IOTC-2015-WPDCS11-INF06

# Alternate improved estimates of the species composition of FAD catches by purse seiners in the Indian Ocean.

*Small is beautiful*

By Dr Alain Fonteneau[1] and Juliette Lucas[2]

Summary

This paper estimates potential errors or bias in the species composition of FAD catches that could have been introduced by the use of the present large and fixed areas in the data processing ran by EU and Seychelles scientists to estimate the species composition of FAD catches. An improved data processing method based on the use of mobile 5° strata during 3 months periods, is proposed. This method was made possible because of the large number of multispecies samples obtained on most FAD catches since 2001. The species composition of FAD catches obtained during recent years by this alternate method estimates identical yearly catches of yellowfin and skipjack, and an average decline of 7.4% of average bigeye catches. Our analysis also shows that the time and area variability in the species composition of FAD catches is much larger than in the today C/E data. It is recommended that such a fine scale method estimating the species composition of tuna catches should be better studied and then used by EU and Seychelles scientists in the near future.

## *1- Introduction: goals of this paper*

All statistics of bigeye catches associated to FADs used by the various tuna RFO (ICCAT, IOTC, IATTC & WCPFC) are entirely based on scientific estimates, and never on the log book data, because they are always widely underestimating the quantities of small bigeye. Then, small tunas caught by PS have to be sampled by scientists: either on board as in the WCPFC area, or during their landing, as in the ICCAT, IOTC and IATTC areas, in order to estimate the real proportion of skipjack and of small yellowfin and small bigeye. However, the methods used to estimate the species composition of the catches and especially the bigeye catches are variable and always questionable. All these methods and their results are facing some statistical uncertainties, inter alia because of inadequate or insufficient sampling, or because of inadequate data processing of the log books and species sampling data (as it was discussed in the an. 2009 document following the ad hoc working group on this subject ).

This work will only tackle the second type of problems related to uncertainties in the data processing, being a follow up of the Fonteneau & Ariz 2015 SCRS paper showing

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that the areas presently used in the data processing of FAD catches in the Atlantic by the EU PS were too large and too heterogeneous. Similar questions may be raised concerning the sampling areas (figure 1) and the fixed quarters that have been used today to estimate the species composition of the PS catches in the Indian Ocean. In the method used today since 2000, the species composition of FAD & of free schools catches have been assumed to be homogeneous in each of these areas (shown by figure 1) & during each quarter. This hypothesis is potentially a questionable one, and the present paper will propose an alternate method allowing estimation of a revised species composition of the FAD catches in the Indian Ocean following a modified version of the method proposed by Fonteneau et Ariz 2015 in the Atlantic.

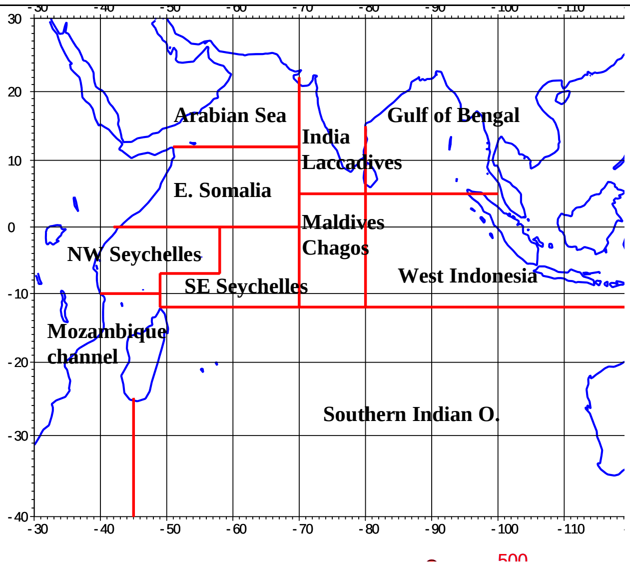


Figure 1a: Original sampling areas used in 1999 in the quarterly data processing of the species composition of the EU & Seychelles PS catches

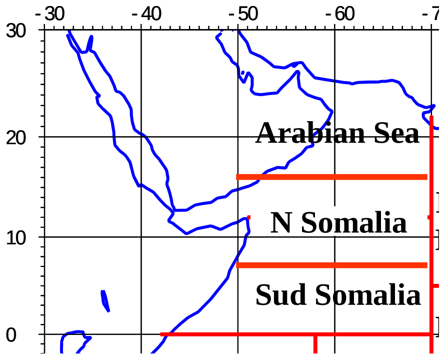


Figure 1b: Modified sampling areas in the North West Indian ocean

This new data processing of the PS FAD catches is based on the logbook data and on the data of the multispecies sampling on purse seiners by 1° squares. In all our calculations, the species composition of FAD catches will be assumed to be identical to the species composition of the sampled sizes in small 5° areas centered around each 1° square fished and by 3 months periods: during the fishing month and also one month before and after the fishing date (see figure 2). This corrected species composition will be estimated only when a minimal numbers of tunas has been sampled in each of these mobile strata.

## *2- Material and methods*

This analysis will be using 2 types of data sets:

- LOG BOOKS: the catches by 1°-month and by size categories of the purse seiners catches estimated in the log books of various PS fleets operating in the Western Indian Ocean; a data set that has permanently been managed by SFA scientists since 1984. Our work was based solely on this data set and not on the file of the original log books managed by national scientists of France and Spain. These catches have been permanently well sampled by scientists since 2001[3] and until 2014 following the

[3] While the sampling rate was very low during the 1998-2000 period.

sampling methods discussed by Pianet et al 2000. The data set contains catches landed by various flags (mainly EU and Seychelles) but also from other flags (France territories, Panama, Italy, Mauritius, etc). This input file used in our analysis contains catches by species and by 3 size categories after correction of their species composition by the method used today (see Pianet & al 2000). Our data processing of this file was conducted independently of the fishing flag combining all flags, based on the result of Pianet & al 2000 showing that the species composition of tunas caught in a given strata was independent of the fishing flag.

