Assessment of accuracy in processing purse seine tropical tuna catches with the T3 methodology using French fleet data

Duparc A. [1], Cauquil P. [1], Depetris M. [1], Dewals P. [1], Floch L[1]., Gaertner D. [1], Hervé A. [1], Lebranchu J. [1], Marsac F. [1], Bach P. [2]

[1] MARBEC, IRD, Univ Montpellier, CNRS, Ifremer, Sète, France

[2] Institut de Recherche pour le Développement, SFA, BP 570, Victoria, Seychelles

Abstract

The multi-species nature of tropical tuna surface fisheries gives rise to a series of difficulties when estimating the catch by species and catch at size statistics. The T3 processing was built about 30 years ago in order to correct biases of the logbook data on species composition and to provide more accurate catch estimates per species for the European purse seine fleet. However, the evolution of fishing practices and the extension of the fishing grounds have challenged the T3 methodology on some parts of it processing. The aim of this paper is first to give the key elements to evaluate the potential biases that could occurs in the catch assessments of tropical tunas of purse seiners and second to explore some ways in order to increase accuracy of catch estimates based on the T3 processing for the future. By comparing catch weights obtain from T3 processing output and from operational landing reports produced by fishing companies, we found a potential overestimation of catch of less dominant species, which lead to an underestimation of dominant species. This bias should be mainly due to the too large spatio-temporal sampling strata used to correct the catch by specific capture reported in logbooks as well as, for a minor part, could be a consequence of the change over time in length-weight relationships used in the T3 processing. We also discussed on the limitations and assumptions of the T3 processing in relation to the data quality and the reliability of the Operational landing reports.

1. Introduction

The multi-species nature of tropical tuna surface fisheries gives rise to a series of difficulties when estimating catch by species and catch by size statistics. Since the 1980s, purse seine catches represented a major component of both Atlantic and Indian Ocean (IO) catches of yellowfin (YFT) and skipjack (SKJ) (45% of total catches in the IO) and a significant proportion (from 15 to 20%) of bigeye (BET) catches. This ratio has slightly changed over time. Since 2008, YFT and SKJ represent 34% of total PS catches in the IO and for SKJ, while BET account for 25%. A substantial proportion of the yellowfin and virtually all the bigeye in those catches are juveniles. Thus, purse seine is an important component of the IO tuna fisheries, requiring accurate estimation of its catch. Before 1984, the species composition of the European purse seiner catches (France and Spain) was directly estimated from the logbooks filled by the skippers. However, it has been observed that biases in the reports of catches by species in logbooks mostly concerned small size fish. The two major biases detected were the report of (1) young yellowfin and young bigeye (<3kg) as skipjack and (2) bigeye of 3-15 kg as yellowfin (Cayré, 1984). These corrections were necessary since the catch by 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. Such procedures were adapted over time to account for changes in fishing strategies and unloading practices in port.

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 (Pallares and Hallier, 1997; Pallares & Petit, 1998; Pianet et al, 1998). Basically, the sampling is stratified in 3 components: Area (10) / Quarter (4) / School type (Free schools and object-associated schools). The goal of the area stratification is to define strata as homogeneous as possible in terms of species composition and size distribution. At each unloading, the purse seiner’s wells (which are the sampling units) are selected to ensure that fish originates from the same (or neighboring) sets with known date, position and school type. Both counting (to define the relative abundance of each species by size group) and size measurements are performed during unloading, according to well-specified guidelines (incl. minimal number of fish to sample). These data are then processed through the T3 methodology to produce corrected catch by species and effort by month and 1°x1° square, and extrapolated size distribution (i.e. raised to the total number of fish caught) by month and 5°x5° square, noting that free schools and object-associated catches are discriminated in the processing. The products of the T3 methodology are the catch and effort statistics and size data provided to the IOTC (and ICCAT in the Atlantic), in full compliance with the Res. 15/01 ad 15/02 of the IOTC.

The evolution of fishing practices, specifically the implementation of FOBs (floating object) and the extension of the fishing areas (Hallier and Parajua 1992, Fonteneau et al, 2000; Davies et al, 2014,) and environmental condition have challenged the T3 methodology on several aspects of the sampling and data processing (Herrera and Báez, 2018). As an example, on the basis of statistical analysis, it has been showed 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). For all of these reasons, the aim of this paper is to give key elements to evaluate potential biases that could occurs in the catch assessments of tropical tunas of purse seiners and secondly, to explore some ways in order to increase accuracy of the T3 processing for future reporting of annual statistics to tuna-RFMOs. First, we investigated the differences in total catch and species catch using the T3 processing compared to the Operational Landing Reports (OLR) provided by companies. Then, we focused on two steps of the T3 processing that could play a key role in the observed pattern of catches: (1) the conversion of the commercial category from logbook to the standard weight-class used for catch assessment, and (2) the length-weight relationship by species. Finally, we further discussed limits and potential bias of T3 processing and OLR and suggested recommendations to overcome them.

2. Material and Methods

2.1. Logbooks

Logbooks constitute the core data of the T3 processing: The whole process aims at 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 the captain, the *bosco* and the chief engineer. IRD get the logbooks the day before the purse seiners come back to ports. While in the past some logbooks were missing, nowadays the logbook coverage reaches 100%.

2.2. Wells plans

For each purse seiner unloading, the well plan is provided by the chief engineer to the IRD staff in the landing place. The well plan contains for each well the information on the set put on the well (date, location, catch by species and commercial categories). In general, the well plan is sent before the arrival of the vessel at port. The combination logbook and well plan is used to set up the well sampling.

2.3. 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 free school and floating object sets. To ensure this coverage, the sampling plan is continuously updated according to strata already sampled and the annual objective. As the logbook and the wells plan are communicated in advance, this enables to determine which wells (i.e. dates, positions and fishing modes) must be sampled. The sampling protocol take into account for the homogeneity of the well's content (e.g., in case of several sets in the same well, it is recommended to select a well containing a single fishing mode, as well as limited dates and spatial locations of the sets).

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 frozen. Sampling team focuses on species identification and size measures. Size measures are performed with callipers. Small individuals, less than 70 cm fork length (FL), are measured in fork length, while larger individuals are measured in predorsal length. Fork length measures use 1 cm and 2 cm length classes steps, according to species, while predorsal length are performed with 0.5 cm steps. Sometimes for a subset of the sample, individuals are weighted using a scale, currently insuring 10 g precision.

In addition to samplings at landing, size and weights of yellowfin, skipjack and bigeye are sampled at canneries as well, using the same devices and protocol, while fish is defrosted. These biometric data were used to assess weight-length relationship that is used in the T3 processing to convert length in weight.

