Improved version of the Tropical Tuna Treatment process: new perspectives for catch estimates of tropical purse seine fishery

- Catches in the Indian Ocean –

Duparc A.[1], Depetris M.[1], Cauquil P.[2], Floch L. [1], Lebranchu J. [1]

Abstract

The Tropical Tuna Treatment is a process created at the end of the 90s by EU scientists to estimate catch of the tropical tuna purse seine fishery, for which logbook declarations were known biased. His main purpose is to provide the best estimations for nominal catch and catch effort spatially represented, to the RFMOs. However, the evolution of fishing practices and the extension of the fishing grounds have challenged the T3 methodology in some parts of it processing. Thus, the used of too large spatio-temporal sampling strata was specifically pointed out as the major cause of biases in the catch estimated. This paper presents the new methodology developed to fix this issue and implications on the output estimations compared to the previous version and logbook declarations. Finally, future improvements were discussed.

Keywords

yellowfin, *Thunnus albacore,* bigeye, *Thunnus obesus,* skipjack, *Katsuwonus pelamis*, T3 methodology

Introduction

Catch estimation is a major stock assessment element in every fishery. In the purse seine fishery, this estimation always has been challenging due to the multi-specific nature of the catch and the structure of the fishery (Lawson 2013). Before 1984, the species composition of the European purse seiner catch (France and Spain) was directly estimated from the logbooks filled by the skippers. However, it has been observed that biases in the reports of catch by species in logbooks mostly concerned small size fish. The two major biases detected were the report of (1) young yellowfin and young bigeye (<3 kg) as skipjack and (2) bigeye of 3-15 kg as yellowfin (Cayré 1984, Báez et al. 2019). Moreover, the catch of species reported in the logbooks was based on commercial (i.e. selling price of fish), rather than biological (identification of catch by species) criteria (ICCAT, 1984). Therefore, a sampling and processing methodology was designed at the end of the 1980s in order to correct biases and to provide more accurate estimates of catch by species for the European purse seine fleet. At the same time, the Tropical Tuna Treatment (T3) was developed by the French National Research Institute for Sustainable Development (IRD) and the Spanish Institute of Oceanography (IEO) to process these sampling data and produce corrected catch by species and effort by month and 1°x1° square in full compliance with the Res. 15/01 ad 15/02 of the IOTC.

The most recent design in catch sampling in port was developed in 1997, following sensitivity analyses performed on various sampling designs during the European project "Echantillonnage Thonier" (ET), 1995-1997 (Pallarés and Hallier 1997, Pallarés and Petit 1998, Pianet 1999). Basically, the sampling was stratified in 3 components: Area (10 items) / Quarter (4 items) / School type (free schools and object-associated schools). The goal of this stratification is to define strata as homogeneous as possible in terms of species composition. At each landing, the

[1] MARBEC, Univ Montpellier, CNRS, Ifremer, IRD, Sète, France
[2] MARBEC, Univ Montpellier, CNRS, Ifremer, IRD, Abidjan, Côte d'Ivoire

purse seiner's wells (which are the primary sampling units) are selected to ensure that fish originates from the same (or neighboring) set with known date, position and fishing mode.

The evolution of fishing practices, specifically the implementation of FOBs (Floating OBject), the extension of the fishing areas (Hallier and Parajua 1992, Fonteneau et al. 2000, Davies et al. 2014) and the environmental condition have challenged the T3 methodology on several aspects of the sampling and data processing (Fonteneau et al. 2017, Herrera and Baez 2019). As an example, on the basis of statistical analysis, it has been shown in the Atlantic Ocean than the size of the spatio-temporal strata should be dramatically reduced in order to reach a better homogeneity in species composition (Deledda et al. 2018). Consecutively, further studies were done to establish state of play in the biases of the T3 process (Duparc et al. 2018) and propose on the improvement of the assessment of species composition (Duparc et al. 2019b). Finally, the T3 process has been completely recoded into an R package and several improvements have been incorporated (Duparc et al. 2020). The aim of this paper is to present the last developments of the T3 process which led to the release version 3.0 and consequences for the nominal catch (NC), catch and effort (CE) aggregated by calendar year over the 2000-2019 period. Moreover, the Development of the T3 v3.0 brought out new improvement ways. We further discussed these development perspectives.

Materiel and Methods

Data sources

Logbooks

Logbooks constitute the core data of the T3 processing: The whole process aims to estimate the species composition per set reported by skippers in logbooks. Logbooks contain information on catch data by set including date, position, and fishing mode, species, and commercial categories. However, weights are estimated visually by captain, bosco and chief engineer. Logbooks are collected the day before purse seiners land to port. While in the past some logbooks were missing, nowadays logbooks coverage reaches 100%.

Landing sampling

Sampling addresses species composition, sizes and weights. Approximately 20% to 30% of annual sets are sampled. The annual sampling plan is conducted in order to cover the wider geographical area and temporal range, for all vessels and for both FSC and FOB sets. To ensure this coverage, the sampling plan is continuously updated according to strata already sampled and the annual objective. As logbooks and well plans are communicated in advance, this enables to determine which wells (i.e. dates, positions and fishing modes) must be sampled.

For each well selected, a sample of 500 individuals in two batches (300 individuals first and 200 individuals in general selected one hour after the first batch) is randomly selected and sampled while fish is unloaded. Sampling team focuses on species identification and size measures (more details on the sampling protocol are given in Duparc et al. 2018).

Landing report

Landing report provides catch in weights unloaded from fish wells. Unlike catch from the logbooks, weights are measured with scales and so are used as a reference for the total catch weight in the T3 process. Species composition is determined through a sampling procedure carried out by an operator contracted by fishing companies and data are detailed per species and commercial category. However, catch dates and positions are absent and only species bought by canneries are mentioned. For these reasons the species composition is not fully available and is not considered reliable for the T3 process. Nowadays the landing report coverage reaches 100%.

The Tropical Tuna Treatment process

The first version of the T3 process (called hereafter T3 v1.0), coded in Fortran language, was described in detail in a precedent IOTC paper (Duparc et al. 2018). General structure in three steps of the T3 v3.0 process (coded in R language, Depetris et al. 2020) remained unchanged (T3 v2.0 being a java coded version similar to the T3 v1.0). The first two levels were similar to the T3 v1.0 but with full revision of the program code with several improvements in terms of transparency, reproducibility and documentation (Protocol available on open archive HAL: https://hal.ird.fr/ird-02132072, Bach et al. 2018, see information paper IOTC-2020-WPTT22(DP)-INF01, Duparc et al. 2020 for details).

Level 1: standardization of the logbook data

On the one hand, logbooks provide a first estimate of catches by species and commercial categories, by sets that are geo-referenced and dated. On the other hand, landing sheets provide weights of landed batches, by species and commercial categories. These weights, which are more suitable than estimates reported on logbooks, are no longer geo-located neither dated. Thus, the first step of stage 1 is to adjust logbook tonnages by calculating a rising factor from the landing weights. Standardized set weights are conserved all along the process.

The T3 methodology is based on the underlying assumption that the specific composition information in the logbooks is strongly biased (Cayré 1984, Duparc et al. 2019b), but considers that the information of the total catch per set and the proportion of each commercial category are correct. Species composition biases are explained by the fact that some species are difficult to identify, while they have the same commercial value, which does not encourage crew members to document species accurately. On the other hand, the weight category of individuals is strongly linked to their commercial value, and this explains why the information is correctly documented. One therefore wants to take advantage of the details given by weight categories. However, the commercial weight categories used by the canneries are not usable out-of-the-box: they are heterogeneous, vary from fleet to fleet and in some cases, there is an overlap between some categories. Consequently, we converted these initial categories into standardized categories (< 10 kg and > 10 kg).

Level 2: sample standardization

Sample data are distribution of measured fishes by well whereas logbook data are catches of species by sets. The aim of this level is to convert samples into set catch by species. The first operation is the allocation of the sample histograms per well and species on each set put on the well. This reallocation is performed proportionally to the representativeness (in catch) of the set in the well. Then the second operation converts samples measurements into weights using length weight relationship with species. Length weight relationships used in the T3 process were the official relationships from RFMO. When conditions are met this operation is weighted by the proportion of small (<10 kg) and large (> 10 kg) individuals taken from the well plan. T3 v1.0 and T3 v3.0 are similar regarding this level (more details are available in Duparc et al. 2018).

Level 3: species composition estimates

In T3 v3.0, this level was totally revised compared to the previous T3 version (T3 v1.0) and was based on the previous results of model comparisons (Duparc et al. 2019b). At this level, species composition is predicted for each major tuna species in non-sampled set with random forest trained with selected sample datasets. Finally, bootstrapping method is used to compute confidence intervals.

Selection of the sample for the training dataset

Estimation of the species composition in the T3 process is directly linked to the sample representativeness. Samples were allocated from well to sets making the assumption that all sets included in a well share the same species composition (in number and size). We so selected samples for modelling according to several criteria to have a higher probability to validate this hypothesis:

- All sets of a well should share the same fishing mode
- All sets of a well must have a maximum distance of 5 degrees
- No more than 5 sets are mixed together in a well
- Selected sets must represent at least 10% of the well catch

The random forest models

Random forest is a non-parametric ensemble modelling technique that uses bagging and a random selection of covariates across numerous classification and regression trees to reconstruct nonlinear relationships and interactions of the covariates (Breiman 2001).