- MULTISPECIES SAMPLES: the file of the basic multispecies samples and of the observed species composition of the multispecies samples (so called NN.T file) was used to estimate the species composition. These samples have been obtained mainly in Seychelles by SFA personnel, but also in other landing ports in Madagascar, Mombasa and others. This file contains for each sample, the fishing month and the fishing area by 1° square, and the sampled weight of each species classified in 3 size categories (<10kg, 10 to 30 kg and >30kg), each of these sampled weights being extrapolated to the weight of the sampled catches. During the studied period 2001-2014 this file contains large numbers of tunas that have been sampled each year: an average of 433,000 major tunas being sampled, measured/counted per year. The yearly numbers of tunas sampled by species are given in table 1.
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Table 1: Number of major tunas sampled each year by species during the period 2001-2014 on the FAD catches of the studied purse seine fleet.

| Year | YFT | SKJ | BET | ALB | Total |
|---|---|---|---|---|---|
| 2000 | 20 739 | 61 705 | 6 209 | 0 | 88 653 |
| 2001 | 47 366 | 207 753 | 19 121 | 296 | 274 536 |
| 2002 | 65 396 | 296 393 | 23 184 | 67 | 385 040 |
| 2003 | 68 963 | 250 639 | 14 287 | 6 | 333 895 |
| 2004 | 62 614 | 280 197 | 21 973 | 4 | 364 788 |
| 2005 | 84 630 | 352 091 | 21 513 | 69 | 458 304 |
| 2006 | 111 461 | 444 113 | 23 891 | 1 | 579 465 |
| 2007 | 77 189 | 354 502 | 40 009 | 29 | 471 729 |
| 2008 | 83 889 | 368 524 | 37 892 | 107 | 490 413 |
| 2009 | 104 933 | 377 890 | 37 498 | 80 | 520 401 |
| 2010 | 140 919 | 413 105 | 35 927 | 45 | 589 997 |
| 2011 | 157 045 | 368 058 | 31 172 | 253 | 556 529 |
| 2012 | 166 692 | 268 611 | 27 608 | 80 | 462 992 |
| 2013 | 182 826 | 277 669 | 38 522 | 53 | 499 070 |
| 2014 | 143 209 | 260 764 | 26 048 | 35 | 430 056 |
| Average | 101 191 | 305 468 | 26 990 | 75 | 433 725 |

A FORTRAN programme was written to estimate a new species composition of the 1°-month FAD catches: this programme has 2 input files and 1 output file; the logbooks data corrected for species composition by the TTT programme used today and the sampling file, and 1 main output file with the monthly FAD catches by 1° squares, with a new species composition corrected by the method under study. This programme is quite fast to run where a period of 14 years is processed in less than 2 mn on a standard laptop.

The species composition in each strata was estimated from the sampled catches, only if a minimum number of tunas have been sampled in each stratum. This calculation is done independently of the total catches in the stratumand only when a minimal numbers of 500, 1000, 2000 or 3000 tunas were sampled in each of these 5°-3 months mobile strata. The yearly rates of strata substitution were estimated for each of these minimal sampling levels. Assuming that the sampling of the landed catches was done on a random basis and without sampling bias, such minimal numbers should allow good estimation of the species composition in each stratum. These levels are for instance typical of survey polls that are used to sample opinion of citizens, these polls being most often run in a range between 500 and 2000 individuals sampled. It should also be noted that in our method, any of the 1°-month sample has been used several times to estimate the species composition in each of the 1° squares fished. This repeated use of the sampling data is well accepted because it is considered that it could not introduce bias in the results.

In the cases when the number of tunas sampled in the 5°-quarter strata did not reach the minimum sampling rate, the original species composition of the FAD catches in the 1° square was retained (this species composition being already corrected on a quarterly basis and in each of the sampling areas shown by figure 1).

a) The proposed method allowing estimation of a revised species composition was based on small m**obile strata estimates**: this corrected species composition was estimated for the catches in each 1° square and month, based (1) on all the multispecies samples collected during the 2 months, before and after the fishing month (including in January and December on samples from the previous or the following year) and (2) on all the multispecies samples taken from the 24 surrounding 1 degree squares (i.e. the size of an area equivalent to a 5° square).

The basis of this method is summarized in figure 2.

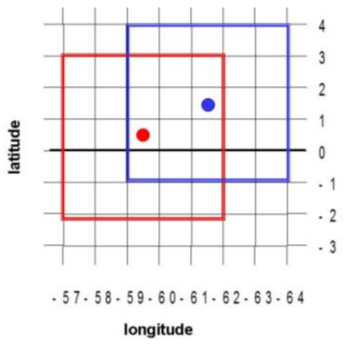


Figure 2: Example of the mobile strata method: January catches in 2 given 1° areas: their species composition will be estimated based on the species composition of the sampled catches in the 5° area centered around the 2 1°-quarter fished, and during the 3 fishing months of December, January and February.

These strata are mobile ones, depending of the fishing date and of the 1° fishing locations, but they are independent of the 4 calendar quarters and of any of the sampling zones used in the today data processing (figure 1).

b) The principle of these mobile small strata have been recently used in the Atlantic (Fonteneau and Ariz 2015) to propose a new corrected species composition of FAD catches. In the Atlantic, these corrections of the species composition were based on the monthly FAD catches of PS, by species and by 1° squares (the ICCAT task2 data), All these calculations of corrected species composition were done independently of the size categories sampled and declared in the log books.

c) The method that was developped in the Atlantic was also applied to the same monthly catches of PS by species and by 1° squares (from the IOTC public domain data), i.e.

independently of the size categories. However the results obtained in the Indian Ocean by this method were totally questionable and always widely overestimating the yellowfin catches. This problem was clearly due to the fact that the large yellowfin, that are quite important in most Indian Ocean FAD samples (when they are rare in the Atlantic), tend to be over sampled in most FAD samples. This sampling bias is very common: when a mixture of small and of large individuals are randomly sampled, there is a well known bias leading to select an excessive proportion of the large individuals. This is why all our data processing of the species composition had to be stratified in 3 size categories: less than 10kg (a category containing all the skipjack catches), 10 to 30kg and over 30kg, 2 categories containing a potential mixture of yellowfin and bigeye. This stratification in 3 size categories has been used since 1991 in the routine correction of species composition done on the EU and Seychelles purse seiners. Consequently, we have developed an improved alternate method based on the log book catches and on the samples stratified in 3 size categories and this method has been the only one used in the Indian Ocean to correct the species composition of FAD catches: such stratified data processing being the only method allowing to estimate a potentially valid species composition. Its basic constraint is that these calculations should be done on the log book data containing detailed information on the catches by set and on the size samples weighted for each species by size category (This new method developed for the Indian Ocean should also be preferably be used in the Atlantic Ocean).