2.4. Landing sheets

Landing sheets provide catch in weights unloaded from fish wells. Unlike catch from the logbooks, weights are measured with scales. Species composition are determined through a sampling procedure carried out by an operator contracted by fishing companies and data is detailed per species and commercial category. However, catch dates and positions are absent and only species bought by canneries are mentioned. Nowadays the landing sheets coverage reaches 100%.

2.5. Operational landing reports

Contrary to sale slips, which are confidential commercial documents, operational landing reports are documents used by the producer organization and fishing companies to monitor catches per species and commercial category, and adapt their fishing strategies among their vessels. They contain a mix of commercial data (derived from sale slips) and landing sheets (described above). Therefore, species composition and sometime on total catch. Species composition was determined by exclusive exhaustive counting or by sampling, depending on the source of information (landing sheet or direct landing) and on commercial data), the cannery or the fishing company. Post hoc corrections may also occur when final estimates of fish sold to canneries become available (e.g. when the catch is transported by cargo to a distant cannery and sale slips are available a few weeks to a few months after the end of the fishing trip). Unsellable fishes (damaged) and fish sale for local markets in different countries (Seychelles, Sri Lanka, Ivory Coast, Madagascar) may not be taken into account in these data.

2.6. The T3 processing

2.6.1. Overview

The T3 processing is divided into three major components.

- The first part aims at standardizing the logbooks catches (step 1),
- The second partaims to standardize and enhance size samples (level 2),
- -Based on results of the first two stages, level 3 aims to correct the specific composition of the catch by commercial category reported in the logbooks by applying the standardized samples composition to them (**Fig. 1**).

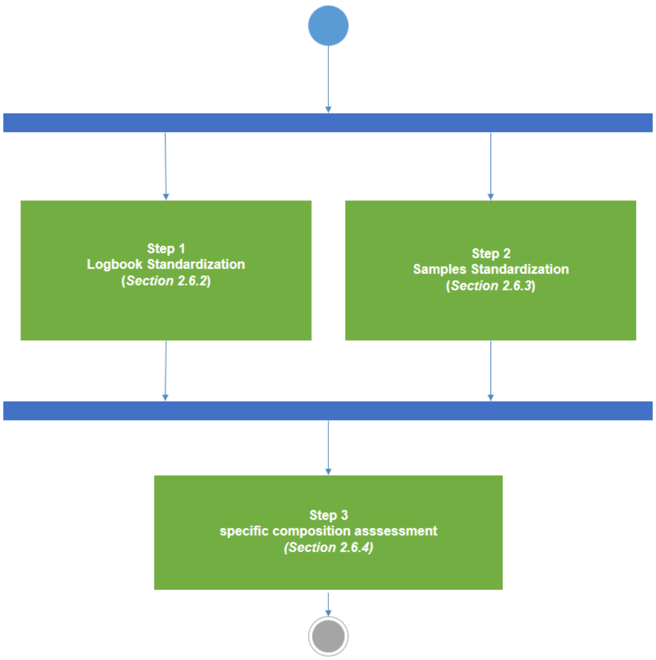

Figure 1: UML Diagram of the main step in T3 processing

2.6.2. Logbook standardization - step 1

Correction of bias on catch in logbook

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, the landing sheets provide the weight of landed lots, by species and commercial categories. These weights, which are more suitable than the estimates reported on the logbooks, are no longer geo-localized neither dated. Thus, the first step of stage 1 is to adjust the logbook tonnages by calculating a raising factor from the landing weight.

Convert weight categories from logbooks to standardized categories

The T3 methodology is based on the underlying assumption that the specific composition information in the logbooks is strongly biased (Cayré, 1984), 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 (**Table 1**).

Table 1: Standardized commercial categories used in the T3 processing

	Atlantic ocean	**Indian ocean**
School associated to object	< 10 kg > 10 kg	< 10 kg > 10 kg
Free and undetermined schools	< 10 kg 10 - 30 kg > 30 kg	< 10 kg > 10 kg

In this study we only consider the <10kg and >10kg categories, the latter being the sum of the 10-30kg and >30kg categories.

2.6.3. Samples Standardization - step 2

This step aims to standardize length measurements, then to distribute them on sampled sets and to raise them to the total catch of these sets.

Reallocation of samples to its sets

Sampling provides sizes histograms by well and species, meaning that the measured individuals can belong to one of the several sets present in the well. The aim of this treatment is to reallocate the histograms per well and species on each set put on the well. This reallocation is performed proportionally to the representativeness (by catch) of the set in the well, determined from the wells plan established by the chief engineer. This process generates histograms of size per species for the sampled set (i.e. for a fishing mode and a date and a geographical position).

Extrapolation of the sampled set to the catch of the sets

Each sample at the set level is then extrapolated to the total catch of the set. In other words, the sum of the individual weight of fish is equal to the catch of the set. In addition, when conditions are met, this processing is weighted by the proportion of small (<10 kg) and large (> 10 kg) individuals taken from the well plan.

One therefore seeks first to assess the proportion of small and large individuals in the sets of the well. This information is obtained by combining:

- The respective total weights of both small and large individuals in the well as reported on the well plan,
- The volume of catch (total or partial) of each set in the well.

The proportion of <10 kg and> 10 kg individuals is then determined for the sample of this well. Because the samples are size histograms, length-weight relationship are used to convert size histograms into weight histograms, before to cumulate them by commercial categories (<10 kg and> 10 kg).

Knowing on the one hand the proportion in weight of small and large individuals , for each set of the well and, on the other hand,in the associated sample, if the number of tuna sampled per category is considered representative, a differentiated small fish / large fish extrapolation is carried out to bring the number of individuals by size classes at the level of the total set catch.

2.6.4.Specific composition assessment - step 3

After correcting and standardizing the catch by species and commercial category at stage 1, then standardizing and extrapolating the size-by-species histograms at stage 2, stage 3 uses these two outputs to apply the specific composition of the samples to each set in the logbooks.

The treatment accounts for the strata defined by:

- Geographical areas (termed, hereafter ET),
- Fishing mode (free schools or school associated to a floating object),
- Year quarter,
- standardized category (<10 kg and> 10 kg).

For each stratum a set of samples is constituted and evaluated. If not qualified, an algorithm expands this samples set by fetching samples from neighboring strata. Once qualified, its specific composition is applied to all the sets of the specific stratum. Notice that only the proportions in YFT, SKJ and BET are thus corrected.

2.7. Statistical analyses

We first compared the T3 processing to the OLR measurement for the total catch and for catch by species. Then we explore the impact of specific steps of the T3 methodology, which may affect the estimates of catches per species. Thus, we investigated particularly, the classification of the commercial categories reported in the logbooks in standardized categories (>10 kg and <10 kg) and the impact of the length weight relationship by species.