A model was separately running for the skipjack (SKJ) and the yellowfin (YFT) and by fishing mode (FOB and FSC). Thus, a total of 4 models were executed. In each one, the proportion of the species in a set was the response variable. We included longitude and latitude as covariates to account for trends in the spatial dimension and year and month for the temporal dimension. Following results of the previous study (Duparc et al. 2019b), we also included the vessel ID and the proportion of species reported in the logbook for the same set. We optimized model parameters for minimizing the OOB error (MSE): Number of trees = 1000, number of variables randomly sampled at each split = 2, number of times the OOB data are permuted per tree = 5.

Year parameter was implemented in the model as the process offers the possibility to use samples of a wider range of years for prediction. This option enables to run the T3 process even for years with a lack of samples (or no sampling in extreme cases). In this paper, year parameter was not used as only the samples of the target year was used for the modelling.

Prediction error (RMSE and MAE) was computed using k-fold cross validation method (k = 10). The spatial autocorrelation of the response variable and model residuals were assessed using Moran index (Cliff and Ord 1981) for distance range from 1 to 10 degrees between sets. Moran's test was performed to test for autocorrelation (Bivand and Wong 2018). The temporal autocorrelation was estimated using autocorrelation function (Venables and Ripley 2002).

Random forest model was not used for the bigeye (BET) because presence and proportion were badly reported in the logbook due to misidentification (Báez et al. 2019) ant the low abundance of the species in catches (Duparc et al. 2019b). We so calculated the BET proportion as 1 less the proportion of SKJ and YFT in the set. Sample proportions were conserved when available.

Then, proportion of species for each non-sampled set was predicted and corresponding catch was calculated for each set. Finally, set catches were summed to estimate annual nominal catch by species and fishing mode, and catch and effort by 1-degree square.

Bootstrap confident interval

Confidence intervals were computed using bootstrap method (Davison and Hinkley 1997). Basic resample method was used with random sampling size equal to the original dataset with replacement (repetition = 500). Intervals were calculated using the basic bootstrap percentile method.

All analyses were performed using R software with packages "ranger" for random forest (Wright and Ziegler 2017), "boot" for bootstrap intervals (Canty and Ripley 2020).

Revision of the 2000 - 2019 series and comparison of the T3 versions

We first presented some descriptive results in the inputs and outputs of the T3 process focusing on the model validity checking.

Secondly, we aimed to compare nominal catch for the 3 methods (logbook declaration, T3 v1.0 and T3 v3.0). We ran T3 processes for period 2000-2019 and represented catch and catch proportions by species and fishing mode.

Finally, we focused on the comparison of the T3 versions of the catch and effort. In this paper we presented catch and proportion in catch by 1-degree square for 2019 only.

Results

Modeling inputs

Sampling vs Reporting

Comparison of proportion of species in catch between the two data source clearly brought out two patterns according to the fishing mode. Regarding FOB sets, higher proportions of YFT was observed in samples than in the logbook declaration while SKJ proportion were lower (**Fig. 1**). However, this discrepancy between the two data source lowered along the years, specifically since 2018. Regarding the free school sets, proportions were more similar except in 2019. Thus, SKJ proportions were 0.05 ± 0.2 on average (median = 0) and YFT proportions 0.86 ± 0.2 (median = 1 and 0.94 for logbook and sampling respectively) in the period 2009-2018, but these proportions leaped in 2019 to 0.4 ± 0.4 and 0.5 ± 0.4 respectively. Regarding BET (not shown here), proportions in FOB were slightly higher in samples except for 2018 and 2019 (in samples: 0.06 ± 0.01; logbook: 0.04 ± 0.02). BET Proportions in free school sets were similar (in samples: 0.07 ± 0.04; in logbook: 0.07 ± 0.15).

Modeling outputs

Several figures and indicators are computed during the process to check for many points and help users to validate the results. For each model (by species and fishing mode):

- Map of the samples with smooth proportions over the fishing ground (example in **Fig. 2**)
- Residual figures (see example for the yellowfin tuna in 2019 on FOB in appendix 1)
- Variable importance
- Prediction error: RMSE, MAE (k-fold)

Mapping the proportion of species in samples clearly highlighted the spatial pattern of the catch (see examples of YFT on FOB in Fig. 2) which justifies the need to account for the location of the set in the modelling. Thus, model residuals were not correlated (Moran Index in **Table 1** and ACF in Appendix for the Year 2019) whatever the species indicating that models correctly performed to account for spatio-temporal structure of the data.

Prediction error of the random forest models was about 0.10 ± 0.01 and for MAE and 0.12 ± 0.01 on average during period 2009-2019 for the FOB sets either for YFT and SKJ (**Table 2**). Regarding the FSC sets, prediction error was lower for SKJ (MAE = 0.07 ± 0.06 and RMSE = 0.10 ± 0.07) than for YFT (MAE = 0.10 ± 0.04 and RMSE = 0.14 ± 0.04). However, in 2019, the prediction error for FSC sets increased to 0.20 MAE and 0.25 RMSE for SKJ and 0.20 MAE and 0.24 RMSE for YFT due to the mix and treatment of free schools dominated by YFT or SKJ under the same category.

Nominal catches

All estimations of nominal catches followed the same general pattern all along the time series but with differences in values varying with the species and the fishing mode (**Fig. 3 and 4**). Indeed, nominal catches reporting from logbook declaration on FOB sets were largely different from estimated NC with T3 processes. On average, discrepancies were 13% higher than the T3 v1.0 and 26% than T3 v3.0 regarding the SKJ. In contrast, the YFT and BET reporting were lower of 91% (60% for t3 v1.0) and 83% (105% for t3 v1.0) than the t3 v3.0 respectively. Regarding the catches on FSC sets, mean differences with logbook declarations were +21%, -15% and -4% for T3 v3.0 (+114%, -1% and -1% for T3 v1.0) respectively for BET, SKJ and YFT.

However, differences between the 3 methods, which are important in 2000, decreased to converge along the 2 decades (Appendix 2) and those whatever the fishing mode. As an instance, differences in FOB catches of BET, SKJ and YFT between declarations and T3 v3 were + 0.004%, -16% and +31% respectively, on average for period 2015-2019.

Regarding nominal catches in terms of species composition, SKJ were overestimated in the logbooks reporting compared to T3 v1.0 estimates (-7% than logbooks), whereas YFT and BET were underestimated (+4% and +3% on average respectively **Fig. 5**). T3 v3.0 exacerbated this pattern with -12% for SKJ and +10% for YFT, but not for BET (+2%).

Catch and effort

The general pattern of catch and effort seems to be similar among the T3 versions, but several differences appeared, specifically regarding the average proportion of species in catches by one-degree square. T3 v1.0 is based on fixed areas to estimates species composition. These areas are still visible in the fitted proportions, as the offshore zone of Tanzania or the one including Maldives in 2019 (**Fig. 6**). T3 v3.0 presented a more gradual change in species composition. For both methods, YFT and SKJ composition followed an inverse gradient from South-west to North-east regarding the FOB sets. The BET proportion increased in catches from west to east of the fishing ground whatever the T3 version used. Regarding the FSC sets, squares with the highest proportion are similar between the 2 version and whatever the species (**Fig. 7**).

As we observed with the nominal catches, the spatial pattern of catches was similar among the two T3 versions but differed in quantities allocated to each species. SKJ catches were lower on the whole whereas YFT catches were higher for FOB sets (**Fig. 8**). Regarding FSC sets, catch effort were more similar, as the difference in estimations between the two T3 version was smaller (**Fig. 9**).

Discussion

Study of nominal catches clearly demonstrated a bias in the declaration compared to modelling estimates based on scientific sampling. Thus, SKJ was overestimated, while YFT and BET were underestimated. All methods for nominal catch estimation (logbook reporting and T3 versions) converged this last year. Considering that the sampling protocol did not change since the end of the 90s (Pallarés and Petit 1998), these results demonstrated that the bias in declarations evolved these last two decades. Quality of declarations could have improved in accordance with stocks management decisions, particularly for the YFT. Thus, since 2018 catch limit on the YFT induced a strong convergence between declaration and estimates by T3. This study also confirmed the necessity for correcting catch data which is the main purpose of the T3 process.

We also found that catches on FSC sets was better declared than for FOB sets. This result should be explained by the higher species diversity, in tunas but also bycatches, under a floating object (Escalle et al. 2019). Furthermore, the estimation of catches by T3 process is particularly important for the FOB sets but remained non-negligible for the FSC.

