ON THE POTENTIAL BIASES OF SCIENTIFIC ESTIMATES OF CATCHES OF TROPICAL TUNAS OF PURSE SEINERS MONITORED BY EUROPEAN SCIENTISTS AND CATCHES REPORTED TO THE ICCAT AND IOTC

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SUMMARY

This document represents a first attempt to explore potential differences between the catches of tropical tunas estimated using the European software T3 and those recorded on sale slips completed by the canning factories purchasing fish from 48 vessels registered with OPAGAC in the Atlantic and Indian oceans, over the period 2011-16. The analysis identified potential sources of bias in estimates of catch of tropical tunas that have been reported to the ICCAT and the IOTC during those years, or probably a longer period. The magnitude of the biases identified varied depending on the ocean, fleet, and size category, with the largest bias recorded in the Indian Ocean, where the catches of yellowfin tuna and bigeye tuna recorded by the IOTC, especially of large size, appear to be well below those obtained from sale slips. To a lesser extent, in the Atlantic Ocean the catches of yellowfin and bigeye tunas seem to be also subject to bias, although in this case underestimation of both large and small fish seem to be responsible. Even though the study is preliminary and the available datasets need to be further explored and cross-verified with actual monitoring of fish in processing plants, the results obtained, if confirmed, could have consequences on the statistics, stock assessments, management advice, and management measures adopted by ICCAT and IOTC.

KEYWORDS

Catch composition; Size composition; Tropical tunas; Purse seining

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1. Introduction

The European purse seine fleet operates in tropical and subtropical waters of the Atlantic, Indian and Pacific oceans (Clermont et al., 2012; Escalle et al., 2017a), in areas under the competence of the four tuna-RFMO that manage stocks of tropical tunas (IATTC, ICCAT, IOTC and WCPFC), which are the target of EU purse seiners. At present all EU purse seiners for tropical tunas are flagged in either France, Italy, or Spain.

The "Institut de recherche pour le développement" (IRD) in France and the "Instituto Español de Oceanografía" (IEO) in Spain are the institutions responsible to produce scientific estimates of catch, effort, and other biological data (e.g. size frequency distribution of tropical tunas and other stocks) for their respective countries. However, while ICCAT and IOTC fully rely on the data reported by the EU, the IATTC and WCPFC have implemented different arrangements and are not covered here (IATTC 2016; Lawson 2013).

The multi-species nature of tropical tuna surface fisheries gives rise to a series of difficulties at the time of estimating basic catch by species and catch by size statistics. Fonteneau (1976) discussed about the difficulty that some skippers have to correctly identify the composition of the retained catch. In the Atlantic and Indian oceans, the IRD and the IEO agreed to harmonize data collection and catch estimation procedures in 1998, with the same sampling and catch estimation procedure adopted for both oceans since that year, and catch estimates for previous years adjusted to account for the new procedures (Pallares & Petit, 1998). The new system used the same sampling protocols and estimation procedures (known as T3) for both oceans, unlike the systems existing between 1980 and 1997, which were specific to each ocean. All systems were based on the correction of catches reported in vessel logbooks using data collected from port sampling.

In addition, European scientists have assisted non-EU countries having purse seiners to implement the European sampling and estimation procedures. This includes Seychelles and Mauritius in the Indian Ocean and Belize, Cape Verde, Côte d'Ivoire, Curaçao, El Salvador, Guatemala, Panama and Senegal in the Atlantic Ocean.

This document presents preliminary results of some exploratory analysis that compare estimates of landings of tropical tunas obtained using the European sampling and catch estimation procedures with data obtained from sale slips produced by the canning factories that acquired those fish, in the Areas of Competence of ICCAT and IOTC and for the period 2011-2016. The study is limited to the fleet ascribed to OPAGAC its main purpose being to assess the concordance of estimates of total catch and catch by species and size category produced by European institutions with the data recorded on the sale slips collected for that period.

While the main purpose of the study was to answer a request from the "Secretaría General de Pesca (SGP)" of Spain to investigate the reason for the large differences identified between the landing statistics reported by operators (FIDES database) and scientific estimates produced using T3, the main results are reported here considering the relevance the findings may have on the management of tropical tunas in both regions.

The objective is to assess the reliability of scientific estimates of catch produced using European procedures as compared to sale slips from canning factories and the consequences that any potential bias identified could have on estimates of total catch and catch by species and size category for EU and other fleets; and the potential consequences of any discrepancy over the status of stocks of tropical tunas, and their management.

2. Methods

2.1 European sampling and catch estimation procedures

European scientists collect the following information from purse seiners in order to produce the statistics required by the flag state/RFMO concerned:

- Logbooks and well plans completed by skippers/chief engineers of tuna purse seiners and handed over at the end of each fishing trip to enumerators and compliance officers;
- Total catches unloaded/transhipped in port reported by the skippers/fishing companies at the end of each unloading operation;
- Data from port sampling, conducted by staff of research institutions in coastal countries with which European scientists have established cooperative arrangements (mainly "Centre de Recherches Océanologiques" in

Abidjan, “Centre de Recherches Océanographiques Dakar Thiaroye” in Dakar, Seychelles Fishing Authority in Victoria, “Unité Statistique Thonière d’Antsiranana” in Diego Suarez, Madagascar);

- Biological samples, collected on an opportunistic manner, intended to provide the information required to convert length samples into weight.

The sampling procedure is summarized in the following paragraphs. Sampling are stratified by:

- fishing mode, with sets to free-swimming and associated tuna schools treated separately;
- fishing area, with 6 areas in the Atlantic Ocean and 8 in the Indian Ocean;
- time-period, with each year broken by quarter (January-March, April-June, July-September, October-December).

Thus, a fish tank is selected for sampling only when all the catches stored in it come from sets recorded for the same fishing mode, fishing area, and time-period;

Collection of samples: where large (≥10kg) and small (<10kg) fish are present in a selected tank fish are randomly selected for each category and measured independently. The objective is to take a minimum number of samples per stratum, with each sample consisting of two sub-samples, taken at different times during the unloading of the selected fish tank.

- If a fish tank contains only large specimens (≥10kg) the sample consists of two sub-samples of 150 specimens each with the pre-dorsal length (length from the tip of the snout to the base of the first dorsal fin) and species of each individual recorded (YFT or BET).

- If a fish tank contains only small fish (<10kg) or a mix of large (≥10kg) and small fish the objective is to monitor 500 small fish (two sub-samples of around 250 specimens each or 300+200), attempting to measure as many large fish (YFT, BET) as possible from those fish unloaded at the time each sub-sample of small fish is taking place.

    - Small fish: the sampling consists on the random selection of small fish as it is unloaded from the tank until the target sampled number is attained with a different approach used for SKJ specimens as compared to YFT and BET:

        - Skipjack tuna: the first 30 SKJ identified from the fish taken for sampling are measured in fork length while all SKJ specimens monitored beyond that number are simply counted (with just the total number recorded in the sampling form);
        - Small yellowfin and bigeye tunas: the fork length and species of all individuals appearing on the sample is recorded until the target sample number is attained;

    - Large fish: All individuals unloaded as small fish are being sampled are classified by species and measured in pre-dorsal length, regardless of their numbers.

The methodology used by European and other scientists to produce catch, effort and size frequency distributions for purse seiners is known as TTT, or T3. The estimation procedure is summarized in Figure 1.

Thus, the samples from all vessels/fish tanks for a given fishing mode, quarter and T3 statistical area are used to correct the species composition of each and every individual set recorded under the same stratum, regardless of the vessel from which samples come from (i.e. the estimation procedure is not specific to the boat). This procedure involves the following steps:

- Conversion of the numbers of fish sampled for length into weight, for which length (fork or pre-dorsal)-weight relationships are used, as adopted by European scientists;
- Estimation of total weight of skipjack tuna using the weight and number of specimens sampled for length and the total number of SKJ monitored;
- Estimation of total weight sampled for other species by summing up the weights of all fish sampled;

- Raising the weights sampled by T3 size class (total ≥10kg & <10kg) to the total reported for each sampling unit (fish tank) and breaking the catches of each size class according to the proportions obtained from the sample;
- Adding the total amounts estimated from all sampling units to obtain the final proportions of YFT, BET (≥10kg & <10kg) and SKJ (<10kg), for each T3 size category.

Once that the final proportions for species composition and size category are obtained for each stratum, those proportions are used to adjust the catches from each individual set following scaling of the catches in logbooks to the totals unloaded, as shown in Figure 1.

Therefore, it is important to bear in mind the following points:

- The European system relies on the total amounts unloaded reported by vessel skippers or fleet representatives; however, landing data is only used in bulk (i.e. each catch entry in a logbook is scaled by the factor obtained by dividing the total catch of tropical tunas unloaded by the total catch of tropical tunas recorded in the logbook of the trip concerned);
- The European system relies on the total amounts of tropical tunas in the category ≥10kg and <10kg recorded in vessel logbooks and well maps;
- The European system relies on multi-vessel port sampling data to break the catches reported under each of the above size categories by species (i.e. it ignores the catches by species reported in logbooks);

The outcome of this process is that the catches of all EU and associated fleets made inside the same stratum (Size category, Fishing mode, Area, Quarter) end up having exactly the same species and size composition. This is a strong assumption as it smooths away any individual vessel effects, unlike what has been described in other regions, like the Pacific Ocean (Lennert-Cody et al. 2008; Escalle et al. 2017b).

Pallares & Petit (1998) provide more details about the sampling and catch estimation procedures used for EU-flagged vessels and vessels from other countries.

2.2 Data sources and preparation

This study covers the activities of 48 purse seiners registered with OPAGAC over the period 2011-2016, which unloaded around 100,000 tons of tropical tunas per ocean per year over that period.

The following data were compiled for each boat:

T3 Output tables: Output tables from the T3 process for the period of reference were provided by the IEO (OPAGAC purse seiners flagged in Spain, Indian and Atlantic oceans), SFA (OPAGAC purse seiners flagged in Seychelles, Indian Ocean), and Vanessa Rojo (staff from OPAGAC responsible for the statistics of OPAGAC's purse seiners not flagged in Spain). The format of the tables is reproduced in Annex 1. Data are presented in logbook format (i.e. one line per day/fishing activity with effort and catches by time, location species/size category). The table also contains information about the date(s) of unloading of the catches that were taken during each fishing trip. The following information was used from this record (fields recorded in bold red font in Annex 1):

ocean: Ocean of activity;
flag: Flag state of the vessel;
vescode: Vessel code as per FIBATO's classification (IEO/IRD Vessel Registry);
year_dbq: Year of unloading;
v_poids_capt_skj : Catch of skipjack tuna in metric tons;
v_poids_capt_yft_cat1: Catch of yellowfin tuna size category 1 (<10kg);
v_poids_capt_yft_cat2: Catch of yellowfin tuna size category 2 (10kg-30kg);
v_poids_capt_yft_cat3: Catch of yellowfin tuna size category 3 (≥30kg);
v_poids_capt_bet_cat1: Catch of bigeye tuna size category 1 (<10kg);
v_poids_capt_bet_cat2: Catch of bigeye tuna size category 2 (10kg-30kg);
v_poids_capt_bet_cat3: Catch of bigeye tuna size category 3 (≥30kg).

Sale slips from canning factories: Sale slips are documents produced by the canning factories of destination of the tuna caught by purse seiners. They reflect the amounts purchased, in weight, for each species and commercial category from each landing. They usually include several size categories for each species, depending on the canning factory. The format of the tables provided by the companies of OPAGAC is provided in Annex 2. The following information was used from the records sent (fields recorded in bold red font in Annex 2):

Nombre del buque: Name of the purse seiner;
Fecha de desembarco: Date of unloading;
Descarga completa? (Si/No): All catches unloaded? (Yes/No);
YFT>10kg: Catch yellowfin tuna ≥10kg;
YFT<10kg: Catch yellowfin tuna <10kg;
BET>10kg: Catch bigeye tuna ≥10kg;
BET<10kg: Catch bigeye tuna <10kg;
SKJ: Catch skipjack tuna.

The landing data collected from the above two sources was aggregated by ocean, boat, flag country (Spain, Seychelles, Other flags), year, and the following species and size categories:

Yellowfin and bigeye tuna weighting 10kg or more (AT≥10);
Yellowfin and bigeye tuna weighting less than 10kg (AT<10);
Skipjack tuna (SKJ).

2.2 Methods

Data were prepared as indicated in the previous section to be able to compare T3 estimates with sale slips for those species groups and size categories for which the weights recorded on sale slips are considered reliable. This is because each of the three groups used fetches a different price in the market, with the highest price paid for specimens AT≥10 and the lowest paid for skipjack tuna. The categories also match those T3 uses, as presented in Figure 1.

Once all data was compiled and aggregated as per the above categories, the two records were compared using simple tables and plots and several statistical tests, including:

- Concordance Correlation Coefficient (CCC): Measures the level of agreement between two continuous variables. A value equal to +1 corresponds to perfect agreement between two measurement methods. A value equal to 0 indicates that the two methods are independent to one another. A value of -1 points to a total mismatch between the two methods (Carrasco & Jover, 2004).
- Intraclass Correlation Coefficient (ICC): The intraclass correlation is commonly used to assess the consistency or reproducibility of quantitative measurements made by different observers measuring the same quantity. Quantifies the concordance between different measurements of a numerical variable. This coefficient estimates the average of the correlations between all possible ordinations of pairs of available observations. The value of ICC ranges from 0 to 1. Therefore, the maximum possible match corresponds to a value of ICC = 1. In this case, all observed variability would be explained by the differences between subjects and not by the differences between the measurement methods. On the other hand, the value ICC = 0 is obtained when the observed concordance is equal to the one that would be expected to occur only by chance (Pita Fernández & Pértegas Díaz, 2004). According to Pita Fernández & Pértegas Díaz (2004), concordance is very strong for values over 0.9, strong for values between 0.71-0. 9, moderately strong for values between 0.51-0.7, weak for values between 0.31-0.5 and poor or inexistent for values <0.31.
- Wilcoxon signed-rank test: A Wilcoxon signed-rank test is a nonparametric test that can be used to determine whether two dependent samples were selected from populations having the same distribution. It assumes that the scale of measurement for x and y has the properties of an equal-interval scale; that the differences between the paired values of x and y have been randomly drawn from the source population; and that the source population from which these differences have been drawn can be reasonably supposed to have a normal distribution. Two data samples are matched if they come from repeated observations of the same subject. Using the Wilcoxon Signed-Rank Test, we can decide whether the corresponding data population distributions are identical without assuming them to follow the normal distribution. The null hypothesis is

that the unloadings obtained from sale slips and T3 are from identical populations. The null hypothesis is rejected for p-values less than the .05 significance level.

- Paired t-test: A paired t-test is used to compare two population means where there are two samples in which observations in one sample can be paired with observations in the other sample. As above, the null hypothesis is rejected for p-values less than the .05 significance level.
  t-test statistisc value can be calculated using the following formula:

$$t = \frac{m}{s/\sqrt{n}}$$

  where,
  m is the mean differences
  n is the sample size (i.e., size of d).
  s is the standard deviation of d
- Bland and Altman method (B&A): The Bland and Altman method is a graphical procedure to evaluate the concordance between two measurement systems (Pita Fernández & Pértegas Díaz, 2004) and quantifies agreement between two quantitative measurements by constructing limits of agreement. These statistical limits are calculated by using the mean and the standard deviation (s) of the differences between two measurements. Bland-Altman plots are extensively used to evaluate two measurements techniques. Bland-Altman plots allow identification of any systematic difference between the measurements (i.e., fixed bias) or possible outliers. The mean difference is the estimated bias, and the SD of the differences measures the random fluctuations around this mean. If the mean value of the difference differs significantly from 0 on the basis of a 1-sample t-test, this indicates the presence of fixed bias. If there is a consistent bias, it can be adjusted for by subtracting the mean difference from the new method (Bland & Altman, 1986).

3. Results

3.1 Landings by flag group

Table 1 shows the species composition obtained from T3 estimates and sale slips by ocean (Top: Atlantic Ocean; Bottom: Indian Ocean), flag category (Right: Spain; Top left; various flags other than Spain; Bottom left: Seychelles), year (2011-2016, and all combined), and species group (AT≥10: YFT+BET ≥10kg; AT<10: YFT+BET <10kg; SKJ).

Spanish fleet: In the Atlantic Ocean, T3 seems to underestimate catches of tunas in the categories AT≥10kg and AT<10kg, while overestimating catches of skipjack tuna, with results that are consistent over the time-period in study. The same applies to the Indian Ocean, although in this case T3 appears to largely underestimate the catches of tunas AT≥10kg (T3: 24%; SSLIP: 31%) and overestimate the catches of skipjack tuna (T3: 50%; SSLIP: 40%), throughout the time series.

Other fleets: The same applies to the Atlantic Ocean although the differences between T3 and SSLIP tend to be lower. For the Seychelles fleet in the Indian Ocean estimates are similar than those for Spain, although differences are somewhat higher.

Figure 2 shows the percentage that each species group category made over the total landings recorded for the OPAGAC fleet during 2011-16, by ocean (RFMO area) and flag (Spain, Seychelles, Other flags), as obtained from sale slips (SS) and T3 output tables (T3). The corresponding values are recorded in Table 1 (Line Total).
As noted before (Table 1), the differences between T3 estimates and amounts on sale slips seem to be quite large.