2.7.1.Comparison between the T3 processing and the OLR weights

Total catches

We tested for general correlation between T3 and OLR total catch by using a simple linear model with ocean and OLR catch as fixed effects. Hereafter, we performed by ocean a Student paired t-tests to assess differences between the two methods, taking into account for the year dependence of the data. Student t-tests were performed for the 2001-2017 period and then the 2009-2017 period to investigate the most recent period.

Catch by species

We assessed for the species composition consistency of catches and processing methods using Intraclass Correlation Coefficient (ICC, Fisher 1954). This coefficient estimates the average of the correlations between all possible ordinations of pairs of available observations. The value of ICC ranges from 0 (random pattern) to 1 (all the variance explain by class categories).

Then, we tested for significance in catch differences between the two processing methods, by species and by ocean, using the Student paired t-test.

Finally, we hypothesized that the intensity of the observed mismatch between the T3 processing estimates and the OLR weights is related to the amount of catch of the species weight category. To measure the intensity of mismatch we calculated the percentage of error between the two processing methods dividing the catch differences between the two methods by their respective average catch. We then used the standard deviation of this percentage, by 1000t intervals, as an accuracy index of the T3 processing. We tested our assumption using a general additive model (gam) to fit for the non-linearity of the relation (Wood 2006) with the SD of percentage as the response variable and the interaction between ocean and smoothing term on average catch between the two methods as fixed effects. Model selection was performed using Akaike's Information Criterion with second order adjustment (AICc) to correct for small-sample bias (Burnham and Anderson, 2003).

2.7.2. Commercial categories among species

In the T3 processing, the 6-20 kg category is split among the >10kg and <10kg categories with a percent of 80% and 20% respectively, following an assumption of uniform distribution of weight over the 6-20 kg category. As the catch assessment may overestimate the small fish (Deledda et al 2018.), we tested the influence of this assumption on the estimate of the YFT catch by allocating 100% of the 6-20 kg category to the >10kg commercial category; considering that only large fishes (YFT and BET) composed the 6-20 kg category.. In case a significant bias of the T3 processing is found, this correction should represent an important percent of the observed differences in catch. Thus we calculated the 20% catch remaining of this 6-20 kg category and compare it to the differences in percentage catch between T3 processing and OLR weight.

2.7.3. Length-Weight relationships

Length-Weight relationship is a key element of the T3 processing as it drives the conversion of the measured fish in weight, with obvious consequences in the estimates of catch by species. However, this relation could evolve in time and space for many reasons (biology, environmental condition, new fishing mode ;Marsac et al. 2006, Chassot et al. 2016, Marsac et al. 2017). The equation of length-weight relationship is:

$$Weight = a.Length^{b} \quad (1)$$

In order to test if changes of parameters values of length-weight relationships would be a source of bias in the species catch assessment of the T3 processing, we used the different parameters of this equation, which have been reevaluated in different studies (**Table 2**). We calculated for each pair of parameters a and b the length threshold that split both BET and YFT between the >10kg and <10kg categories. The results can be interpreted as follows:

- If the threshold of length increases, i.e. coefficients a and/or b of the curve decrease, it means fishes were thinner than before and consequently this increases the proportion of <10kg fishes in the catch estimate,
- If the threshold of length decreases, i.e. coefficients a and/or b of the curve increase, it means fishes were bigger than before and consequently this increases the proportion of >10kg fishes in the catch estimate.

Table 2: Length/weight relationship for BET and YFT in Atlantic (AO) and indian (IO) oceans. a and b are the coefficients of the equation (1). Length (fork length in cm) at 10kg is the predicted length for a fish of 10 kg. Sampling start and sampling end correspond to the period covered by the equation. * The year before the reference was taken when the information on the sampling period was not available.

ocean	species	a	b	Length at 10kg	sampling start	sampling end	References
AO	BET	0.000012494	3.1208	77.9108293	1967	1968	Lenarz 1972
AO	BET	0.0000215	2.984	79.3079766	1979	1980	ICCAT 1980*
AO	BET	0.00002396	2.9774	77.2191931	1967	1968	Parks et al. 1982
AO	YFT	0.00002153	2.976	80.2082565	1965	1975	Caveriviére et al. 1976
AO	YFT	0.000021804	2.96989	80.591155	1967	1968	Lenarz 1972
AO	YFT	0.000032269	2.89759	78.5411272	1987	2015	Chassot 2015
IO	BET	0.00002217	3.01211	75.3645778	1987	2015	Chassot et al. 2016
IO	BET	0.000027	2.951	77.0963163	1984	1985	Cort 1985*
IO	YFT	0.00001888	3.0195	78.6461439	1984	2006	Marsac 2006
IO	YFT	0.00002459	2.9667	77.7560711	1987	2015	Chassot et al. 2016

3. Results

3.1. Total catches

Total catch estimates with the T3 processing and calculated from the Operational landing report (OLR) are highly correlated for both oceans (Atlantic Ocean, AO: R^2= 0.97; Indian Ocean, IO: R^2=0.99) during the 2001-2017 period. Although intercepts and slopes did not differ from 0 and 1 respectively, the total catch series obtained with the T3 processing are slightly higher than those from the OLR for the IO (**Fig.2**), with a difference about 2 ± 1 % on average over the 2001-2017 period (**Table 3**). However, since 2009, this difference has not been found significant, which confirm in the IO an increase of the accuracy over time (**Fig.3**).