Reasons explaining result differences between T3 v1.0 and v3.0 versions

General nominal and spatial patterns of catches were similar between the T3 versions. This result was expected because the weight of the catches was standardized according to the landing weight and conserved all along the processes. Thus, estimation of species composition mainly explains the differences. The main weakness of the T3 v1.0 is the spatial distribution of the catches due to the too larger static areas considered homogenous in species composition, as it was identified in the past years (Deledda et al. 2018, Duparc et al. 2018). The new T3 v3.0 corrected this bias by integrating the precise location of each set instead of the large areas averaging. Therefore, spatial proportions of catch were more gradually distributed. Moreover, the temporal variation was assessed at a monthly scale instead of the quarter of the previous T3 version. This finer time resolution also enables a more precise variation in the catch estimations.

Secondly, T3 v3.0 includes the proportion of the species in the logbook declaration as a parameter. This last, which appeared to be of prime importance in the model (high impurity value), carries the raw information of each set and so the natural variation of catches. Contrary to T3 v1.0, T3 v3.0 process account for local variation in catches which can explain differences between the two versions.

A last point of divergence between the two T3 versions is the classification of unknown fishing mode. T3 v1.0 assumed the unknown fishing modes are free schools by default. This hypothesis was true until the beginning of the 20s when the use of floating object exploded (Hallier and Parajua 1992, Fonteneau et al. 2000, Davies et al. 2014). Nowadays, most of unknown fishing modes were FOB sets because of the current strategies of the fishing industries. This issue was fixed in T3 v3.0, in which each unknown fishing mode was classified from a supervised classification according to the species composition in the declarations. The number of unknown sets is rare this last year and so have a very limited impact on the catch estimates. But this classification is particularly useful for historical data.

Future developments and challenges for the T3 process

T3 v3.0 process was fully rewritten in R language. During its development, new ways of improvement appeared in numerous investigations of the database and from first results presented above in this paper. The main points of improvement are described hereafter.

1- Fishing mode reporting and classification

School type characterization is a difficult task because the presence or absence (no detection) of a floating object is not an enough indicator to ensure the species composition of the catch. Thus, schools associated with a floating object presenting all the characteristics of a free school could be recorded and vice versa. Moreover, the denomination free school is interpreted as a free school of YFT by default as it was the very most abundant type. However, “free schools “of skipjacks and bigeyes also exist but are grouped together under the same fishing mode. Therefore, the model less performed in 2019 where catch on SKJ free school was more important as usual.

The random forest is flexible enough to distinguish these free school “subtypes” through the use of the species proportion of the logbook declaration as model parameter. However, the precision of the predictions should be improved if classification of school were better. Therefore, a supervised clustering could be applied before the modelling of species composition to reclassify all sets and create homogenous fishing mode groups with lower intra-group variance than the ones currently used. Tests have to be performed to estimate the gain in precision.

2- Model parametrization and sensitivity analyses

Our results also showed that the prediction error is influenced by the amount of data used for training random forest models. Thus, a limited quantity of samples is available depending on the fishing strategies. This last decade the free school sets could be insufficient in some years leading to an increase of the prediction error. In this paper only French sample of the year of interest were used. T3 v3.0 process is able to train models with a larger period of samples or with samples from other fleets. Sensitivity analyses have to be performed to determine the minimum number of samples required to obtain robust result. Year and fleet effect also have to be investigated.

3- Length weight relationship

The length weight relationships (LWR) are used in the T3 process to convert length measurement in samples to weight. Species composition could so be directly influenced by the parameter values in this relation. Currently, the LWR parameters from RFMOs are taken as references. Yet, these LWR suffer from discontinuities in data collection and some of them are outmoded.

We so recommend a standardized process to ensure continuity in the robustness of the relationship which should be based on:

- a standard protocol: sampling intensity, frequency, spatial and temporal covering should be clearly defined,
- a standard modelling of the LWR, i.e. a reproducible statistical method,
- a validity framework: LWR should be defined for a validity period, a zone (ocean or smaller area) and a stock.

  This process should be acknowledged and recommended by tuna RFMOs.

4- Tuna catches of the local markets (also called Faux Poisson).

The part of the catch not sold to the canneries is redirected toward the local market (also known under the expression "Faux poisson", Kothias Amon et al. 1996). Small or damaged individuals of target species could represent an important part of the local market but are not well account in the nominal catches (Duparc et al. 2019a). Catches landed to the local market increased this last decade since the development of FAD fishing in the mid-nineties (Chavance et al. 2010; Chavance et al. 2015). In Indian Ocean, this flow is not well known as in the Atlantic Ocean, as it is more recent, and its data collection should be developed to estimate the number of major tunas concerned. Then, catches of the local market will be incorporated in the T3 process.

5- Accounting for uncertainties of the data collection

This is the first time that confidence intervals were computed for the nominal catch, catches and effort. This gives an idea of the reliability that Scientifics could have in the catch estimates. It is often forgotten that declarations in the logbook are also estimates for which there is no standardized protocol and no information on their validity. The T3 v3.0 process so bring new information relevant for the stock management. This first version of the confidence interval based on bootstrap accounts for the uncertainties due to prediction errors of the different models. However, the uncertainty inherent to the data collection was not considered. As an instance, errors on fish measurements, length-weight conversions and fishing mode reporting were not took into account. Several field studies have to be conducted to estimates these errors before their incorporation in the T3 process (example with the BET misclassification, Báez et al. 2019).

Acknowledgement

We thank the Producer Organization ORTHONGEL and its member fishing companies CFTO, SAPMER and SAUPIQUET for their collaboration in the data collection. We are also grateful for all technical staff that collected data used in the T3 processing and in this paper. The data were collected through the Data Collection Framework (Reg 2017/1004 and 2016/1251) funded by both IRD and the European Union.

References

Bach, P., P. Cauquil, M. Depetris, A. Duparc, L. Floch, J. Lebranchu, and P. Sabarros. 2018. Procédures d'échantillonnage des thonidés tropicaux débarqués par les senneurs dans les océans Atlantique et Indien. HAL.

Báez, J. C., A. Duparc, J. Ruiz, F. Manzaneque, A. Pérez San Juan, M. Pernak, A. Salgado, P. Bach, J. Lucas, and M. L. Ramos. 2019. Assessing the misidentification rate for bigeye and yellowfin juveniles in brine sampled at Port Victoria (Indian Ocean): consequences for the species composition estimates of landings. Pages 1–10 Report of the 21th session of the IOTC Working Party on Tropical Tunas. IOTC, San Sabastián, Spain.

Bivand, R. S., and D. W. S. Wong. 2018. Comparing implementations of global and local indicators of spatial association. TEST 27:716–748.

Breiman, L. 2001. Statistical modeling: The two cultures (with comments and a rejoinder by the author). Statistical science 16:199–231.

Canty, A. J., and B. Ripley. 2020. boot: Bootstrap R (S-Plus) Functions. R package version 1.3-25.

Cayré, P. 1984. Procédure suivie pour la composition spécifique des statistiques Thonières. Col. Vol. Sci. Pap. ICCAT 21:102–107.

Cliff, A. D., and J. K. Ord. 1981. Spatial processes. Models and applications. London.

Davies, T. K., C. C. Mees, and E. J. Milner-Gulland. 2014. The past, present and future use of drifting fish aggregating devices (FADs) in the Indian Ocean. Marine Policy 45:163–170.

Davison, A. C., and D. V. Hinkley. 1997. Bootstrap Methods and their Application. Davison, A. C. & Hinkley, D. V. Cambridge University Press.

Deledda, G., D. Gaertner, and H. Demarcq. 2018. Combining dFADs catch data and ecological factors for detecting hot spots of juveniles'bigeye tuna. Col.Vol.Sci.Pap. ICCAT 75:1–12.

Depetris, M., A. Duparc, L. Floch, P. Cauquil, and J. Lebranchu. 2020. OB7-IRD/t3: Beta version of T3 software. Zenodo.

Duparc, A., M. J. Amandé, M. Lesage, P. Cauquil, D. Gaertner, P. Pascual Alayon, and P. Bach. 2019a. Local market of the tropical purse seine fishery: update and perspective for its assessment in Abidjan. Col.Vol.Sci.Pap. ICCAT 76:983–991.

Duparc, A., V. Aragno, M. Depetris, L. Floch, P. Cauquil, J. Lebranchu, D. Gaertner, F. Marsac, and P. Bach. 2019b. Assessment of the species composition of major tropical tunas in purse seine catches : a new modelling approach for the Tropical Tuna Treatment processing. Pages 1–35 Report of the 21th session of the IOTC Working Party on Tropical Tunas. IOTC, San Sabastián, Spain.

Duparc, A., P. Cauquil, M. Depetris, P. Dewals, D. Gaertner, A. Hervé, J. Lebranchu, F. Marsac, and P. Bach. 2018. Assessment of accuracy in processing purse seine tropical tuna catches with the T3 methodology using French fleet data. Case of the French fleet in Indian Ocean. Pages 1–19 Report of the 20th session of the IOTC Working Party on Tropical Tunas. IOTC, Victoria, Seychelles.

Duparc, A., M. Depetris, L. Floch, P. Cauquil, P. Bach, and J. Lebranchu. 2020. Development status of the new Tropical Tunas Treatment (T3) software. Pages 1–5 Report of the 22nd session of the IOTC Working Party on Tropical Tunas - Data preparatory meeting. Online/virtual.