In addition, the box plot charts shown in Figure 3a-d present median values (black horizontal line), 25th and 75th percentiles (box lower and upper margins), whiskers and outliers (as per R default definition) from the landings of tropical tunas available for the OPAGAC fleet, by boat and year (covering 2011-16), with data presented separately for sale slips (SS: orange bars) and T3 estimates (T3: green bars), broken by ocean (AO: Atlantic Ocean; IO: Indian Ocean) and flag group (ESP: Spain; SYC: Seychelles; OTH: Other flags).

Figure 3a shows that total catches of tropical tunas estimated using T3 and from sale slips are very similar across both oceans and groups of fleets, with only some slight differences recorded in the Indian Ocean. Overall, the difference is 1% or lower and therefore the landing reports that T3 uses seem to be accurate. As for the size categories presented in figures 3b-d they confirm the differences expressed before for each fleet and ocean.

3.2 Landings by year

Box plots in Figure 4 show total catches of tropical tunas and catches for each species and size group, by ocean and year. In general, there appears to be consistency in the magnitude of the bias recorded for each species group and size class over the time period. However, those differences seem to have been higher since 2014 in the Indian Ocean and 2015 in the Atlantic Ocean, especially regarding the category AT<10 kg.

3.3 Landings by ownership

Figure 5 presents box plots by ocean and ownership group. In the same way, the magnitude of the bias seems to be consistent for all ownership groups and categories under consideration.

3.4 Statistical tests

The following sections show the results of the statistical tests performed to assess the concordance of T3 estimates and sale slip data in absolute (Absolute values) and relative terms (Relative values category <10kg). The difference between the two is that in the former the analysis compares the final estimates of catch from both methods regardless of the cumulative impact that the bias in estimates for the size category >10kg may have on the estimates of the amounts of AT<10 kg and SKJ; while the latter assess solely the difference in estimates of SKJ and AT<10 kg within the category <10kg.

Thus, the purpose of the first analysis is to assess the potential bias of final estimates of catch while the second assess the potential bias of estimates of juvenile fish which will point to problems in sampling design or its implementation (i.e. the species composition obtained from sampling data differs from the real species composition of the category <10 kg).

3.4.1 Absolute values

Table 2 shows the results of the concordance (CCC and CCI), Wilcoxon signed-rank, paired t- and Bland and Altman tests performed for the above data, with Bland and Altman dispersion and difference plots presented in Figures 6a-d (by species group, ocean and for all flags combined) and Annex 3 (Figure 8, details by flag).

Both concordance analysis show a high level of correlation between T3 results and Sale Slips, with moderate-low levels of correlation only obtained for the Seychelles fleet in the Indian Ocean, in particular for the category AT≥10kg. This is probably because Concordance correlation methods tend to be highly sensitive to sample heterogeneity (Giavarina 2015) which may originate from vessels having different targeting practices (free versus associated schools) and/or fishing grounds (e.g. number of access agreements each vessel has secured to operate the ZEE of coastal states).

The results from paired t-test, Wilcoxon signed-rank test and Bland and Altman method presented in Table 2 and plots (Figure 6a-d; Annex 3, Figure 8) are useful to appreciate how catches estimated using T3 may be biased. Thus, the ρ-values obtained from the two former are only significant (ρ-values higher than 0.05) when the total unloadings for all three tropical tunas combined are compared, being well below significance levels in all other cases. This proves that catches from sale slips and T3 estimates differ and that difference cannot be attributed to chance. This is also shown through the deviation from average landing values presented in Table 4 (B&Ad), and Bland and Altman plots (Figures 6 & 8), where that difference is expressed in absolute terms (mid panel) and as the percentage deviation (right panel) that amounts on sale slips represent when compared to average values from the two records (Bland and Altman method). Thus, the distance between the continuous horizontal black line and the broken horizontal black line shows the absolute systematic error (in % and absolute).

Both dispersion and Bland and Altman plots for total catches of tropical tunas tend to indicate that estimates of total catches by both systems are very similar and not likely to be subject to error.

On the contrary, the analysis run for each commercial category appears to indicate that T3 estimates may be subject to bias of various magnitudes, depending on the size category, fleet, and ocean under consideration. The largest potential biases relate to the category AT≥10 kg in the Indian Ocean (≈35%, Figure 6b, bottom) and, to a lesser extent, Atlantic Ocean (≈15%, Figure 6b, top), with T3 grossly underestimating catches under this category.

On the contrary, estimates for the category AT<10 kg seem to be subject to higher bias in the Atlantic Ocean (≈25%, Figure 6c, top) than in the Indian Ocean (≈10%, Figure 6c, bottom), with large unloadings prone to bias of higher magnitude than small unloadings (dispersion plot Figure 6c). As for skipjack tuna, it is also subject to a potentially large bias, higher in the Indian Ocean (>20%) than in the Atlantic Ocean (≈10%).

It is important to note that Figure 6 shows results by ocean and all flags combined while Table 2 and Figure 8 present results by flag, and the magnitude of the bias may vary depending on the flag group. However, there does not seem to be a large deviation between the results presented below and those for each individual fleet (see figures in Annex 3, Figure 8).

3.4.2 Relative values category < 10kg

The Bland & Altman plots presented in Figures 7a-b and Figure 9 show similar results to those obtained in the previous section (Figures 6 and 8) with a clear bias towards underestimation of juvenile bigeye and yellowfin tunas versus overestimation of skipjack tuna when sampling data is used. However, in this case, the magnitude of the bias is very similar in both oceans, representing around 10% in terms of overestimation of SKJ and around 20% of underestimation of tuna in the category AT<10kg. As indicated before, this would indicate that the European sampling fails to capture the species composition of tuna <10 kg, for at least the breakdown of catches of skipjack tuna and those of YFT+BET combined (the breakdown of YFT and BET within this category was not compared as the accuracy of sale slips is unknown).

3.5 Likely impact on catch-at-size data (Indian Ocean)

3.5.1 Consistency of Catch-at-Size data

Catch-at-size and catch-and-effort data reported by EU and Seychelles to the IOTC was used to assess the consequences on length frequency distributions of the bias identified through comparison of catches of tropical tunas estimated using T3 and reported in sale slips. To do this, the number of fish sampled per size class reported by the EU and Seychelles as catch-at-size was converted to weight using the length-weight equations available for European purse seiners, for each species, as reported by Chassot *et al*. (2016). However, although the EU and Seychelles report catch-at-size tables to the IOTC (i.e. the available length frequency samples are raised to represent total catch) the catches estimated using this procedure differed substantially from the catches reported in the catch-and-effort file (Figure 10), which also represent the total catch estimated for the fishery, and match those reported as nominal catch for EU and Seychelles.

Figure 10 shows how catches estimated using the available catch-at-size data and Chasot *et al*. (2016) equations differ from the catches reported by each IOTC CPC in the catch-and-effort file, for the entire time-series (1981-2017). The difference is expressed as the percentage the difference between weights estimated using catch-at-size data and catches in the catch-and-effort file represent for each species and year. Thus, a negative value in Figure 10 means that weights estimated from catch-at-size data are higher than those obtained from the catch-and-effort file, and the contrary applies to positive values (weights from catch-at-size smaller). While weights estimated from catch-at-size tend to be higher than those from catch-and-effort, this and the magnitude of the differences is not consistent over the time series or for the EU and Seychelles. Thus, three periods can be identified for the EU (from 1981 to 1990; from 1991 to 2012; from 2013 to date); and three for Seychelles (from 1997 to 2013, excluding 2007 in which many catch-at-size records seem to be missing; from 2014 to 2016; 2017). Furthermore, a good match between catch estimates from both tables seem to occur only in 2017 for the Seychelles fleet (Figure 10b).

Figure 11 shows the difference in estimates considering all 5 degrees square and month strata for EU and Seychelles purse seiners for which catches are available in the catch-and-effort file, for each year and species, over the entire time-series (1981-2011). The strata from both EU and Seychelles are combined in this case as the main purpose of this is to assess the amount of strata for which estimates match (the difference between CAS and CE represents less than 1% of the catch reported as CE) and those for which that difference is higher, in order of magnitude (1-5%; 5-20%; >20%; total lack of catch-at-size data).

The following issues shall be pointed out:

- Complete lack of catch-at-size data for some CE strata: overall, 15% of the strata for which CE exists does not have catch-at-size data (Figure 11, the three species). Although in recent years the number of empty CAS strata seems to be lower, the reasons why no CAS is available for such a large number of strata is unknown;

- Large amount of strata showing a high difference between catches estimated from CAS and those reported as CE: overall, the magnitude of the difference between CAS and CE was over 5% of the weight in between 50% (BET) and 70% (SKJ) of the strata (excluding those strata included above). This means that the difference in weight between CAS and CE is 5% or lower for just 14 (SKJ)-32 (BET)% of the strata; and lower than 1% only for 5% (all species) of them. This points to problems with the estimation procedure and/or inconsistent use of length-weight equations over the time series;
- Lack of consistency in the magnitude of the differences over the time series: This is covered before (Figure 10) and points to the fact that the bias in estimates is not systematic, which makes it more difficult to address. This may be due to the use of different software packages for the estimate of CAS and lack of historical reviews, over the entire time-series, when new data has become available. The fact that the only year for which CAS and CE match is 2017 for the Seychelles seem to confirm this point.

3.5.2 Potential bias to length distribution

Figure 12a-c show the length frequency distributions of YFT, BET and SKJ for the period 2011-16 (data combined for EU and Seychelles) reported by the EU (T3) and the same corrected for the biases estimated by species and size category (≥10kg and <10kg). The adjustment does not consider the biases indicated in 3.5.1 or the fact that length samples may also be biased within each size category, only accounting for the biases in catch and size class presented in Table 1.

As indicated, this results in more specimens of YFT and BET per length class, with proportionally more fish on the category ≥10kg, and less specimens of SKJ over the entire length distribution. The consequences of these changes on the selectivity of the purse seine gear were not assessed and warrant further examination.

4. Discussion

The following points can be drawn from the results presented in this study:

- **The total combined landings of tropical tunas T3 uses for the OPAGAC fleet** (Table 2 & Figure 3a), **are similar to those obtained from sale slips**, with no large deviations detected; the deviations recorded are likely to originate from weighing of the fish at unloading, which T3 uses, and weights recorded in the canning factories of destination; however, the fact that total landings for both T3 and sale slips come from the same source (fishing industry) warrant for the reason of the existing discrepancies to be further investigated and selection of data from the best source used for future estimates;
- **T3 appears to underestimate, to a much larger degree in the Indian Ocean, the amount of yellowfin tuna and bigeye tuna of over 10kg unloaded** (Tables 1-2, Figures 3b, 5b, 6b); considering that T3 relies on the amounts of large tuna (AT≥10 kg) reported in vessel logbooks/well maps rather than landing statistics, this points to a potential bias due to a **likely underreporting of large fish on logbooks**; the fact that the difference is larger in the Indian Ocean, where there seems to be a larger amount of fish of intermediate sizes (between 10-20kg) tends to confirm that skipper logbooks/well maps do not record accurately the amount of large fish, leading to T3 underestimating this component; this has also consequences on the amounts that are estimated for other species (next point);
- **T3 appears to overestimate the catches of skipjack tuna and underestimate the catches of small yellowfin and bigeye tuna** (Tables 1-2, Figures 3c-d, 5c-d, 6c-d, 7a-b); as indicated previously, skipjack tuna tends to fetch a lower market price than small yellowfin and bigeye tunas and therefore the amounts of SKJ on sale slips are considered reliable, or at least a good approximation to the highest possible amount unloaded for this species, as some canning factories may record some juvenile YFT and BET as part of the SKJ component in order to purchase the fish at a lower price (never the contrary); thus, the differences between sale slips and T3 estimates point to **issues related with sampling protocols and/or poor implementation of sampling in port**.
- **Potential lack of consistency in the use of length-weight equations over the time-series** (Figures 10-11): The accuracy of T3 estimates relies highly on the relationships that are used to convert length measurements into weight for each species and size category (Marsac *et al.*, 2017). However, the

deviations shown in figures 10-11 point to **the use of more than one set of length-weight equations over the time-series probably as a consequence of the time-series of catch and catch-at-size being only partially updated following changes in length-weight equations for one or more species.** In addition, **the set of equations currently in use could be subject to bias, especially for the smaller sizes of yellowfin tuna and bigeye tuna (<10kg),** with a likely overestimation of weights**.** This is in line with Garner and Copp (1997) who indicate that length-weight relationships could be affected by changes in the ontogeny of the fish throughout their life story. This calls for a review of the existing length-weight equations (Chassot *et al*. 2016), and evaluation of whether more accurate estimates of weight could be obtained through the use of size class dependent length-weight relationships or other alternative procedures.

Tables 3a-b illustrate the potential consequences that the confirmation of the biases identified in this document would have on the catches recorded by ICCAT (3a) and IOTC (3b) for purse seine fleets covered by the European sampling scheme. For this comparison, nominal catch data from the ICCAT and IOTC databases was downloaded and catches extracted for all purse seine fleets that are covered through the European sampling scheme and catch estimation procedures (T3), assuming that all fleets are subject to the same bias than the OPAGAC fleet.

As presented in Table 3a, **the ICCAT database may record catches of yellowfin tuna and bigeye tuna well below the values that would be expected if the biases identified in this analysis are confirmed**. Thus, YFT catches for the period 2011-2016 may have been between 7,000 and 10,000 tons, with recent years showing a higher difference. The difference between reported and corrected catches is also high for the BET, with corrected catches around 3,000 tons higher than recorded catches, over the time-period. As for SKJ, the difference between recorded and corrected catches ranges between 10,000-15,000 tons, with the highest difference recorded in 2016.

Table 3b shows that **recorded and corrected catches differ by a greater order of magnitude in the Indian Ocean**, including differences between 20,000-30,000 tons for YFT (higher corrected catches); 1,000-4,000 tons for the BET (higher corrected catches): and 20,000-30,000 for the SKJ (lower corrected catches).

In addition to the above, the potential bias identified in the catches and size categories of yellowfin and bigeye tuna would translate into catch-at-size tables showing different size distributions than the ones currently existing (Figure 12), with a higher amount of specimens of sizes equivalent to weights 10kg or over and less than 10 kg, with a lower increase for the latter. This could have **marked consequences on estimates of catch by species and selectivity for the purse seine gear; and stock assessments and advice for those species**.

5. Conclusion

This document represents a first attempt to explore potential differences between the catches of tropical tunas estimated using the European software T3 and those recorded on sale slips completed by the canning factories purchasing fish from 48 vessels registered with OPAGAC in the Atlantic and Indian oceans, over the period 2011-16.

Although the study is preliminary and the available datasets need to be further explored and cross-verified with actual monitoring of fish in processing plants, the results obtained indicate that the system European scientists use to sample purse seine landings and estimate catches and catch-at-size could be subject to bias which, if confirmed, could have consequences on the statistics, stock assessments, management advice, and management measures adopted by both organizations.

As the discrepancies are further investigated through the use of sale slip data of higher resolution (by individual trip, fishing mode, destination market, etc.), plant sampling and details from vessel logbooks and T3 output (catches by trip by fishing mode by species and size), it is advisable that the ICCAT and the IOTC consider contemplating alternative scenarios of catch and size frequency distributions in assessing the status of the stocks of tropical tunas, through the incorporation of catch series and catch-at-size matrices adjusted for the biases identified in this study. Considering that European scientists adopted the existing sampling scheme in 1998, it is recommended that alternative scenarios contemplate extending the time-series for as long as required.

The results of this study, while preliminary, stress the need for a thorough review of the sampling and catch estimation protocols European scientists have been using since 1998. In conducting this review, European

scientists should contemplate verifying the validity of T3 to estimate the catches of individual vessels, especially where those estimates are used for purposes like quota monitoring. The results of this study and previous work seem to invalidate its use for that purpose.

6. Acknowledgments

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Table 1: Species composition (percentage) estimated using T3 and obtained from sale slips, for vessel unloadings of the OPAGAC fleet during 2011-2016, by flag group, year and species group, and totals estimated from all unloadings.

	Spain	T3			SSLIP			Other	T3			SSLIP		
		AT>10	SKJ	AT<10	AT>10	SKJ	AT<10		AT>10	SKJ	AT<10	AT>10	SKJ	AT<10
ATLANTIC OCEAN	2011	25	61	15	31	52	18	2011	23	60	17	23	55	22
	2012	21	67	12	24	62	14	2012	26	62	12	27	57	17
	2013	17	74	9	20	69	11	2013	20	69	11	21	63	16
	2014	19	67	13	25	58	18	2014	22	67	11	23	66	11
	2015	20	62	17	23	51	26	2015	19	66	14	21	60	20
	2016	22	63	15	28	53	18	2016	19	66	15	22	56	22
	Total	21	66	14	25	58	18	Total	21	65	13	23	60	18
	Spain	T3			SSLIP			Seychelles	T3			SSLIP		
		AT>10	SKJ	AT<10	AT>10	SKJ	AT<10		AT>10	SKJ	AT<10	AT>10	SKJ	AT<10
INDIAN OCEAN	2011	20	53	27	29	44	28	2011	21	51	28	30	41	29
	2012	36	40	25	46	29	25	2012	36	40	24	44	30	26
	2013	*na*	*na*	*na*	*na*	*na*	*na*	2013	15	46	39	28	40	32
	2014	21	51	28	28	41	30	2014	16	55	28	27	45	29
	2015	29	47	24	35	35	30	2015	24	48	27	34	33	33
	2016	18	55	27	24	46	31	2016	12	59	29	20	50	30
	Total	24	50	26	31	40	29	Total	21	51	29	30	40	30

Table 2: Results from the Concordance Correlation Coefficient (CCC) of Lind and Intraclass Correlation Coefficient (ICC) analysis; and deviation from the mean (MT) estimated using Bland and Altman (B&A) analysis; results include point (ρ_c; ρ_i) and lower bound (LB) and upper bound (UB) estimates for each test. Data are presented by Ocean, Flag group (Spain/Other), and for all flags combined (All).