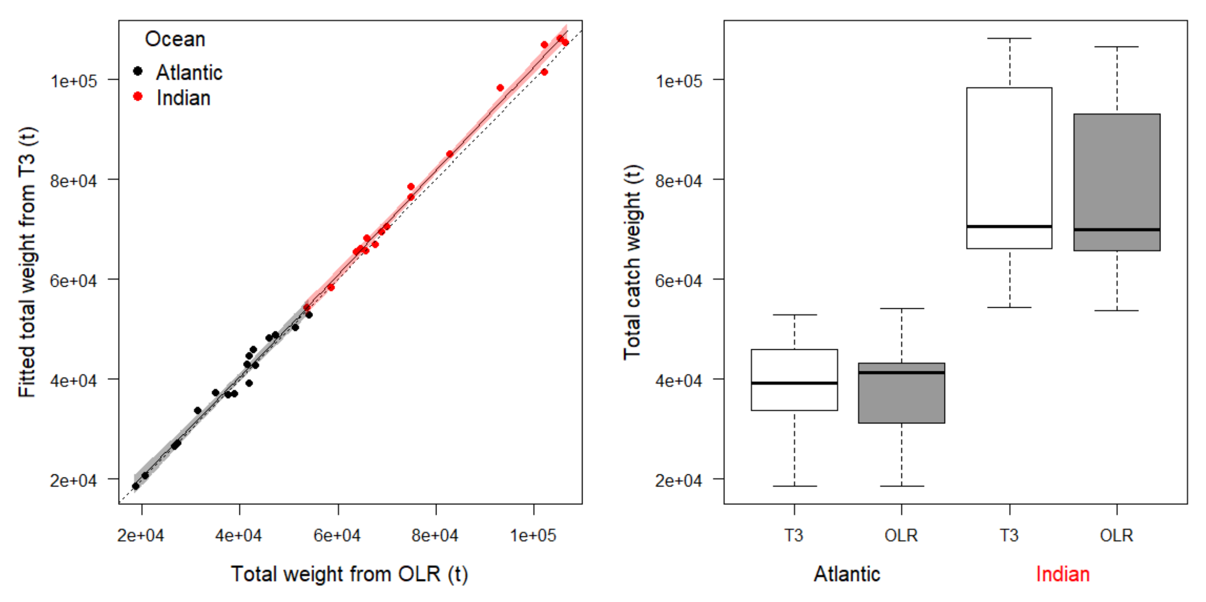

Figure 2: Total catch estimates from the T3 processing against the total catch calculated from the Operational landing report (OLR) for the Atlantic and Indian oceans (left panel). Lines correspond to fitted value by linear model and coloured polygons are the 95% confidence interval or the mean. The dotted line corresponds to equality between the two variables (i.e., intercept 0 and slope 1). Total catch estimates by assessment method and ocean (right panel).

Table 3: Comparison of total catch estimates with the T3 processing and the OLR. CI_L and CI_U are the Lower and Upper limits of the 95% confidence intervals, respectively.

Period	Ocean	t	df	p-value	Mean (t)	CI_L (t)	CI_U (t)
2001-2017	AO	1.16	16	0.26	487	-404	1378
	IO	3.7	16	0.002	1590	679	2502
2009-2017	AO	1.35	7	0.22	939	-710	2589
	IO	2.08	7	0.076	746	-102	1594

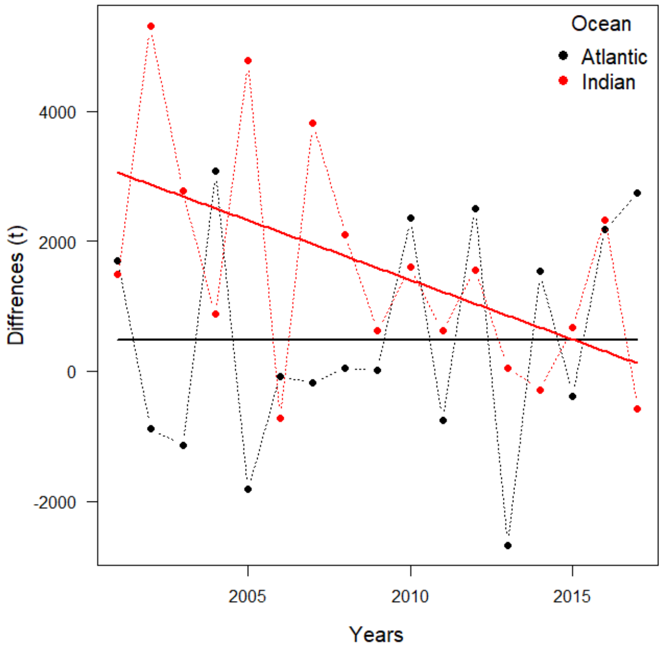

Figure 3: Differences between total catches estimated by the T3 treatment and by the Operational Landing Report over the 2001-2017 period. Lines represent fitted mean value from simple linear model.

3.2. Catch by species

The species composition was highly similar between the two assessment methods (ICC for AO = 0.88 [0.72,0.98] and IO=0.82[0.62,0.97). However, testing separately for differences for each standardized categories brought out a pattern of mismatch. Thus, dominant categories, such as Skipjack tuna (SKJ) and Yellowfin tuna (YFT) + 10 kg, were underestimated with the T3 processing compared to the OLR method (**Fig. 4**, **table 4**). Conversely, less dominant species (Bigeye tuna, BET, Albacore, ALB) tend to be overestimated. This pattern is more pronounced in the IO for which catch for each standardized category were significantly different.

Beyond the species and standardized categories, the proportion of mismatch between the T3 processing estimates and the OLR ones was highly dependent on the amount of species caught. Thus, the standard deviation of the difference between the 2 methods decreases sharply with the size of the catch (**Fig. 5**, see **table 5** for model selection).

Table 4: Comparison of catch estimates by species for each standardized category with the T3 processing and the OLR using a student t-test. Differences are given in tons and in proportion of total catch over species. CI_L and CI_U are the Lower and Upper limits of the 95% confidence intervals

Ocean	Species cat.	t	df	p-value	Mean (t)	CI_L (t)	CI_U (t)	Mean (%)	CI_L (%)	CI_U (%)
AO	YFT +10	-3	16	0.009	-1185	-2022	-346	-0.036	-0.049	-0.028
	SKJ	0.74	16	0.47	177	-331	685	-0.001	-0.01	0.01
	YFT -10	2.02	16	0.059	446	-20	912	0.011	0	0.022
	BET	8.53	16	<0.001	1018	731	1304	0.024	0.02	0.03
	ALB	4.14	16	<0.001	30	15	45	0.001	0.0003	0.0013
IO	YFT +10	-2.19	16	0.04	-989	-1947	-32	-0.021	-0.03	-0.01
	SKJ	-6.091	16	<0.001	-2516	-3391	-1640	-0.042	-0.056	-0.029
	YFT -10	10.54	16	<0.001	3405	2721	4091	0.043	0.034	0.053
	BET	7.1	16	<0.001	1729	1213	2245	0.02	0.014	0.026
	ALB	-1.22	16	0.24	-40	-106	29	-0.0004	-0.0011	0.0004