Escalle, L., D. Gaertner, P. Chavance, H. Murua, M. Simier, P. J. Pascual-Alayón, F. Ménard, J. Ruiz, F. Abascal, and B. Mérigot. 2019. Catch and bycatch captured by tropical tuna purse-seine fishery in whale and whale shark associated sets: comparison with free school and FAD sets. Biodiversity and Conservation 28:467–499.

Fonteneau, A., P. Pallarés, and R. Pianet. 2000. A worldwide review of purse seine fisheries on FADs. Pages 15–35 Pêche thonière et dispositifs de concentration de poissons. Le Gall, J., Cayré, P. et Taquet.

Fonteneau, A., P. Pascual Alayon, and E. Chassot. 2017. From large fixed to small mobile spatio-temporal strata: improving estimates of species and size composition of the landings of the European purse seine fishery in the atlantic ocean. Collect. Vol. Sci. Pap. ICCAT 73:829–849.

Hallier, J. P., and J. I. Parajua. 1992. Review of tuna fisheries on floating objects in the Indian Ocean. Pages 195–221 International Workshop on Fishing for Tunas Associated with Floating Objects. La Jollia, USA.

Herrera, M., and J. C. Baez. 2019. On the potential biases of scientific estimates of catches of tropical tunas of purse seiners the EU and other countries report to the ICCAT and the IOTC. SCRS-2018-136. Col-Vol-Sci-Pap ICCAT 75:2202–2232.

Kothias Amon, J. B., F. X. Bard, and A. Hervé. 1996. Mise à jour des quantités de Faux poissons débarquées par les senneurs à Abidjan. Collect. Vol. Sci. Pap. ICCAT 45:227–228.

Lawson, T. 2013. Update on the estimation of the species composition of the catch by purse seiners in the Western and Central Pacific Ocean, with responses to recent independent reviews. Pages 1–40 9th Regular Session of the Scientific Committee. Western and Central Pacific Fisheries Commission, Pohnpei, Federated States of Micronesia.

Pallarés, P., and J. P. Hallier. 1997. Analyse du schéma d'échantillonnage mutlispécifique des thonidés tropicaux. Pages 1–57. Rapport scientifique, IEO/ORSTOM, Madrid.

Pallarés, P., and Ch. Petit. 1998. Tropical tunas : new sampling and data processing strategy for estimating the composition of catches by species and sizes. Collect. Vol. Sci. Pap. ICCAT 48:230–246.

Pianet, R. 1999. Évolution du système de collecte et de traitement des données de la pêche thonière des senneurs européens et assimilés de 1981 à 1998. WPDCS99-09-IOTC:74–96.

Venables, W. N., and B. D. Ripley. 2002. Modern Applied Statistics with S. Springer.

Wright, M. N., and A. Ziegler. 2017. ranger: A Fast Implementation of Random Forests for High Dimensional Data in C++ and R. Journal of Statistical Software 77.

Tables

Table 1: Moran index estimate and significance of the Moran test for YFT on FOB in 2019.

Distance lag	Estimate	Variance	p-value
1	0.0166	0.0025	0.68
2	-0.0525	0.0009	0.11
3	-0.0100	0.0005	0.77
4	-0.0205	0.0003	0.35
5	-0.0209	0.0002	0.26
6	-0.0073	0.0002	0.77
7	-0.0100	0.0001	0.57
8	-0.0073	0.0001	0.66
9	-0.0093	0.0001	0.44
10	-0.0034	0.0000	0.98

Table 2: Mean prediction error (RMSE and MAE) of the random forest models by species and fishing mode for the 2009-2019 period.

Index	Fishing mode	Species	mean.value	min.value	max.value	sd
MAE	FOB	SKJ	0.10	0.09	0.12	0.01
MAE	FOB	YFT	0.10	0.09	0.12	0.01
MAE	FSC	SKJ	0.07	0.01	0.20	0.06
MAE	FSC	YFT	0.11	0.06	0.20	0.04
RMSE	FOB	SKJ	0.13	0.11	0.15	0.01
RMSE	FOB	YFT	0.13	0.12	0.15	0.01
RMSE	FSC	SKJ	0.10	0.02	0.25	0.07
RMSE	FSC	YFT	0.14	0.08	0.24	0.04

Figures

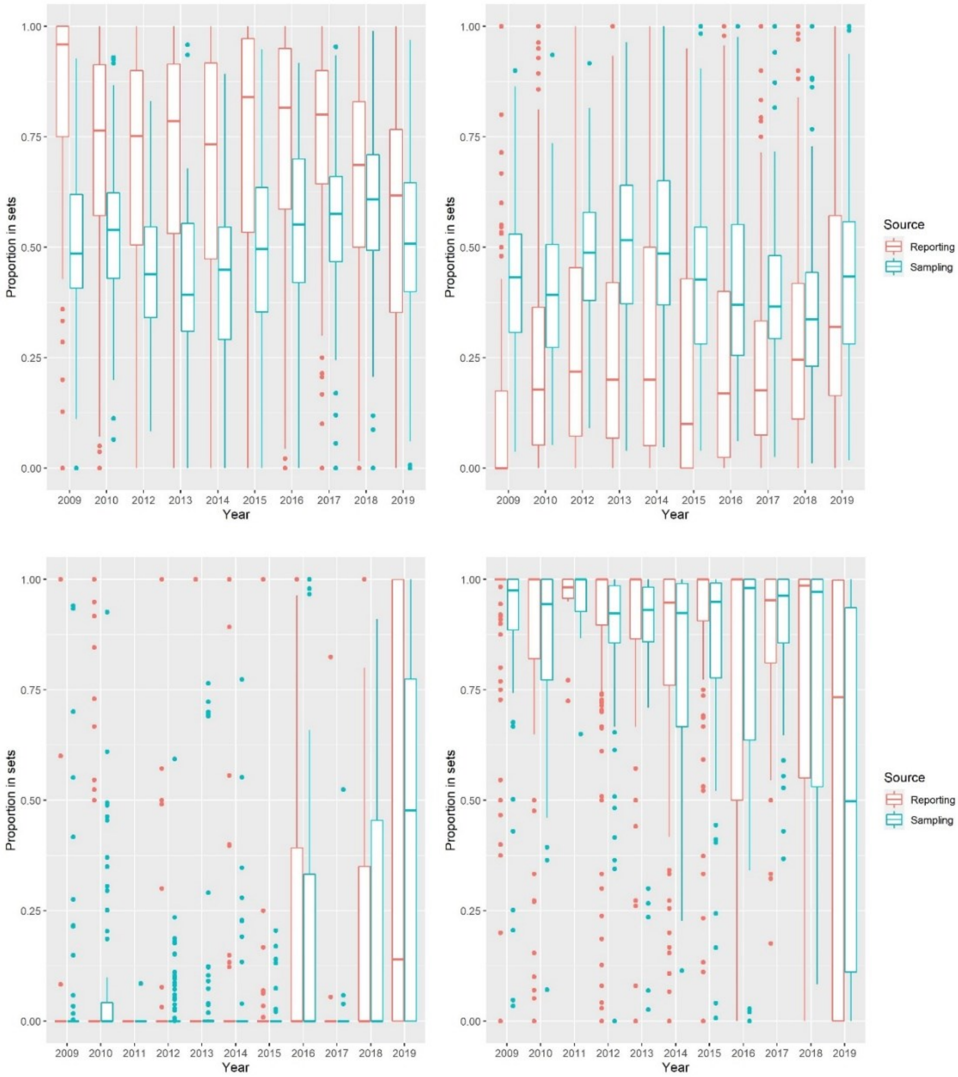

Figure 1: Boxplot of proportion of SKJ and YFT from logbook reporting and landing sampling by fishing mode in the 2009-2019 period.

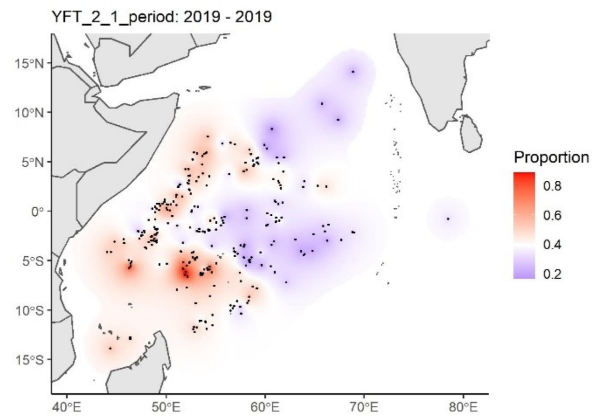

Figure 2: Map of proportion of YFT in sample-sets on FOB in 2019. Colors correspond to fitted values of a simple kriging interpolation all over the fishing ground (99 % kernel density area).