Top left: Total unloadings for the three tropical tuna species combined

Top right: Unloadings of Yellowfin tuna and Bigeye tuna of 10kg and above

Bottom left: Unloadings of Yellowfin tuna and Bigeye tuna of under 10kg

Bottom right: Unloadings of skipjack tuna (of under 10kg)

Com. Cat.	Total Unloaded Tropical Tunas						Yellowfin/Bigeye tuna ≥10kg (AT≥10)					
Ocean	Atlantic Ocean			Indian Ocean			Atlantic Ocean			Indian Ocean		
Flag	Spain	Other	All	Spain	Other	All	Spain	Other	All	Spain	Other	All
$CCC\rho_c$	**0.99**	**0.97**	**0.98**	**0.96**	**0.94**	**0.95**	**0.92**	**0.93**	**0.93**	**0.83**	**0.62**	**0.74**
CCC_{LB}	*0.97*	*0.95*	*0.97*	*0.82*	*0.86*	*0.90*	*0.81*	*0.90*	*0.88*	*0.74*	*0.44*	*0.64*
CCC_{UB}	*0.99*	*0.98*	*0.99*	*0.99*	*0.98*	*0.98*	*0.97*	*0.95*	*0.95*	*0.89*	*0.75*	*0.82*
$ICC\rho_i$	**0.99**	**0.97**	**0.98**	**0.96**	**0.94**	**0.95**	**0.93**	**0.93**	**0.93**	**0.82**	**0.56**	**0.72**
ICC_{LB}	*0.97*	*0.95*	*0.97*	*0.93*	*0.88*	*0.92*	*0.85*	*0.89*	*0.89*	*0.67*	*0.24*	*0.57*
ICC_{UB}	*0.99*	*0.98*	*0.99*	*0.98*	*0.97*	*0.97*	*0.97*	*0.96*	*0.95*	*0.91*	*0.77*	*0.82*
WSRTρ	**0.24**	**0.27**	**0.15**	**0.15**	**0.17**	**0.95**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
t	*-0.7*	*-1.1*	*-1.3*	*0.5*	*-1.6*	*-0.8*	*-4.5*	*-3.5*	*-5.3*	*-8.5*	*-7.1*	*-10.7*
df	*25*	*67*	*93*	*33*	*26*	*60*	*25*	*67*	*93*	*33*	*26*	*60*
ρ	**0.52**	**0.27**	**0.20**	**0.65**	**0.12**	**0.40**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
CI_L	*-339*	*-208*	*-194*	*-236*	*-734*	*-351*	*-418*	*-156*	*-207*	*-852*	*-1219*	*-953*
CI_U	*176*	*60*	*42*	*374*	*87*	*142*	*-156*	*-42*	*-95*	*-524*	*-674*	*-652*
$B\&A_d$	**82**	**74**	**76**	**-69**	**323**	**105**	**287**	**99**	**151**	**688**	**946**	**802**
$B\&A_{LB}$	*-1193*	*-1033*	*-1073*	*-1819*	*-1754*	*-1821*	*-363*	*-373*	*-399*	*-251*	*-432*	*-370*
$B\&A_{UB}$	*1357*	*1180*	*1225*	*1682*	*2400*	*2031*	*936*	*572*	*701*	*1628*	*2324*	*1975*

Com. Cat.	Yellowfin/Bigeye tuna <10kg (AT<10)						Skipjack tuna (SKJ)					
Ocean	Atlantic Ocean			Indian Ocean			Atlantic Ocean			Indian Ocean		
Flag	Spain	Other	All	Spain	Other	All	Spain	Other	All	Spain	Other	All
$CCC\rho_c$	**0.76**	**0.63**	**0.67**	**0.85**	**0.88**	**0.87**	**0.97**	**0.94**	**0.95**	**0.79**	**0.81**	**0.79**
CCC_{LB}	*0.61*	*0.52*	*0.59*	*0.69*	*0.75*	*0.78*	*0.94*	*0.91*	*0.93*	*0.67*	*0.64*	*0.71*
CCC_{UB}	*0.86*	*0.72*	*0.74*	*0.93*	*0.94*	*0.92*	*0.98*	*0.97*	*0.97*	*0.87*	*0.90*	*0.86*
$ICC\rho_i$	**0.75**	**0.59**	**0.64**	**0.85**	**0.88**	**0.86**	**0.97**	**0.94**	**0.95**	**0.77**	**0.79**	**0.78**
ICC_{LB}	*0.52*	*0.42*	*0.51*	*0.73*	*0.76*	*0.78*	*0.93*	*0.91*	*0.93*	*0.59*	*0.60*	*0.65*
ICC_{UB}	*0.88*	*0.73*	*0.75*	*0.92*	*0.94*	*0.92*	*0.99*	*0.96*	*0.97*	*0.88*	*0.90*	*0.86*
WSRTρ	**0.00**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
t	*-4.7*	*-8.4*	*-9.7*	*-3.1*	*-2.7*	*-4.2*	*4.9*	*5.6*	*7.4*	*10.4*	*6.4*	*11.7*
df	*25*	*67*	*93*	*33*	*26*	*60*	*25*	*67*	*93*	*33*	*26*	*60*
ρ	**0.00**	**0.00**	**0.00**	**0.00**	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
CI_L	*-388*	*-390*	*-365*	*-402*	*-406*	*-352*	*277*	*220*	*276*	*805*	*579*	*776*
CI_U	*-152*	*-241*	*-241*	*-86*	*-55*	*-124*	*673*	*462*	*480*	*1198*	*1128*	*1096*
$B\&A_d$	**270**	**315**	**303**	**244**	**230**	**238**	**-475**	**-341**	**-378**	**-1002**	**-853**	**-936**
$B\&A_{LB}$	*-315*	*-301*	*-303*	*-662*	*-656*	*-652*	*-1456*	*-1340*	*-1374*	*-2128*	*-2241*	*-2183*
$B\&A_{UB}$	*856*	*932*	*909*	*1151*	*1116*	*1128*	*506*	*659*	*619*	*125*	*535*	*311*

Table 3a: Catches of tropical tunas recorded in the ICCAT database for purse seine fleets under the European sampling and catch estimation scheme (YFTr, BETr, SKJr); and catches corrected using the results obtained from the present analysis (YFTr, BETr, SKJr). Catches (metric tons) are presented by ocean, species and year.

ICCAT	PS EU+OTHER REPORTED			PS EU+OTHER CORRECTED		
	YFTr	BETr	SKJr	YFTc	BETc	SKJc
2011	54,935	19,724	96,581	61,948	23,073	86,218
2012	57,302	17,463	105,580	64,995	20,548	94,802
2013	48,932	16,395	119,282	56,328	19,579	108,702
2014	55,061	17,059	110,210	62,743	20,166	99,421
2015	65,172	15,382	116,639	74,087	18,139	104,966
2016	79,213	21,351	140,132	89,809	25,112	125,774

Table 3b: Catches of tropical tunas recorded in the IOTC database for purse seine fleets under the European sampling and catch estimation scheme (YFTr, BETr, SKJr); and catches corrected using the results obtained from the present analysis (YFTr, BETr, SKJr). Catches (metric tons) are presented by ocean, species and year.

IOTC	PS EU+SYC REPORTED			PS EU+SYC CORRECTED		
	YFTr	BETr	SKJr	YFTc	BETc	SKJc
2011	98,630	19,302	118,098	121,195	22,875	91,961
2012	108,697	14,132	72,885	126,242	15,830	53,643
2013	116,255	23,159	104,357	138,429	26,597	78,745
2014	114,868	18,264	118,645	139,266	21,356	91,155
2015	122,750	21,729	119,107	147,615	25,203	90,768
2016	125,222	20,100	166,886	156,154	24,175	131,880

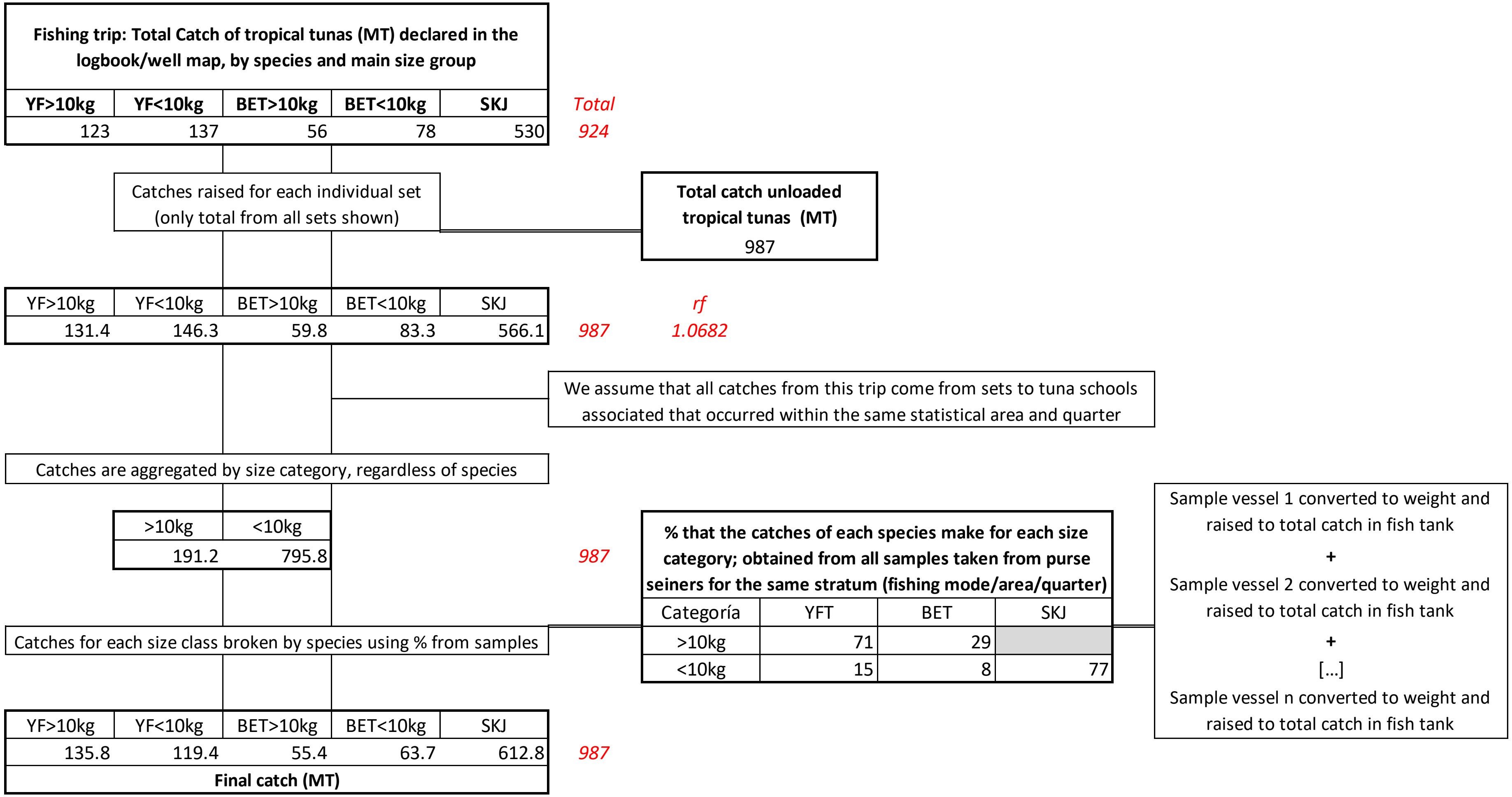


Figure 1: Flow chart summarising the procedure used by European and Seychelles scientists to estimate catches by species and size for the tuna purse seine fishery in the Atlantic and Indian oceans.

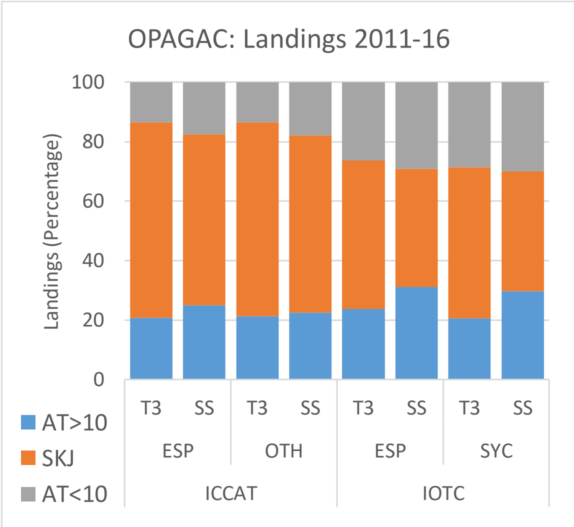


Figure 2: Contribution (percentage) that each species group category made over the total catches unloaded by the OPAGAC fleet during 2011-16, by type of document (Sale Slips (SS) or T3 estimates), RFMO Area and Flag group.

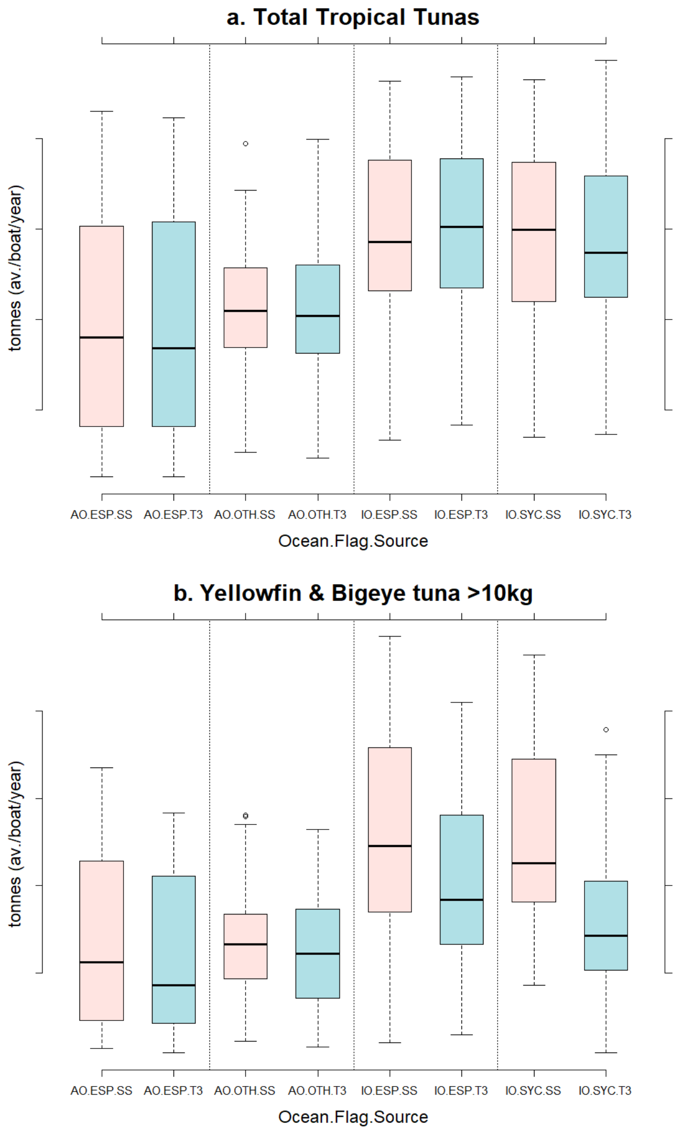


Figure 3: Box plots showing catches unloaded (in metric tons) per boat, ocean (AO: Atlantic Ocean; IO: Indian Ocean) and flag group for the OPAGAC fleet, over the period 2011-16.

a. Total catches of tropical tunas unloaded: shows box plots for total catches of tropical tunas unloaded per boat per year, with box plots presented in pairs including Sale Slips (SS: orange boxes) and T3 estimates (T3: green boxes);

b. Catches of specimens of yellowfin tuna and bigeye tuna weighing 10 kg or more: as above but only for large specimens of YFT & BET (AT≥10 kg);

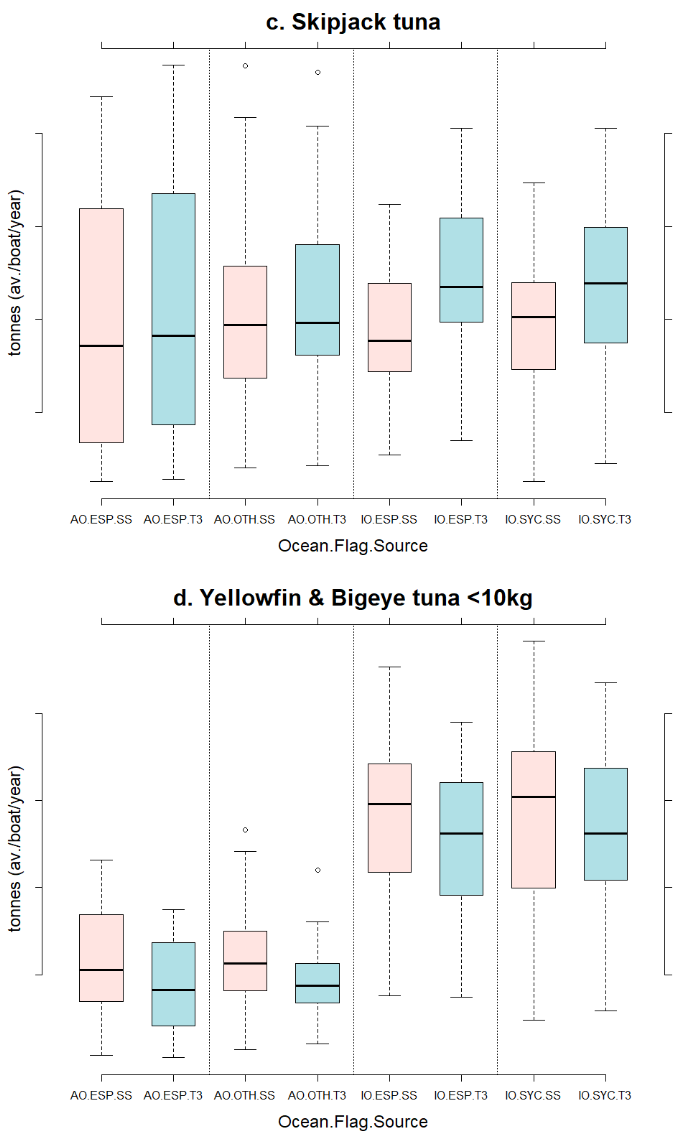


Figure 3(cont.): Box plots showing catches unloaded (in metric tons) per boat, ocean (AO: Atlantic Ocean; IO: Indian Ocean) and flag group for the OPAGAC fleet, over the period 2011-16.

c. Catches of specimens of skipjack tuna: as above but only for specimens of SKJ, with all specimens assumed to belong to the category <10kg;

d. Catches of specimens of yellowfin tuna and bigeye tuna weighing less than 10 kg: as above but only for small specimens of YFT & BET (AT<10 kg).