## *3- New estimates of corrected yellowfin and bigeye catches by the PS fleets*

### 3-1- Total catches by species

The yearly FAD catches by species of the PS fleets (combining various flags) used as input of our model (so called the “old data”) and the proposed corrected species composition estimated by our method (so called “new data”), assuming a minimal number of 1000 tunas sampled by 5°-3month stratum, are shown by table 2.

Table 2: Yearly FAD catches by species, old & new data

| | OLD DATA | | | | NEW DATA | | |
|---|---|---|---|---|---|---|---|
| Year | YFT | SKJ | BET | Total | YFT | SKJ | BET |
| 2001 | 39 266 | 124 055 | 14 426 | 177 746 | 40 287 | 125 627 | 11 770 |
| 2002 | 53 748 | 185 639 | 21 820 | 261 208 | 53 285 | 187 356 | 20 514 |
| 2003 | 66 325 | 144 087 | 11 804 | 222 216 | 68 538 | 144 445 | 9 217 |
| 2004 | 44 880 | 115 396 | 15 375 | 175 650 | 47 787 | 115 802 | 11 986 |
| 2005 | 57 084 | 143 422 | 13 386 | 213 892 | 59 563 | 142 725 | 11 583 |
| 2006 | 65 479 | 186 867 | 11 790 | 264 136 | 67 686 | 185 287 | 11 124 |
| 2007 | 40 248 | 106 768 | 14 861 | 161 877 | 41 651 | 106 736 | 13 473 |
| 2008 | 39 411 | 120 149 | 17 278 | 176 838 | 39 434 | 120 011 | 16 552 |
| 2009 | 49 840 | 140 042 | 21 625 | 211 507 | 50 549 | 139 977 | 20 933 |
| 2010 | 71 495 | 143 369 | 18 296 | 233 159 | 74 287 | 142 272 | 16 600 |
| 2011 | 76 030 | 117 518 | 13 735 | 207 284 | 75 547 | 117 672 | 14 064 |
| 2012 | 65 650 | 78 320 | 9 565 | 153 535 | 66 509 | 77 464 | 9 470 |
| 2013 | 100 763 | 111 287 | 20 539 | 232 589 | 100 449 | 111 028 | 21 112 |
| 2014 | 80 508 | 122 647 | 15 399 | 218 554 | 81 268 | 122 040 | 15 209 |
| **Ave 2001-2006** | **54 464** | **149 911** | **14 767** | **219 141** | **56 191** | **150 207** | **12 699** |
| **Ave 2007-2014** | **65 493** | **117 513** | **16 412** | **199 418** | **66 212** | **117 150** | **15 927** |
| **Ave 2001-2014** | **60 766** | **131 398** | **15 707** | **207 871** | **61 917** | **131 317** | **14 543** |

The yearly species composition of FAD catches estimated by the proposed method based on small mobile strata appears to be very similar to the data submitted by scientists to the IOTC (these catches being already corrected by the method described by Pianet & al 2000). While the yellowfin and the skipjack old & new total catches appear to be nearly identical (table 1 and figure 3a & 3b): yellowfin average FAD catches during the 2001-2014 are showing a small average decline of 2%, skipjack average catches being identical. On the other hand, bigeye catches are showing during some years distinct levels and showing an average decline of 7.4% during the studied period (figure 3c).

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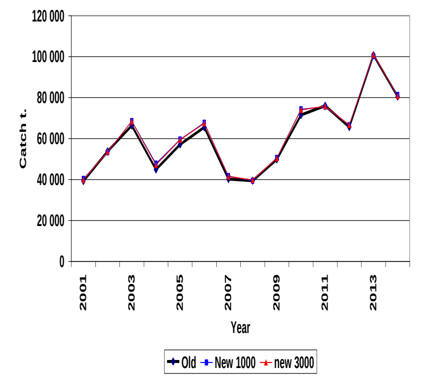
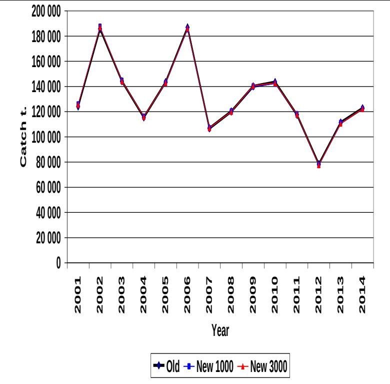
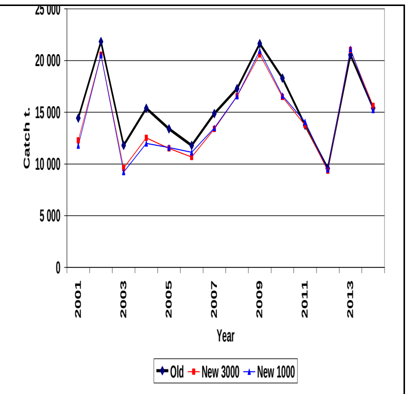
|   |   |   |
| Figure 3a: Total yearly FAD catches of yellowfin: old and new, under 2 minima of sampling levels (1000 & 3000 tuna sampled) | Fig3b: idem for skipjack | Figure 3c: Idem for bigeye |

As a final result, the average species composition of the FAD catches by 5° areas appears to be very similar in the old statistics of FAD catches and in our revised new statistics. This great similarity is also well shown at geographical level by the 2 maps of average catches estimated using the 2 methods, see figure 4.

