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FROM LARGE FIXED TO SMALL MOBILE SPATIO-TEMPORAL STRATA: IMPROVING ESTIMATES OF SPECIES AND SIZE COMPOSITION OF THE LANDINGS OF THE EUROPEAN PURSE SEINE FISHERY IN THE ATLANTIC OCEAN

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SUMMARY

This paper analyzes potential errors in the species composition of the EU purse seine landings. This species composition was based on the hypothesis that sizes and species composition are homogeneous during quarters and in large areas and by fishing mode. The analysis of sampling data is showing that large areas and quarters are often heterogeneous. An alternate data processing based on Small Mobile Strata (SMS method) is proposed to estimate improved species composition. Species composition in each 1°-month was estimated, based on samples at the immediate time and space vicinity of each catch. This method was applied to the 2002-2015 data. These results are showing that the today species composition are overestimating bigeye catches on FAD and free schools (average of 10 and 13%), especially in coastal zones. SMS results are also showing that the today species composition is smoothing and masking the time and space variability of species composition (free schools and FAD catches). A new data processing method, following the guidelines of SMS, should be developed and used to estimate the past and future catch statistics of purse seiners.

RÉSUMÉ

Le présent document analyse les erreurs potentielles dans la composition par espèce des débarquements des senneurs communautaires. Cette composition par espèce se basait sur l'hypothèse selon laquelle les tailles et la composition par espèce sont homogènes pendant les trimestres et dans de vastes zones et par mode de pêche. L'analyse des données d'échantillonnage révèle que les vastes zones et les trimestres sont souvent hétérogènes. Un traitement des données alternatif basé sur de petites strates mobiles (méthode SMS) est proposé afin d'estimer la composition par espèce améliorée. On a estimé la composition par espèce dans chaque carré-mois de 1º, sur la base des échantillons prélevés immédiatement après et à proximité de chaque capture. Cette méthode a été appliquée aux données de 2002-2015. Ces résultats montrent que la composition par espèce aujourd'hui surestime les prises de thon obèse réalisées sous DCP et en bancs libres (moyenne de 10 et 13%), notamment dans les zones côtières. Les résultats du SMS montrent également que la composition par espèce aujourd'hui lisse et masque la variabilité spatio-temporelle de la composition par espèce (prises en bancs libres et sous DCP). Une nouvelle méthode de traitement des données, suivant les directives du SMS, devrait être mise sur pied et utilisée pour estimer les statistiques de capture antérieures et futures des senneurs.

RESUMEN

Este documento analiza posibles errores en la composición por especies de los desembarques del cerco europeo. Esta composición por especies se basaba en la hipótesis de que las tallas y la composición por especies son homogéneas durante los trimestres y en grandes zonas y por modo de pesca. El análisis de los datos de muestreo está demostrando que las grandes zonas y los trimestres son a menudo heterogéneos. Se propone un procesamiento alternativo de los datos basado en pequeños estratos móviles (método SMS) para estimar mejor la composición

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por especies. Se estimó la composición por especies en cada 1º-mes basándose en muestras tomadas inmediatamente después y en las inmediaciones de cada captura. Este método se aplicó a los datos de 2002-2015. Estos resultados están demostrando que la composición por especies actual está sobrestimando las capturas de patudo sobre DCP y banco libre (media del 10 y 13%), especialmente en zonas costeras. Los resultados del SMS están mostrando también que la composición por especies actual está alisando y enmascarando la variabilidad en el tiempo y el espacio de la composición por especies (capturas sobre DCP y banco libre). Debería elaborarse un nuevo método de procesamiento de los datos, siguiendo las directrices del SMS, y utilizarse para estimar las estadísticas de captura pasadas y futuras de los cerqueros.

KEYWORDS

Purse seining, species composition, statistical sampling, multispecies fisheries

1. Introduction

The species and size composition of the catch statistics of the European and associated flags purse seine fishery has been estimated over the last two decades from data processing rules and spatio-temporal strata established in 1998 with data collected during 1991-1996 (Pallarés and Hallier, 1998; Pallarés and Petit, 1998). This data processing procedure, known as *"Traitements des Thons Tropicaux"* (TTT), is still in use nowadays and it assumes the homogeneity of the species composition of all catches coming from a stratum defined by quarters, large areas, distinct size categories (<10 kg, 10-30 kg and>30kg), and fishing modes (school associated with a floating object or free-swimming school) (**Figures 1 and 2**). In the mid-1990s, the fishery was however restricted to smaller fishing grounds than nowadays and few size-frequency samples describing the catch composition were available at this time (**Figure 3**). The data processing is also based on the assumption that the composition of the catches is independent of the flag. Although such an assumption may be valid when vessels of various flags are simultaneously fishing within a small area (e.g. in the case of concentration), this homogeneity in the species composition of the catch remains questionable when a component of the fleet operates in distinct and distant fishing grounds of the same TTT area than the other components, as often observed in the fishery.. In this case the TTT method area estimating an average species composition of all these catches in the wide area, then masking the observed heterogeneity in species composition.

Furthermore, very large numbers of samples aboard purse seiners have been collected in the eastern Atlantic Ocean over the last 12 years. Most of purse seiner fishing trips were sampled during unloading at the ports of Dakar (Senegal), Abidjan (Côte d'Ivoire) and Tema (Ghana) following a protocol implemented concomitantly with TTT and consistent since 1998. Information on the origin (position and date) of the size-frequency samples has been retrieved from the brine-freezing well plans and skipper logbooks and validated with VMS data since the early 2000s. Such good sampling coverage and accuracy in spatio-temporal information of the samples should now be used to consider smaller strata within the estimation procedure of the species composition of the purse seine catch so as to assess the relevance and limits of the current data processing and eventually improve the estimates that constitute Task I and Task II data.

The main goals of this work will be to analyse the potential problems and errors in the today species composition of fish aggregating devices (or FADs) FAD and free schools catches, and to propose a new improved data processing of the logbook and sampling data based on smaller and more homogeneous strata. This work is a widely improved follow up of the original method proposed by Fonteneau et al. (2015) that was built under the same basis but that was based on the ICCAT TASK2 data.

2. Data and method

Two types of data have been used in this new data processing:

- logbook data with daily catches by 1° squares, by species and by size categories, by fishing mode, these data being already tentatively corrected by the today TTT method, covering all logbooks collected on the EU and associated flags purse seiners (later called EU&al PS).

- data from the multispecies size samples by 1° and month, by fishing mode, covering all data collected on the EU&al PS landings (the so-called *NN.T file). All samples with a unique fishing mode[4] have been kept and used in the analysis, even when samples where obtained from a mixture of catches from various neighbouring sets, possibly from distinct areas and distinct quarters (the basic rule in the sampling program is to avoid to sample these catches of ambiguous origin, and an average of 3.7% of the sampled tunas have been taken during the studied period on these catches). This point should be further studied and the potential elimination of these samples of questionable origin should probably be envisaged in future alternate SMS calculations. The basis of our new data processing method was already proposed by Fonteneau et al. at the SCRS 2015 meeting. This data processing was based on the use of small mobile strata, the **SMS** method: using a species composition estimated from all the samples done + or – 1 month around the fishing month, and + or – 2.5° around each 1° fishing location (**Figure 4**). This calculation was done only when enough samples have been collected in each stratum, for instance more than 1000, 2000 or 3000 tuna sampled in the stratum, and otherwise the species composition estimated today by the TTT method was kept. Here, the minimal numbers of tunas that should be sampled in such small strata in order to obtain a realistic species composition has been estimated based on an ad hoc bootstrap study conducted in 3 very well sampled strata, this study being done separately for free schools and for FAD catches (Appendix 1). Based on this bootstrap, it has been estimated (at least temporarily) that a minimal number of 1500 and of 2000 tunas sampled was sufficient to show the species composition in the SMS strata (this minimum level being independent of the catch). However, it will be noticed later that this minimal number of tunas sampled is an important factor in the SMS calculations, for instance widely conditioning the amount of non-sampled strata (**Figure 5**). Various alternate rates of minimal sample sizes (i.e. 1000, 2000, 3000) have been used for sensitivity analysis, showing that the threshold in the number of fishes to consider in the processing, at least in a range between 1000 and 3000 tunas sampled per stratum, does not significantly alter the yearly species composition of the SMS catches (**Figure 6c**). In the rare cases when the number of sampled tunas was insufficient in a given 5°-3month stratum, it was decided to keep in this 1° square the species composition that has been estimated by the TTT method.

Two additional important points in the today SMS method are that:

- While the SMS calculations in our 2015 paper were based on the ICCAT TASK2 data, i.e. on the total catches by 1°square and month, our revised 2016 SMS method is now based on the logbook data and on the set by set catches classified in 3 size categories that are used in the TTT method (<10 kg, 10 to 30 kg and >30kg; all skipjack catches being classified in category 1).

- All the cases of the heavily fished and well sampled 1°-month (most often corresponding to free schools tuna feeding or spawning concentrations) have been processed separately: solely using the samples from this 1°-month strata when the number of fish sampled in the 1°-month was already reaching the standard sampling minimum number used. This rule probably adds a more realistic variability in the large catches by species by 1°-month & it was used in our base case statistics.

All these SMS calculation have been programmed in FORTRAN, a program called “SMS”. This program was quite complex to program, but it is quite easy to use (few and simple parameters are needed to run it) and it is very fast to run: only 2 minutes needed to process 15 years of data for all the flags.

3. Results

3.1 Main SMS results

Species composition of the yearly FAD catches by the EU&al PS fleet estimated by TTT and SMS show that:

- skipjack FAD catches area nearly identical in the SMS and TTT results
- yellowfin catches estimated by SMS are 5% larger than in the TTT results
- bigeye catches estimated by SMS are much lower, average=11% (between 4and 24 %, depending of the year) than in the TTT results (**Figure 6**). The SMS results also show that the differences between TTT and SMS results are quite variable for each country, these differences being more important for French catches than for the catches of other flags (Spain and others) (**Figures 7 and 8**).