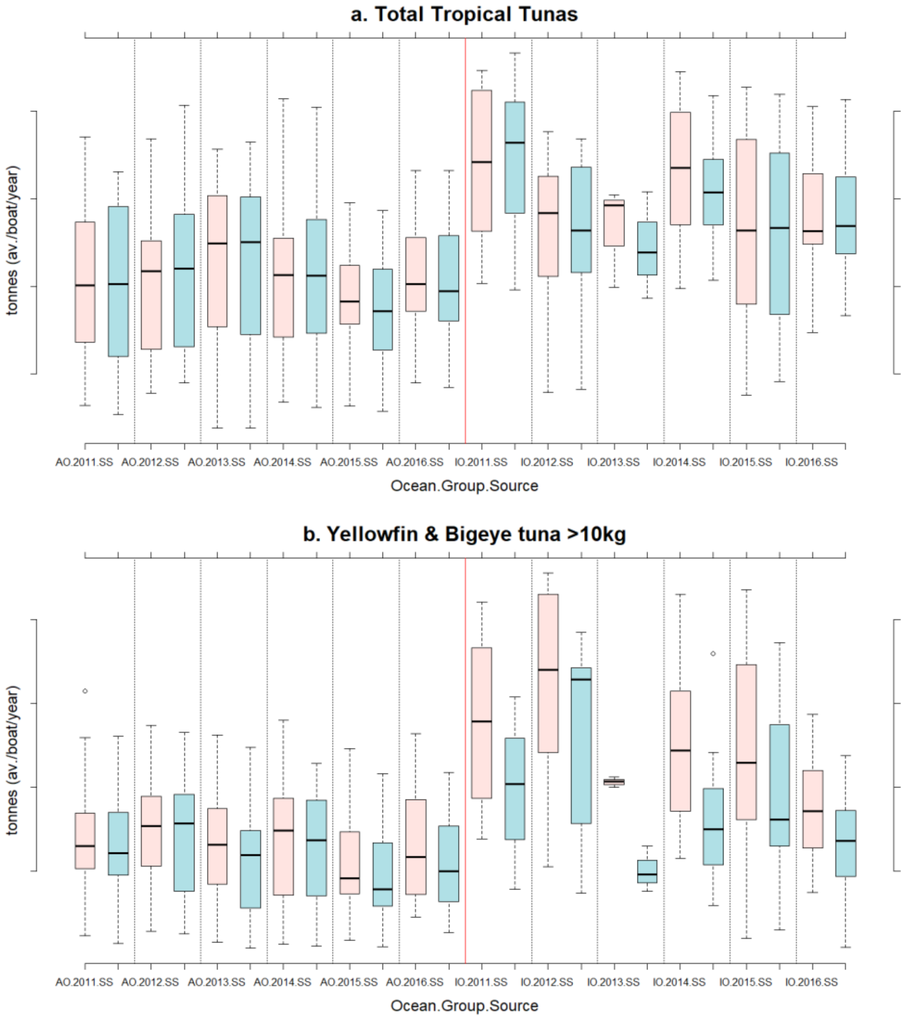
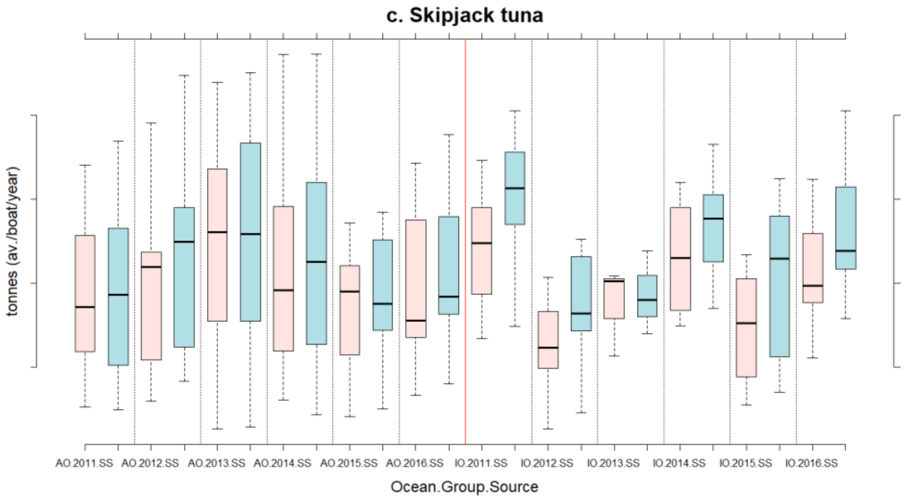


Figure 4: Box plots showing catches unloaded (in metric tons) per boat, ocean (AO: Atlantic Ocean; IO: Indian Ocean) and year for the OPAGAC fleet, over the period 2011-16.

a. Total catches of tropical tunas unloaded: shows box plots for total catches of tropical tunas unloaded per ocean per year, with box plots presented in pairs including Sale Slips (SS: orange boxes) and T3 estimates (T3: green boxes);

b. Catches of specimens of yellowfin tuna and bigeye tuna weighing 10 kg or more: as above but only for large specimens of YFT & BET (AT≥10 kg);



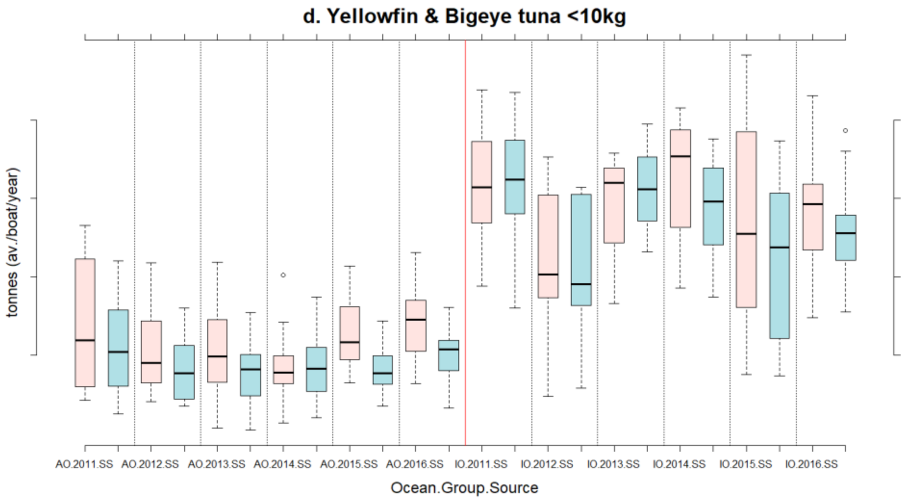
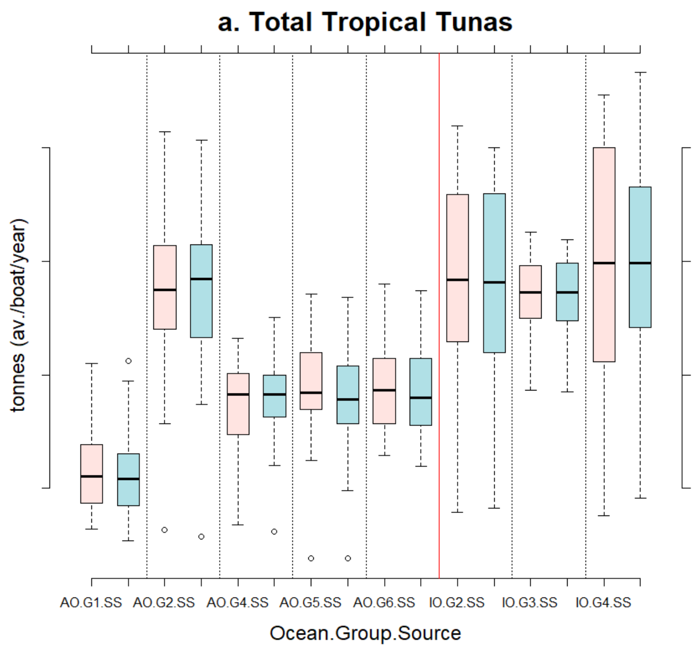


Figure 4(cont.)**:** Box plots showing catches unloaded (in metric tons) per boat, ocean (AO: Atlantic Ocean; IO: Indian Ocean) and year for the OPAGAC fleet, over the period 2011-16.

c. Catches of specimens of skipjack tuna: as above but only for specimens of SKJ, with all specimens assumed to belong to the category <10kg;

d. Catches of specimens of yellowfin tuna and bigeye tuna weighing less than 10 kg: as above but only for small specimens of YFT & BET (AT<10 kg).



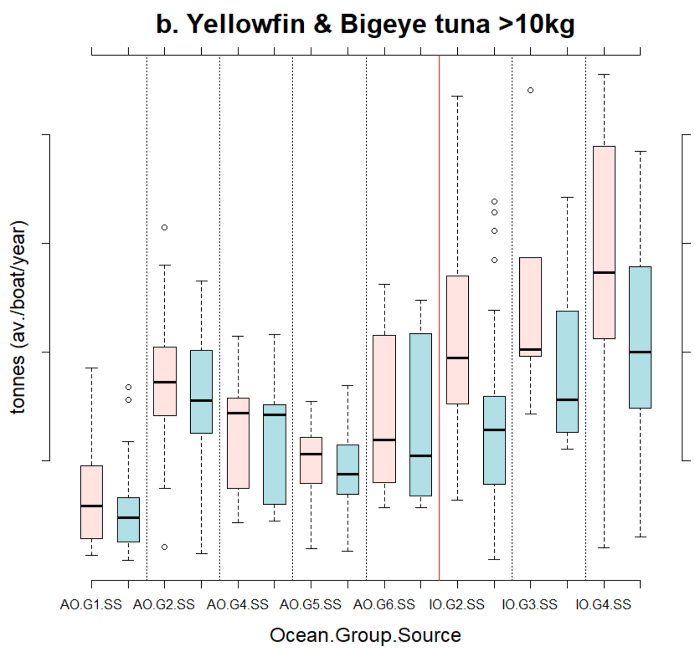
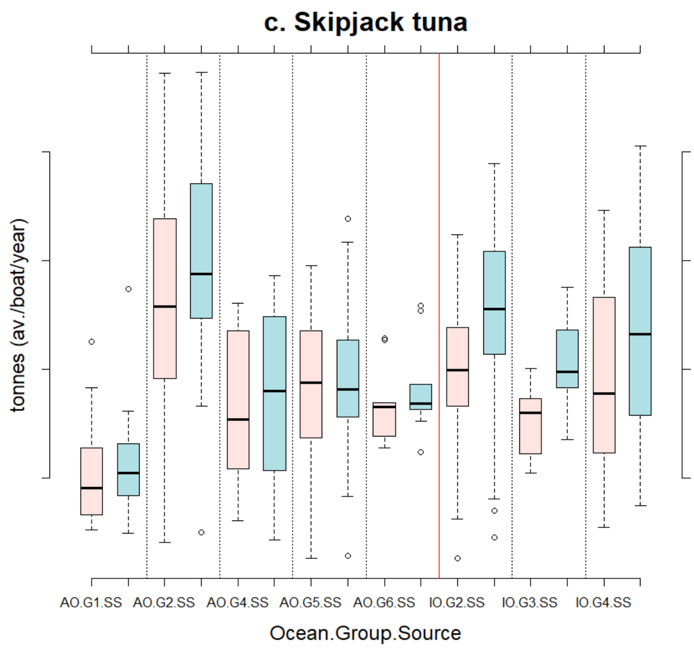


Figure 5: Box plots showing catches unloaded (in metric tons) per boat, ocean (AO: Atlantic Ocean; IO: Indian Ocean) and ownership for the OPAGAC fleet, over the period 2011-16.

a. Total catches of tropical tunas unloaded: shows box plots for total catches of tropical tunas unloaded per ownership per year, with box plots presented in pairs including Sale Slips (SS: orange boxes) and T3 estimates (T3: green boxes);

b. Catches of specimens of yellowfin tuna and bigeye tuna weighing 10 kg or more: as above but only for large specimens of YFT & BET (AT≥10 kg);



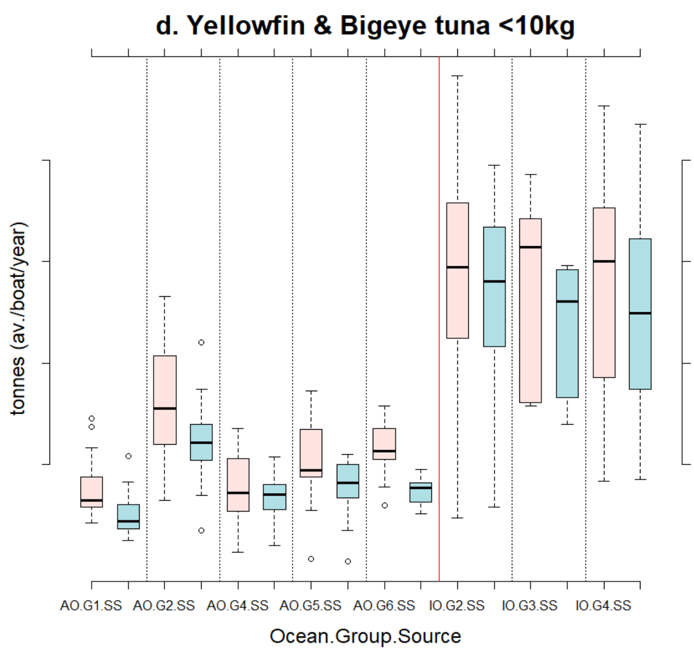


Figure 5(cont.)**:** Box plots showing catches unloaded (in metric tons) per boat, ocean (AO: Atlantic Ocean; IO: Indian Ocean) and ownership for the OPAGAC fleet, over the period 2011-16.

c. Catches of specimens of skipjack tuna: as above but only for specimens of SKJ, with all specimens assumed to belong to the category <10kg;

d. Catches of specimens of yellowfin tuna and bigeye tuna weighing less than 10 kg: as above but only for small specimens of YFT & BET (AT<10 kg).

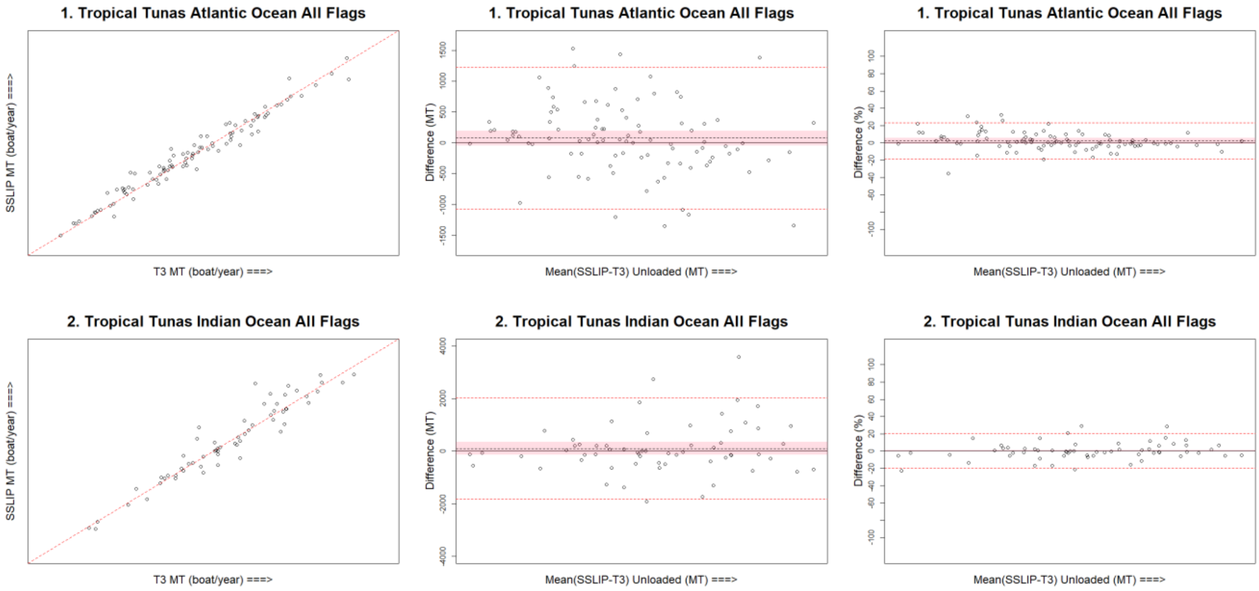


Figure 6a: Dispersion and difference Bland and Altman plots used to compare T3 estimates and unloadings of tropical tunas obtained from sale slips provided by the OPAGAC fleet for the period 2011-16, by RFMO Area (ICCAT [1]; IOTC [2]).