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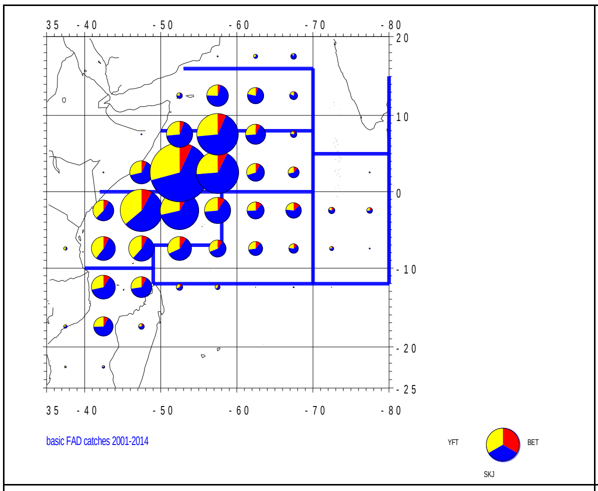
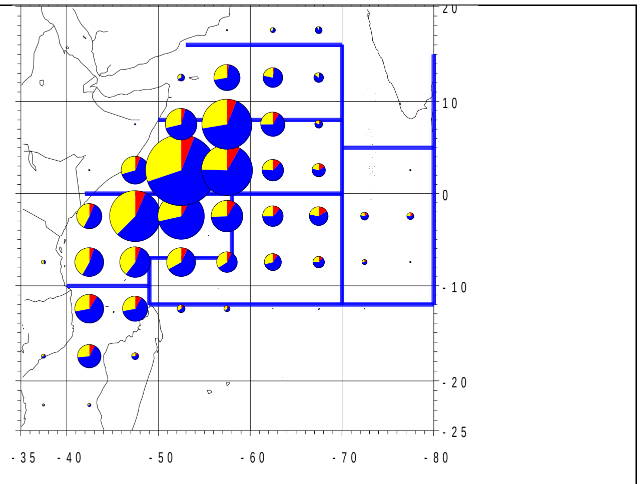
|   |  |
| Figure 4 a: Average catches on FADs by the studied fleet during the period 2001-2014 based on the today statistics | Figure 4b: idem based on the revised species composition |

Potential differences in species composition are not visible in these 2 maps, but the same average map showing in percentages the balance between yellowfin and bigeye catches are showing some visible differences between the today and our proposed corrected species composition (see figure 5).

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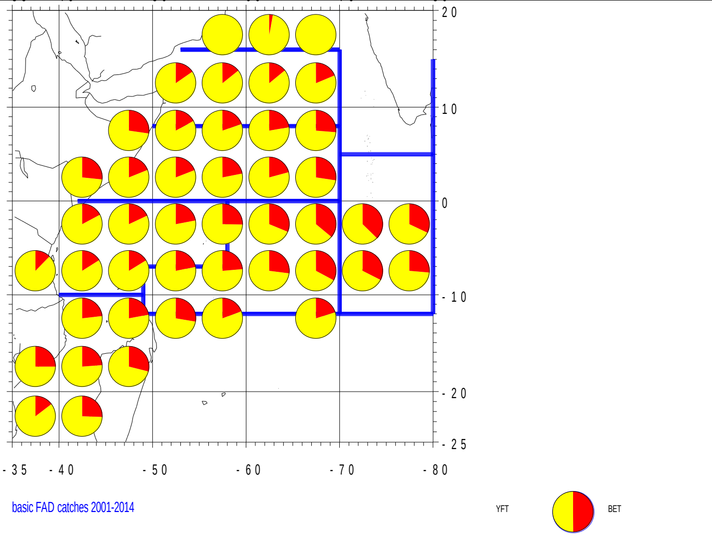
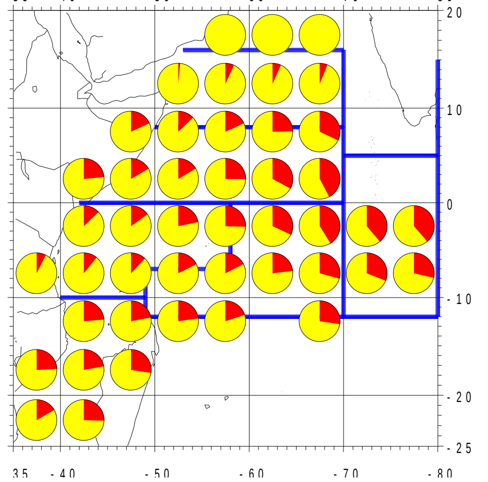
|   |   |
| Figure 5a: Average catches on FADs of yellowfin and Bigeye (in %) by the studied fleet during the period 2001-2014 based on the old statistics | Figure 5b. idem based on the revised species composition |

Some differences in the average ratio of bigeye and yellowfin catches are visible on these maps, for instance in the northern areas where the corrected amount of bigeye catches tends to be reduced, but they are clearly minor ones.

The yearly rates of strata substitution in our method are shown by figure 6, showing that the substitution rates have been always low or vey low during the entire period 2001-2014. These rates are of course higher when a high minimal number of 3000 tuna sampled are used to correct the species composition in each stratum:  done at an average rate of  10.7 % of the total catches. These substitution rate are very low with the minimal number of 500 tuna sampled; done on an average rate of only 1.6 % of total catches.

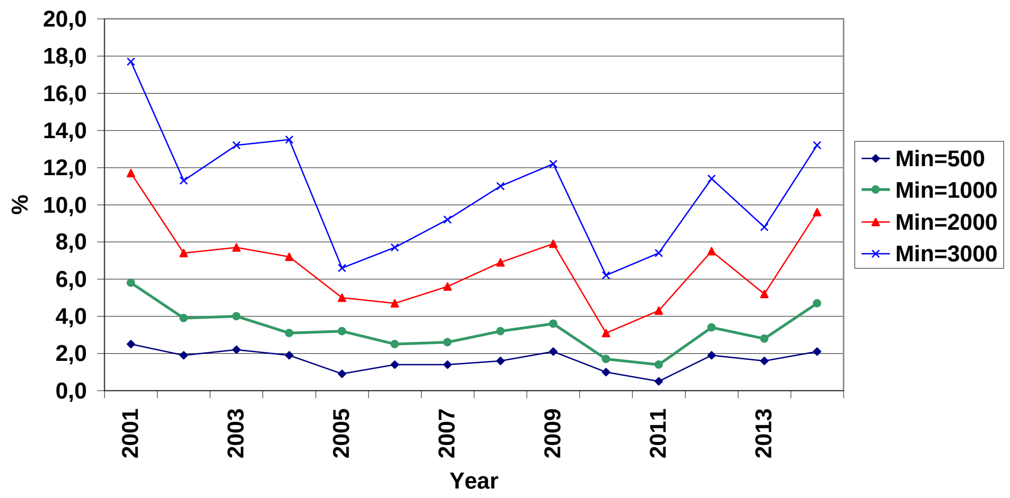



Figure 6: Rates of strata substitution expressed as weight of insufficiently sampled catches vs total catches under 4 levels of minimal sample sizes by 5°-3 months: 500, 1000, 2000 & 3000 individuals sampled.