These significant differences in the yellowfin and bigeye catches are mainly due to differences in the catches of small yellowfin and small bigeye.

3.2 Rates of insufficient sampling in the SMS data processing

A lack of sufficient sampling data was encountered for:

- 14.0 % of the EU&al PS FAD catches during the average period 2002-2015 (based on a minimum sample size of 2000 tunas obtained from the bootstrap results).

- 15.9 % of the EU&al PS free schools catches, same period, based on a lower minimum sample size of 1500 tunas obtained from the bootstrap results).

The results of SMS data processing under various minimal sampling levels per strata indicate that the number of unprocessed SMS strata is higher with a higher minimum sample size, and smaller in the opposite case (see **Figure 5** for FAD catch). However, our results show that the species composition of FAD and free school catches estimated by SMS is quite robust to the minimal sample size chosen in the calculations (**Figure 6c**). It was concluded that the lack of local sufficient sampling does not significantly affect the final species composition estimated by SMS.

3.3 Amount of well sampled 1°-month strata

The average yearly percentages of the well sampled EU&al PS catches that have been processed during the 2002-2015 period at a 1°square-month level because sufficient numbers of samples were already obtained at this level are shown by **Figure 9**. The proportion of well sampled catches at the 1°-month level was at an average 2002-2015 of:

- 3.0 % of the FAD catches
- 5.6 % of the free schools catches

These levels of well sampled catches at a 1°-month level are indicative of the quite high level of sampling developed on the EU&al catches. It should be kept in mind that in our proposed data processing the original species composition from the sampling of these catches will be kept in the SMS results (while they are lost today in the results submitted to ICCAT).

3.4 Average number of sampled tunas used in the SMS calculations

While the minimal number of sampled tunas was chosen at 1500 for free schools and 2000 FAD associated schools, the SMS data processing estimating the species composition was most often based on much larger sample sizes (keeping in mind that each sample was repeatedly used in the calculations). For instance, the average numbers of tuna sampled in the SMS species composition was based:

- For the free schools catches on an average number of 4600 tunas sampled in each average corresponding 5°-3 months neighbouring strata.

- For the FADs catches: on an average number of 4000 tunas sampled in the corresponding 5°-3 month neighbouring strata.

4. Comparison of SMS & TTT Species composition by 1°-month and errors in the today TTT TASK2

4.1 On the global reasons explaining the differences in the TTT & SMS results and method used in order to compare TTT & SMS TASK2

Most of the differences between the TTT & SMS results are logical ones, being simply due to the too wide TTT areas (**Figures 1 and 2**) and long duration (and potential heterogeneity) of the quarters used in the TTT calculations. The today sampling data are clearly showing various major temporal and area heterogeneities in the sampled species composition of FAD & of free schools catches that have been more or less constantly observed in the landings. As an example, the major geographical heterogeneity observed in the relative proportion of small bigeye and small yellowfin caught under FADs are clearly inconsistent with the large areas used by TTT (**Figure**

10). The spatial heterogeneity in the species composition of FAD catches from coastal and offshore fishing zones is for instance well shown by the species composition of FAD samples observed in the 3 areas shown in **Figure 11**, while the average species composition in each of these areas is shown by ternary plots in **Figure 12**. These 3 ternary diagrams are showing that there is always a mixture of the 3 species in the 3 areas, dominated by skipjack catches, sometimes showing some samples of pure skipjack, especially in coastal areas. However, a distinct pattern of species composition frequencies is observed between the northern area 1 and the southern offshore areas 2 & 3 (that are quite similar). It can for instance be noted that the coastal area north of the equator is very seldom showing rates of bigeye over 30%, but significant frequency of yellowfin rates over 30%, and very rarely large bigeye. On the opposite, the 2 southern areas are showing higher frequencies of samples with more than 30% of bigeye and very rare samples showing over 30% of yellowfin and less pure skipjack samples. Small amounts of large yellowfin are observed in most type of FAD sets, and also frequently of large bigeye in the 2 southern areas. It should also be noticed that this basic geographical problem has been reinforced by the fact that Spanish (and associated flag) PS are most often fishing in a much wider fishing zone than French PS (**Figures 13a and 13b**), then often showing for these offshore catches peculiar species composition often found in these remote areas. As a result, the TTT data will produce species composition of the French fleet that will be frequently "contaminated" by the species composition sampled on the Spanish catches (on the opposite bias: Spanish offshore catches being affected by French coastal catches). In order to identify and analyze the potential differences between the TTT and SMS results, we have identified a list of selected strata that are characterized by large differences between the today TASK2 obtained by the TTT method, and by our SMS (and by the samples)[5]. In each of these identified cases, fishing maps of these strata were made, and the statistical reasons explaining these differences were identified and explained.

4.2 French PS FAD catches by species during the 3rd quarter of 2005 in the Anno Bom and Cape Lopez area

Spanish and French PS have been fishing during this period in quite distinct areas: French PS fishing in coastal areas off Cape Lopez and Spanish in more offshore areas in the South West central Atlantic. As a result, the French bigeye catches on FADs estimated by the TTT method and its large areas are overestimated because of the large number of samples from the Spanish fleet south of the Equator, where bigeye is more abundant than yellowfin. As a result French bigeye FAD catches are overestimated by 82%, compared to the SMS results that are solely based on French samples from the fishing area (**Figures 14a** and **14b**).

4.3 French PS FAD catches by species during the 2nd quarter of 2013 in the area off Guinea

A large concentration of FAD catches in the coastal area off Guinea was fished during this period in an area where large numbers of samples are showing low rates of bigeye: only 3.6%. On the opposite, the present TTT results have been estimating that there was a significant 9% of bigeye in the French FAD catches. This overestimated percentage of bigeye is again the consequence of the offshore Spanish samples in the large and heterogeneous area used in the TTT data processing. As a result, the French bigeye catches within this stratum are overestimated by 150% in May 2013 (**Figures 15a** and **15b**).

4.4 PS FAD catches by species in the Cote d'Ivoire EEZ

Yearly bigeye % & catches on FADs by the EU&al PS in the Cote d'Ivoire and Ghanaian EEZ are much larger in the present TTT task2 statistics than in the original sampling data and in the SMS results (see **Figure 16**). It can be concluded that bigeye FAD catches estimated today by TTT in this area are clearly overestimated, this problem being due to the very large area used in the TTT data processing of the FAD catches from this area (south of 4°N).

4.5 PS FAD catches by species in the Guinea and Sierra Leone EEZ

Yearly percentages of bigeye in the FAD catches by the EU&al PS in the Guinea & Sierra Leone EEZ are much larger in the present TTT task2 statistics than in the original sampling data and in the SMS results (**Figure 17**). It can be concluded that bigeye FAD catches estimated today by TTT in this area are clearly overestimated, this problem being due to the quite large and heterogeneous area used in the TTT data processing of the FAD catches from this area, the species composition in the coastal area being contaminated by the species composition sampled in the offshore areas where bigeye is more abundant.

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[5] Surprisingly, this basic comparison of the monthly catches by 1° squares by species estimated by TTT and observed in the sampling data has never been presented to ICCAT scientists. This basic comparison is very informative and its results should be visible and routinely analyzed by scientists.

4.6 January 2010 free schools catches in the 1°square 301002

Large amount of large tuna were caught by the EU&al PS on free schools in January 2010 in the area 301002. Based on the TTT results, there was 11% of big bigeye in these catches. On the opposite, large bigeye were very seldom noticed in the log books, and large bigeye were very rarely sampled in the large amount of samples collected on these catches, 16 samples and local sampled weights over 128 t of yellowfin sampled, these samples showing only 400 kg of bigeye sampled! As a result, species composition estimated by TTT and by SMS are widely distinct (**Figures 18a** and **18b**). The maps showing the monthly species composition of the samples during the 1 quarter of 2010 (**Figure 19**) help to understand the origin of the problem in the TTT results: large amount of bigeye are visible in the March samples, and at a distance of about 500 miles west of the fishing location in January. As a result the species composition of large tunas caught in the entire area south of the equator during the 1st quarter are showing significant percentage of large bigeye. It can then be concluded that the SMS results are more realistic than the TTT results.

4.7 January & February 2013: exploitation of 2 free school yellowfin equatorial concentrations

These 2 large concentrations of large yellowfin have been described in details and analyzed by Fonteneau *et al.* 2016. The today results of the TTT method are showing that the large catches from these 2 concentrations (total catch of 7300 t) in January and February were showing an heterogeneity in their species composition (**Figure 20**) (keeping in mind that the Equator is a frontier between 2 distinct areas in the TTT data processing): for instance showing large bigeye catch by French PS (318 t), south of the Equator, but without bigeye caught north of Equator. On the opposite, the sampling data and the SMS results are showing nearly identical species composition north and South of the Equator. It may be concluded that the present TTT method and its very large strata, associated to its questionable fixed frontiers, cannot estimate well the peculiar species composition of these small scale fishing events, while the SMS method could reach this target, at least and only if the catches from these concentrations have been well sampled (as in this case).

4.8 Free schools catches by the EU&al PS in June 2011

Total catches on free schools in the 1° square 201001 in June 2011 area are showing a very peculiar species composition and a dominant catch of bigeye. This 1° square was heavily fished in June 2011 by 10 purse seiners, 47 positive sets on free schools, producing a large total catch of 1000 tons. Bigeye catches in this 1°month were estimated by the TTT method at 588 t. (corresponding to a majority of the total catches: 58%) while yellowfin catches were estimated at only 98 tons. On the opposite, bigeye catches estimated by SMS are reaching only 92 t (based on the large numbers of samples collected in the 5°-3 month around this fishing date and location) (**Figure 21**). The uncorrected species composition in the log books is showing a catch estimated at 43% of yellowfin (92% at sizes >10kg), 24% of skipjack (possibly including some small yellowfin & bigeye), and 33% of bigeye (82% at sizes >10kg) (keeping in mind that large yellowfin and large bigeye are most often well identified by skippers in the log books). It can be noted that the peculiar species composition of the TTT results in this 1°-month strata was due to a data processing problem and also possibly to the small numbers of samples used in this case by TTT (samples from 2 Spanish purse seiners). This type of TTT error is probably very rare, as its data processing is most often producing too much smoothing; it should also be concluded that the species composition estimated by SMS is probably more realistic, being based on a larger number of samples that have been obtained at an immediate vicinity of the fished 1° square that have been used by SMS (while these neighbouring samples have been eliminated by the TTT data processing because of its quite artificial equatorial frontier).