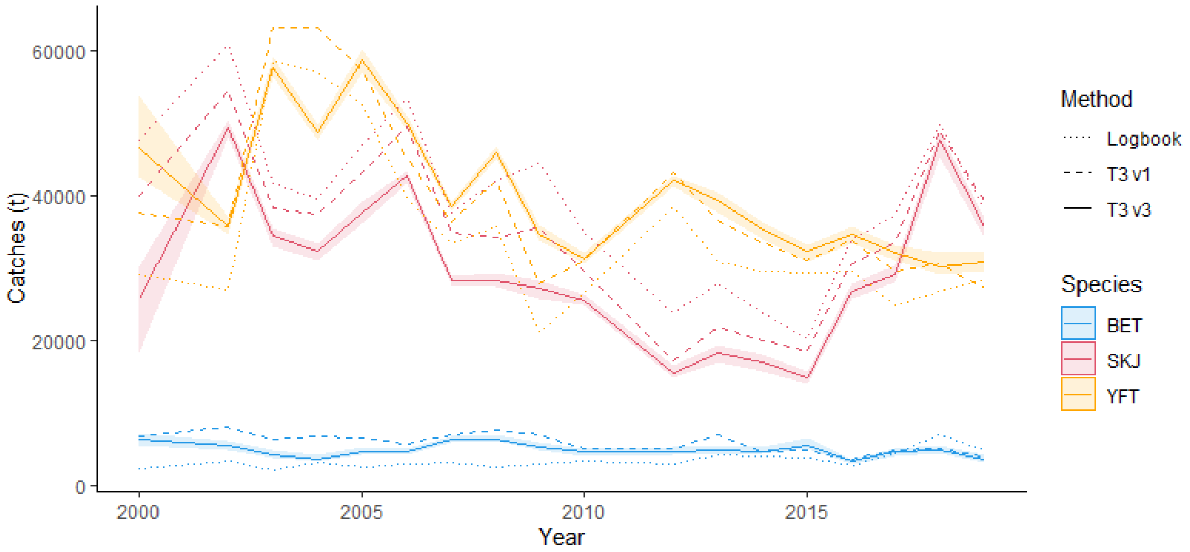

Figure 3: Total Nominal catches by species obtained thought several methods for the French tropical purse seine fishery during the 2000-2019 period

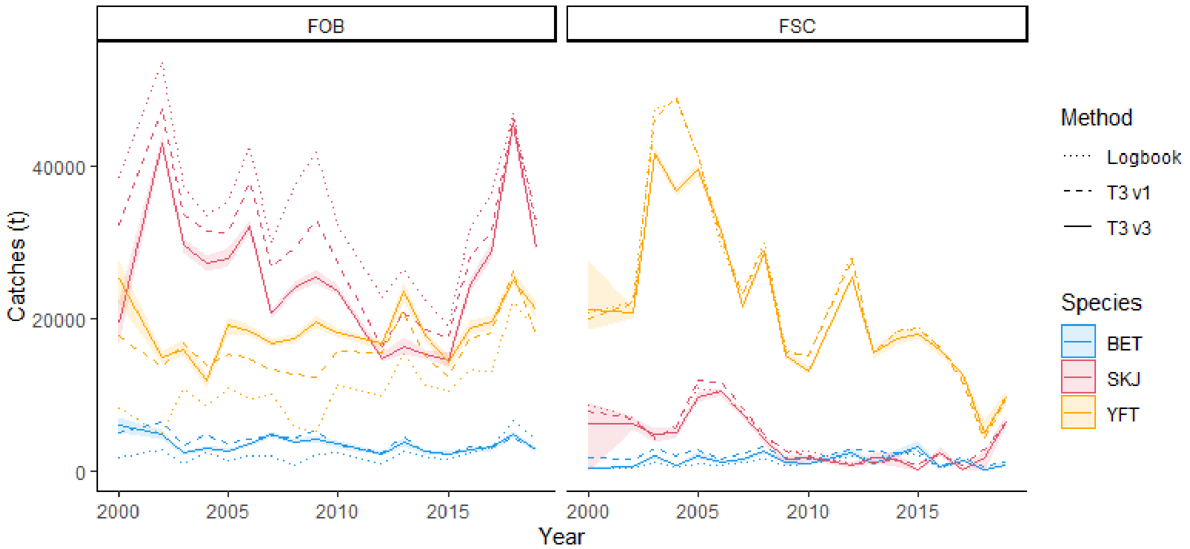

Figure 4: Total Nominal catches by species and fishing mode obtained thought several methods for the French tropical purse seine fishery during the 2000-2019 period.

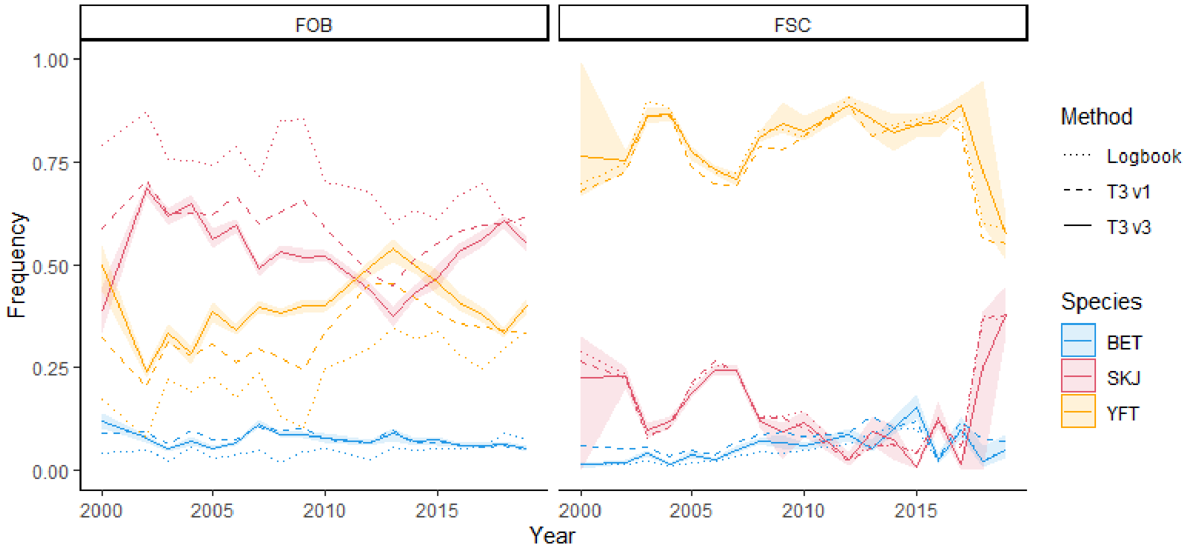

Figure 5: Proportion of species in nominal catches by fishing mode obtained thought several methods for the French tropical purse seine fishery during the 2000-2019 period.