Left panel: Unloadings estimated using T3 (x axis) versus those obtained from sale slips (y axis), with line of equality.

Mid panel: Plot of differences (metric tons per vessel per year) between T3 estimates and sale slip data versus the mean of the two measurements (av(Sale Slip – T3)). The bias is represented by the gap between the x axis corresponding to a zero differences, and the parallel broken black line to the x axis. Confidence intervals (metric tons) are represented through the pink-shaded area and 1.96*se (metric tons) through the broken red lines.

Right panel: Plot of differences (%) between T3 estimates and sale slip data versus the mean of the two measurements (av(Sale Slip – T3)). The bias is represented by the gap between the x axis corresponding to a zero differences, and the parallel broken black line to the x axis. Confidence intervals (%) are represented through the pink-shaded area and 1.96*se (%) through the broken red lines.

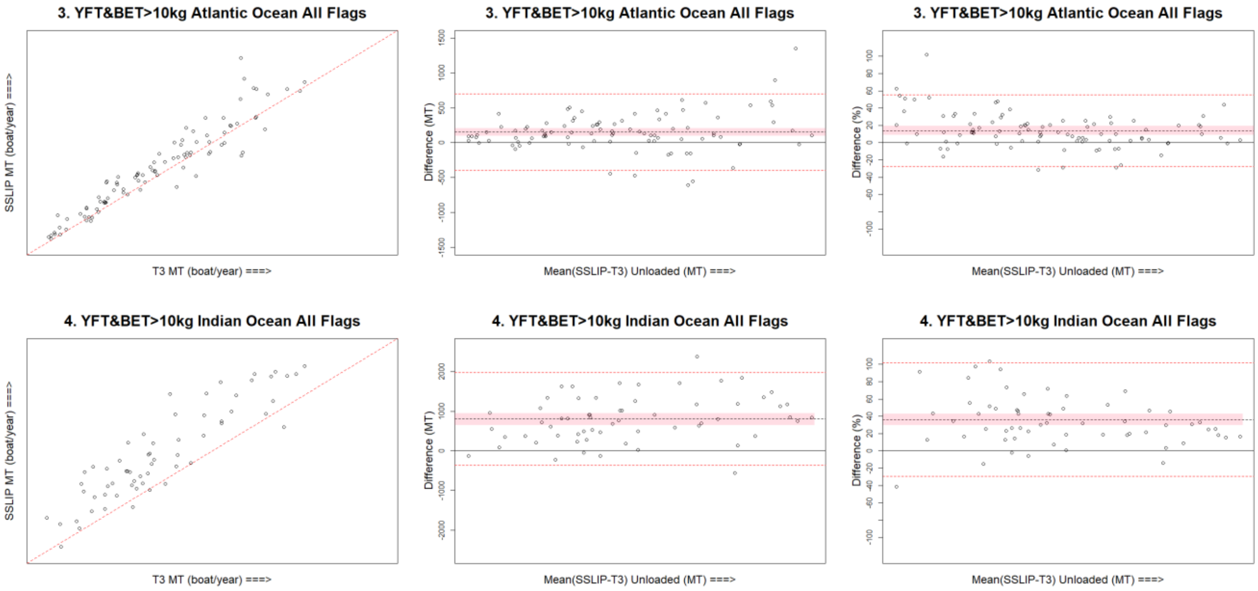


Figure 6b: Dispersion and difference Bland and Altman plots used to compare T3 estimates and unloadings of yellowfin tuna and bigeye tuna ≥10kg (AT≥10 kg) obtained from sale slips provided by the OPAGAC fleet for the period 2011-16, by RFMO Area (ICCAT [3]; IOTC [4]).

Left panel: Unloadings estimated using T3 (x axis) versus those obtained from sale slips (y axis), with line of equality.
Mid panel: Plot of differences (metric tons per vessel per year) between T3 estimates and sale slip data versus the mean of the two measurements (av(Sale Slip – T3)). The bias is represented by the gap between the x axis corresponding to a zero differences, and the parallel broken black line to the x axis. Confidence intervals (metric tons) are represented through the pink-shaded area and 1.96*se (metric tons) through the broken red lines.
Right panel: Plot of differences (%) between T3 estimates and sale slip data versus the mean of the two measurements (av(Sale Slip – T3)). The bias is represented by the gap between the x axis corresponding to a zero differences, and the parallel broken black line to the x axis. Confidence intervals (%) are represented through the pink-shaded area and 1.96*se (%) through the broken red lines.

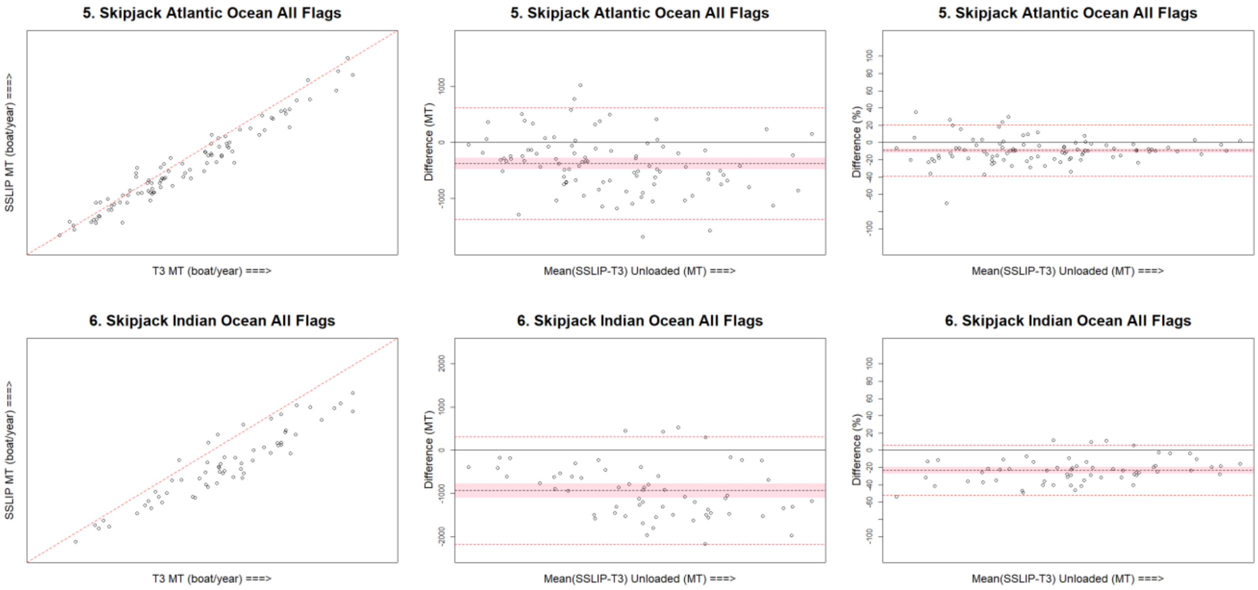


Figure 6c: Dispersion and difference Bland and Altman plots used to compare T3 estimates and unloadings of skipjack tuna obtained from sale slips provided by the OPAGAC fleet for the period 2011-16, by RFMO Area (ICCAT [5]; IOTC [6]).

Left panel: Unloadings estimated using T3 (x axis) versus those obtained from sale slips (y axis), with line of equality.
Mid panel: Plot of differences (metric tons per vessel per year) between T3 estimates and sale slip data versus the mean of the two measurements (av(Sale Slip – T3)). The bias is represented by the gap between the x axis corresponding to a zero differences, and the parallel broken black line to the x axis. Confidence intervals (metric tons) are represented through the pink-shaded area and 1.96*se (metric tons) through the broken red lines.
Right panel: Plot of differences (%) between T3 estimates and sale slip data versus the mean of the two measurements (av(Sale Slip – T3)). The bias is represented by the gap between the x axis corresponding to a zero differences, and the parallel broken black line to the x axis. Confidence intervals (%) are represented through the pink-shaded area and 1.96*se (%) through the broken red lines.

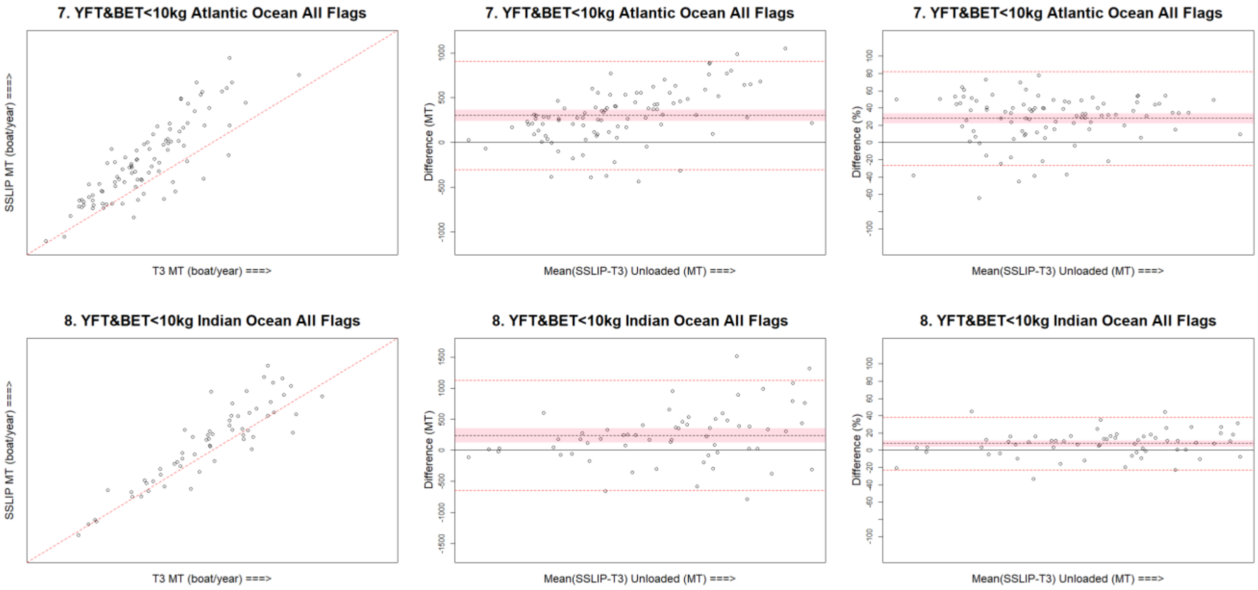


Figure 6d: Dispersion and difference Bland and Altman plots used to compare T3 estimates and unloadings of yellowfin tuna and bigeye tuna <10kg (AT<10 kg) obtained from sale slips provided by the OPAGAC fleet for the period 2011-16, by RFMO Area (ICCAT [7]; IOTC [8]).

Left panel: Unloadings estimated using T3 (x axis) versus those obtained from sale slips (y axis), with line of equality.
Mid panel: Plot of differences (metric tons per vessel per year) between T3 estimates and sale slip data versus the mean of the two measurements (av(Sale Slip – T3)). The bias is represented by the gap between the x axis corresponding to a zero differences, and the parallel broken black line to the x axis. Confidence intervals (metric tons) are represented through the pink-shaded area and 1.96*se (metric tons) through the broken red lines.
Right panel: Plot of differences (%) between T3 estimates and sale slip data versus the mean of the two measurements (av(Sale Slip – T3)). The bias is represented by the gap between the x axis corresponding to a zero differences, and the parallel broken black line to the x axis. Confidence intervals (%) are represented through the pink-shaded area and 1.96*se (%) through the broken red lines.

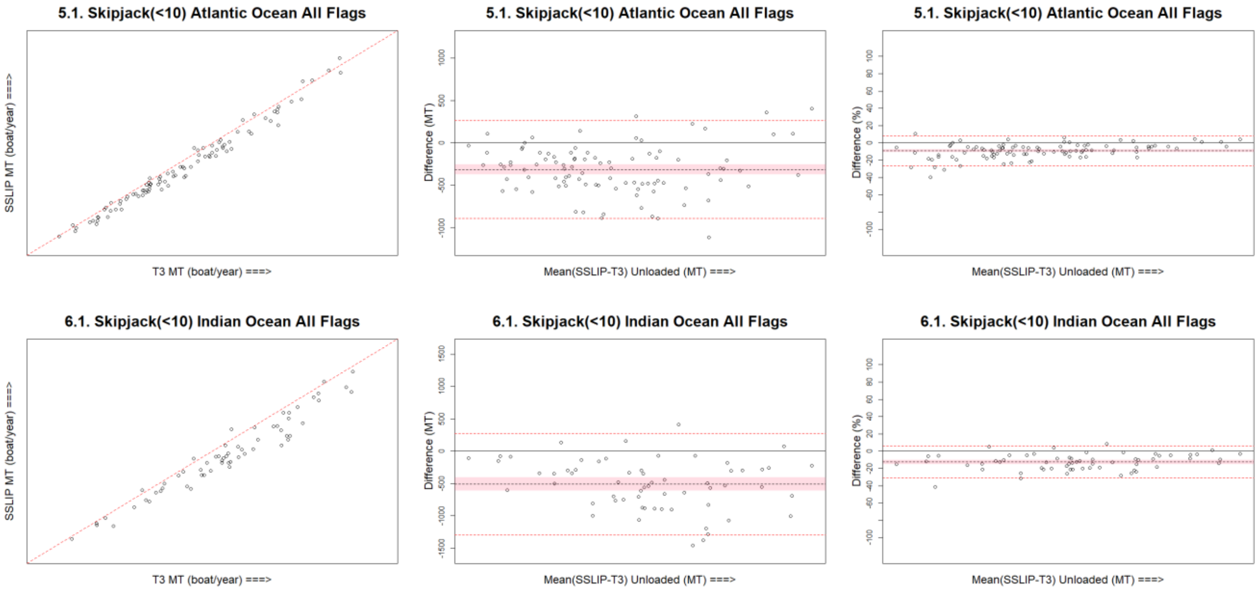


Figure 7a: Dispersion and difference Bland and Altman plots used to compare the species composition obtained from T3 estimates and unloadings obtained from sale slips exclusively for the category <10kg (SKJ on one side and yellowfin tuna and bigeye tuna combined on the other (AT<10 kg). Comparison of estimates of SKJ data for the period 2011-16, by RFMO Area (ICCAT [5.1]; IOTC [6.1]).

Left panel: Unloadings estimated using T3 (x axis) versus those obtained from sale slips (y axis), with line of equality.
Mid panel: Plot of differences (metric tons per vessel per year) between T3 estimates and sale slip data versus the mean of the two measurements (av(Sale Slip – T3)). The bias is represented by the gap between the x axis corresponding to a zero differences, and the parallel broken black line to the x axis. Confidence intervals (metric tons) are represented through the pink-shaded area and 1.96*se (metric tons) through the broken red lines.
Right panel: Plot of differences (%) between T3 estimates and sale slip data versus the mean of the two measurements (av(Sale Slip – T3)). The bias is represented by the gap between the x axis corresponding to a zero differences, and the parallel broken black line to the x axis. Confidence intervals (%) are represented through the pink-shaded area and 1.96*se (%) through the broken red lines.