These very low rates of strata substitution are due to the intense multispecies sampling that has been conducted each year during the studied period (table 1), and also due to the fact that these samples have been de facto randomly covering all tuna catches, thus allowing to sample most of the fishing time & area strata. Such permanent high sampling rates gives more freedom in the data processing of the samples and in the estimates of the species composition.

Our case results will be based on a minimal sample of 1000 tunas sampled by 5°-quarter, this minimal level being estimated as being a good compromise between a moderate rate of strata substitution and an uncertainty in the sampling of the real species composition of the FAD catches that is estimated to be quite low. The comparison of the species composition estimated under these 4 levels shows that there are only minor differences in these results concerning total catches by species (see figure 3 at the annual level), as well as in most time & area strata.

## 3-2- Inter-annual geographical distribution of bigeye FAD catches

This study is focused on bigeye catches, because the amount of this quite rare species appears to be more difficult to estimate. Our results shows that during the 2001-2014 period, the species composition and the total amount of bigeye catches appear to be quite similar in the official and in our revised processed data (table 2). However, a minor difference between these 2 bigeye catch levels can be observed during some years: for instance in 2001, 2003 and 2004 our proposed revision is leading to a substantial revision of the FAD bigeye catches (an average loss of 17%). It is interesting to examine the geographical origin of these reduced catches in order to understand their potential causes. In order to examine this question, peculiar yearly fishing maps have been done during selected years. Each of these yearly maps is showing the average level of total FAD bigeye catches by 5° squares (as it was submitted to the IOTC) but adding coloured pies that are showing:

(1) in red; the average weight of bigeye that should be added to each 5° square bigeye catch, (these red catches being potentially larger than the official catches shown by the circle, when the average catch in the 5° would need to be multiplied by a factor of over 2 )

(2) in green; the average weight of bigeye that should be subtracted to each 5° square bigeye catch during this year (these green catches are always smaller than the today catches shown by the circle).

These fishing maps that shows the yearly changes in the FAD bigeye catches have been done as examples:

- for the years 2012 & 2014, showing stable bigeye catches in the old data and in our proposed revision (an increase of 600 t. and a decline of 200 t.), figure 7.
- for the years 2001 and 2004, showing a large difference between the old and revised catches (a decline of 2700 and of 3300 t.), figure 8.

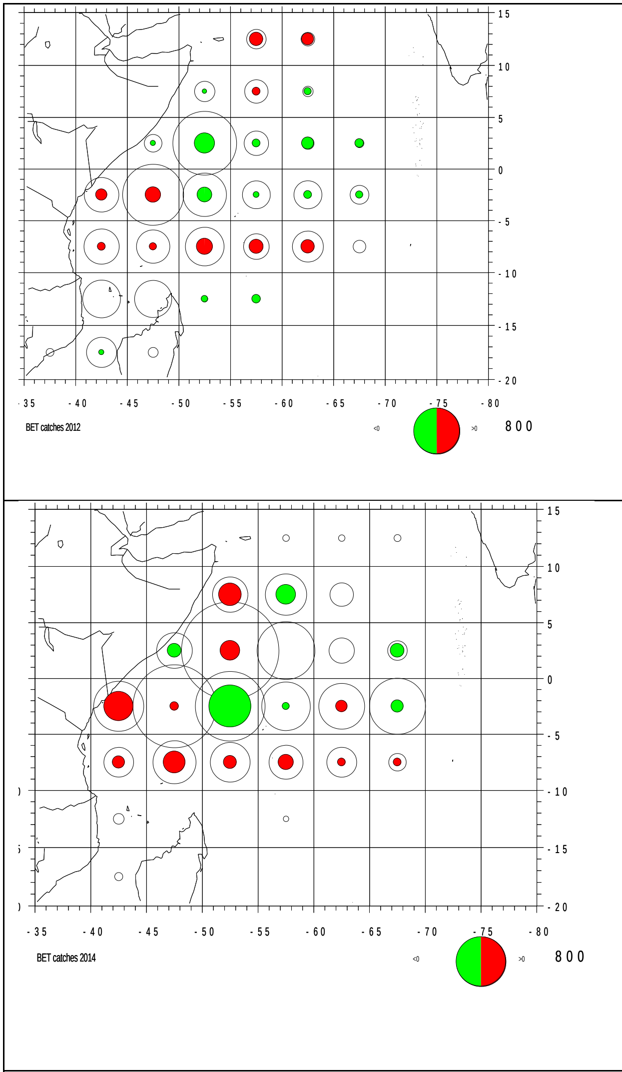



Figure 7: Fishing maps showing changes in estimated bigeye FAD catches in 2012 (upper figure 7a) and in 2014 (lower figure 7b)