5. Discussion

Our SMS method has not been used before 2002 because of the quite low numbers of samples available during the period 1991-2001, but the 2 years 2000 and 2001 could also be possibly analyzed by SMS because of their sampling levels (see **Figure 3)**. It can be also be noted on this figure that the major increase in the sampling rates observed since 2000 was related to the generalization of a new sampling scheme where large fractions of the sampled catches are not measured but solely identified by species. Our data processing method based on small mobile strata, is probably facing very minor potential risks of bias or of systematic errors. It should also be noted that total yearly **SMS** catches by species are very stable compared to the TTT results, showing only small and expected changes in the estimated yellowfin and bigeye catches: a significant decrease of bigeye catches and a minor increase of yellowfin catches (while most often skipjack catches tend to be unchanged). It should be concluded that this global consistency between the TTT and SMS results is due to the fact that those 2 methods are based on the same data sets, namely log books by size categories and multispecies sampling results, but simply working on a widely distinct time and area stratifications in their data processing. On the other side, our **SMS** results appear to be always much more realistic to show the fine scale spatio-temporal variability in the species composition observed in the samples, a variability that is hidden in the TTT results (by definition). Another serious advantage of this SMS is that our method is independent of any artificial and fixed time or area frontier: its calculations are never assuming a questionable and constant homogeneity of species composition in a selected large time & area strata. As a consequence, its results are not conditioned by the changes in fisheries, for instance by increasing fishing zones and/or by changes in the environment producing changes in the biological frontiers between fishing zones that are potentially producing changes in the species composition. Furthermore, an interesting point is that, in most or all cases, the SMS results appear to be much more realistic to show the real species composition of these local catches from tuna concentrations that are caught in small time & area strata (knowing that these large catches have been most often well sampled, and often showing a peculiar species composition, even at small distances. It should also be kept in mind that these homogeneous tuna concentrations may be fished at the frontier between 2 areas or/and of 2 quarters: a serious problem in TTT, but well handled by the SMS method.

Only 5 simple basic parameters are needed in our SMS data processing:

1) Size of the area: today + or – 2° squares, this size being easily modified
2) Duration of the mobile data processing strata: today + or - 1 month, , this duration being easily modified
3) Minimal numbers of tunas sampled in the strata: today 1500 for free schools and 2000 for FAD catches
4) Accept or not to run the data processing at a 1°-month level, when enough samples are already available in this smaller stratum, and its minimal sampling level
5) Establish rules to estimate species composition in the poorly sampled catches? (our today method to keep the species composition estimated by the TTT method being questionable and provisional)

However, it should be kept in mind that our method is facing various potential problems and sources of uncertainties such as:

1) The potential effects of its repeated use of the same samples in the SMS calculation? In our SMS method, the same sample taken in each 1°-month will be repeatedly used to estimate the species composition of catches from various 1°-months. This repeated use of the samples will of course introduce some artificial smoothing in the species composition estimated by SMS in each 1° area, but we tend to consider that this type of method does not introduce any serious bias in the results, but simply producing a time and space small scale smoothing of the estimated species composition. The same smoothing was in fact already a fundamental factor in the results of the TTT method used today by the EU statistics: as the species composition of each set during a quarter and in large areas was estimated from all the samples from this large strata. Our small scale SMS smoothing is in fact similar to the TTT smoothing, but based on smaller numbers of samples and in small mobile strata. At least this small scale smoothing cannot introduce large statistical biases at an oceanic scale as the today TTT method and its very large and heterogeneous areas. This point should be further studied by statisticians.

(2) The excessive smoothing of species composition by SMS when there are clear frontiers in the species composition of tuna catches: when there is a clear biological frontier in a given peculiar area (for instance an environmental front, an effect of a continental shelf or of a deep canyon, etc.), potential geographical heterogeneities in the species composition in relation with this area will be lost: our SMS method will most often provide smoothed estimate of the species composition at a 5° scale. This potential problem is for instance faced for the species composition of catches associated to sea mounts and in their neighbouring squares:

- In the today TTT data processing: the species composition is estimated to be the same in large areas, for all potential sea mounts and outside of them in very large areas.

- In the SMS method, the species composition of catches from the sea mount and from its neighbouring squares will be smoothed, then potentially losing the potential peculiarity of the sea mount catches, and also “contaminating” the species composition estimated in the areas neighbouring the sea mount.

This inadequate smoothing will always occur, unless in cases when large catches and large samples have been obtained in the 1°-month strata in all sides of its frontiers (this intensive sampling of each sea mount catches being very seldom available. However the analysis of the time and space heterogeneity of free schools and FAD catches species composition is most often showing that these biological frontiers in the species composition of tuna catches have been very rarely observed, at least in the Atlantic.

3) The choice of the samples used in the analysis: the minimal number of tuna sampled and the potential elimination of samples done on several sets when these sets are too heterogeneous in term of fishing dates or/and fishing locations.

6. Conclusion and recommendations

This study has been showing for the first time a major result obtained by the sampling program of EU&al PS landing in the Atlantic oceans: these multispecies sampling are so intense that they cover most of the catches even at a fine time and area scale and consequently, these results allow to do during recent years fine scale data processing of the species composition. Our SMS method is based on a very simple concept, but such improved data processing method can easily be used and without risk of serious statistical bias: this method provides TASK1 and TASK2 results that are clearly much more in agreement with sampling data and then more realistic realistic than the today TTT results. It should also be noticed that the statistical bias introduced since 2006 in the TTT data processing of the EU PS landings, that has been sometimes producing excessive catches of large bigeye (a well known problem analyzed by Fonteneau & al 2009, but still pending), would also be corrected by our SMS method based on the observed species composition of the samples. The potential interest of SMS is clear for the data processing of both the FAD and the free school catches, today as well as in the future, for instance in case of fishery changes due to global warming and to subsequent changes in fishing zones (such as the changes in species composition recently observed in the Senegal and Mauritania area analyzed by Fonteneau et al 2016). Another potential interest of the SMS results is that they are clearly more realistic to show the real geographical distribution of the yellowfin and bigeye catches on FADs, this result being of fundamental importance when planning a closure of a given area in order to reduce the catches of small yellowfin or bigeye. As an example, our SMS results are casting some doubts on the validity of the past and today ICCAT FAD moratorium, because the real catches of small bigeye associated to FADs north of the Equator in the closed area are probably much lower than in the today ICCAT TASK2. An ideal moratorium of FAD catches targeting a reduction of bigeye catches should be based on a realistic geographical distribution of bigeye FAD catches. Furthermore, the estimated changes in the total catches of yellowfin (about +5%) and of bigeye (about -10%) may also play some role in the results of the stock assessment models, as most of these changes in total catches are predominantly observed in the catches of small fishes that are conditioning the estimated fishing mortalities on juvenile yellowfin and bigeye. In such a context, our recommendation is that an in depth statistical study should be conducted as soon as possible upon the basic principles of our proposed SMS method, and that a new data processing method and its data processing program, probably following the basic rules of our SMS method, should be urgently developed by the EU scientists. This new data processing should of course cover the estimates of species composition (as SMS) but also the corresponding TASK2 catch at size by 5°-month (a basic prospect that has not been envisaged in our study). This new data processing should be routinely used in the future. It should also be used to correct the past recent history of TASK2 PS TASK2 catches and the historical catch at size tables (at least since 2000 or 2002).

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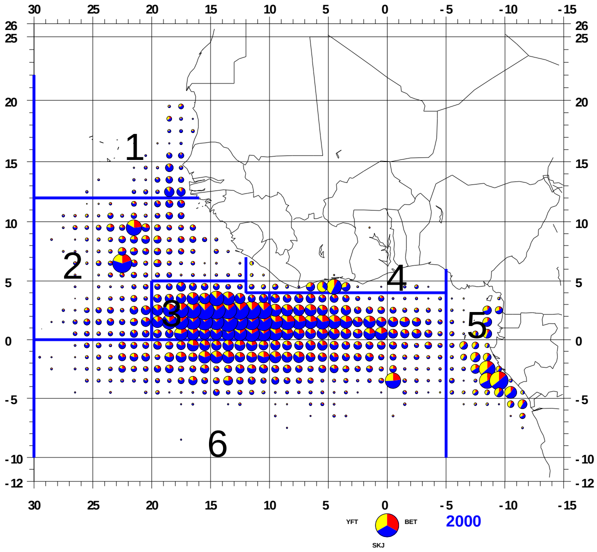


Figure 1a. Mean annual distribution of tropical tuna catch associated with floating objects during 1991-1996. Blue lines delineate the areas established since 1998 to estimate the species composition of FOB-associated catch (skipjack blue, yellowfin yellow, bigeye red).

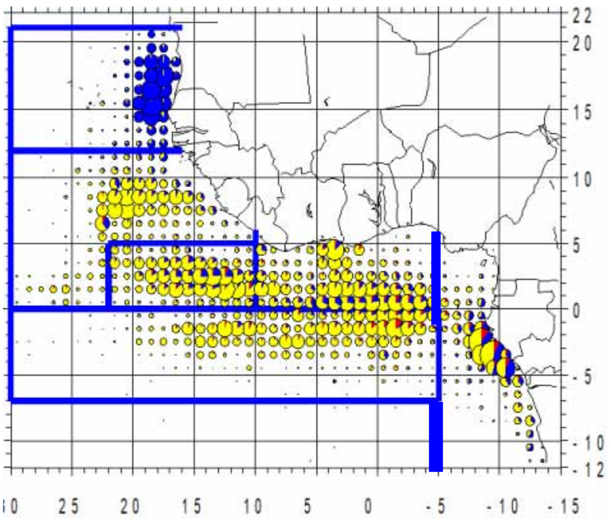


Figure 1b. Mean annual distribution of tropical tuna catch on free schools catches during 1991-1996. Blue lines delineate the areas established since 1998 to estimate the species composition of free school catches.