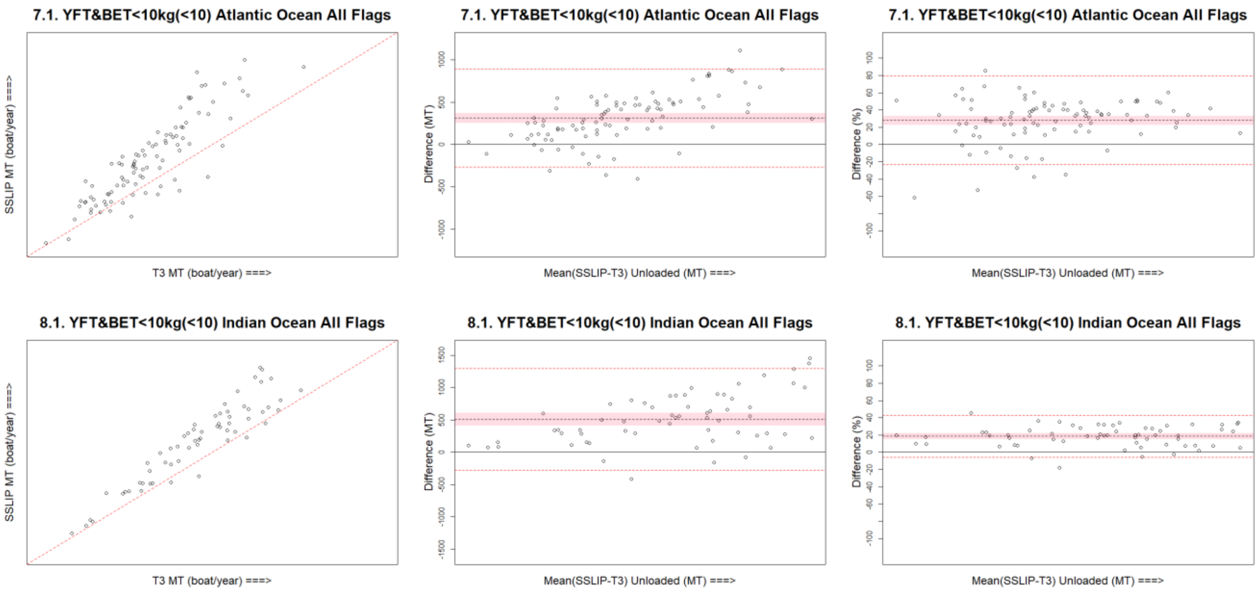


Figure 7b: Dispersion and difference Bland and Altman plots used to compare the species composition obtained from T3 estimates and unloadings obtained from sale slips exclusively for the category <10kg (SKJ on one side and yellowfin tuna and bigeye tuna combined on the other (AT<10 kg). Comparison of estimates of AT<10 kg data for the period 2011-16, by RFMO Area (ICCAT [1]; IOTC [2]).

Left panel: Unloadings estimated using T3 (x axis) versus those obtained from sale slips (y axis), with line of equality.
Mid panel: Plot of differences (metric tons per vessel per year) between T3 estimates and sale slip data versus the mean of the two measurements (av(Sale Slip – T3)). The bias is represented by the gap between the x axis corresponding to a zero differences, and the parallel broken black line to the x axis. Confidence intervals (metric tons) are represented through the pink-shaded area and 1.96*se (metric tons) through the broken red lines.
Right panel: Plot of differences (%) between T3 estimates and sale slip data versus the mean of the two measurements (av(Sale Slip – T3)). The bias is represented by the gap between the x axis corresponding to a zero differences, and the parallel broken black line to the x axis. Confidence intervals (%) are represented through the pink-shaded area and 1.96*se (%) through the broken red lines.

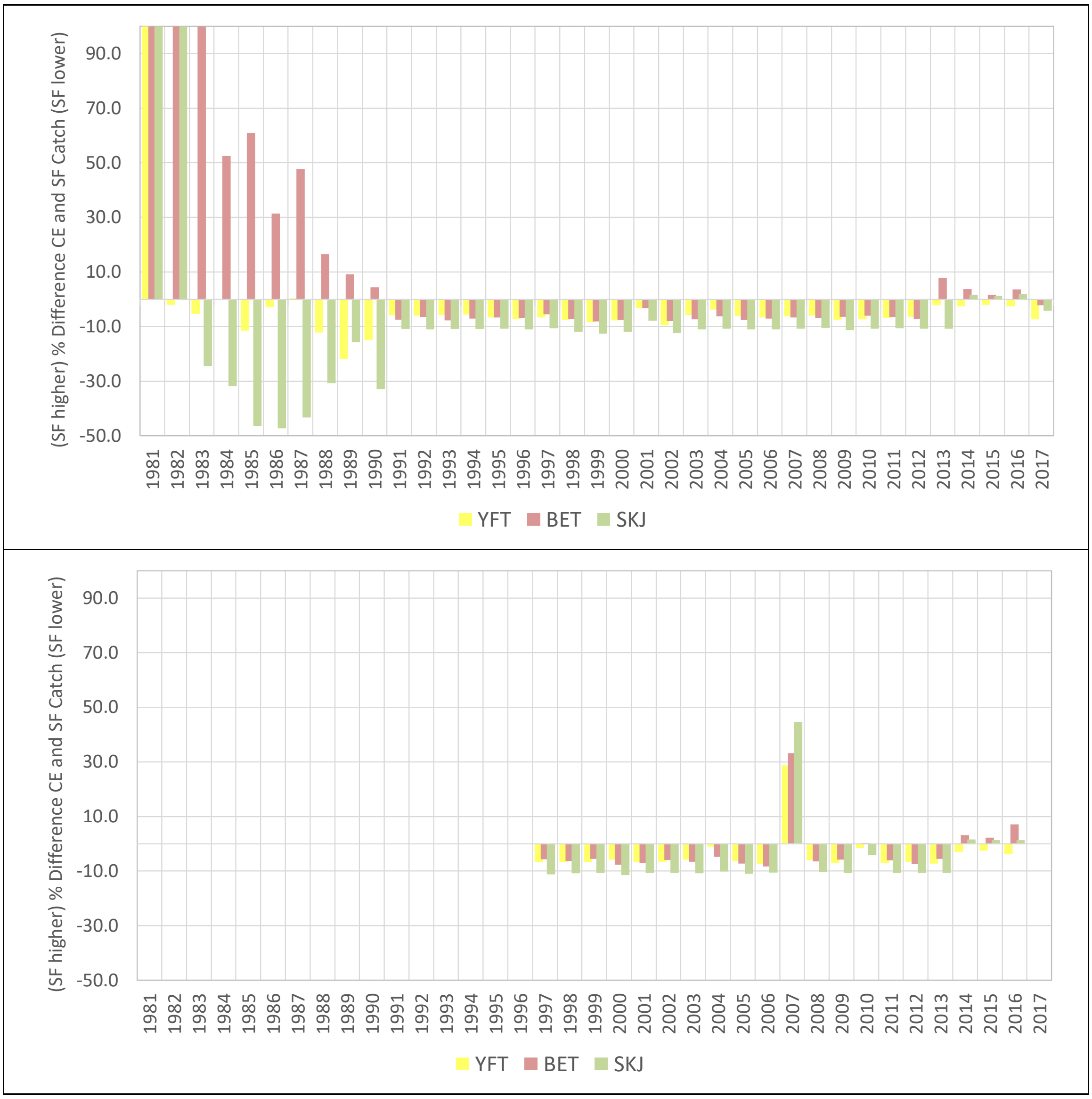


Figure 10: Difference in catches estimated using the number of fish per size class reported by the EU (top) and Seychelles (bottom) to the IOTC, and the length-weight relationships EU scientists use to convert numbers into weight for each size class (Chasot *et al*. 2016) and the catches reported by the EU and Seychelles to the IOTC, obtained from IOTC's Catch-and-Effort table. Data covers the entire time series (1981-2017) for each CPC and species. The difference is expressed as the percentage the difference between weights estimated using catch-at-size data and catches in the catch-and-effort file represent for each species and year. A negative value in the figure means that weights estimated from catch-at-size data are higher than those obtained from the catch-and-effort file, and the contrary applies to positive values (weights from catch-at-size are lower).

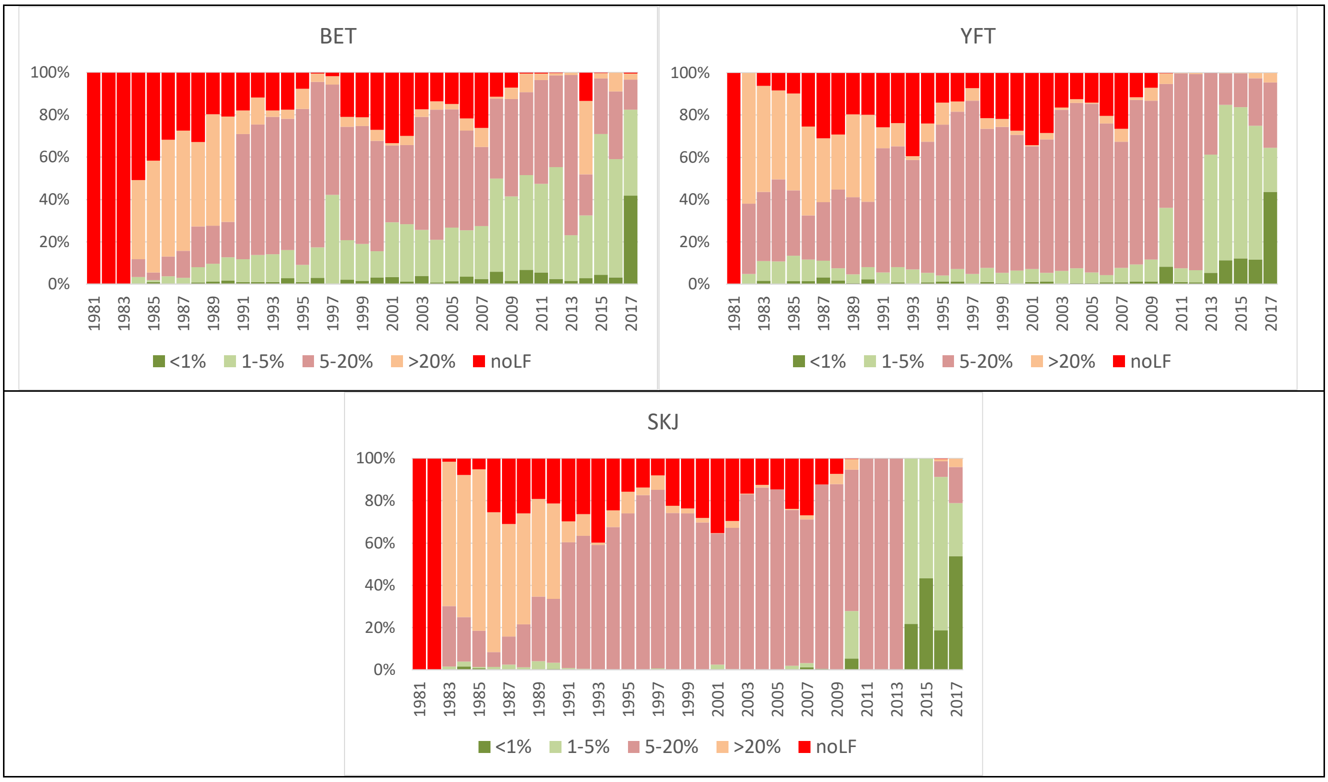


Figure 11: Difference in catches estimated using the number of fish per size class reported by the EU (top) and Seychelles (bottom) to the IOTC, and the length-weight relationships EU scientists use to convert numbers into weight for each size class (Chasot *et al*. 2016) and the catches reported by the EU and Seychelles to the IOTC, obtained from IOTC's Catch-and-Effort table. Data covers the entire time series (1981-2017) for each species, for the EU and Seychelles fleet combined. The difference is expressed as the percentage of strata in the catch-at-size table whose weight differs from that reported as catch-and-effort, according to the following categories:

- <1%: percentage that the number of strata for which the weight estimated from CAS data deviates less than 1% from the weight recorded as CE represents over the total number of strata in which catches are recorded in CE;
- 1-5%: the weight estimated from CAS data deviates between 1-5% from the weight recorded as CE;
- 5-20%: the weight estimated from CAS data deviates between 5-20% from the weight recorded as CE;
- >20%: the weight estimated from CAS data deviates more than 20% from the weight recorded as CE;
- noLF: size data not available at all for strata in which catches are recorded in the CE file.

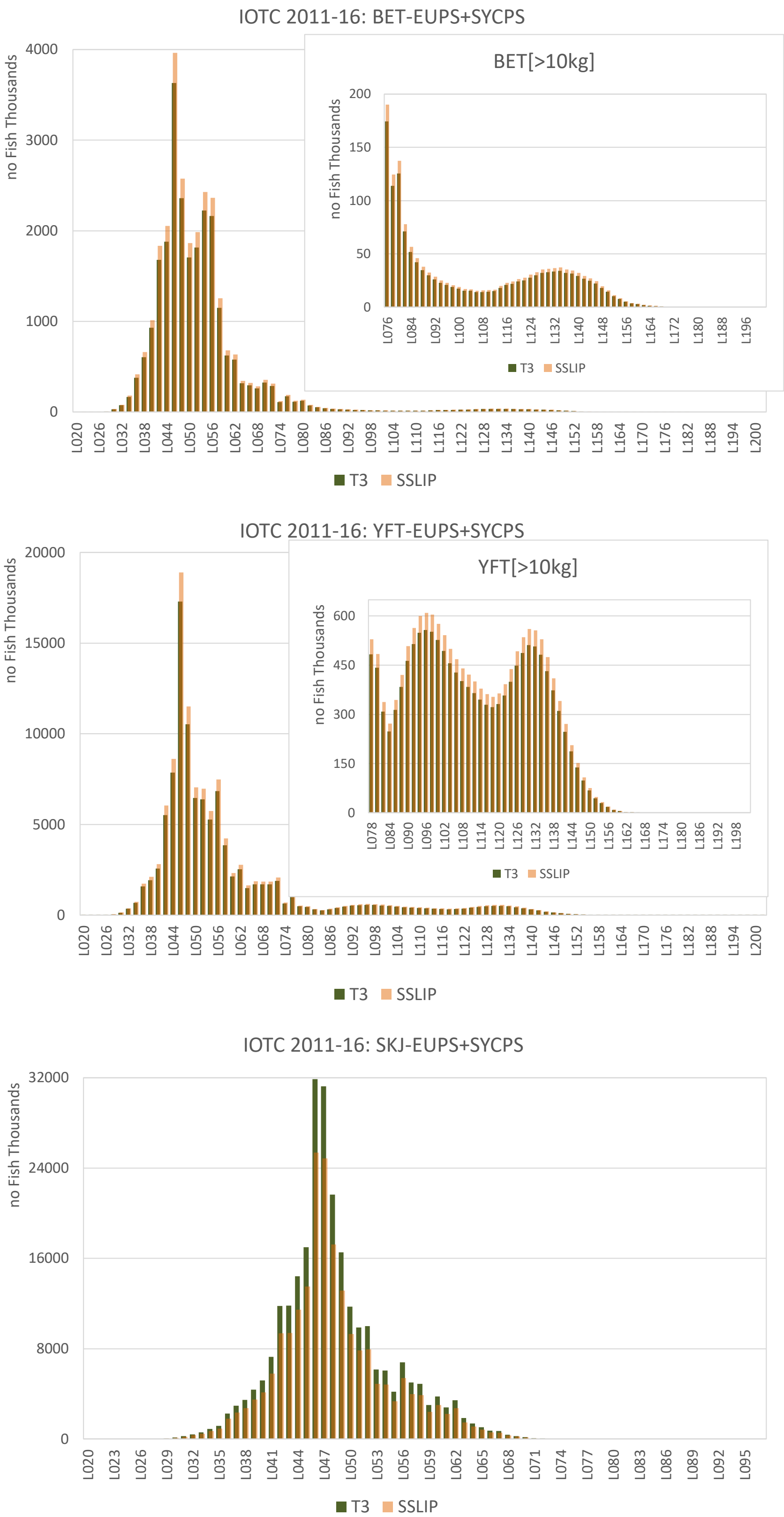


Figure 12: Length frequency distributions of YFT, BET and SKJ for the period 2011-16 (data combined for EU and Seychelles) reported to the IOTC by the EU (T3) versus those corrected for the biases estimated by species and size category (≥10kg and <10kg). The adjustment does not consider the biases indicated in the section 3.5.1 or the fact that length samples may also be biased within each size category, only accounting for the biases in catch and size class presented in Table 1.