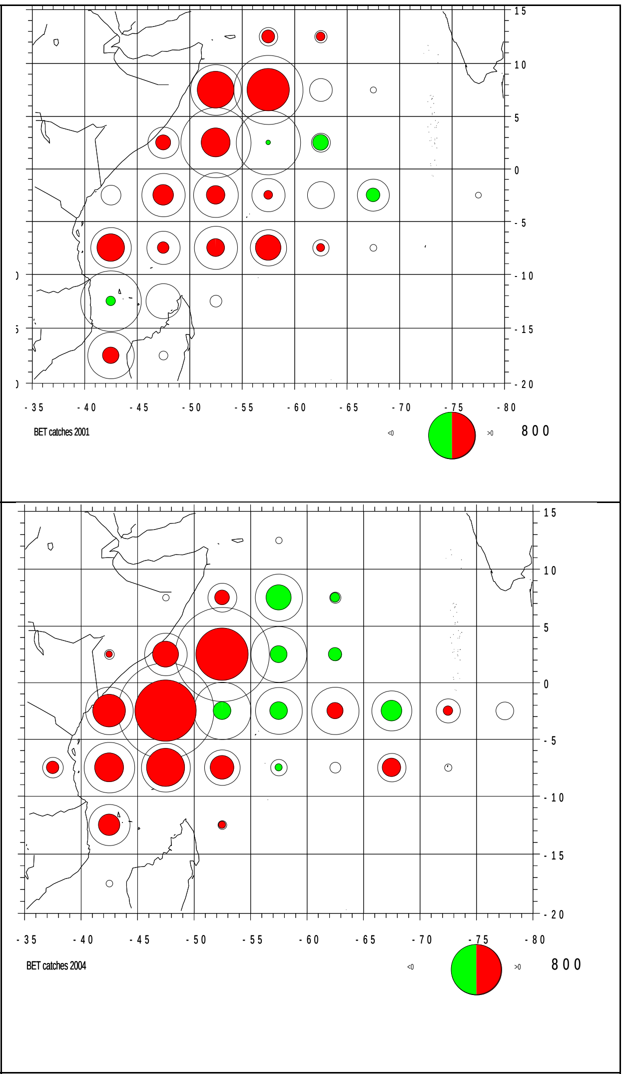



Figure 8: Fishing maps showing changes in estimated bigeye FAD catches in 2001 (upper figure 8a) and in 2004 (lower figure 8b)

These maps are showing that localized correction of the bigeye catches are most often estimated by our method: these corrections are minor ones in some years (2012), but significant in other cases (2001, 2004 and 2014). Even when the total bigeye catches remain stable after our correction, significant changes in some areas may be estimated by our correction (for instance in 2014). This result is logical: the current data processing method tend to smooth all the potential geographical heterogeneities within each of its large area and each quarter, while our proposed method allows identification of these heterogeneities.

### *3-3- Geographical heterogeneities in the present sampling areas?*

Our catches by species that are estimated at a finer geographical scale and independently of any fixed frontier between statistical areas, are often showing some potential geographical heterogeneities inside the quite large statistical areas used today. This point is easily shown, taking as an example the heterogeneity in the South Somalia area: comparing the species composition between (1) a heavily fished 5° square area off Somalia, between 5°N and the equator and between 50 & 55°E and (2) in the eastern basin of the same south Somalia area (between 8°N-equator and east of 55°E. This study was done selecting the 20 months of highest catches in this core 5° square during the 2001-2014 period (all these monthly catches being over 8.500 t., average catch of 13.000 t.). This comparison is well summarized by figure 9 showing the old and the corrected percentages of bigeye in this core area, compared to the percentages of bigeye in the east Somalia area (east of 55° East).

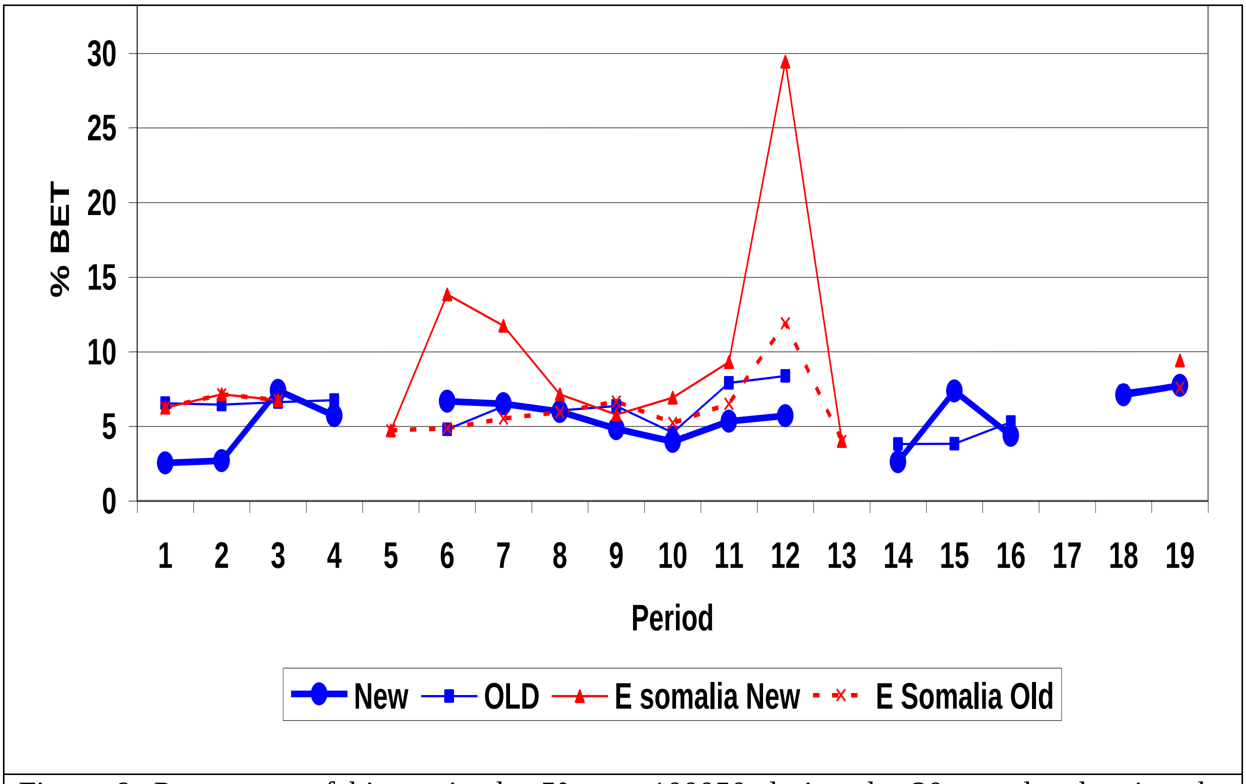



Figure 9. Percentage of bigeye in the 5° area 100050 during the 20 months showing the highest total monthly catches in the 5° sq. during the 2001-2014 period, and percentages of bigeye in the East Somalia area estimated today and by our correction.