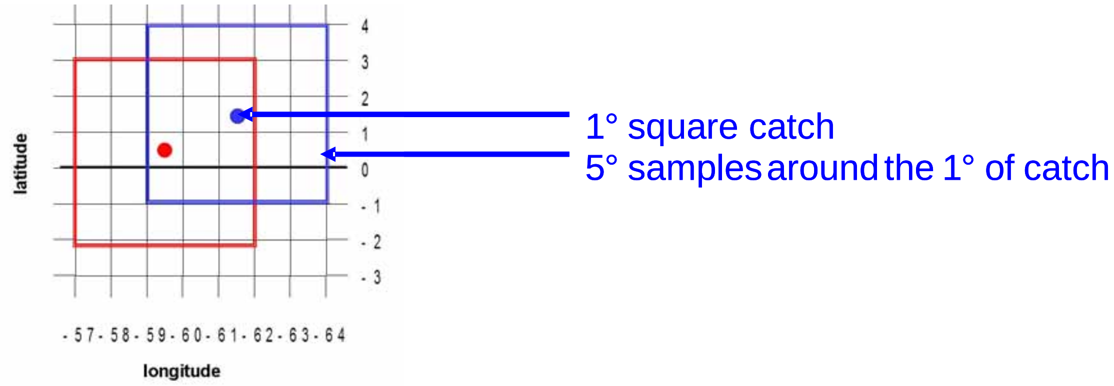


Figure 2. Base of the SMS method: species composition of each catch in given 1° square-month is estimated based on the species composition of adjacent samples, at a distance + or 1 of 2°, and during the 2 months before and after the catch.

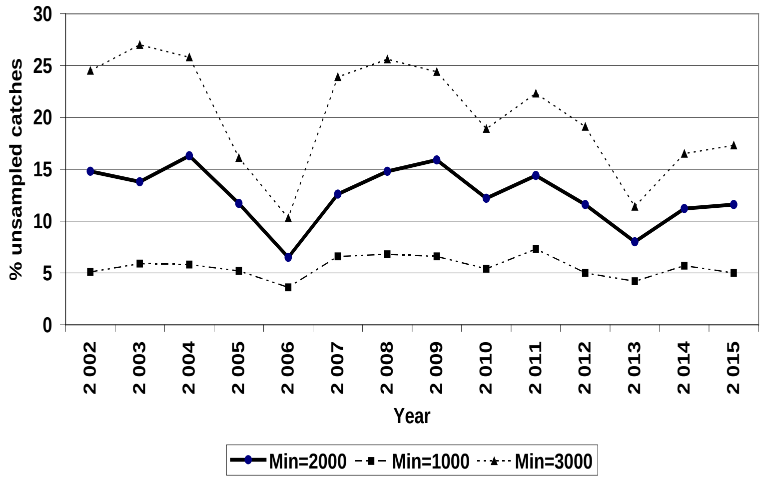


Figure 3. Yearly percentages of insufficiently sampled FAD catches in the SMS data processing of EU&al PS FAD catches based on 3 levels of minimum sample size.

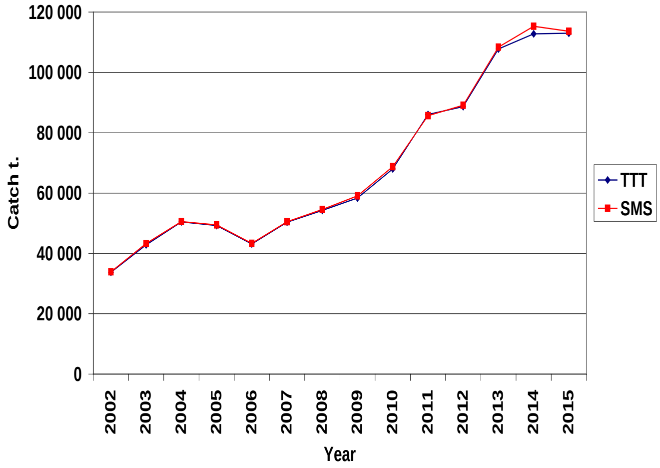


Figure 4a. Yearly catches of FAD skipjack estimated by the TTT & the SMS methods.

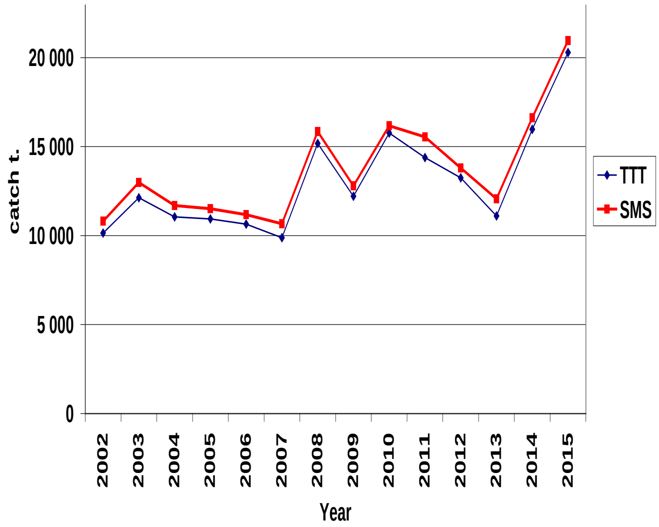


Figure 4b. Yearly catches of FAD yellowfin estimated by the TTT & the SMS methods.

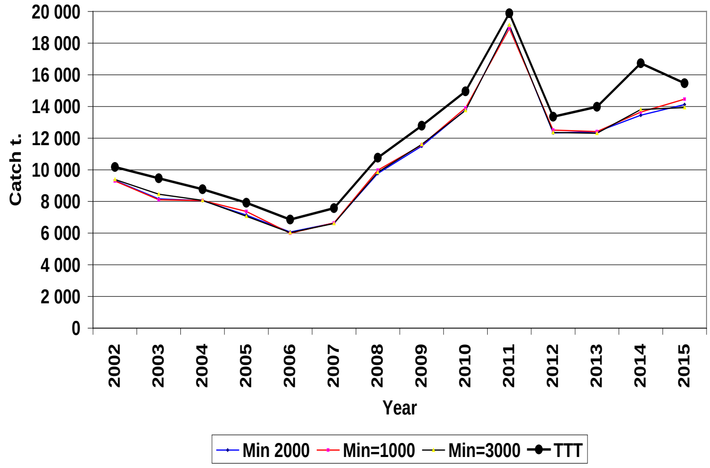


Figure 4c. Yearly catches of FAD bigeye estimated by the TTT & the SMS methods (SMS results based on 3 levels of minimal sample sizes).

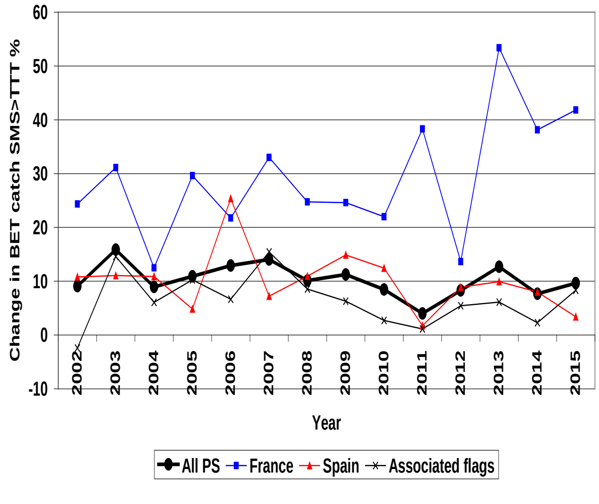


Figure 5. Change in bigeye FAD catches between TTT & SMS for each type of flag and for the combined PS fleet.

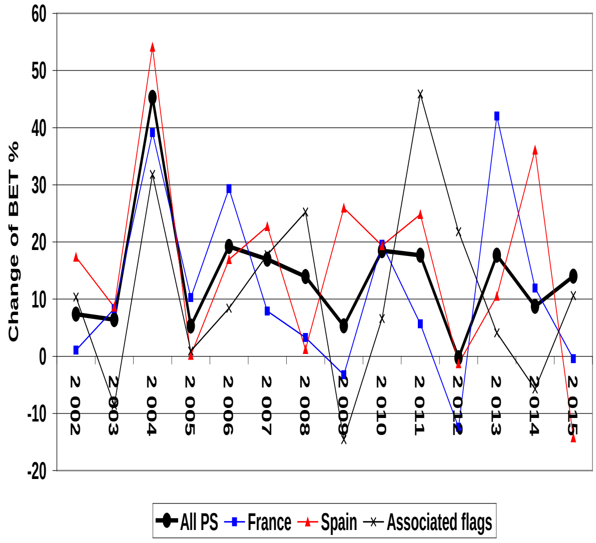


Figure 6. Change in bigeye free schools catches between TTT & SMS for each type of flag and for the combined PS fleet.