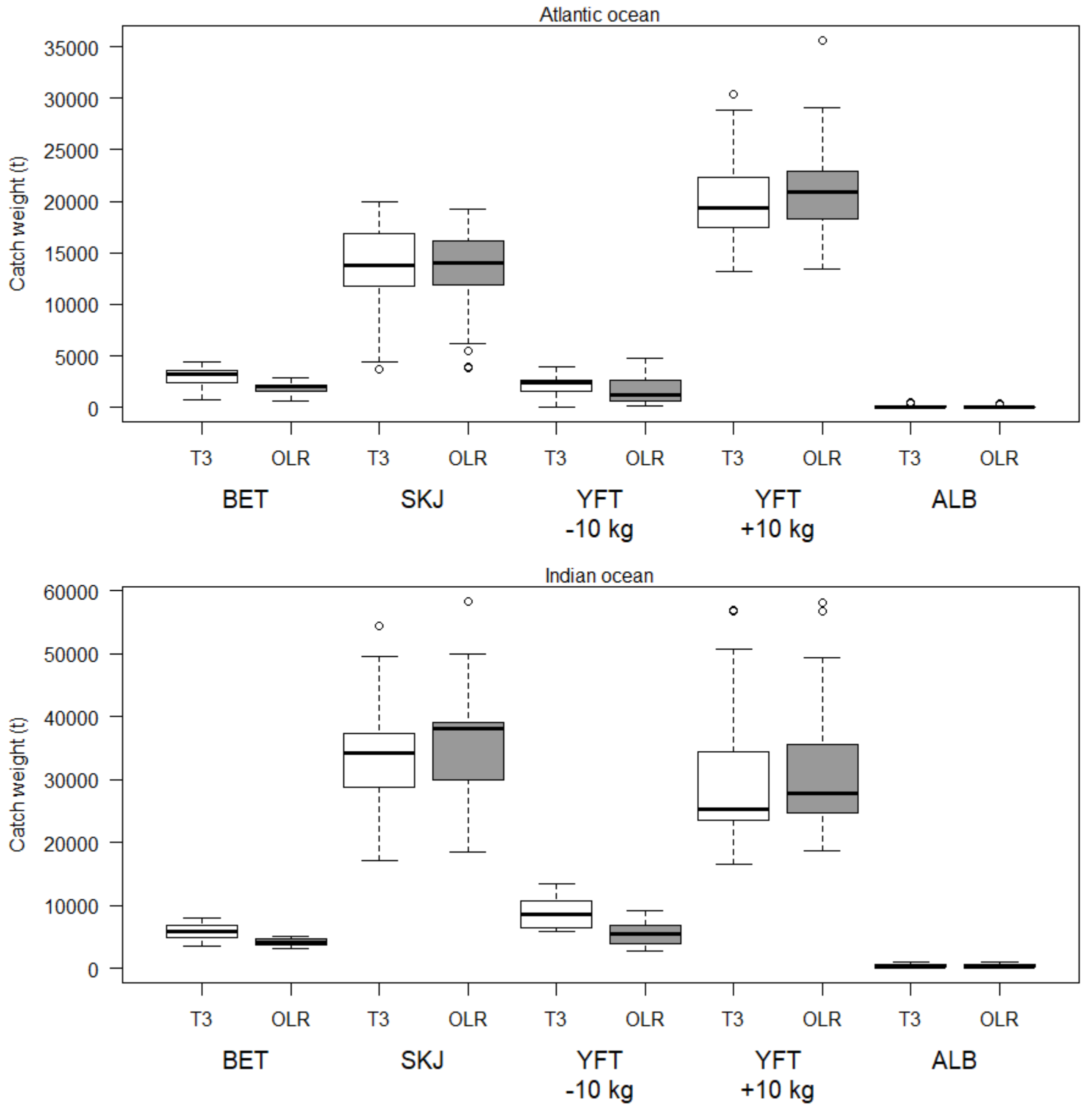

Figure 4: Catch estimates by species and standardized categories using the T3 processing or the Operational Landing Report (OLR) for the AO and the IO.

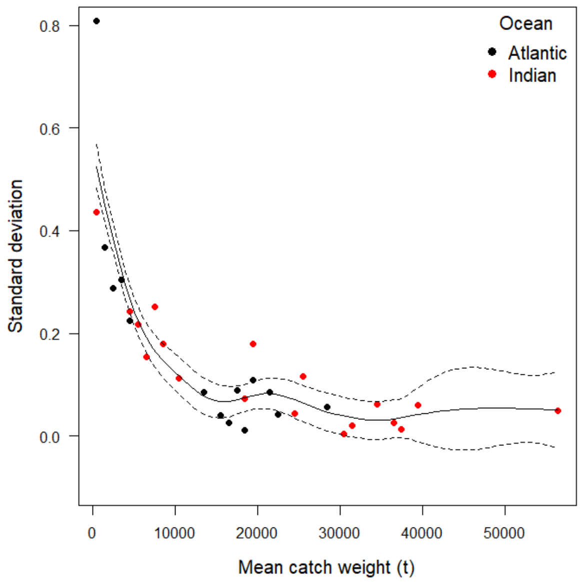

Figure 5: Standard deviation against mean catch estimates of the difference between the T3 processing and the Operational Landing Report. Solid and dashed lines represent the fitted mean and the se of the gam model, respectively.

Table 5: Model selection of gam based on AICc

Parameters	edf	Deviance explained	ΔAICc
s(weight)	7.09	82.9	0
s(weight) x ocean	11.5	90.4	2.29
s(weight) + ocean	7.69s	82.6	3.02
null	1	0	38.4
ocean	2	3	39.8

3.3. Catch by commercial categories among species

Commercial categories, which cover the 10 kg threshold (6-20kg), concerned a low proportion of sets in both oceans for BET and YFT (μ ± CI95% = 0.030 ± 0.010 for BET and 0.016 ± 0.005 for YFT). Patterns were quite similar between oceans with a marked decrease in the report of this category for BET in logbook over the years (**Fig. 6**). In terms of catch, the 20% part that concerns <10 kg for BET and YFT represents only 37 ± 27 t and 97 ± 35 t (μ ± CI95%) respectively for AO and IO (**Fig. 7**), far fewer than the observed differences for YFT >10 kg between the T3 processing and the OLR (μ ± CI95%= 0.039 ± 0.035 for AO and 0.08 ± 0.03 % 2003 year except for IO, see Appendix A for details).

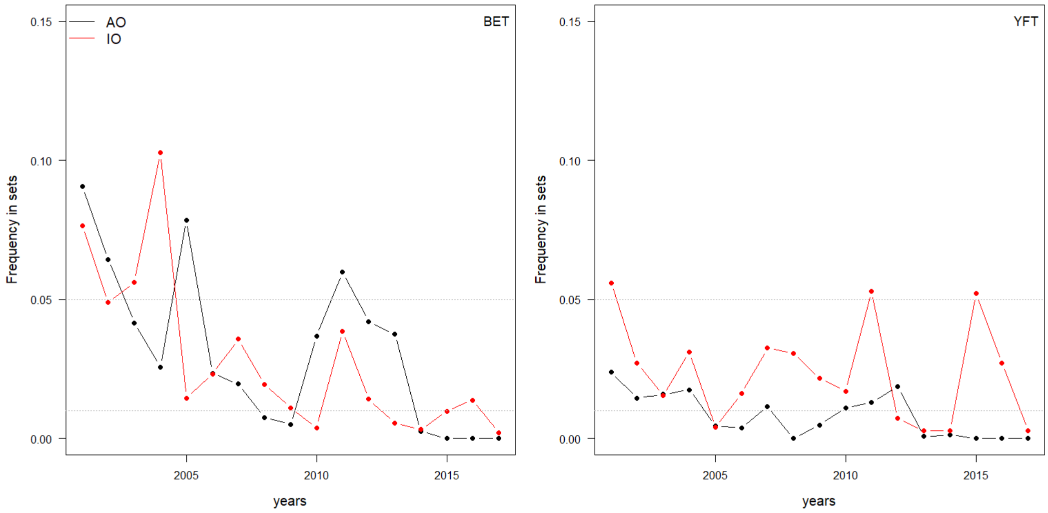

Figure 6: Frequency of 6-20 kg commercial category in sets by ocean for BET (left panel) and for YFT (right panel)