The results shows that:

- Percentages of bigeye in the core fishing area tend to be similar in the old and in our revised statistics, but the revised catches of bigeye are often lower that the old catches (showing an average decline of 16% of these monthly estimated bigeye catches)

- Percentage of bigeye in the eastern part of the Somalia area in the old statistics are similar to the percentage of bigeye in the core area, simply because the species composition in the entire Somalia area was widely conditioned by the large number of samples in the core area. On the other hand, in our revised estimates based on the local samples, the percentage of bigeye tend to be often much larger than in the core area, simply because the multispecies samples from this area often show higher percentage of bigeye.

Similar examples of the geographical heterogeneities in the species composition observed in the current statistical zones appears to be quite clear in most of our areas. Such geographical heterogeneity was for instance often observed in the NW Seychelles area: its western component off Kenya & Tanzania most often showing a lower proportion of bigeye than in the sub-area north of Seychelles. These heterogeneity patterns should be studied in more details.

It should be kept in mind that a fully realistic knowledge by scientists of the real percentages by fine tie and area strata is an essential component for managers when they are planning a closed fishing area targeting the conservation of bigeye stocks.

## 3-4- Monthly heterogeneities in the species composition?

The current method for estimating the species composition of FAD catches is working by large areas and quarters from the calendar, always creates a smoothing in its estimated species composition within its large time and area strata. On the other hand, the results of our proposed method based on small and mobile time & area sampling strata tend to produce much more variability in the estimated monthly species composition. An infinite number of examples could easily be identified comparing the monthly 5° squares species composition estimated by the 2 methods, the old and the new one. Two examples were kept to show this typical heterogeneity in the estimated species composition, simply selecting two 5° squares heavily fished on FADs in 2014 (a total catch of 28.500 & 36.000 tons in each of the 2 sectors) and showing the monthly percentages of bigeye in the FAD catches estimated by the 2 methods (figures 10 a & 10b).

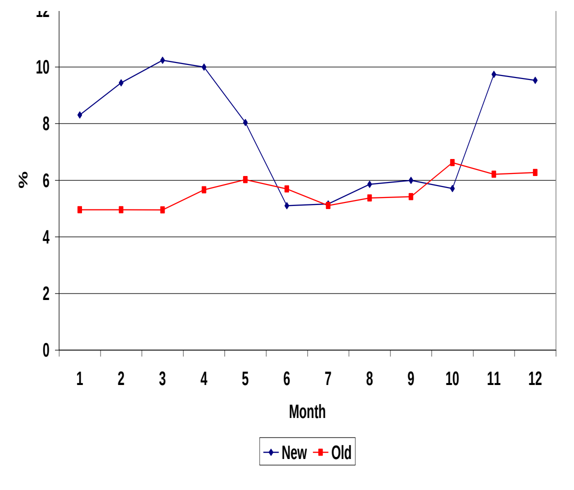



Figure 10a: Monthly percentage of bigeye in the FAD catches estimated in the 5° area 200050 by the today and by the revised method.

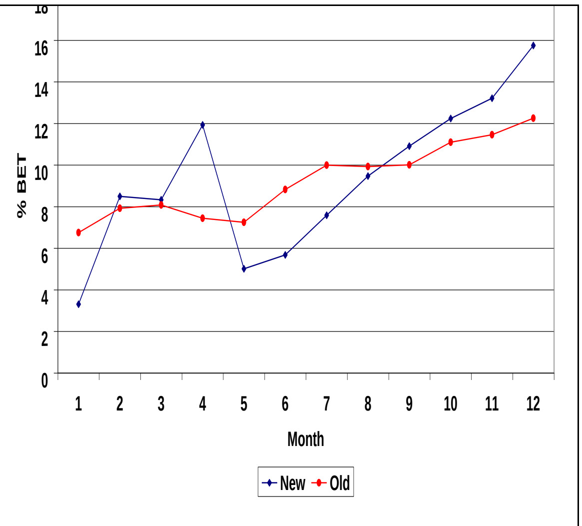



Figure 10b: Monthly percentage of bigeye in the FAD catches estimated in the 5° area 100050 by the today and by the revised method

These 2 figures, are simply given as examples, showing the systematic differential pattern in the monthly species compositions that are estimated in most/all areas by the 2 methods: the proposed method based on small time & area sampling data always showing much more variability between month, than the smoothed species composition estimated today based on large fixed areas and quarters.

### *3-5- Species composition of tuna catches during tuna concentrations*

These tuna concentrations have been studied by various authors & studies (Fonteneau 1986 and 1991, Ravier et al 2000, Fonteneau 2008, Toihir 2009). These fishing “hot spots” tend to be localized and showing limited durations, but they probably allow to catch a majority of the tunas caught yearly by purse seiners in the Atlantic and Indian Ocean. In the current data processing, their location and fishing periods may be positioned on the geographical limits of our statistical areas and in short periods at the limit between 2 adjacent quarters, thus creating a peculiar problem in the results of the data processing (as these homogeneous fishing events are processed in distinct strata). In general the species composition estimated for these localized catches in the current method being used will tend to be highly affected by samples caught in the same quarter and in the wide statistical areas used in the present data processing. As a consequence, if a given tuna catches in such localized concentration were showing peculiar species composition, the species composition estimated by the current data processing will estimate that all the catches from the concentration, or outside of it, was identical. As an example, the FAD tuna concentration identified in the Tohir 2009 study, exploited in October 2004 in the area between 4°N & 2°N and between 49° & 52°E was examined. While the percentage of bigeye in these large FAD catches (over 10000 t.) was estimated in the old statistics at 4.1 % of the total catches, our study based on local samples has estimated that there was only 2.9% of bigeye in the revised catches.

This case is only taken as an example, but there should be no doubt that the method used today and its very large strata cannot estimate well the species composition of these small scale events. Furthermore and as a potential example of these problems, if 2 independent large concentrations of FAD associated tunas are exploited during the same quarter in the same statistical area, and if each of these 2 concentrations is showing a distinct species composition, the species composition estimated by the traditional method for each concentration will be the average species composition in the area/quarter (the real species composition of each concentration being lost!). On the other hand, the results obtained by our proposed method would probably be much more realistic and able to clearly identify the real species composition of each of these major tuna concentrations.