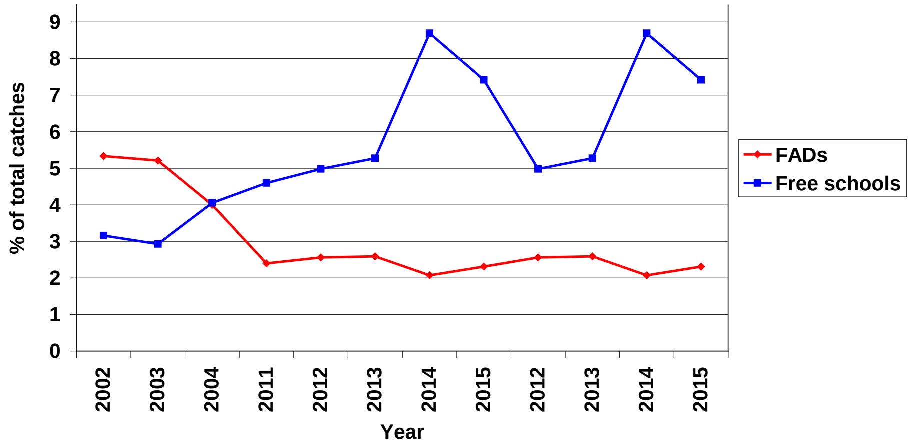


Figure 7. Yearly percentages of well sampled FAD and free schools catches at the 1°-month level (EU&al PS).

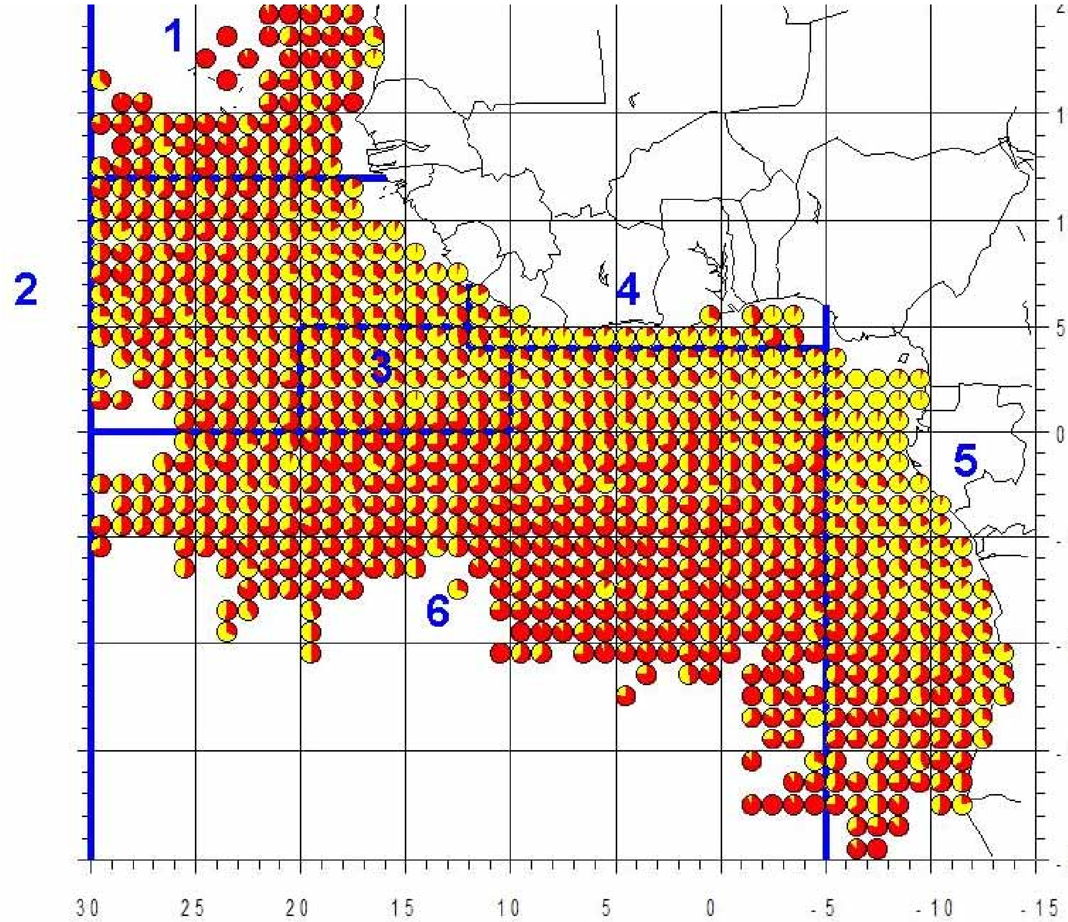


Figure 8. Average species composition by 1° squares of the FAD samples, solely based on yellowfin & bigeye catches, average 2000-2014, in percentage (yellowfin in yellow and bigeye in red).

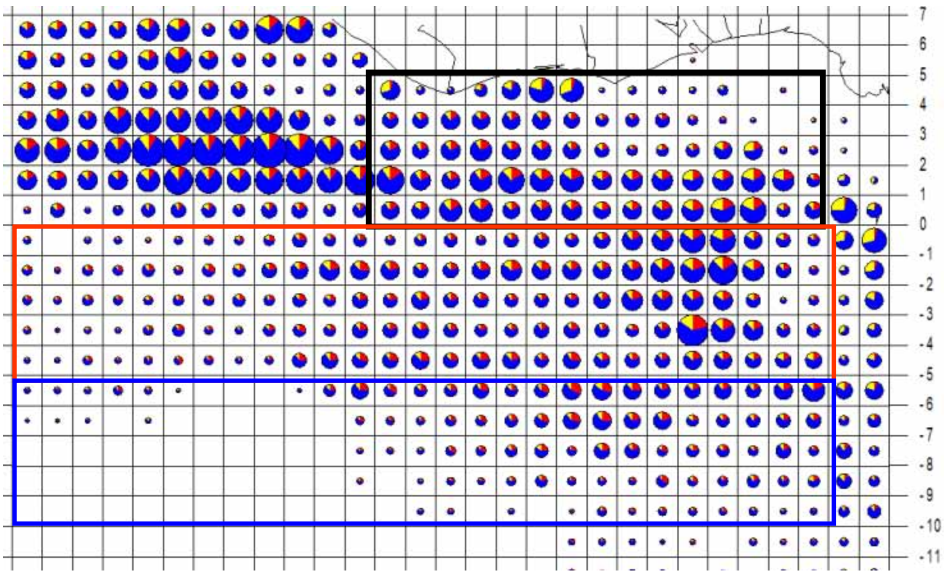


Figure 9. Average catches by PS on FAD during the 2002-2015 period and 3 areas selected to analyse the variability of the sampled species composition.

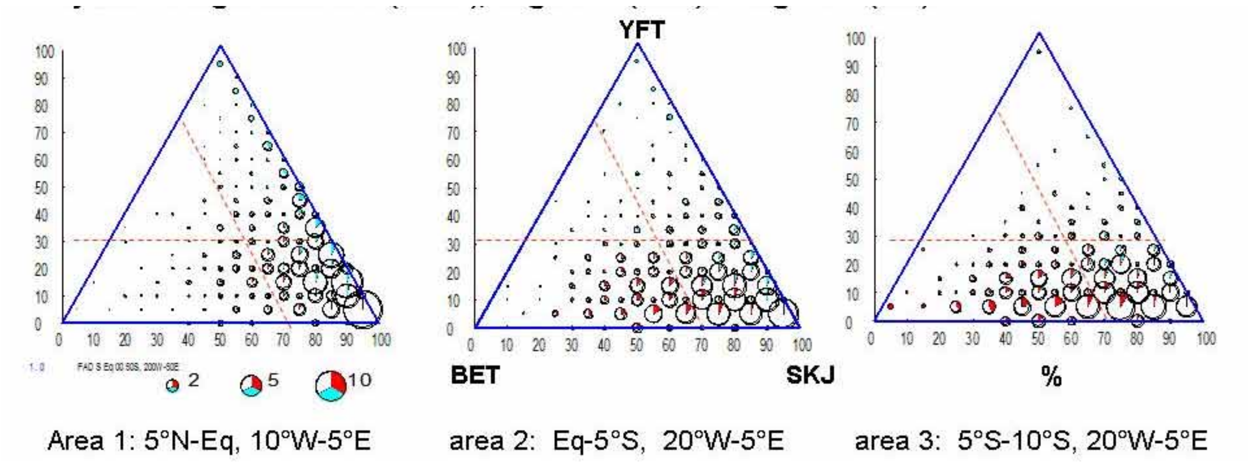
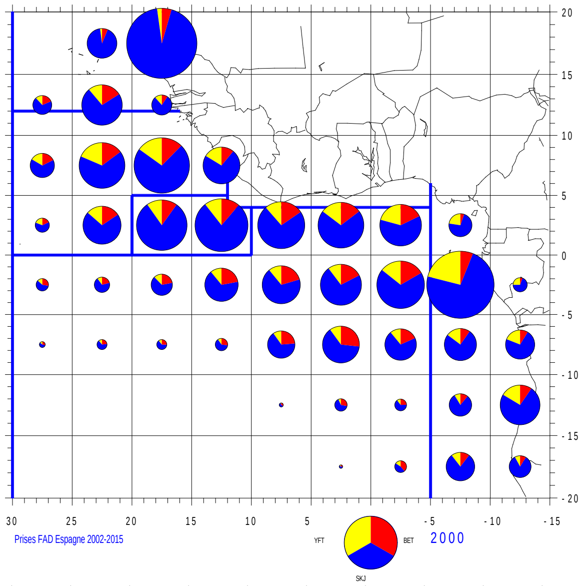


Figure 10. Frequency of observed species composition (in %), 2002-2015, for the FAD samples in the 3 areas shown by figure 11.