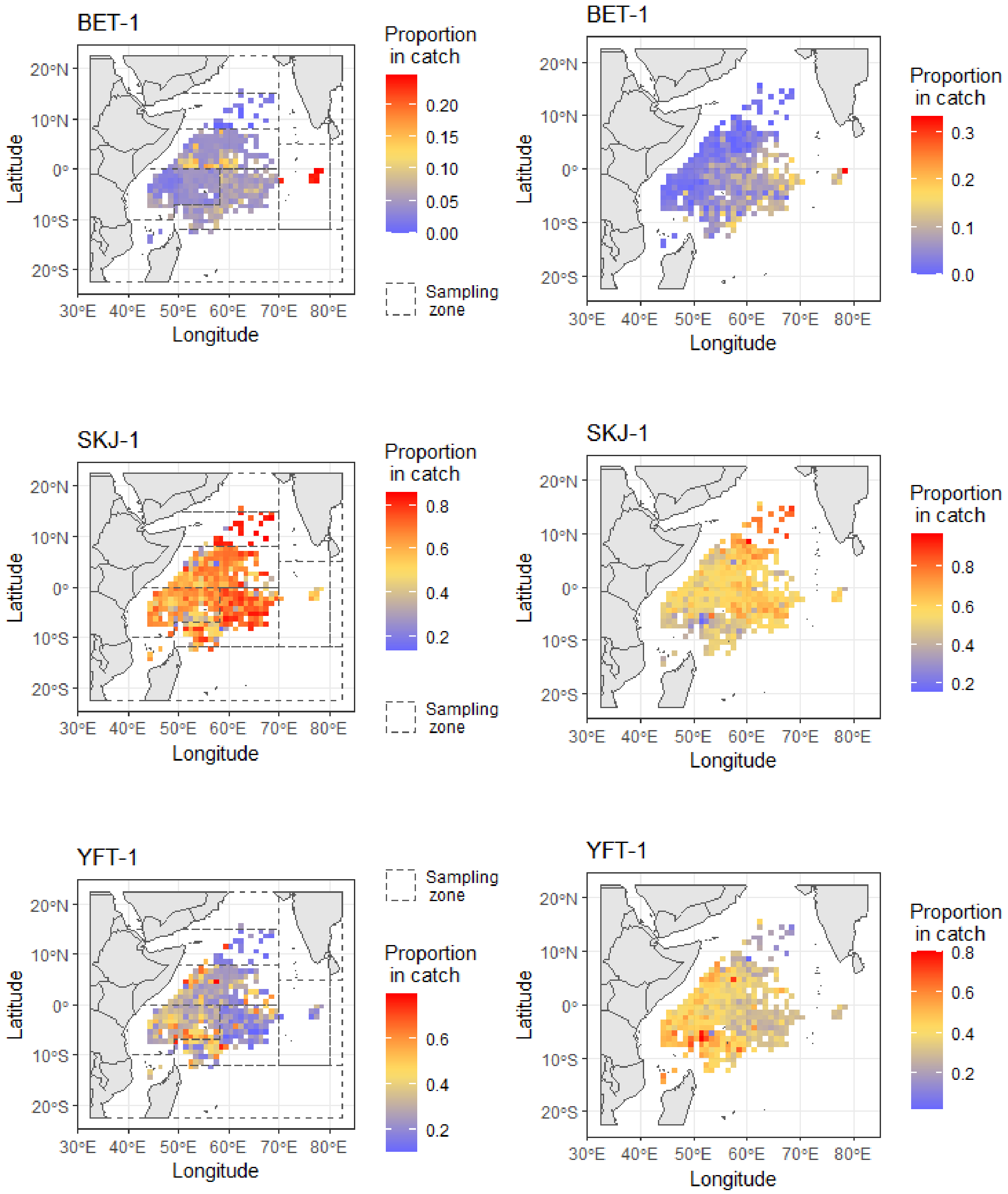

Figure 6: Mean proportion of species in catch on school associated to a floating object in 2019 issued from T3 v1.0 (left panels) or T3 v3.0 (right panels) methods. (Warning: Legend ranges vary between panels).

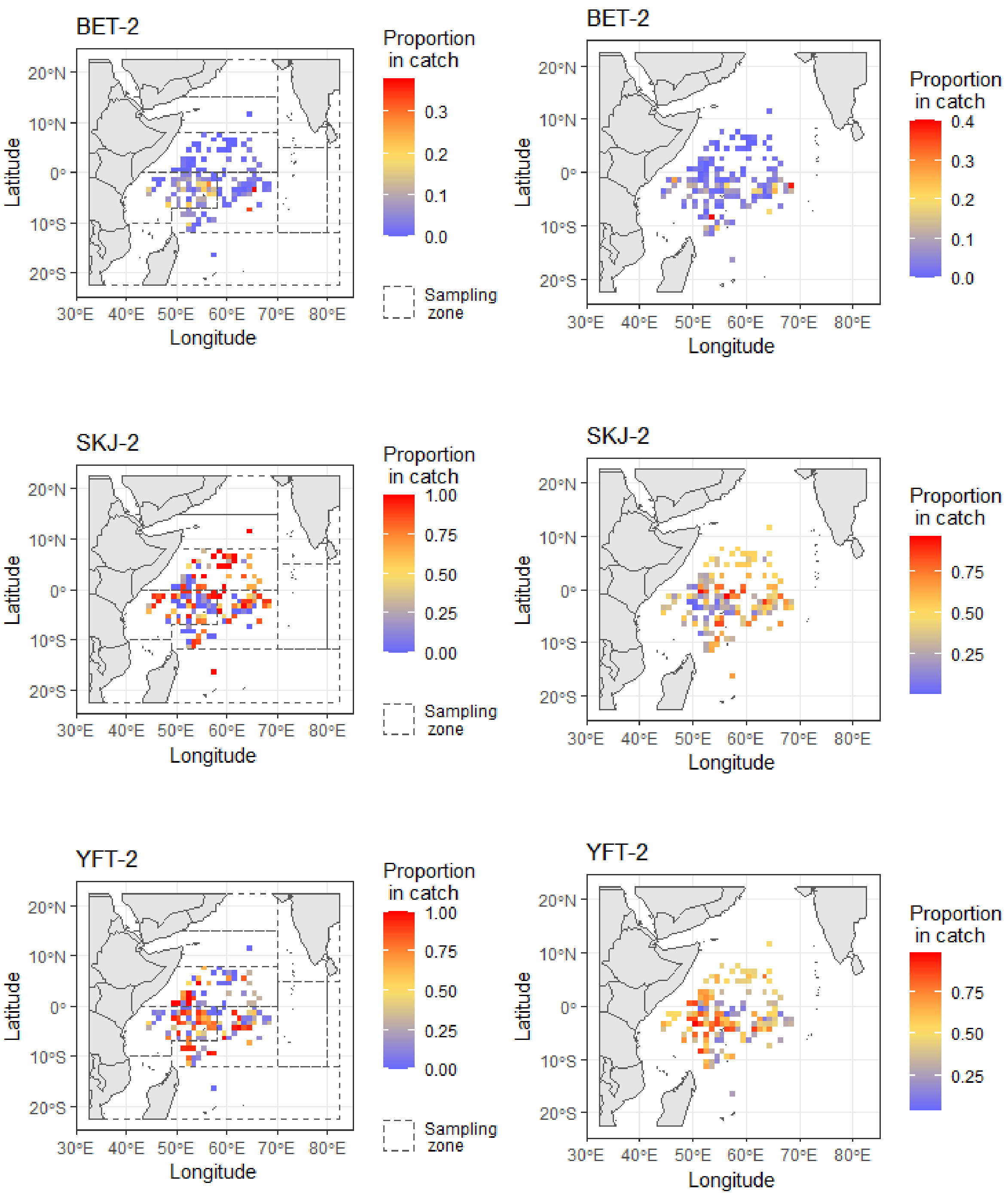

Figure 7: Mean proportion of species in catch from T3 v1.0 and T3 v3.0 on Free school sets in 2019. (Warning: Legend ranges vary between panels).

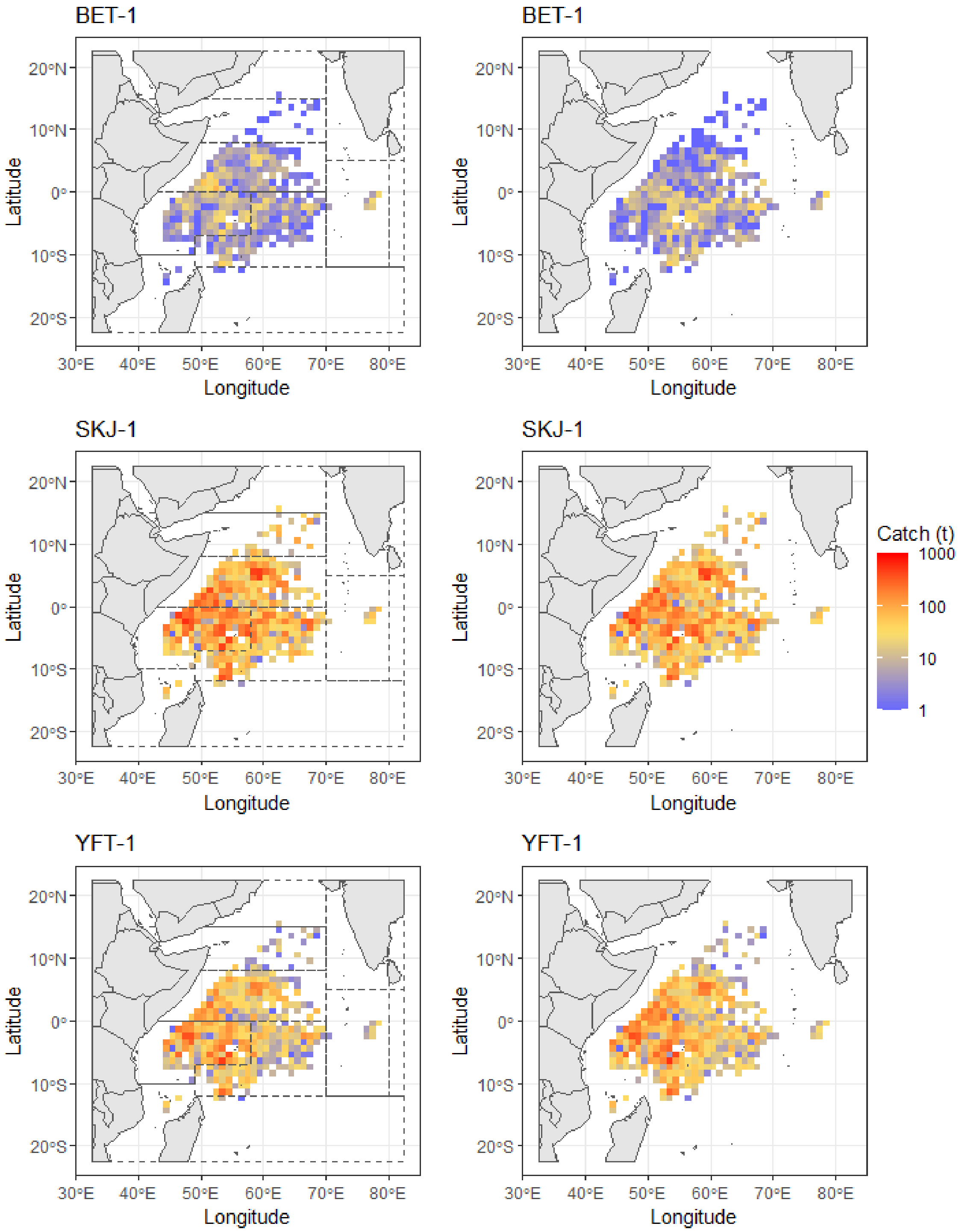

Figure 8: Total catches by species on school associated to a floating object in 2019 issued from T3 v1 (left panels) or T3 v3 (right panels) methods.

