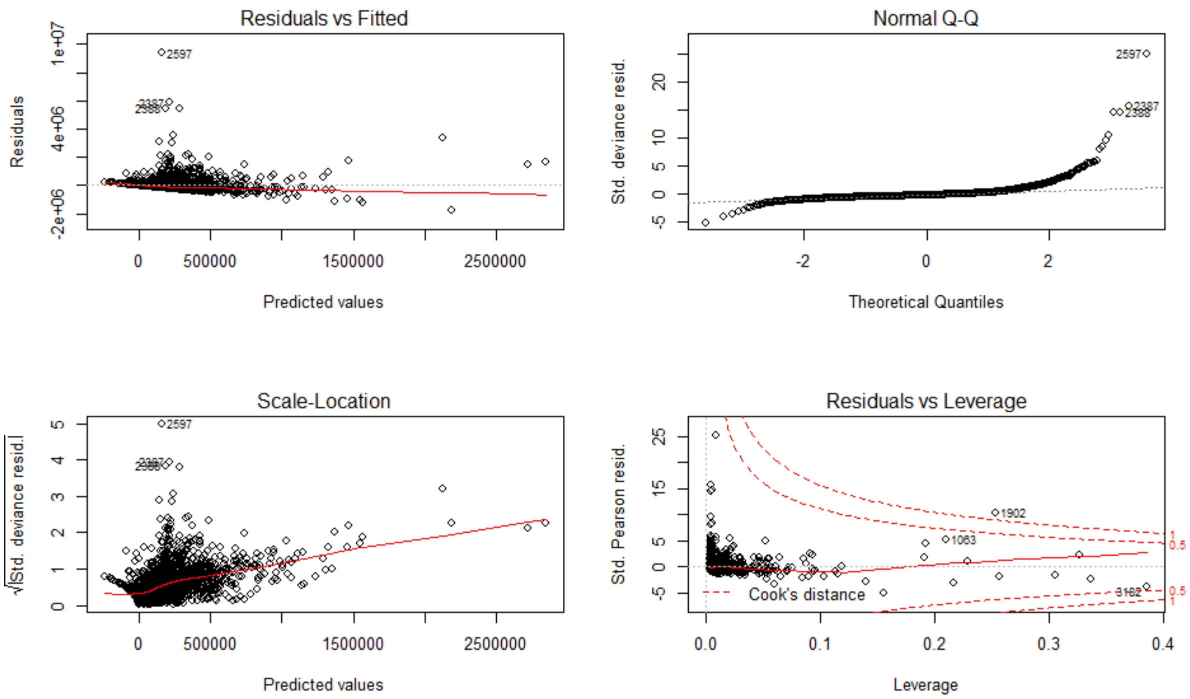

Figure 15: Residual diagnostic for Model on SKJ

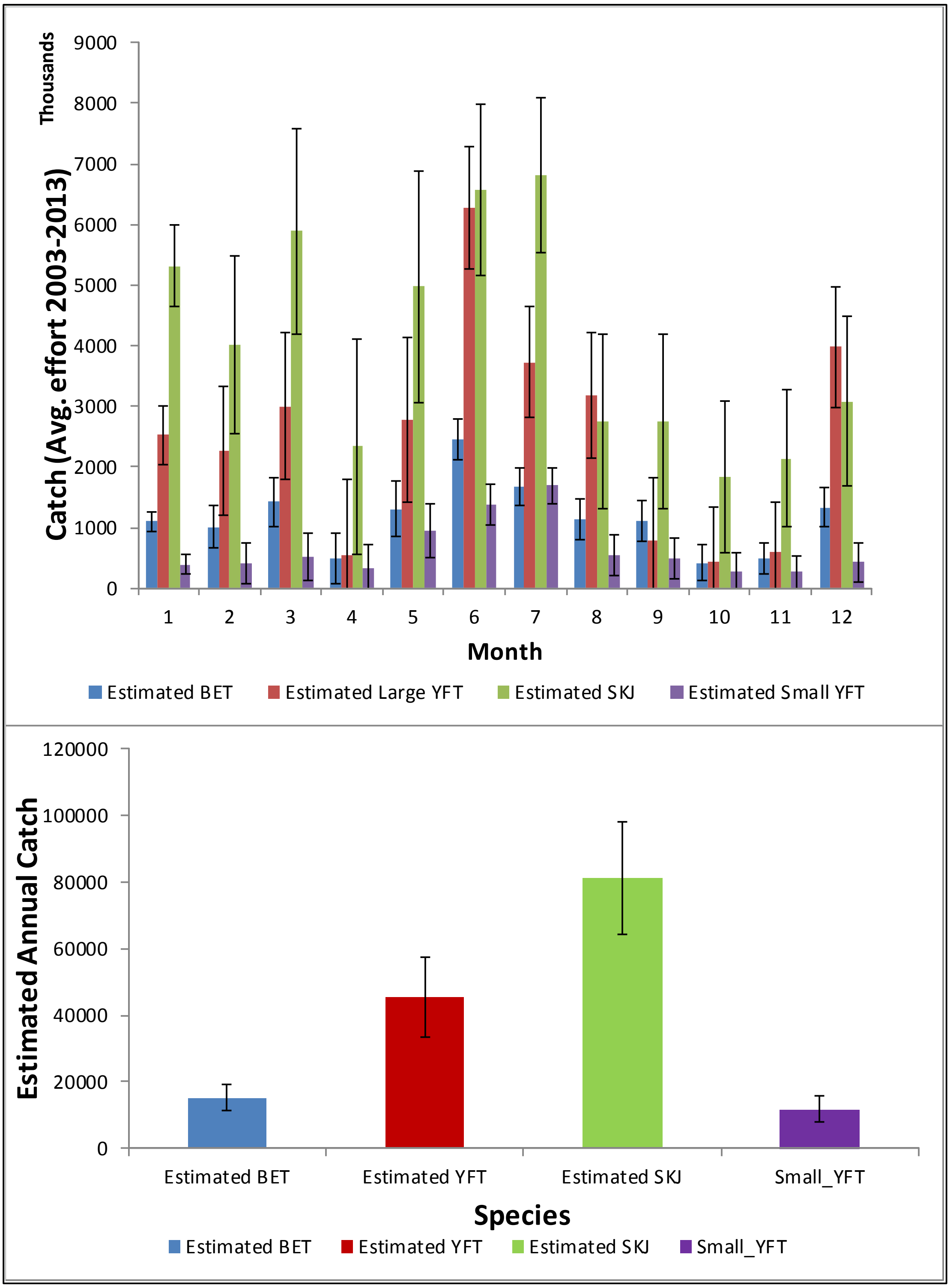

Figure 16: Estimated catch by species and month (above panel) and all year (lower panel) based on average effort distribution and 400000 SPB for BET.