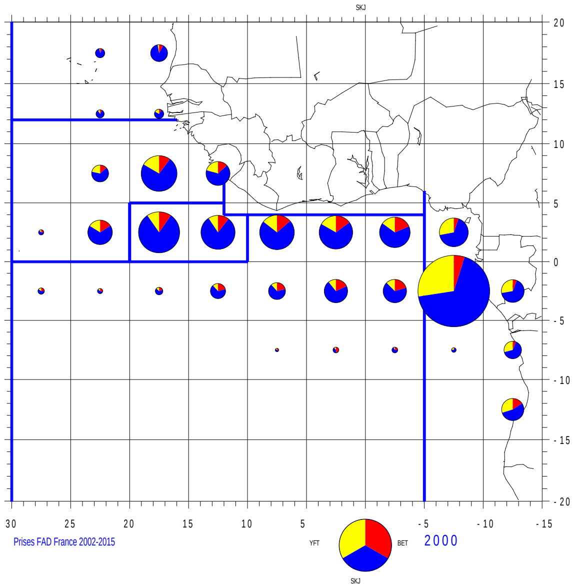
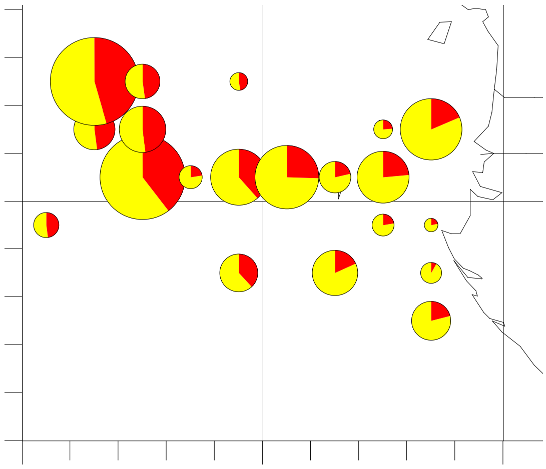


Figure 11a. Average FAD catches by the Spanish fleet during the 2002-2015 period and areas used in the TTT data processing.

Figure 11b. Average FAD catches by the French fleet during the 2002-2015 period and areas used in the TTT data processing.



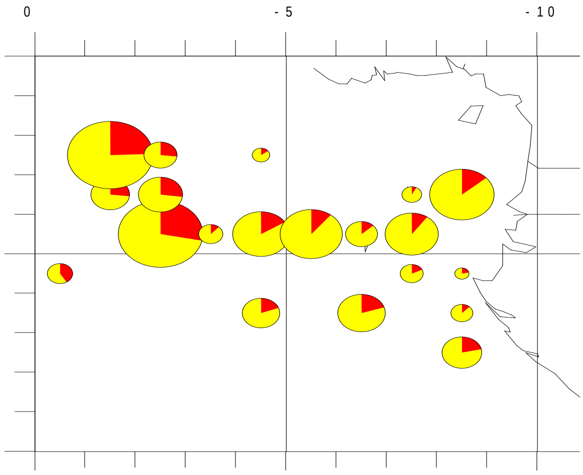
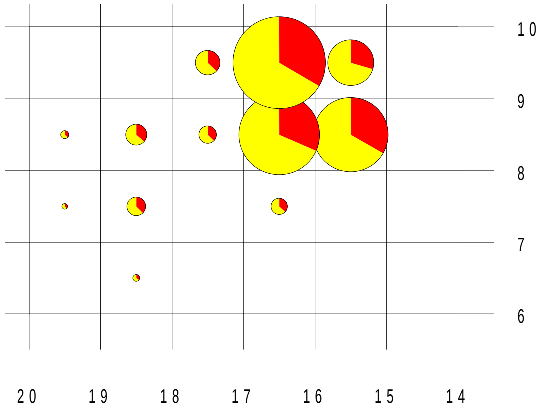


Figure 12a. Yellowfin and bigeye FAD catches by French PS estimated by TTT in the Cape Lopez Anno Bom area in July 2005.

Figure 12b. Yellowfin and bigeye FAD catches by French PS estimated by SMS in the Cape Lopez Anno Bom area in July 2005.



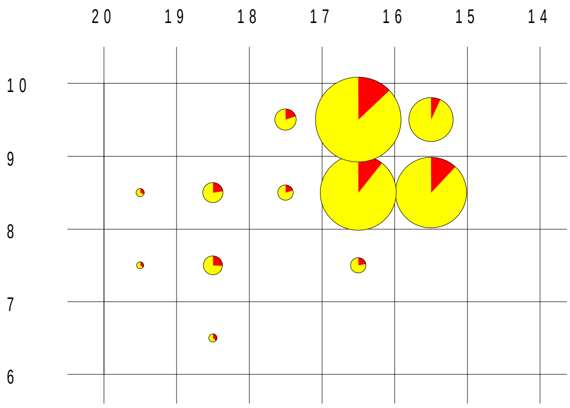
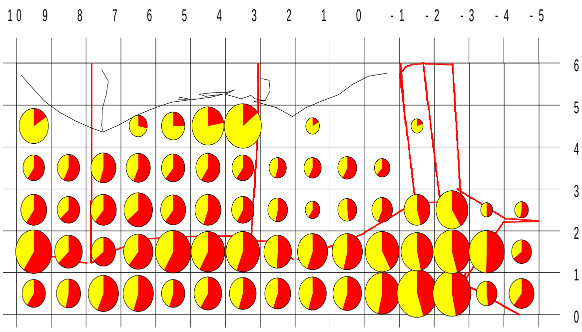


Figure 13a. Yellowfin and bigeye FAD catches estimated by TTT in the Guinea dome area in May 2013.

Figure 13b. Yellowfin and bigeye FAD catches estimated by SMS in the Guinea dome area in May 2013.



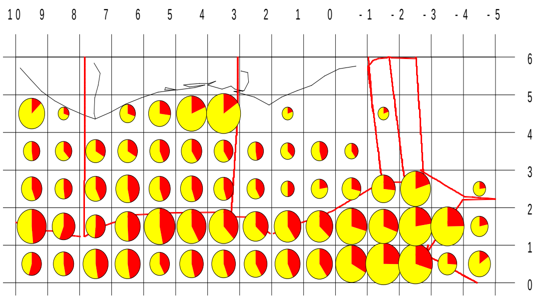
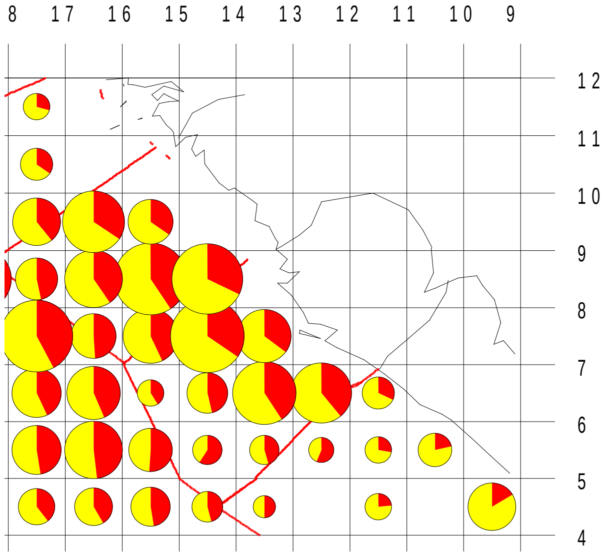


Figure 14a. Average yellowfin and bigeye FAD catches estimated by TTT in the Cote d'Ivoire and Ghana EEZ (2002-2015).

Figure 14b. Average yellowfin and bigeye FAD catches estimated by SMS in the Cote d'Ivoire and Ghana EEZ (2002-2015).



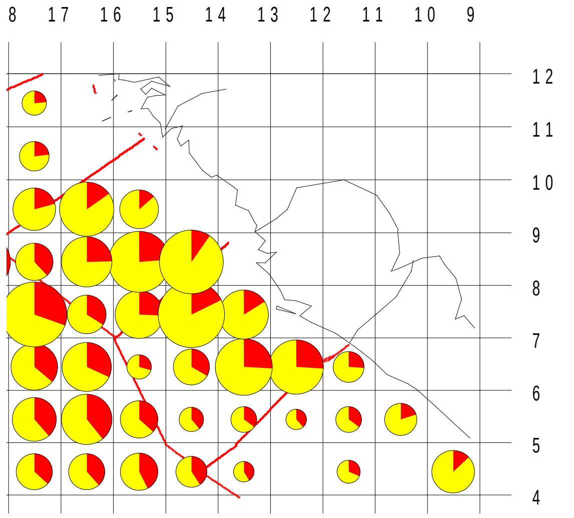
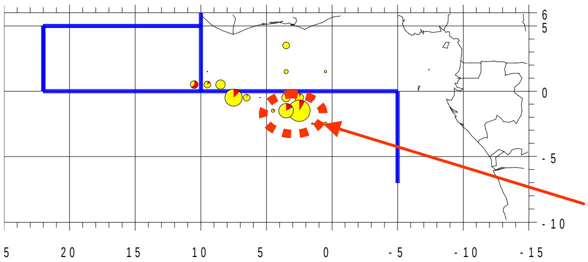


Figure 15a. Average yellowfin and bigeye FAD catches by the EU&al PS estimated by TTT in the Guinea and Sierra Leone EEZ (2002-2015).

Figure 15b. Average yellowfin and bigeye FAD catches by the EU&al PS estimated by SMS in the Guinea and Sierra Leone EEZ (2002-2015).



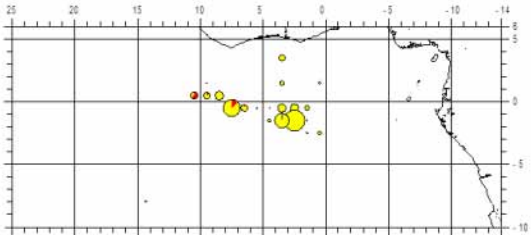
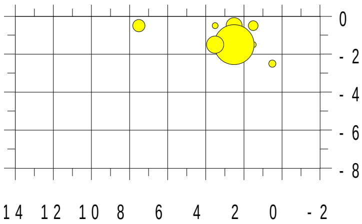
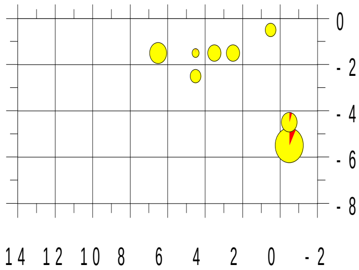


Figure 16a. January 2010 free schools catches by species of French PS, as estimated by TTT.