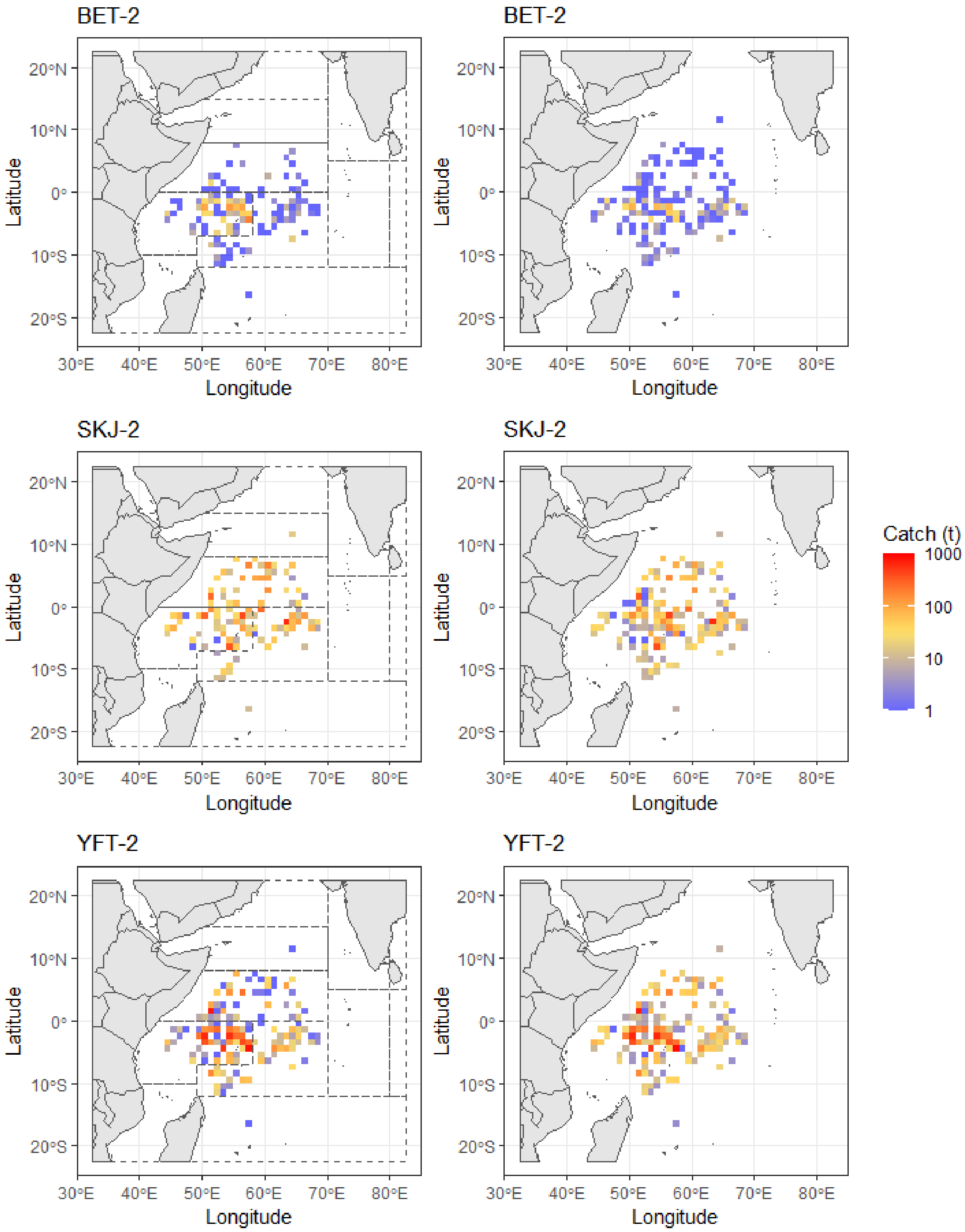

Figure 9: Total catches by species on free school sets in 2019 issued from T3 v1.0 (left panels) or T3 v3.0 (right panels) methods.

Appendices

Appendix 1: output of model checking of the t3 v3.0 process. Example with proportion of yellowfin tuna in set associated to floating object in 2019.

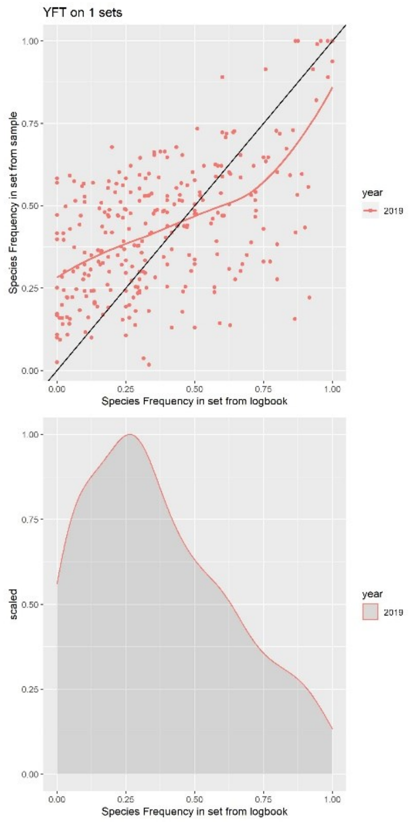

Figure A1-1: Species proportions estimated from sample-sets (t3 v3.0) against proportions in logbook (top panel). Distribution of species proportions in logbook declarations (bottom panel).

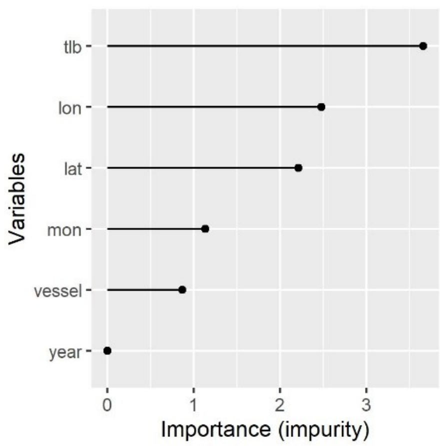

Figure A1-2: Importance (impurity value) of parameters in the random forest model from the t3 v3.0.

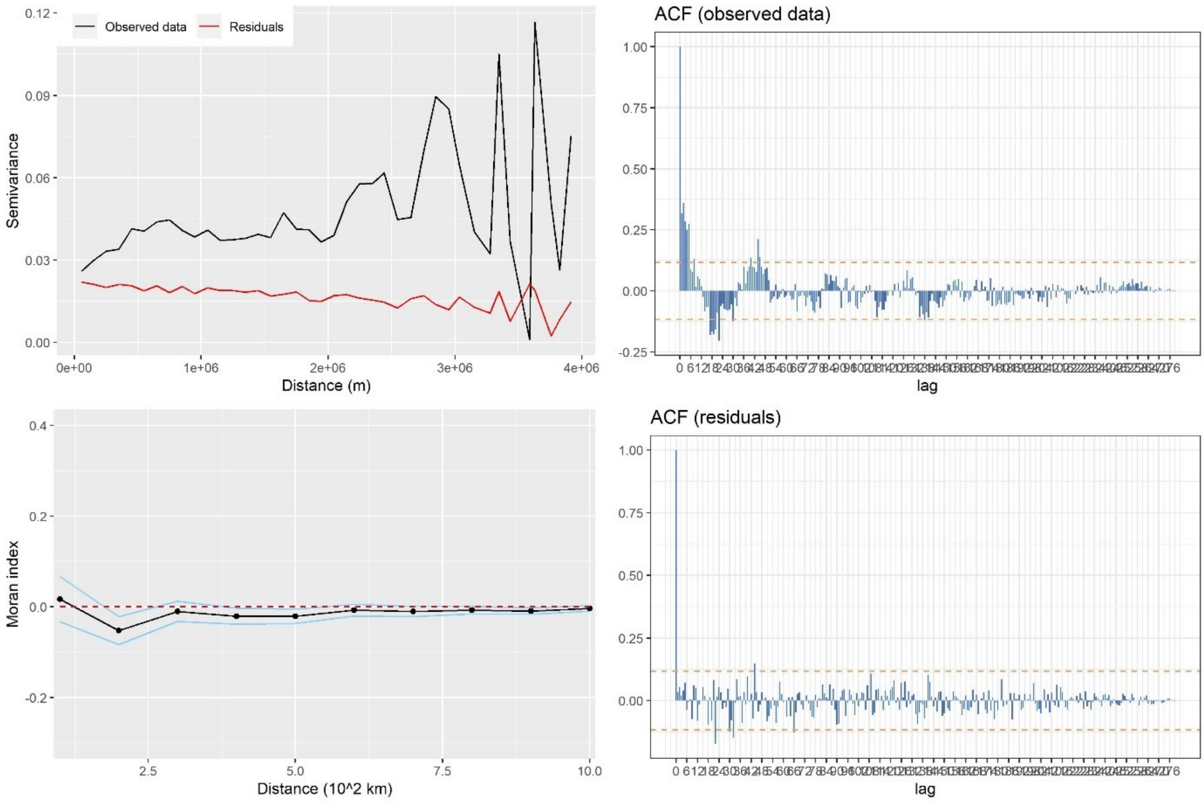

Figure A1-3: outputs of t3 v3.0 process for spatial and temporal autocorrelation checking. Top-left panel: variogram. Bottom left panel: Moran index of the model residuals (mean and variance). Top and bottom right panel: ACF for observed species proportions and model residuals.