## *4- Discussion*

Our proposed method does not significantly modify the total catches of the PS FAD fishery, but it probably allows to better evaluate the real time and space heterogeneity of the species composition of FAD associated tunas. This time and area variability of the species composition may be an important factor. It could for instance easily explained the lower catches of bigeye estimated by our method, compared to the current catch and effort data. If the species composition of FAD catches tend to be distinct in a heavily exploited strata or in others areas, it could easily introduce bias in the species composition as currently estimated.

However, the results obtained by this method are of course somehow dependent of the quality and of the reliability of the sampling data. Our current study has been using all the samples identified as being caught on FAD samples, based on the average fishing location and the average fishing date associated to each sample. However it should be kept in mind that a significant percentage of the samples are not associated with a given set, and with an exact position and date, but corresponding to a combination of sets taken during a short period and in a limited area. Alternative data processing should explore this uncertainty, for instance solely keeping in this analysis all FAD samples taken at close proximity and during a known short period (This information being quite well identified in the sampling file and also easy to use).

A global advantage of our proposed method is its flexibility to face changes in the fishing zones by the FAD fisheries and potential changes in the frontiers between environmental areas, for instance due to:

1) **Environmental changes**: the potential effects of global warming on the latitudinal frontiers between biotopes frontiers (and statistical areas) as they have been modelled by Dueri and al 2014 and/or the effects of declining subsurface oxygen rates that have been well shown by Stamma et al 2012 that may alter the species composition of tuna catches in some areas.

2) **New fishing zones**: often developed at the periphery of the traditional fishing zones, for instance when the Indian Ocean PS fishery moved in the peculiar fishing zones: in Chagos waters (1993), in the Northern Somalia area (1999), off Iran (1996) and in the eastern Indian Ocean following the El Niño event observed in 1998 in the Indian Ocean. This potential problem faced by the existing data processing was for instance well shown by the northern extension of the FAD fishing in the Somalia area used in the original data processing (figure 1a & 1b). While in 2000 (Pianet & al) the species composition of FAD catches was assumed to be homogeneous between the Equator and 12°N, the fine scale analysis of the samples has been showing since 2001 that the rate of bigeye in the FAD catches was quickly declining north of 8°N, leading to adopt a new stratification of the Somalia area, figure 1b (after several years of errors in the data processing). If significant numbers of multispecies samples have been collected on the catches taken outside the traditional fishing grounds, our estimated species composition will be fully valid in each of these new and unknown time and area fishing units, independently of any hypothesis on the geographical status of these new fishing zones.

It should be nonetheless recognized that the statistical uncertainties of the proposed method have not yet been thoroughly evaluated, and this statistical analysis should of course be conducted. Various sources of uncertainties in the model should for instance be better studied such as:

a) D**uration between catch and samples**: our analysis was based on 3 months periods, but the same method could be applied based on any selected daily durations, as the exact fishing day are known for both the catch and the samples (our today FORTRAN program already handle this option).
b) **Distance between catches and selected samples**: a distance of 170 miles corresponding to a 5° square has been selected in our work, but this distance could easily be modified in alternate runs (our today FORTRAN program already handle this option).

c) **Minimal numbers of tunas sampled** in the strata that estimated to be valid to estimate the species composition. Our study has been working in a range between 500 and 3000 tunas sampled selecting a base case of 1000 tunas as a minimum level, but this parameter would need to be studied by statistical or simulation studies.
d) **Strata substitutions**: the current method has not been doing any strata substitution, but simply keeping the previous correction of the species composition when there was not enough samples available (these substation rates being today most often very low). Alternate strata substitution schemes should preferably be studied.

## *5-Conclusion*

This proposed use of small mobile strata use to estimate a corrected species composition of FAD catches was made possible by the large scale & intensive multispecies sampling of the FAD catches that has permanently been conducted in the Eastern Indian Ocean since 2001.

There should be little or no doubt that these revised estimates of FAD catches by species, solely based on a mobile fine scale 5° & 3 months periods sampling, and that can be obtained with very few strata substitutions, are probably much stronger than the present statistics based on the large and potentially heterogeneous fishing zones and fixed quarters. In 1997 these large fixed areas and quarters from the calendar were estimated to be the best method (following the Pianet et al 2000 work), simply because of the limited samples available during this period, but today it should be concluded that this method is not the best way to estimate the real species composition of the FAD catches and of its time and space heterogeneity.

Our proposed method would not significantly modify the estimated total catches by species, but this method based on fine scale estimates of species composition could offer various improvements in the estimated species composition by fine time and area strata, for instance:

1) Providing more realistic estimates of the tuna species taken during localized exploitation of tuna concentrations.
2) Our proposed method based on 5°-3 months samples, would be valid for most type of time and space heterogeneity of new fishing zones.
3) Such small scale & mobile data processing would effectively handle any potential variability or changes in the species composition, between years and geographical area.
4) This method would also allow estimation without bias of the species composition observed in new fishing zones.

This proposed new method has been solely targeting the FAD catches because these tunas are most often caught at small sizes and because their species composition is more difficult to estimate. However this method could also be envisaged for the analysis of free school catches, as these catches may also show some spatial and temporal variability that are not visible in the existing data processing. This potential problem may for instance be observed as for FADs in the data processing of free schools catches taken on highly localized tuna concentrations (as in Fonteneau & al 2008).

Furthermore, while this method based on mobile small time and areas has been used only solely to estimated the species composition, its use could also be envisaged to estimate the catch at size of the 3 species of tropical tunas (as the same large areas used today could face the same type of problems encountered in the species composition estimates).

Our conclusion and recommendation is that a fully validated and official revision of the species composition should be conducted as soon as possible for all FAD catches, simply based on the basic rules proposed by this method. It is also recommended that the future method used in the data processing of the sampling data leading to estimating corrected species composition of the landings should be conducted in close cooperation with the ICCAT and the IATTC scientists, because these 2 tuna RFOS are facing the same types of statistical problems when analyzing the multispecies port sampling data.

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