Figure 16b. January 2010 free schools catches by species of French PS, as estimated by SMS.





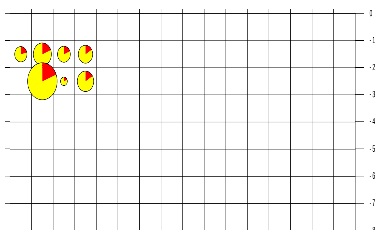
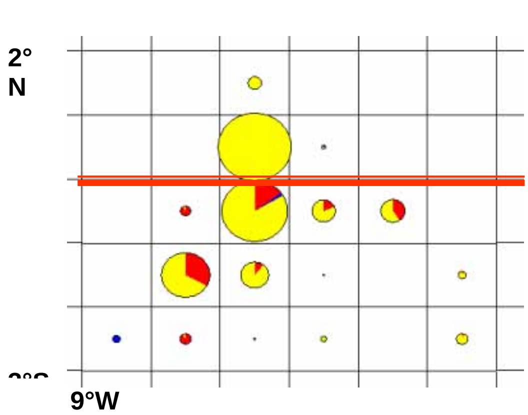


Figure 17a. Species composition of the free schools samples in January 2010 (bigeye in red).

Figure 17b. Idem for February 2010 samples.

Figure 17c. Idem for March 2010 samples.



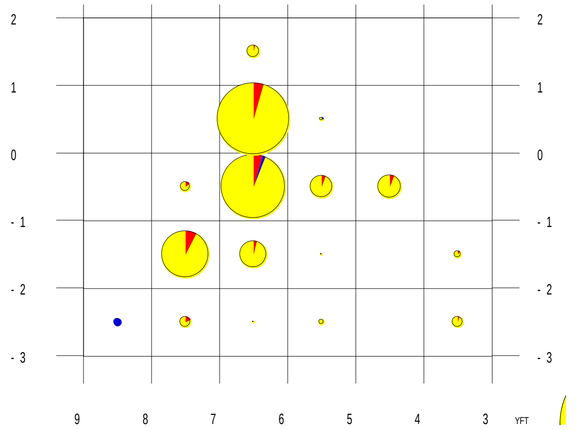
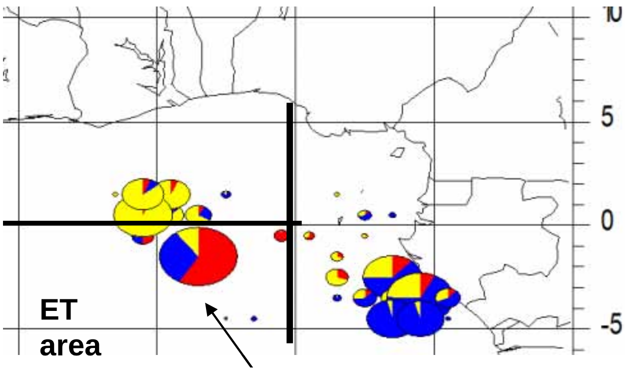


Figure 18a. Free school catches by species by EU PS in January and February 2013 as estimated by TTT (bigeye in red).

Figure 18b. Idem estimated by the SMS method.



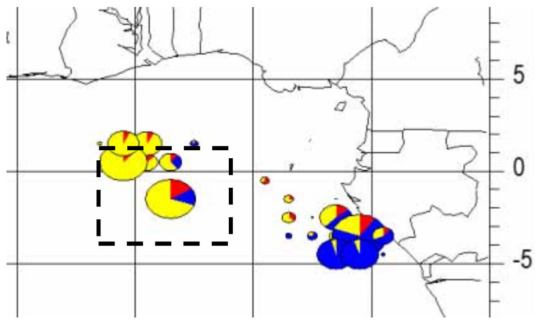


Figure 19a. Free school catches by species by the EU&al PS in June 2011 as estimated by TTT, and TTT areas (yellowfin in yellow, skipjack in blue and bigeye in red).

Figure 19b. Free school catches by species by the EU&al PS in June 2011 as estimated by SMS, and SMS area corresponding to the square 201001.

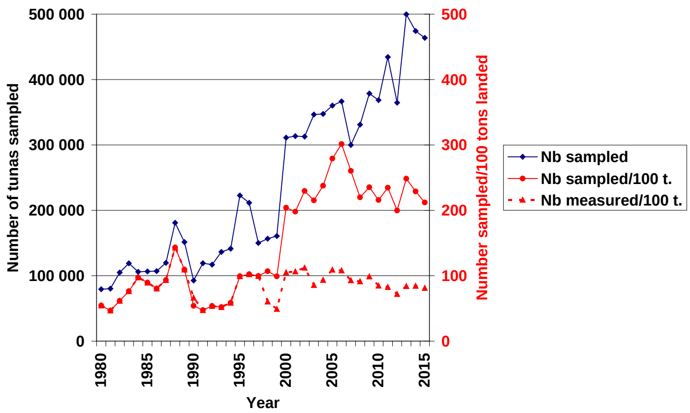


Figure 20. Yearly numbers of major tunas sampled on the EU&al landing of purse seiners and average yearly numbers of tunas sampled and of tunas measured per 100 tons of tunas.

Annex 1

BOOTSTRAP ANALYSIS OF THE SPECIES COMPOSITION HETEROGENEITY IN HOMOGENEOUS STRATA: WHAT MINIMAL NUMBER OF SAMPLED TUNAS?

When scientists are estimating by a random sampling the species composition of the PS tuna landings, as it has been done routinely in the Atlantic since 1980, this task may quite easy or very difficult, depending of biodiversity of the landed catches. It is for instance very easy to sample the biodiversity of pure schools of skipjack or of large yellowfin that are sometimes observed in some areas & seasons. However, there is a mixture of several species in most landings and then sufficient numbers of tunas should be sampled in each stratum in order to sample well & without bias the various patterns of biodiversity of the samples from each stratum. In the SMS method based on small time & area strata, one of the basic question is: what is minimal number of samples or of tunas sampled needed to estimate the species composition of each 1°-month catch with a reduced uncertainty in the estimated percentages of each species. A bootstrap study has been done on the sampling data obtained in selected strata in order to better estimate this minimal number of sampled tunas. This simple statistical method, allowing to estimate the uncertainties in the estimated species composition of FAD & free schools catches, was done in several 5°-quarter strata selected in heavily fished area and well sampled catches. Three case studies have been selected for the study of the 2 fishing modes, FAD and of free schools samples. The choice and the main characteristics of these selected strata are shown by table 1.

It should first be kept in mind that while the SMS calculations are based on a minimum number of tunas sampled in each 5°-3 months strata (for practical reasons), our bootstrap analysis will be based on the number of selected samples. In such context, it is important to know the average numbers of tuna sampled in each of our PS samples are showing:

- an average number of 305 tunas were sampled in free schools samples (period 2002-2015) (keeping in mind that most of these tunas are sampled for sizes)

- FAD samples were showing a larger average of 494 tunas (2002-2015) (Keeping in mind that many of these tunas are solely identified and counted, but not measured)

The yearly numbers of tunas in each of the samples belonging to FAD and free schools catches are shown by **Figure 1**. This figure is showing a quite low between year's variability of these numbers of tunas sampled on the average FAD & free schools samples. The observed species composition in each of the 6 strata of this case study are shown on figure 2a and 2b by their DeFinetti ternary plots. These figures are showing the observed frequency of each combination of percentages of yellowfin, skipjack and bigeye in the sampled catches (in weight). **Figure 3** summarizes the bootstrap results showing the estimated uncertainty in the average percentage of bigeye (based on 1000 resampling), as a function of the number of samples used to sample each strata. The red line in each figure is showing the real percentage of the species in each sampled population, the red ogive are showing the average number used in the today SMS and the vertical line showing the minimal number of tunas used in the present SMS calculations. These bootstrap results are mainly indicative, but they help in the choice of minimal & significant sample sizes that could be selected in the SMS data processing. These today first bootstrap results are for instance already showing that while the uncertainty in the species composition may be very important at very small sample sizes, there is a rapid decline in the uncertainties at increasing sample sizes, and especially in a range over 10 samples, i.e. at the average sampling levels in the SMS calculations. Our proposed minimal level of 1500 (free schools) and of 2000 tunas (FADs) sampled in each of our 5° and 3 months strata, corresponding to an average of 5 and 4 free schools and FAD samples. These minima tend to correspond to quite large uncertainties in the species composition, but they would probably appear to be reasonable starting bases, keeping note that the real numbers of tuna sampled by 5°-3months (shown by the red ogives on figure 3) are most often much larger than these minima: an average of 17 samples being used to estimate the species composition of the average catches on FADs by 1° & month, and an average of 14 samples used in the free schools estimates, see **Figure 4**.

As a conclusion, while the SMS results are clearly facing some serious uncertainties in each 5°-3 months stratum at low sampling levels, these SMS sampling errors are probably random ones, and then they should not introduce statistical bias (as often in the today TTT data processing), This complex question would clearly need further statistical studies, for instance more extensive bootstrap studies of the species composition variability and studies leading to establish variable minimal numbers of tunas sampled, depending of the large scale biodiversity of samples.

Table 1. Main characteristics of the 6 quarterly and 5° strata that have been selected to ran bootstrap analysis of FAD and of free schools samples.