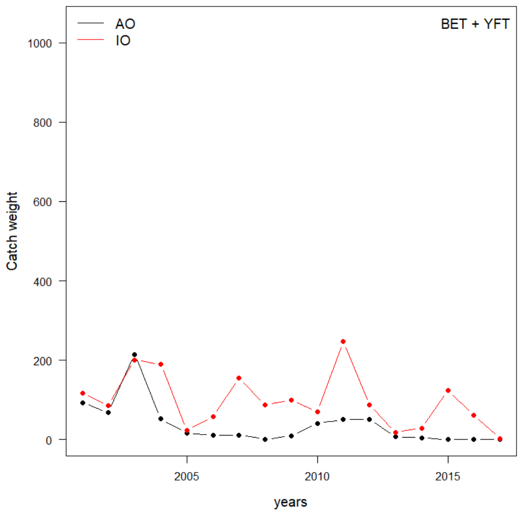

Figure 7: Catch estimate of the commercial category 6-20kg BET and YFT allocated to <10 kg categories among year and oceans

3.4. Length-Weight relationships

Over the 10 references that established length-weight relationships for BET and YFT in both oceans, the threshold length tended to decreased over time, meaning a higher weight in recent decade for the same length than before the 80's (**Fig. 8**). However, this trend is not significant (Wilcoxon test W=20, p-value=0.15). Indeed there no length-weight relationship for both species in the IO before 1980 and no relationship for BET in the AO after 1980. Consequently, we could not conclude to significant variation of length-weight relationship over the last 40 years.

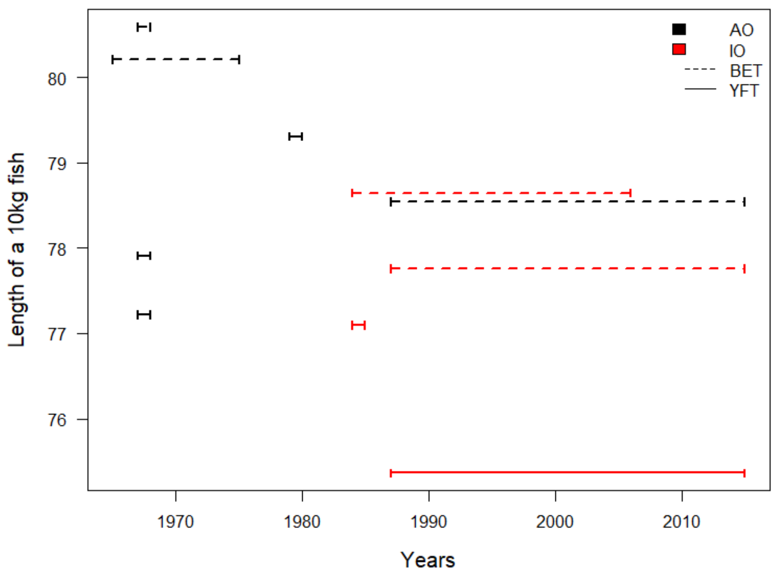

Figure 8: Length (FL in cm) for a fish (BET and YFT) at 10 kg based on different weight-length relationships used over time for the Atlantic (AO) and the Indian (IO) oceans.

4. Discussion

4.1. Total catch differences

On average the two assessment methods (T3 processing and OLR) converged in the estimation of the total tropical tuna catches, even if they differed in the Indian Ocean of about 2% for the period 2001-2017). This difference of total catches is easily explained by the origin of data source. Indeed, the T3 processing used the total catch at unloading (from landing sheets) that takes into account for all species caught (including several non-target species) except the fish sale on local market. On contrary the OLR catch only account for good quality target species and salable individuals (retained by the canneries). In such situation, the total catch estimate obtained in the T3 methodology can only be mechanically equal or higher than those from the OLR method.

4.2. Bias on catch per species and sources of error

Examining species composition, some biases were identified. Overestimation of less dominant species and, consequently, underestimation of dominant species has been clearly pointed out by our study. As Herrera and Báez (2018), we found that YFT >10kg catch were underestimated by T3 processing but contrary to their results, we found a similar pattern for SKJ. Our results indicated that the occurrence of a given species / standardized category in sets catches is a key element which explains the accuracy of T3, independently from the market price of the commercial category. These results suggest that the T3 process needs to consider a threshold to predict efficiently the catch in non-sampled fishing set (about 10 000 t/yr).

In respect of the 2 steps of the T3 processing that may lead to such observed, patterns were investigated. First, tests on the conversion of commercial categories to the standardized ones (<10kg, >10kg) did not explained the observed differences, likely due to the very low amount of catch affected by this correction (even if some improvements could be done, see 4.4 for this point).

Regarding the length-weight relationships, we could not conclude to a significant variation since 1965 because of the low number of studies available in the literature. However, some authors (Marsac et al. 2006, Chassot et al. 2016, Marsac et al. 2017) pointed out an increase of weight at length for BET, SKJ and YFT in the Indian Ocean that the patterns highlighted our results. If such a shift in length-weight relationship has occurred over the last 40 years, it could lead to an underestimation of >10 kg fishes both for BET and YFT. However, the magnitude of such an evolution has to be further investigated as Marsac et al. (2017) only points out "that change are significant but relatively limited" because of the multi-specific corrections that balanced each other. However, the most important conclusion here is the needs to use consistent parameters with the fishing period to accurately estimate weight and catch at size. To do so, temporal dynamics of the length-weight relationships have to be properly modeled at least for adults (see 4.4 section for recommendation).

Beyond these points, recent papers have already identified steps of the T3 processing that could lead to an overestimation of the less abundant species. Indeed, the use of too large spatial strata in the species composition correction processing (see 2.6.4 section for details) induces too much smoothing. By assessing the same presence into all fishing sets of the same strata, the smoothing would artificially give too much (or too less) weight (Fonteneau et al. 2017a, Deledda et al. 2018). For instance, Fonteneau et al. (2017a) estimated an overestimation of BET catch close to 10-13% in AO as result of the use of these too large spatial strata.