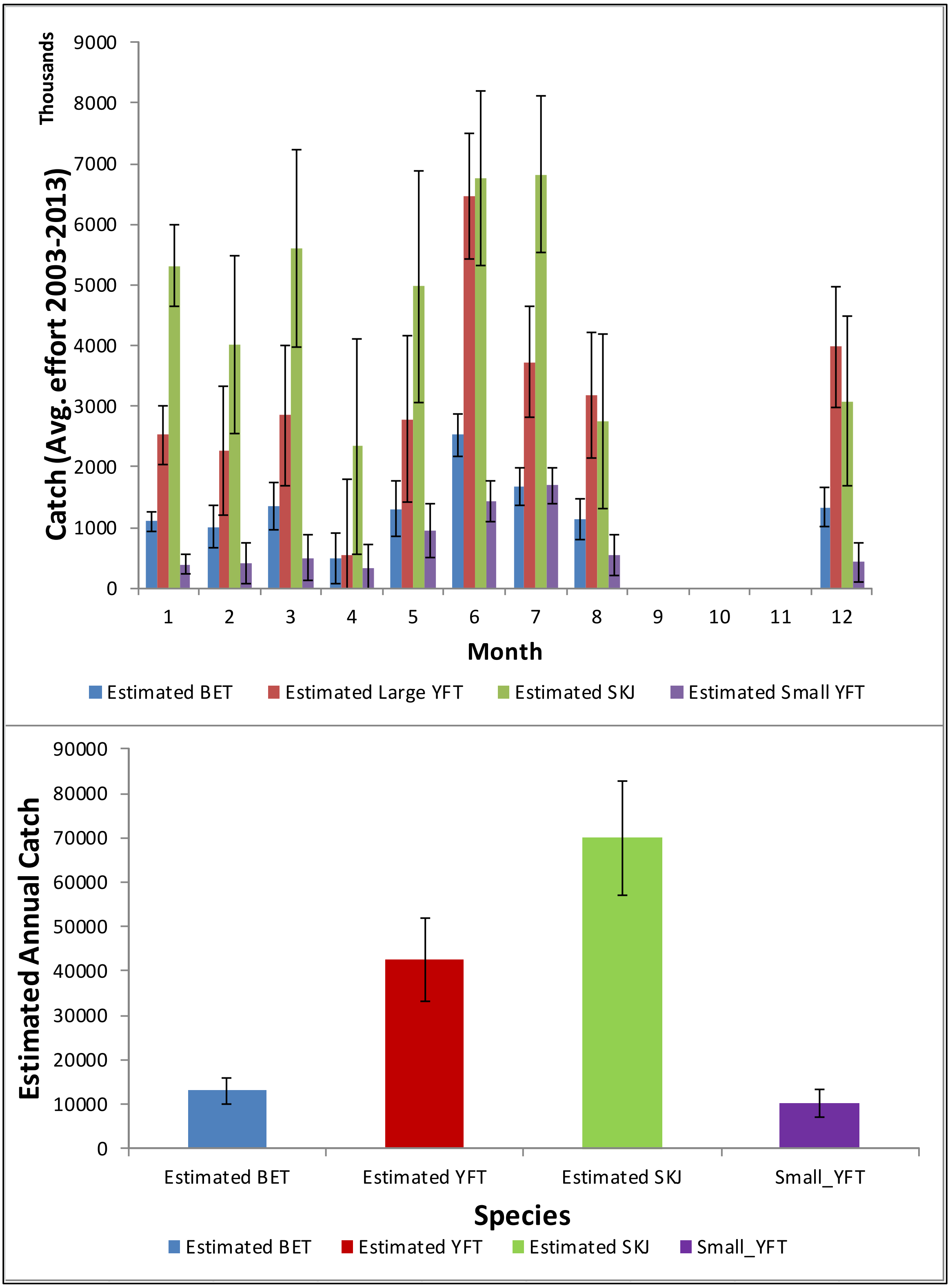

Figure 17: Estimated catch by species and month (above panel) and all year (lower panel) based on one closure of 3 months (Sep, Oct, Nov) and 400000 SPB for BET. The goal is try to limit BET to 10000 T and keep YFT near 40000T