Catch type	Area	5°square	Year	quarter	number of samples
FAD	Senegal Mauritania	415015	2013	3	142
FAD	PICOLO	400015	2011	4	142
FAD	Cap Lopez	200005	2013	3	134
free schools	Senegal Mauritania	415015	2004	2	50
free schools	PICOLO	400015	2004	1	86
free schools	Cap Lopez	200005	2013	2	123

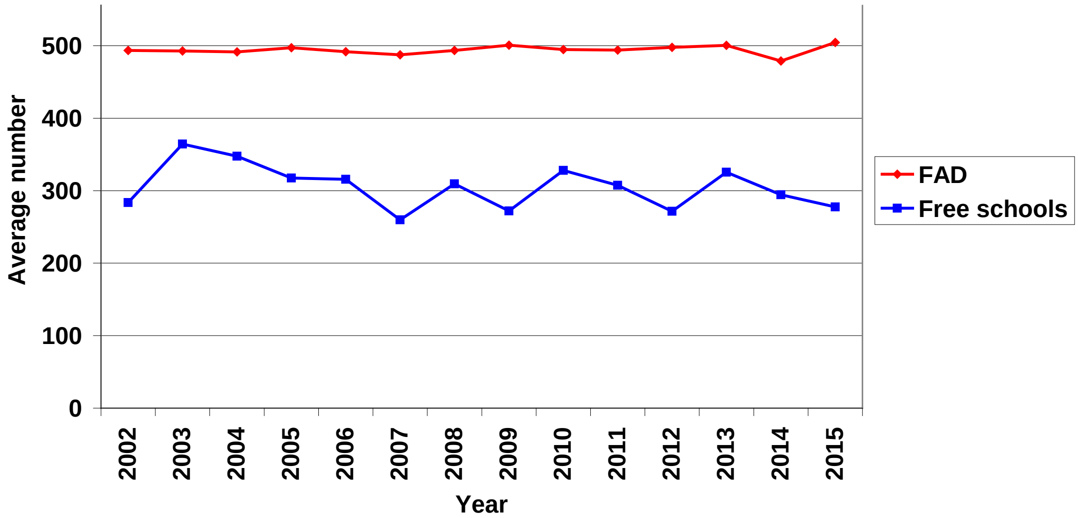


Figure 1. Average yearly numbers of tunas sampled in an average FAD and free schools samples (EU&al PS landings).

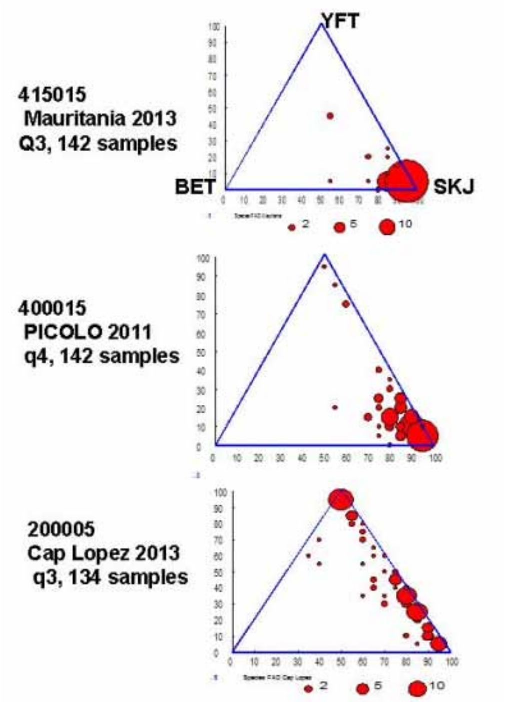


Figure 2a. Species composition observed in 3 strata with large and well sampled catches on FAD schools analysed by bootstrap.

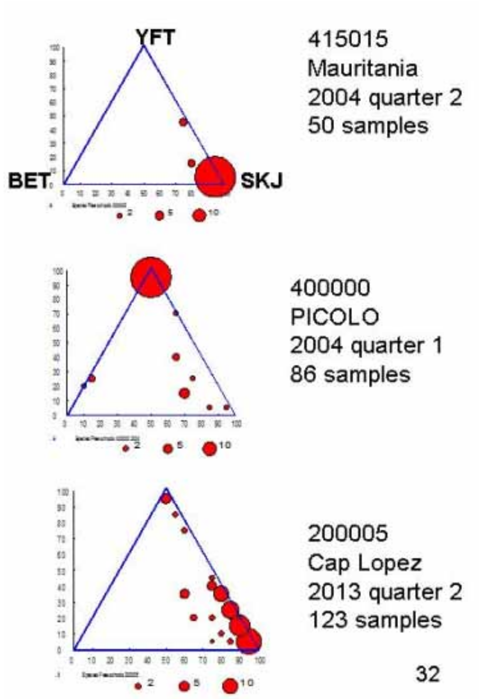
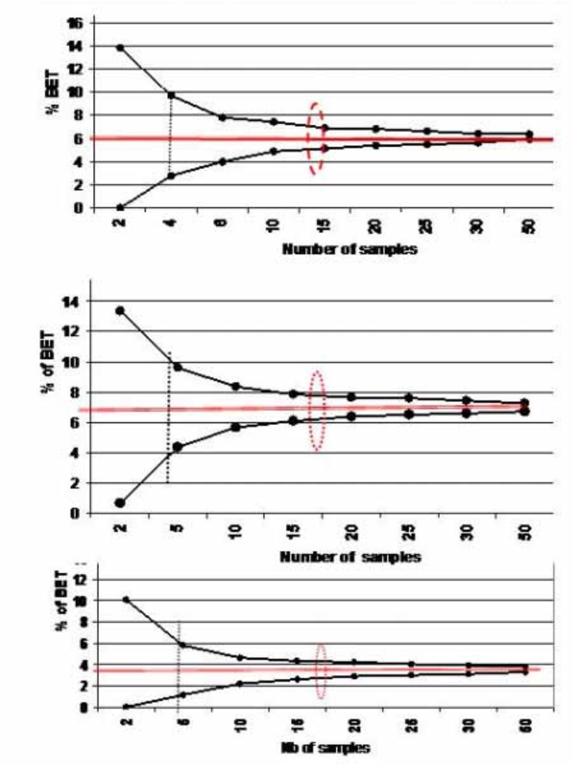


Figure 2b Species composition observed in 3 strata with large and well sampled catches on free schools analysed by bootstrap.



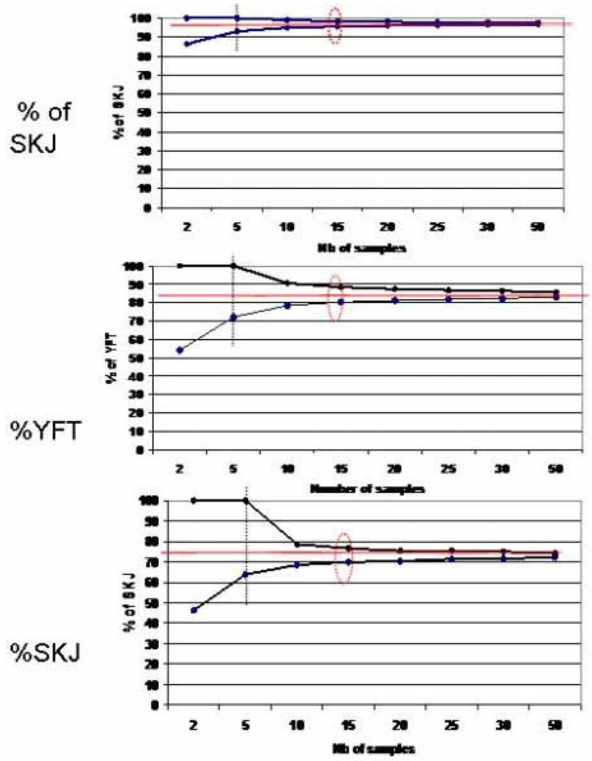


Figure 3a. Uncertainty in the average percentage of bigeye estimated by bootstrap under various level of sampling of FAD catches in the 3 strata shown by Figure 2a.

Figure 3b. Uncertainty in the average percentage of selected species estimated by bootstrap under various level of sampling of free schools catches in the 3 strata shown by Figure 2b.

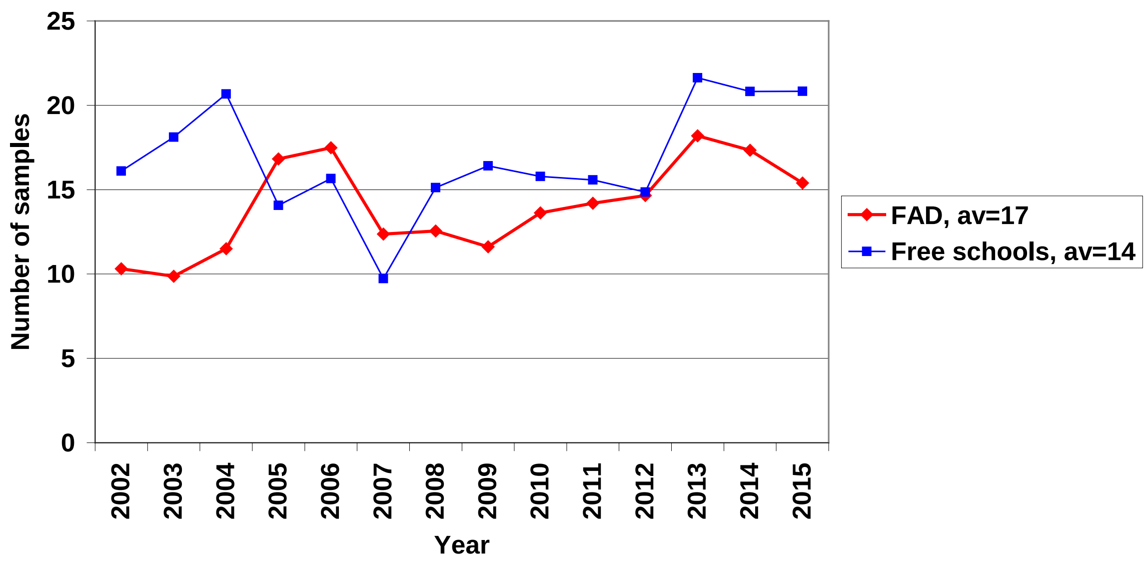


Figure 4. Average numbers of samples used yearly by SMS in order to estimate the species composition in each 1°month.

Fonteneau Alain, Pascual Alayon P.J., Chassot Emmanuel
(2017)

From large fixed to small mobile spatio-temporal strata : improving estimates of species and size composition of the landings of the European purse seine fishery in the Atlantic ocean

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