Finally, the fish sale on local markets called "faux-poisson" in the Atlantic Ocean was also pointed out as a potential source of biais for the T3 catch estimates by Fonteneau et al. (2017b). Indeed, Faux-poisson in the Atlantic Ocean (landed in the AO, Abidjan) was composed during 2005-2009 of only 5-6% and 6-7% of BET and YFT (Chavance et al. 2010) whereas total catches estimation by the T3 processing were about 10.3 ± 1.1% and 15.0 ± 1.5% for these 2 species, respectively during the same period (mean ± se). From this discrepancy in species composition, standardization of logbooks (see details in section 2.6.2), which assumes that the species composition is similar between Faux-poisson and cannery fluxes, should induce an overestimation for YFT and BET mostly for small fishes as we showed for YFT<10kg. This bias could accentuate the previous biais due to the large dimension effects of the too large strata in the correction processing. The faux-poisson correction should therefore be further integrated in T3 as it represents non negligible market flow for landings mainly mainly of minor (Romagny et al. 2000) but also of major tuna species (SKJ :43%, Chavance et al. 2010).

4.3. Operational landing report reliability and other bias

A non-exclusive assumption is that the OLR could be biased in the opposite way leading to an increase in the mismatch with the T3 processing. Indeed, species determination, and particularly small individual, is known to be a complex task (Bard 1986) and as the market price for small YFT or BET is similar to SKJ, canneries could over-report small fishes as SKJ. In addition, as crews of French purse seiners are remunerated on the price of the catch, commercial data was aggregated for small fishes until the implementation of the YFT quota in 2017. Thus, commercial categories usually contain a mix of species for small fishes that could lead to an overestimation for SKJ (Bard 1986). OLR and sale slips used different methods for correcting catch and species composition that could have the same or different bias. The methodological processes leading to the estimate of the species composition in the different canneries, or aggregation of data by the different fishing companies to produce operational landing reports, have to be perfectly understood before to drawn conclusions on the reliability of these documents.

Moreover, the potential sources of bias of commercial data are one of the reasons that lead to a change in the monitoring of catches by ORTHONGEL in the Indian Ocean in 2017. In order to assess more accurately the consumption of the YFT quota by the French tropical tuna purse seine fleet, landing sheets have been used to monitor YFT catches, after a correction of species composition through a sampling procedure (Maufroy et al. 2017), instead of OLR data. In 2017, the difference between the monitoring of yellowfin tuna catches by ORTHONGEL and T3 estimates was low (approximately 1%).

Finally, we found, as Herrera and Báez (2018), higher differences in catch per species in the IO than in the AO, which questions the quality of each of the data sources used in these studies (sale slips, commercial data and T3 estimates). It should be stressed that the T3 processing is dependent of many data sources that increase the risks of errors and biases. The differences between these two independent studies highlights the need of transparency and error assessment all along the data chain treatment, i.e. from the logbook to the sampling.

4.4. Future ways of improvement for T3 and recommendations

In this context, we propose several recommendations to be discussed by interested scientists, national statistical administrations and the Secretariat of tRFMOs , in order to further the quality of PS catch statistics:

- Inspite likely its would most probably have low effect, the overlap caused by the categories that cover the 10kg (6-20 kg) should be corrected as accurately as possible,
- It can also be recommended to update length-weight relationships by accounting for inter and intra annual spatio-temporal variations, as well as the fishing mode, particularly for adults for which the stage of maturity has an effect on the condition of fish,
- Improve modelling of the species composition including spatial structure of the species composition of catches and or adding spatial environmental variables to avoid for over smoothing in catch prediction
- Reconsider the spatial stratification in which species composition is assumed to be homogeneous
- Increase the coverage of sets sampled to reduce the spatio-temporal resolution of the sampling plan as reduced as possible.

5. Acknowledgments

We thank the Producer Organization ORTHONGEL and its member fishing companies CFTO, SAPMER and SAUPIQUET for the provision of operational landing reports. We also are 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.

6. References

Bard f.X. 1986. Note sur l'échantillonnage pluridisiplinaire des thons tropicaux au port d'Abidjan. Col.Vol.Sci.Pap. SCRS/1985/047. ICCAT, 25: 37-45

Burnham, K. P., and D. R. Anderson. 2003. Model selection and multimodel inference: a practical information-theoretic approach. Springer Science & Business Media

Caverivière A. 1976. Longueur prédorsale, longueur à la fourche et poids des Albacore (*Thunnus albacares*) de l'Atlantique Cah. O.R.S.T.O.M., sér. Océanogr., LI»~. <YIV, no 3, 1YlG: 201-208

Cayré P. 1984. Procédure de suivi pour la révision de la composition spécifique des statistiques thonières FISM. Col.Vol.Sci.Pap. ICCAT, 21 (2): 102-107

Chassot E. 2015. A review of morphometric data available for tropical tunas: Updating relationship for purse seine fisheries data processing. T3 working group, 1-19

Chassot E., Assan C., Esparon J., Tirant A., Delagado de Molina A., Dewals P., Augustin E and Bodin N. 2016. Length-weight relationships for tropical tunas caught with purse seine in the Indian ocean: Update and lessons learned. IOTC-2016-WPDCS12

Chavance P., Amon Kothias J.B., Dewals P., Pianet R. , Amandè MJ, Delagodo de Molina A. and Djoh A. 2010. Statistics on tuna surface fishery's bycatch landed in Abidjan, Côte d'Ivoire, for the 1982-2009 period. ICCAT, SCRS/2010/140, 1-8

Cort, J.L. 1985. Data on tuna fishing by Spanish vessels in western Indian Ocean. In Expert Consultation on Stock Assessment of Tunas in the Indian Ocean, p. 165-167. In Expert Consultation on Stock Assessment of Tunas in the Indian Ocean, Colombo, Sri Lanka, 28 November -2 December 1985, 364 p. IPTP Coll. Vol. Work. Doc. 1.