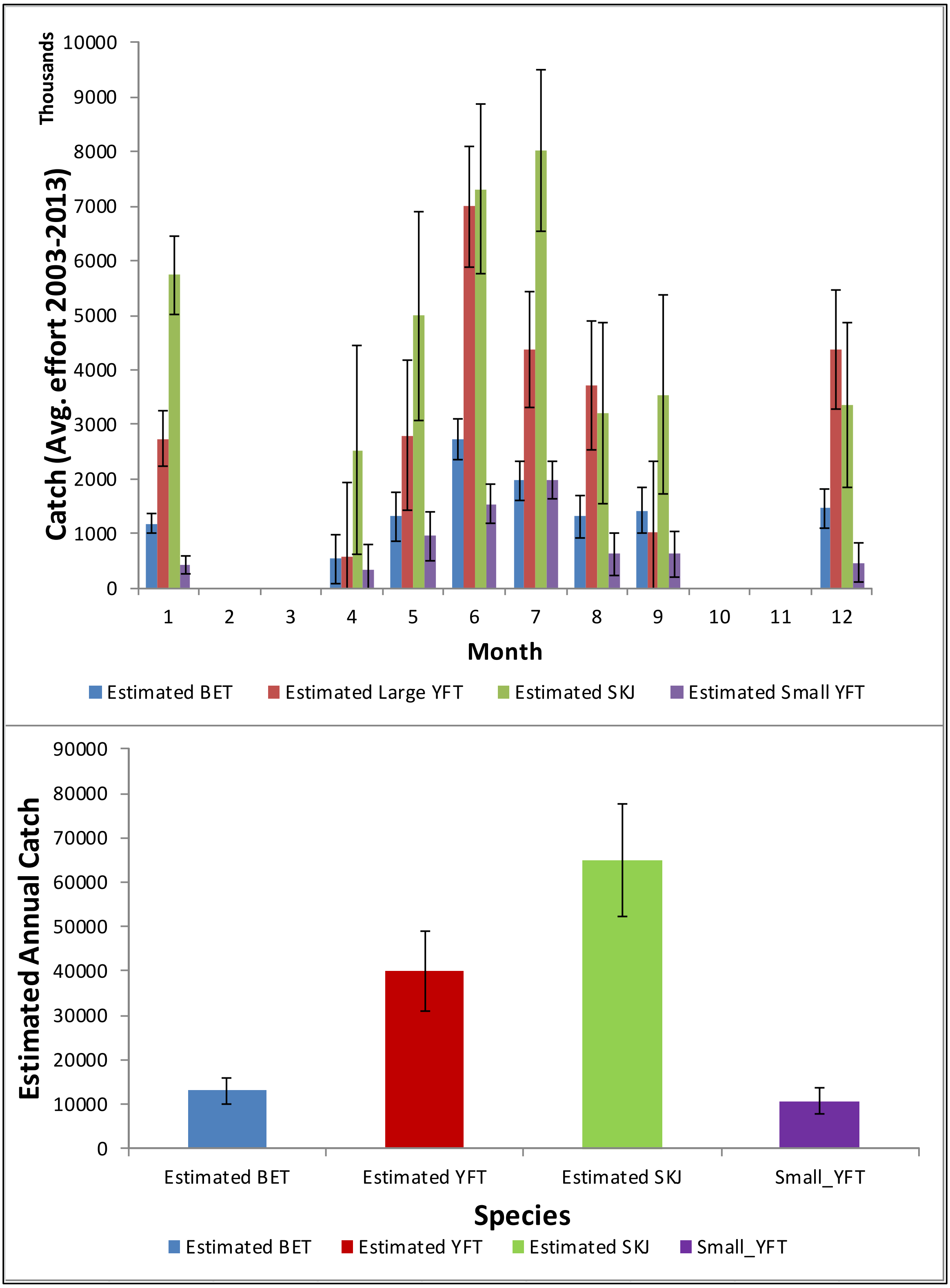

Figure 18: Estimated catch by species and month (above panel) and all year (lower panel) based on two closures of 2 months each (Sep & Oct, Feb & March) and 400000 SPB for BET. The goal is try to limit BET to 13000 T and keep YFT near 40000T.