ANNEX 1. Output Table from the T3 Process

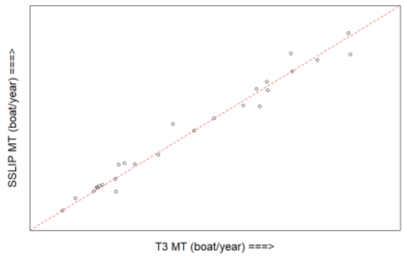
ID	Primary key
ocean	**ocean of activity**
port	port of activity
flag	**Flag state of the vessel**
engine	Type of engine as per FIBATO's classification
vescode	**Vessel code as per FIBATO's classification**
vestype	Type of vessel as per FIBATO's classification (all purse seiners)
vescat	Vessel category as per FIBATO's classification
year_dbq	**Year of unloading**
month_dbq	Month of unloading
day_dbq	Day of unloading
year_d_act	Year of activity
month_d_act	Month of activity
day_d_act	Day of activity
hour_d_act	Hour of activity
fortnight	Fortnight of activity
quarter	Quarter of activity
quadrant	Quadrant of activity as per ICCAT's standards
latdeg	Degrees of latitude of activity
latmin	Minutes of latitude of activity
londeg	Degrees of longitude of activity
lonmin	Minutes of longitude of activity
cwp1x1	One degree square grid as per CWP's standards
cwp5x5	Five degrees square grid as per CWP's standards
c_zet	*Unknown (?)*
c_zee	Exclusive Economic Zone of activity as per AVDTH's classification
v_tmer	Number of hours at sea
v_tpec	Number of fishing hours
v_tpec_std	Number of fishing hours standardized as per AVDTH'S STANDARDS
v_nb_calees	Total number of fishing sets
v_nb_calee_pos	Number of sets with catch (positive set)
v_nb_calee_nulles	Number of sets with no catches (null or blank)
n_act	Serial number assigned to each individual activity recorded for the day (1, 2, etc.)
c_opera	Code of type of operation as per AVDTH's standards
flag_expert	*Unknown (?)*
c_assoc1	Code type of association category 1 as per AVDTH's standards
c_assoc2	Code type of association category 2 as per AVDTH's standards
c_assoc3	Code type of association category 3 as per AVDTH's standards
c_assoc4	Code type of association category 4 as per AVDTH's standards
c_assoc5	Code type of association category 5 as per AVDTH's standards
c_assoc_reduced	Code type of association aggregate as per AVDTH's standards
codeassocg	Code type of association aggregate as per AVDTH's standards
v_temp_s	Sea surface temperature in degrees C
v_cour_dir	Direction of the current in degrees
v_cour_vit	Speed of the current in knots
v_rf3	*Unknown (?)*
v_dur_cal	Length of the fishing set in hours, where applicable
v_poids_capt_yft	Catch of yellowfin tuna in metric tons
v_poids_capt_skj	**Catch of skipjack tuna in metric tons**
v_poids_capt_bet	Catch of yellowfin tuna in metric tons
v_poids_capt_alb	Catch of albacore in metric tons
v_poids_capt_lta	Catch of little tunny (Atlantic black skipjack) in metric tons
v_poids_capt_fri	Catch of frigate tuna in metric tons
v_poids_capt_shx	Catch of sharks in metric tons
v_poids_capt_dsc	*Unknown (?)*
v_poids_capt_you	*Unknown (?)*
v_poids_capt_kaw	Catch of kawakawa in metric tons
v_poids_capt_lot	Catch of longtail tuna in metric tons
v_poids_capt_blf	Catch of bluefin tuna in metric tons
v_poids_capt_yft_cat1	**Catch of yellowfin tuna size category 1 (<10kg)**
v_poids_capt_yft_cat2	**Catch of yellowfin tuna size category 2 (10kg-30kg)**
v_poids_capt_yft_cat3	**Catch of yellowfin tuna size category 3 (≥30kg)**
v_poids_capt_bet_cat1	**Catch of bigeye tuna size category 1 (<10kg)**
v_poids_capt_bet_cat2	**Catch of bigeye tuna size category 2 (10kg-30kg)**
v_poids_capt_bet_cat3	**Catch of bigeye tuna size category 3 (≥30kg)**

ANNEX 2. Output Table Sale Slips

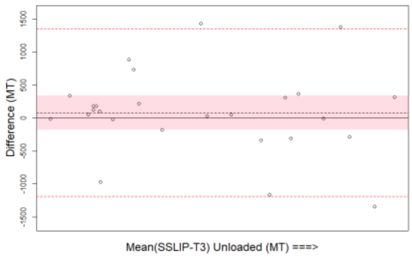
Nombre del buque	**Name of the purse seiner**
Fecha de desembarco	**Date of unloading**
Fecha inicio Marea	Date start of the trip
Fecha Fin Marea	Date end of the trip
Descarga completa? (Si/No)	**All catches unloaded? (Yes/No)**
Total no descargado (kg)	Total catch not unloaded (kg)
Total descargado (kg)	Total catch unloaded (kg)
YFT>10kg	**Catch yellowfin tuna ≥10kg**
YFT<10kg	**Catch yellowfin tuna <10kg**
BET>10kg	**Catch bigeye tuna ≥10kg**
BET<10kg	**Catch bigeye tuna <10kg**
SKJ	**Catch skipjack tuna**
ALB	Catch albacore
Melva/Bacoreta	Catch frigate tuna/Atlantic black skipjack
Otros	Catch other species

ANNEX 3. Bland & Altman Plots by Flag Group

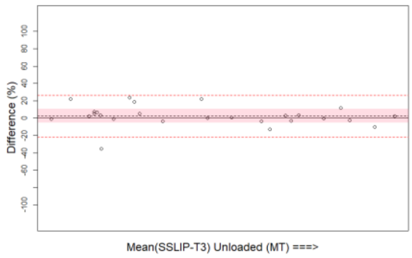
1a. Tropical Tunas Atlantic Ocean Spain



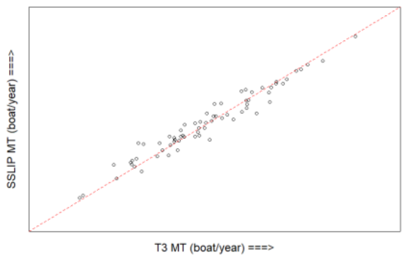
1a. Tropical Tunas Atlantic Ocean Spain



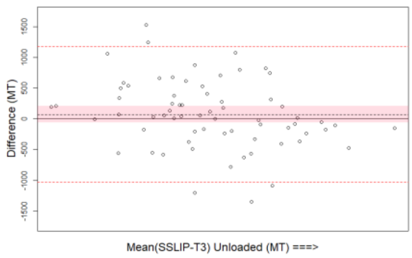
1a. Tropical Tunas Atlantic Ocean Spain



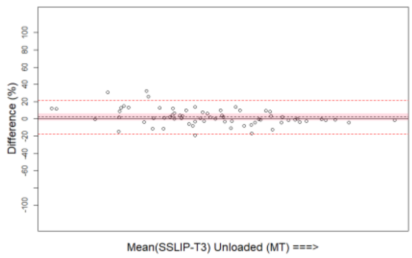
1b. Tropical Tunas Atlantic Ocean Other Flags



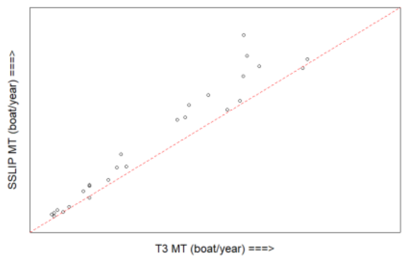
1b. Tropical Tunas Atlantic Ocean Other Flags



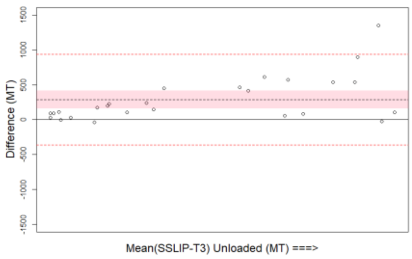
1b. Tropical Tunas Atlantic Ocean Other Flags



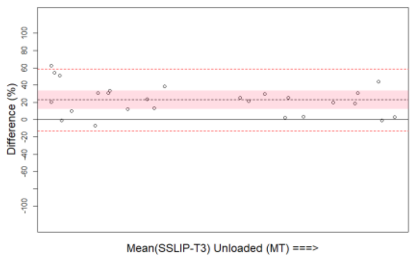
3a. YFT&BET>10kg Atlantic Ocean Spain



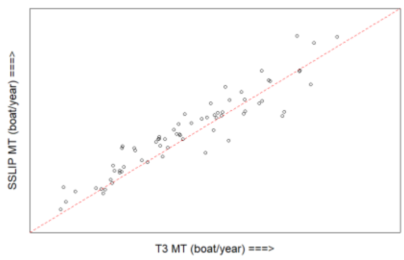
3a. YFT&BET>10kg Atlantic Ocean Spain



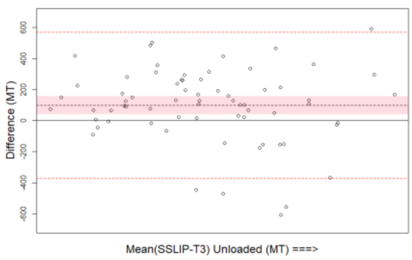
3a. YFT&BET>10kg Atlantic Ocean Spain



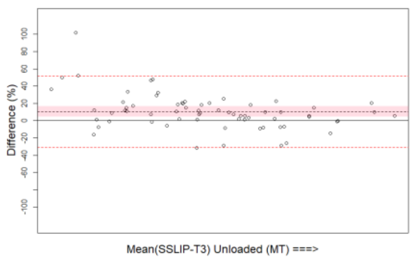
3b. YFT&BET>10kg Atlantic Ocean Other Flags



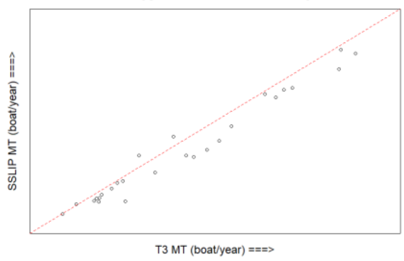
3b. YFT&BET>10kg Atlantic Ocean Other Flags



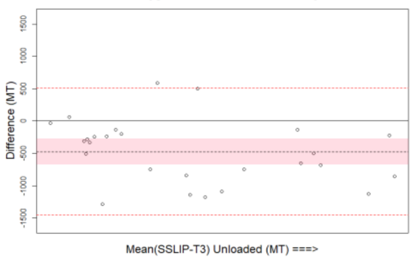
3b. YFT&BET>10kg Atlantic Ocean Other Flags



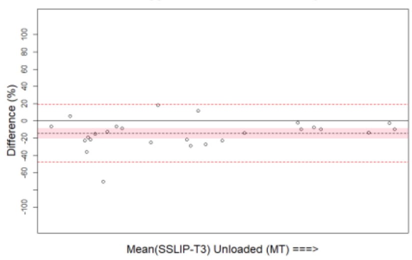
5a. Skipjack Atlantic Ocean Spain

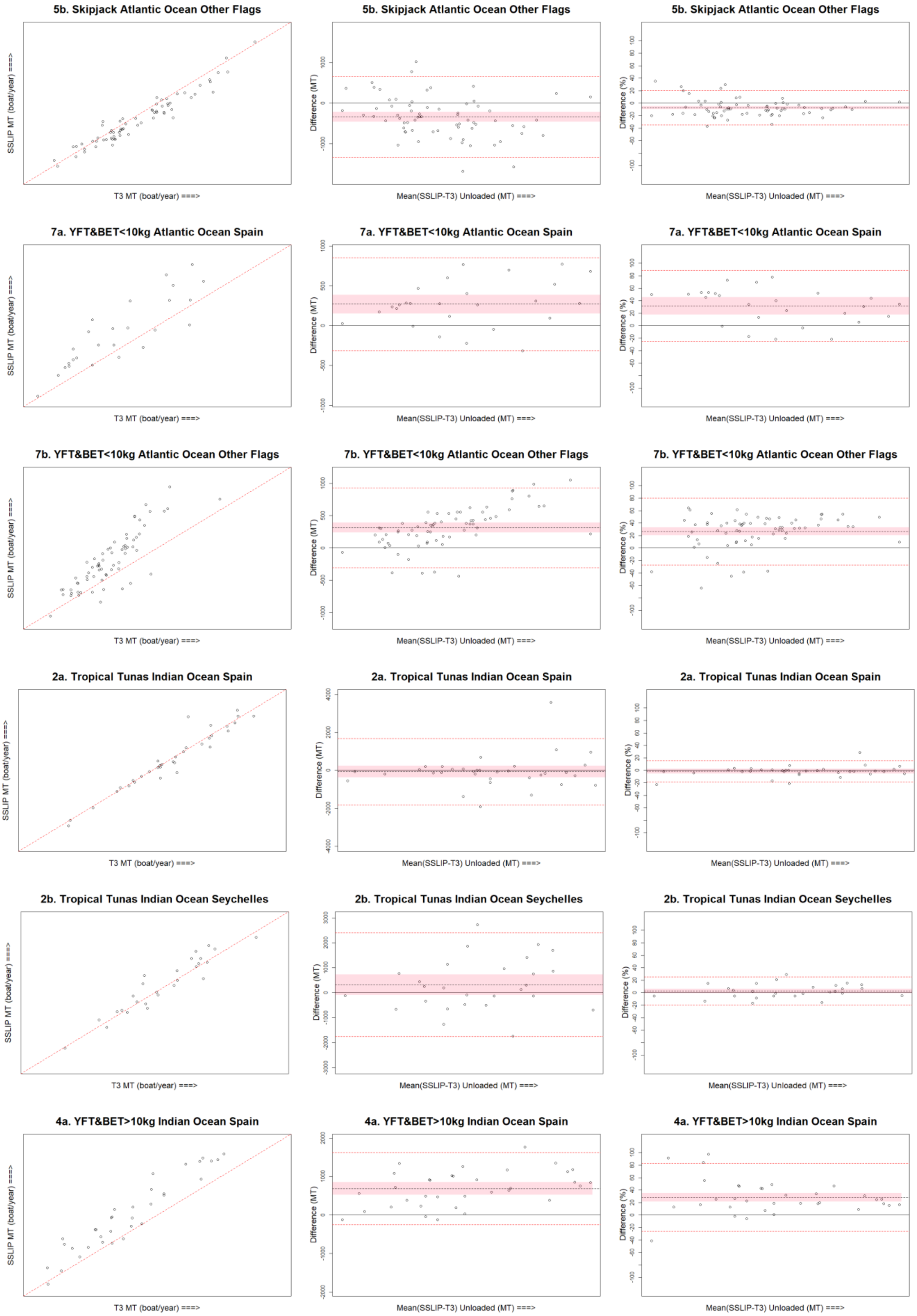


5a. Skipjack Atlantic Ocean Spain

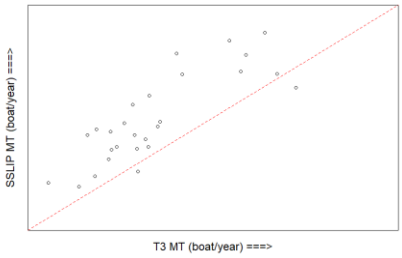


5a. Skipjack Atlantic Ocean Spain

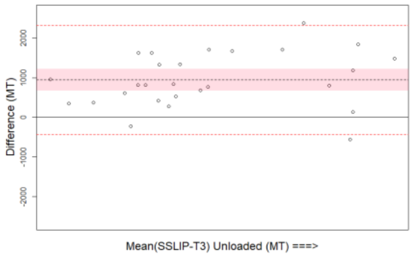



5b. Skipjack Atlantic Ocean Other Flags
SSLIP MT (boat/year) ===>
T3 MT (boat/year) ===>
5b. Skipjack Atlantic Ocean Other Flags
Difference (MT)
Mean(SSLIP-T3) Unloaded (MT) ===>
5b. Skipjack Atlantic Ocean Other Flags
Difference (%)
Mean(SSLIP-T3) Unloaded (MT) ===>
7a. YFT&BET<10kg Atlantic Ocean Spain
SSLIP MT (boat/year) ===>
T3 MT (boat/year) ===>
7a. YFT&BET<10kg Atlantic Ocean Spain
Difference (MT)
Mean(SSLIP-T3) Unloaded (MT) ===>
7a. YFT&BET<10kg Atlantic Ocean Spain
Difference (%)
Mean(SSLIP-T3) Unloaded (MT) ===>
7b. YFT&BET<10kg Atlantic Ocean Other Flags
SSLIP MT (boat/year) ===>
T3 MT (boat/year) ===>
7b. YFT&BET<10kg Atlantic Ocean Other Flags
Difference (MT)
Mean(SSLIP-T3) Unloaded (MT) ===>
7b. YFT&BET<10kg Atlantic Ocean Other Flags
Difference (%)
Mean(SSLIP-T3) Unloaded (MT) ===>
2a. Tropical Tunas Indian Ocean Spain
SSLIP MT (boat/year) ===>
T3 MT (boat/year) ===>
2a. Tropical Tunas Indian Ocean Spain
Difference (MT)
Mean(SSLIP-T3) Unloaded (MT) ===>
2a. Tropical Tunas Indian Ocean Spain
Difference (%)
Mean(SSLIP-T3) Unloaded (MT) ===>
2b. Tropical Tunas Indian Ocean Seychelles
SSLIP MT (boat/year) ===>
T3 MT (boat/year) ===>
2b. Tropical Tunas Indian Ocean Seychelles
Difference (MT)
Mean(SSLIP-T3) Unloaded (MT) ===>
2b. Tropical Tunas Indian Ocean Seychelles
Difference (%)
Mean(SSLIP-T3) Unloaded (MT) ===>
4a. YFT&BET>10kg Indian Ocean Spain
SSLIP MT (boat/year) ===>
T3 MT (boat/year) ===>
4a. YFT&BET>10kg Indian Ocean Spain
Difference (MT)
Mean(SSLIP-T3) Unloaded (MT) ===>
4a. YFT&BET>10kg Indian Ocean Spain
Difference (%)
Mean(SSLIP-T3) Unloaded (MT) ===>

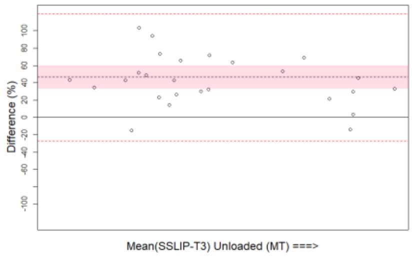
4b. YFT&BET>10kg Indian Ocean Seychelles



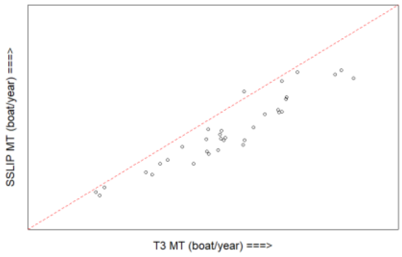
4b. YFT&BET>10kg Indian Ocean Seychelles



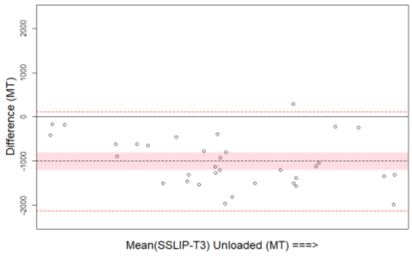
4b. YFT&BET>10kg Indian Ocean Seychelles