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

Deledda G., Gaertner D. and Dermarcq H. 2018. Combining dFADs catch data and ecological factors for detecting hot spots of juveniles'bigeye tuna. ICCAT, SCRS/2018/038, 1-12

Fisher R. A. 1954. Statistical methods for research workers. Edinburgh

Fonteneau, A., Pallares, P., Pianet, R. 2000. A worldwide review of purse seine fisheries on FADs. In J.Y. Le Gall, P. Cayre´, M. Taquet (Eds.), Pêche thonière et dispositifs de concentration de poisons,28, Actes Colloques-IFREMER, pp15-35

Fonteneau A., Pascual Alayón P.J. and Chassot E. 2017a. 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. SCRS/2016/182 Collect. Vol. Sci. Pap. ICCAT, 73(2): 829-849

Fonteneau A., Dewals P. and Pascual Alayón P.J. 2017b. On the faux poisson tuna landings in Abijan : Analysis of recent data and proposal to create a task2 file of faux poissons tuna catches for major and minor tunas. SCRS/2017/196, ICCAT, 74(5): 2022-2037

ICCAT 1980. Working group on juvenile tropical tunas. Col.Vol.Sci.Pap. Brest, 13: 1-129

ICCAT 1984. Meeting of the working group on juvenile tropical tunas. Col.Vol.Sci.Pap. Brest, 21 (1): 1-289

Hallier J.P. and Parajua J.I. 1992. Review of tuna fisheries on floating objects in the Indian Ocean. In: Fishing for tunas associated with floating objects. La Jolla : IATTC, 25 p. International Workshop on Fishing for Tunas Associated with Floating Objects, La Jolla (USA), 1992/02/11-14.

Herrera M. and Báez J.C. 2018. 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 IOTC. ICCAT-2018-SCRS-136

Lenarz W.H. 1972. Length-weight relations for five eastern tropical Atlantic scombrids. NOAA Fishery bulletin, 72 (3): 848-850

Marsac F., Poitier M., Peignon C., Lucas V., Dewals P., Fonteneau A., Pianet A. and Ménard F. 2006. Updated biological parameters for Indian Ocean yellowfin tuna and monitoring of forage fauna of the pelagic ecosystem, based on a routine sampling at the cannery in Seychelles. IOTC-2006-WPTT-09, 1-15

Marsac F., Báez, Floch L. and Fonteneau A. 2017. Potential changes affecting species composition and tuna catch at size for purse seine. IOTC-2017-WPDCS-13-20.

Maufroy A., Goujon M., Floch L. and Bach P. 2017. The challenge of monitoring the consumption of the YFT quota in real time: the case of the French tropical tuna purse seine fleet. IOTC-2017-WPDCS13-21, 1-6

Pallarès P. and Hallier J.P. 1997. Analyse du schéma d'échantillonnage multi-spécifiques des thonidés tropicaux. Rapport scientifique. IEO/ORSTOM, Programme N°95/37.

Pallarés P. and Petit Ch., 1998. Tropical tunas: new sampling and data processing strategy for estimating the composition of catches by species and sizes. Col. Doc. Cient. ICCAT, Vol. XLVIII (2): 230-246 (SCRS/97/28)

Parks W., Bard F.X., Cayré p., Kume S. and Santos Guerra Al. 1982. Length-weight relation for Bigeye tuna captured in the eastern Atlantic ocean SCRS/1981/059. Col.Vol.Sci.Pap. ICCAT, 17 (1): 214-225

Pianet R., P. Pallarés and Ch. Petit, 1998. New sampling and data processing strategy for estimating the composition of catches by species and sizes in the European purse seine tropical tuna fisheries. 7th IPTP Expert Consultation, Victoria, 9-14 Nov. 1998; IPTP/CTOI, TWS/98/4/13.

Romagny, B., Ménard, F., Dewals, P., Gaertner, D., N'Goran, N. 2000, Le "faux-poisson" d'Abidjan et la pêche sous DCP dérivants dans l'Atlantique tropical Est : circuit de commercialisation et rôle socio-économique. In:Le Gall J.Y. (ed.), Cayré Patrice (ed.), Taquet M. (ed.). Pêche thonière et dispositifs de concentration de poissons. Plouzané : IFREMER, 2000, p. 634-652.

Wood, S. N. 2006. Generalized additive models: an introduction with R. Chapman and Hall/CRC.

7. Appendix A

Table A1: Catch weight of Yellowfin tuna (YFT) > 10kg assessed with the T3 processing and the Operational landing report (OLR). Dif weight is the differences in catch weight between the two methods; coverclass is the catch for YFT and for Bigeye tuna (BET) of the commercial category 6–20 kg reported in logbooks and coverclass20 is the 20% of this cover class; percent of dif catch is the percentage of Dif weight that represent coverclass20

Ocean	Year	T3 catch (t)	OLR catch (t)	Mean catch (t)	Dif catch (t)	Dif catch (%)	coverclass (t)	coverclass20 (t)	Percent of dif weight
AO	2001	28883	27406	28145	1477	5%	462	92	6%
AO	2002	30348	35639	32993	-5291	-16%	342	68	1%
AO	2003	28365	29134	28750	-769	-3%	1075	215	28%
AO	2004	20725	21423	21074	-698	-3%	261	52	7%
AO	2005	19599	22850	21224	-3251	-15%	82	16	1%
AO	2006	17433	19023	18228	-1590	-9%	52	10	1%
AO	2007	13245	13417	13331	-171	-1%	57	11	7%
AO	2008	15408	15760	15584	-352	-2%	3	1	0%
AO	2009	17596	18903	18250	-1307	-7%	47	9	1%
AO	2010	17555	18328	17941	-773	-4%	203	41	5%
AO	2011	19540	20941	20241	-1401	-7%	254	51	4%
AO	2012	16702	15815	16259	887	5%	253	51	6%
AO	2013	18076	21530	19803	-3454	-17%	35	7	0%
AO	2014	19371	19855	19613	-484	-2%	23	5	1%
AO	2015	16261	17980	17121	-1718	-10%	0	0	0%
AO	2016	22267	23573	22920	-1306	-6%	0	0	0%
AO	2017	22973	22910	22941	63	0%	0	0	0%
IO	2001	27896	29167	28531	-1270	-4%	581	116	9%
IO	2002	25037	24340	24688	697	3%	433	87	12%
IO	2003	56733	56674	56703	59	0%	1003	201	338%
IO	2004	56865	58020	57443	-1155	-2%	948	190	16%
IO	2005	50684	49382	50033	1302	3%	120	24	2%
IO	2006	36196	41924	39060	-5727	-15%	287	57	1%
IO	2007	30547	29511	30029	1037	3%	773	155	15%
IO	2008	34006	35485	34746	-1478	-4%	435	87	6%
IO	2009	17154	19202	18178	-2048	-11%	501	100	5%
IO	2010	19837	19025	19431	812	4%	350	70	9%
IO	2011	23349	24813	24081	-1463	-6%	1235	247	17%
IO	2012	34506	33866	34186	640	2%	433	87	14%
IO	2013	23851	27741	25796	-3890	-15%	91	18	0%
IO	2014	25308	24986	25147	323	1%	142	28	9%
IO	2015	23504	25191	24348	-1687	-7%	616	123	7%
IO	2016	23894	24662	24278	-768	-3%	309	62	8%
IO	2017	16581	18783	17682	-2202	-12%	15	3	0%