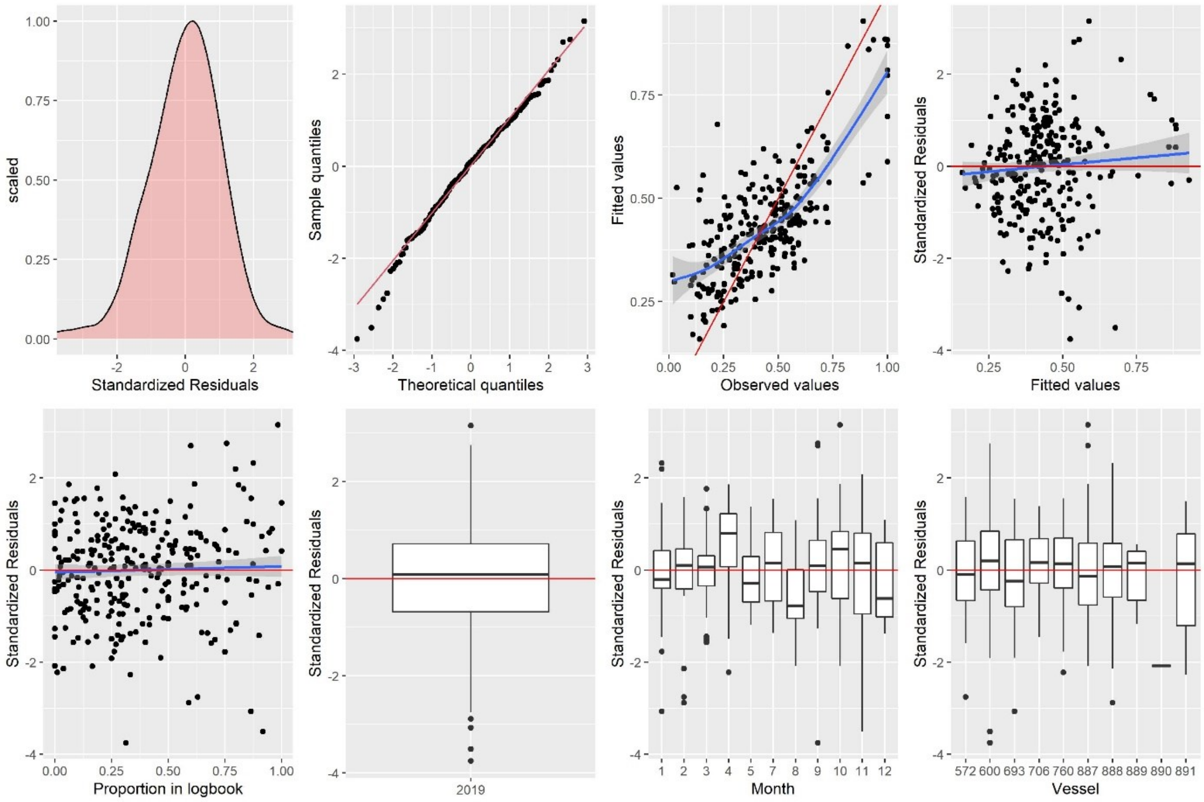

Figure A1-4: outputs of t3 v3.0 process for model residual checking.

Appendix 2: Comparison of nominal catches fitted by T3 methods and reported in logbooks.

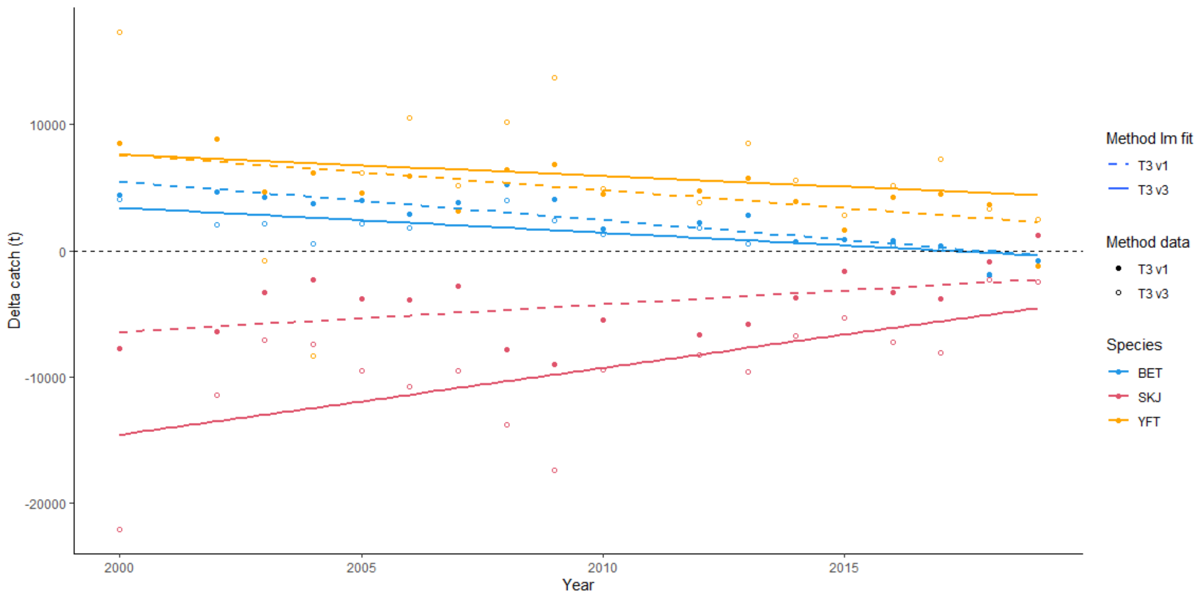

Figure A2-1: Delta of annual nominal catches by species the two T3 versions. Delta corresponds to the difference between nominal catch fitted by T3 methods and reported in logbooks.

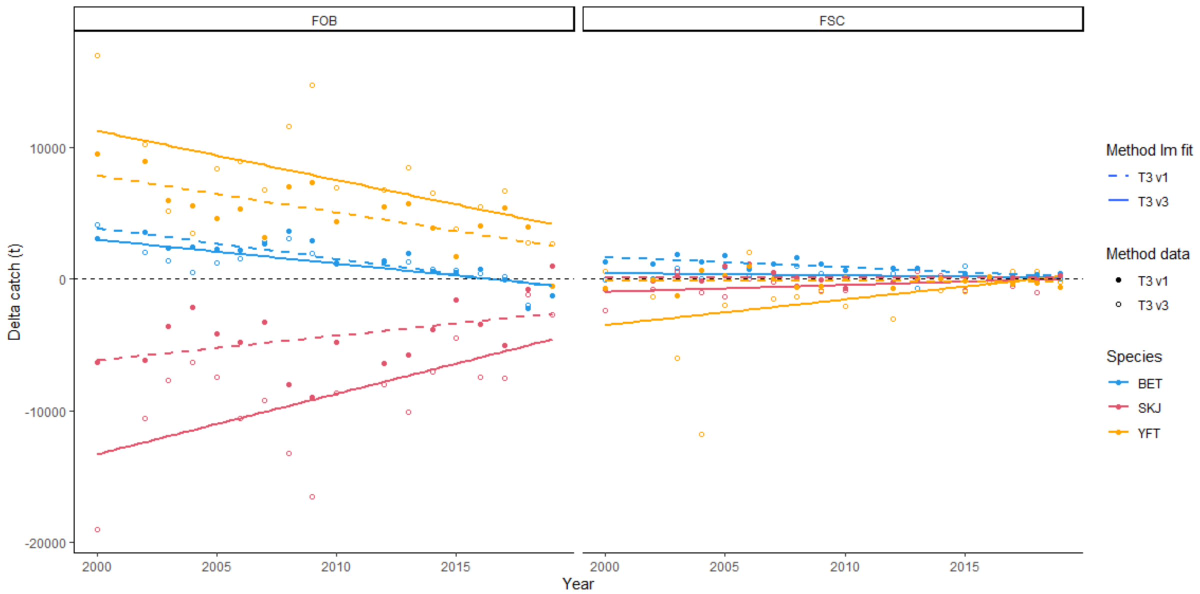

Figure A2-2: Delta of annual nominal catches by species, fishing mode for the two T3 versions. Delta corresponds to the difference between nominal catch fitted by T3 methods and reported in logbooks.