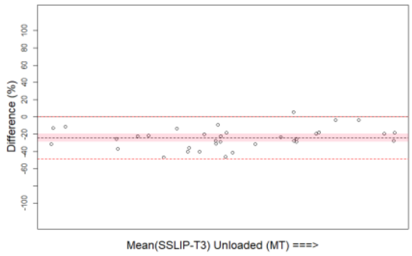
6a. Skipjack Indian Ocean Spain



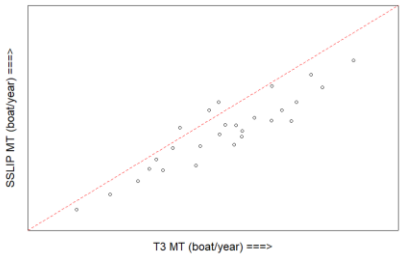
6a. Skipjack Indian Ocean Spain



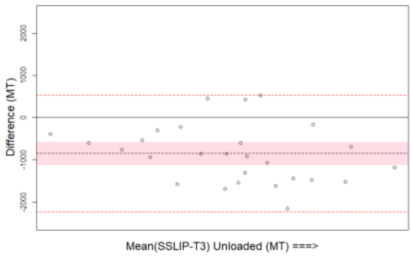
6a. Skipjack Indian Ocean Spain



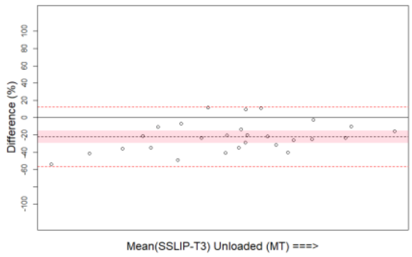
6b. Skipjack Indian Ocean Seychelles



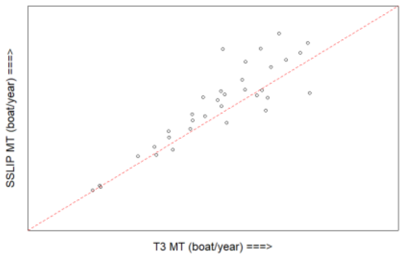
6b. Skipjack Indian Ocean Seychelles



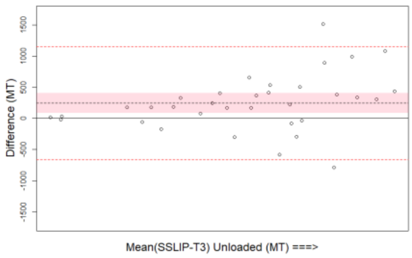
6b. Skipjack Indian Ocean Seychelles



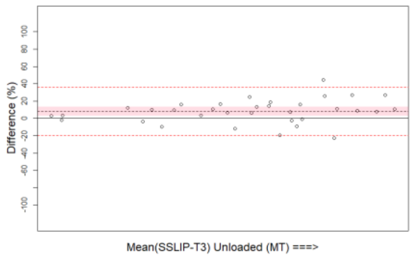
8a. YFT&BET<10kg Indian Ocean Spain



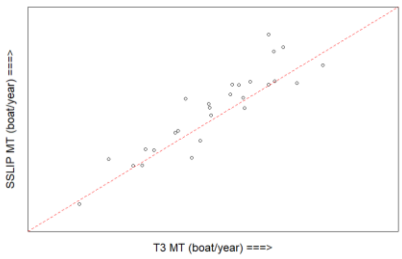
8a. YFT&BET<10kg Indian Ocean Spain



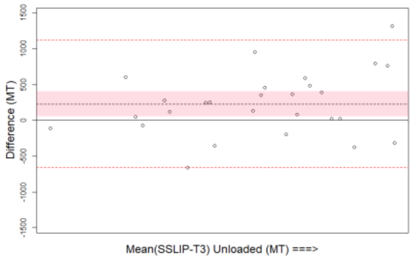
8a. YFT&BET<10kg Indian Ocean Spain



8b. YFT&BET<10kg Indian Ocean Seychelles



8b. YFT&BET<10kg Indian Ocean Seychelles



8b. YFT&BET<10kg Indian Ocean Seychelles

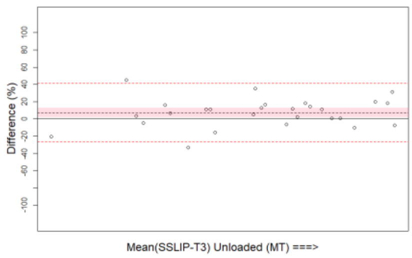


Figure 8 (previous pages)**:** Dispersion and difference Bland and Altman plots used to compare T3 estimates and unloadings obtained from sale slips provided by the OPAGAC fleet for the period 2011-16, by species and commercial category group, flag group and RFMO Area.

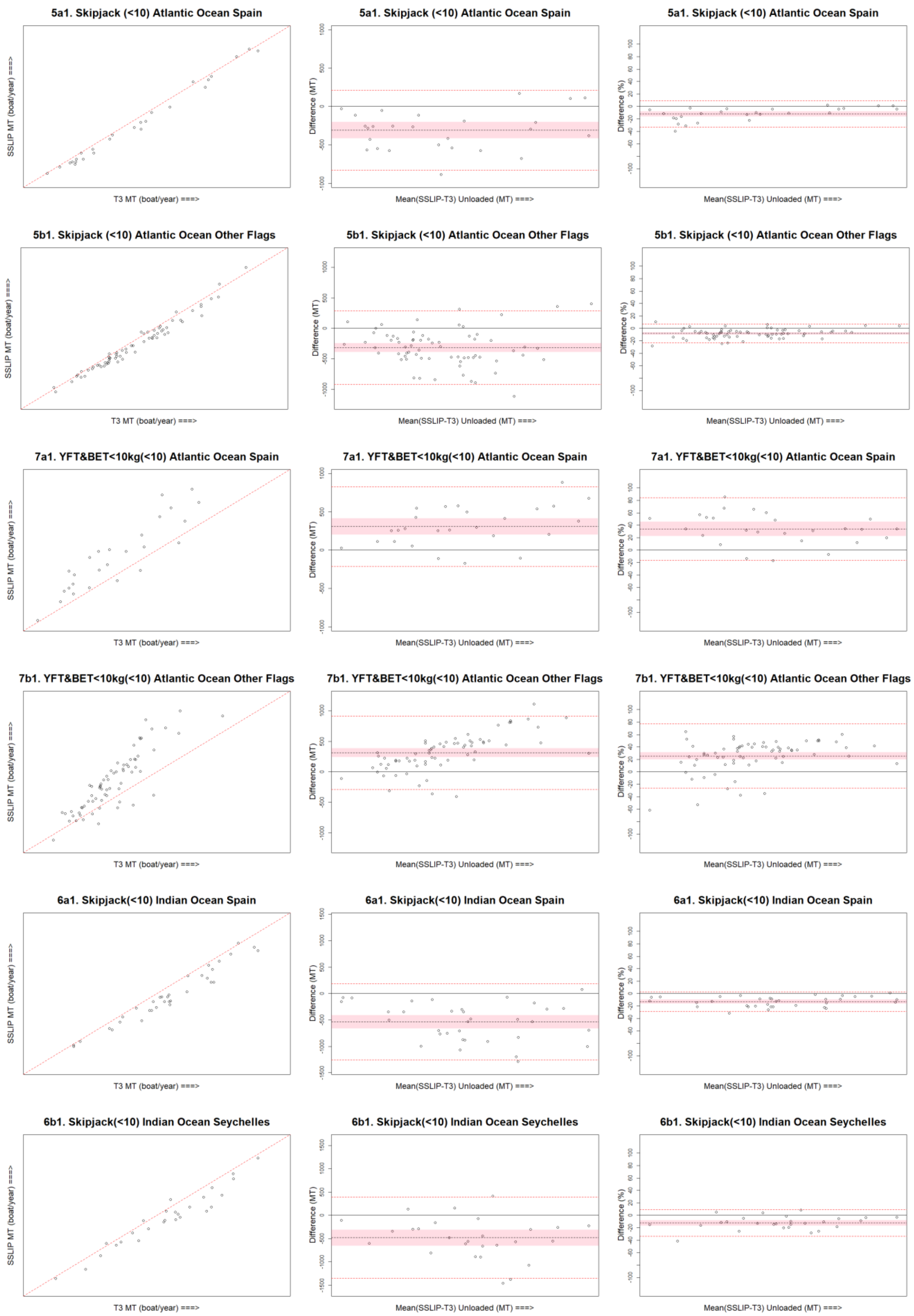
Left panel: Unloadings estimated using T3 (x axis) versus those obtained from sale slips (y axis), with line of equality.
Mid panel: Plot of differences (metric tons per vessel per year) between T3 estimates and sale slip data versus the mean of the two measurements (av(Sale Slip – T3)). The bias is represented by the gap between the x axis corresponding to a zero differences, and the parallel broken black line to the x axis. Confidence intervals (metric tons) are represented through the pink-shaded area and 1.96*se (metric tons) through the broken red lines.
Right panel: Plot of differences (%) between T3 estimates and sale slip data versus the mean of the two measurements (av(Sale Slip – T3)). The bias is represented by the gap between the x axis corresponding to a zero differences, and the parallel broken black line to the x axis. Confidence intervals (%) are represented through the pink-shaded area and 1.96*se (%) through the broken red lines.

ATLANTIC OCEAN:

1a. OPAGAC Spain: Total unloadings of tropical tunas
1b. OPAGAC Other Flags: Total unloadings of tropical tunas
3a. OPAGAC Spain: Unloadings of yellowfin & bigeye tunas ≥10 kg
3b. OPAGAC Other Flags: Unloadings of yellowfin & bigeye tunas ≥10 kg
5a. OPAGAC Spain: Unloadings of skipjack tuna
5b. OPAGAC Other Flags: Unloadings of skipjack tuna
7a. OPAGAC Spain: Unloadings of yellowfin & bigeye tunas <10 kg
7b. OPAGAC Other Flags: Unloadings of yellowfin & bigeye tunas <10 kg

INDIAN OCEAN:

2a. OPAGAC Spain: Total unloadings of tropical tunas
2b. OPAGAC Seychelles: Total unloadings of tropical tunas
4a. OPAGAC Spain: Unloadings of yellowfin & bigeye tunas ≥10 kg
4b. OPAGAC Seychelles: Unloadings of yellowfin & bigeye tunas ≥10 kg
6a. OPAGAC Spain: Unloadings of skipjack tuna
6b. OPAGAC Seychelles: Unloadings of skipjack tuna
8a. OPAGAC Spain: Unloadings of yellowfin & bigeye tunas <10 kg
8b. OPAGAC Seychelles: Unloadings of yellowfin & bigeye tunas <10 kg


5a1. Skipjack (<10) Atlantic Ocean Spain
SSLIP MT (boat/year) ===>
T3 MT (boat/year) ===>
5a1. Skipjack (<10) Atlantic Ocean Spain
Difference (MT)
Mean(SSLIP-T3) Unloaded (MT) ===>
5a1. Skipjack (<10) Atlantic Ocean Spain
Difference (%)
Mean(SSLIP-T3) Unloaded (MT) ===>
5b1. Skipjack (<10) Atlantic Ocean Other Flags
SSLIP MT (boat/year) ===>
T3 MT (boat/year) ===>
5b1. Skipjack (<10) Atlantic Ocean Other Flags
Difference (MT)
Mean(SSLIP-T3) Unloaded (MT) ===>
5b1. Skipjack (<10) Atlantic Ocean Other Flags
Difference (%)
Mean(SSLIP-T3) Unloaded (MT) ===>
7a1. YFT&BET<10kg(<10) Atlantic Ocean Spain
SSLIP MT (boat/year) ===>
T3 MT (boat/year) ===>
7a1. YFT&BET<10kg(<10) Atlantic Ocean Spain
Difference (MT)
Mean(SSLIP-T3) Unloaded (MT) ===>
7a1. YFT&BET<10kg(<10) Atlantic Ocean Spain
Difference (%)
Mean(SSLIP-T3) Unloaded (MT) ===>
7b1. YFT&BET<10kg(<10) Atlantic Ocean Other Flags
SSLIP MT (boat/year) ===>
T3 MT (boat/year) ===>
7b1. YFT&BET<10kg(<10) Atlantic Ocean Other Flags
Difference (MT)
Mean(SSLIP-T3) Unloaded (MT) ===>
7b1. YFT&BET<10kg(<10) Atlantic Ocean Other Flags
Difference (%)
Mean(SSLIP-T3) Unloaded (MT) ===>
6a1. Skipjack(<10) Indian Ocean Spain
SSLIP MT (boat/year) ===>
T3 MT (boat/year) ===>
6a1. Skipjack(<10) Indian Ocean Spain
Difference (MT)
Mean(SSLIP-T3) Unloaded (MT) ===>
6a1. Skipjack(<10) Indian Ocean Spain
Difference (%)
Mean(SSLIP-T3) Unloaded (MT) ===>
6b1. Skipjack(<10) Indian Ocean Seychelles
SSLIP MT (boat/year) ===>
T3 MT (boat/year) ===>
6b1. Skipjack(<10) Indian Ocean Seychelles
Difference (MT)
Mean(SSLIP-T3) Unloaded (MT) ===>
6b1. Skipjack(<10) Indian Ocean Seychelles
Difference (%)
Mean(SSLIP-T3) Unloaded (MT) ===>

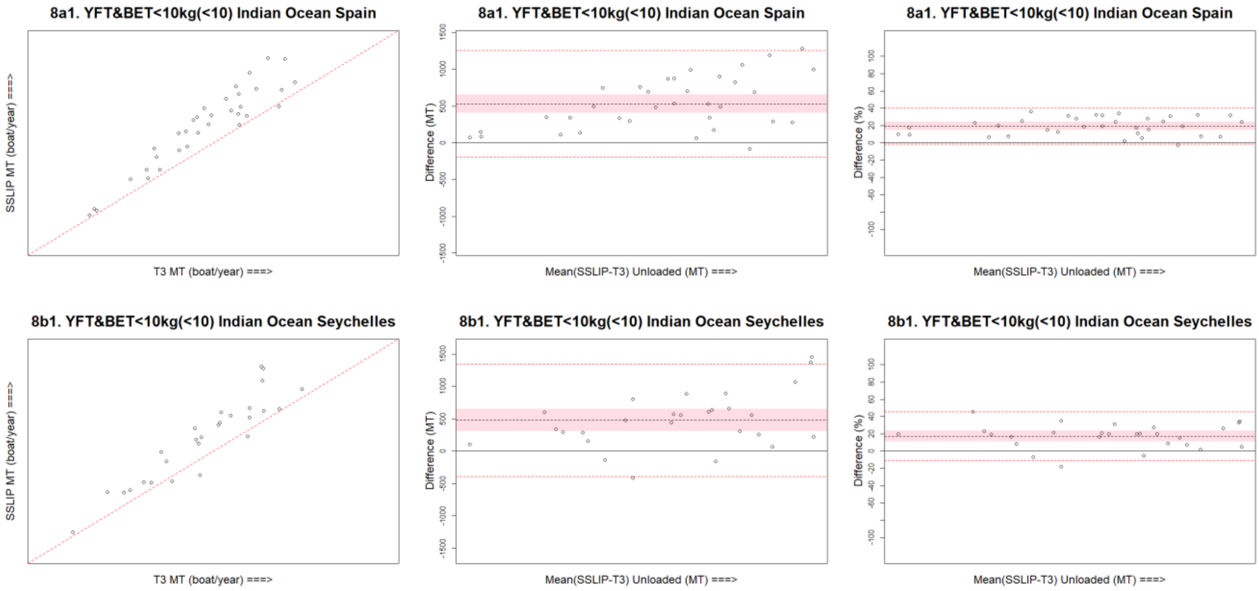


Figure 9 (previous pages)**:** Dispersion and difference Bland and Altman plots used to compare T3 estimates and unloadings obtained from sale slips provided by the OPAGAC fleet for the period 2011-16, by species and commercial category group, flag group and RFMO Area.

Left panel: Unloadings estimated using T3 (x axis) versus those obtained from sale slips (y axis), with line of equality.
Mid panel: Plot of differences (metric tons per vessel per year) between T3 estimates and sale slip data versus the mean of the two measurements (av(Sale Slip – T3)). The bias is represented by the gap between the x axis corresponding to a zero differences, and the parallel broken black line to the x axis. Confidence intervals (metric tons) are represented through the pink-shaded area and 1.96*se (metric tons) through the broken red lines.
Right panel: Plot of differences (%) between T3 estimates and sale slip data versus the mean of the two measurements (av(Sale Slip – T3)). The bias is represented by the gap between the x axis corresponding to a zero differences, and the parallel broken black line to the x axis. Confidence intervals (%) are represented through the pink-shaded area and 1.96*se (%) through the broken red lines.

ATLANTIC OCEAN:
5a1. OPAGAC Spain: Unloadings of skipjack tuna
5b1. OPAGAC Other Flags: Unloadings of skipjack tuna
7a1. OPAGAC Spain: Unloadings of yellowfin & bigeye tunas <10 kg
7b1. OPAGAC Other Flags: Unloadings of yellowfin & bigeye tunas <10 kg

INDIAN OCEAN:
6a1. OPAGAC Spain: Unloadings of skipjack tuna
6b1. OPAGAC Seychelles: Unloadings of skipjack tuna
8a1. OPAGAC Spain: Unloadings of yellowfin & bigeye tunas <10 kg
8b1. OPAGAC Seychelles: Unloadings of yellowfin & bigeye tunas <10 kg