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# SPATIO-TEMPORAL PATTERNS OF JUVENILES IN EU PURSE SEINE FLEET CATCHES TARGETING TROPICAL TUNAS OVER THE PERIOD 1990-2019

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*SUMMARY*

*The knowledge of the juvenile distribution in fisheries is essential to better manage the fishing effort on a stock. The exploration of a large dataset which covers 30 years of the purse seine fishery sampling enabled to study the spatio-temporal dynamic of the juvenile catches of the yellowfin and bigeye tunas. Results showed the existence of several areas of prime importance in terms of catch and concentration in juveniles with seasonal variations. Thus, the south of the fishing ground (Cape Lopez) was fished during winter month and the north during summer months (Cape Verde, Senegal y Mauritania). Offshore coastal zone and Gulf of Guinea were fished almost all along the year. This seasonal pattern is quite stable since the 90s but the proportion of juveniles in schools associated with floating objects tended to increase in both species. This preliminary study opened the way for further research on this important component of the fish stocks.*

*RÉSUMÉ*

*La connaissance de la répartition des juvéniles dans les pêcheries est essentielle pour mieux gérer l'effort de pêche sur un stock. L'exploration d'un vaste jeu de données couvrant 30 ans d'échantillonnage de la pêcherie à la senne a permis d'étudier la dynamique spatio-temporelle des captures de juvéniles d'albacore et de thon obèse. Les résultats ont montré l'existence de plusieurs zones de première importance en termes de capture et de concentration des juvéniles avec des variations saisonnières. Ainsi, le sud de la zone de pêche (Cap Lopez) était pêché pendant les mois d'hiver et le nord pendant les mois d'été (Cabo Verde, Sénégal et Mauritanie). La zone côtière offshore et le golfe de Guinée ont été pêchés presque toute l'année. Bien que ce schéma saisonnier soit stable depuis les années 1990, la proportion de juvéniles dans les bancs associés à des objets flottants avait tendance à augmenter pour ces deux espèces. Cette étude préliminaire a ouvert la voie à d'autres recherches sur cette composante importante des stocks de poissons.*

*RESUMEN*

*El conocimiento de la distribución de los juveniles en las pesquerías es esencial para gestionar mejor el esfuerzo pesquero en un stock. La exploración de un gran conjunto de datos que abarca 30 años de muestreo de la pesquería de cerco permitió estudiar la dinámica espacio-temporal de las capturas de juveniles de rabil y patudo. Los resultados mostraron la existencia de varias zonas de importancia primordial en cuanto a la captura y concentración de juveniles con variaciones estacionales. Así, el sur del caladero (Cabo López) se pescaba durante el mes de invierno y el norte durante los meses de verano (Cabo Verde, Senegal y Mauritania). En la zona costera y en el golfo de Guinea se pescaba casi todo el año. Esta pauta estacional es bastante estable desde los años 90, pero la proporción de juveniles en los cardúmenes asociados a objetos flotantes tendió a aumentar en ambas especies. Este estudio preliminar abrió el camino a nuevas investigaciones sobre este importante componente de los stocks de peces.*

*KEYWORDS*

*Size distribution, Atlantic Ocean, major tunas, yellowfin, bigeye,* Thunnus albacares, Thunnus obesus

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## Introduction

Tropical tuna purse seine fisheries typically target large yellowfin (*Thunnus albacares*, YFT) and bigeye (*Thunnus obesus*, BET) tunas on free-swimming schools and skipjack (*Katsuwonus pelamis*) and juveniles of yellowfin and bigeye associated with drifting objects. In particular, they have strongly modified the fishing strategies of purse seiners that fish on a combination of free-swimming and DFAD-associated schools. Juveniles of tropical tunas represent a substantial proportion of purse seine catch on DFADs in the three oceans, which has raised particular concern for some bigeye stocks that have been subject to overfishing in the past. Catches of juvenile tunas by DFAD fishing may also result in a decrease in recruitment for fisheries that target adult tunas such as longliners (Fonteneau et al. 2013). This component is so important to ensure the sustainability of stocks that ICCAT decided in 1997 to create a moratorium on FAD fishing with the aim of reducing fishing effort on juveniles of bigeye tuna (Escalle et al. 2017). In the last decades, tropical tuna purse seine fishery has changed its fishing strategy, shifting towards FAD fishing to the detriment of free-school fishing (Hallier and Parajua 1992, Fonteneau et al, 2000; Davies et al, 2014). In the mid-2000s there was a change in fishing behavior, going from 30% in the early 90s to 70% of sets to objects in recent years (SCRS/2019/076).

Taking into account Rec. 19-02 of last year and considering what was agreed by the tropical group on the exploration of historical data of monthly catches and catch-by-size data in the PS fishery. The authors present in this paper a first exploration of European data (France and Spain) on YFT and BET juveniles throughout the entire historical period of this industrial fishery in the Atlantic Ocean.

As a "background" on this type of study, Fonteneau, analyzes the length frequencies of yellowfin catches by purse seiners and FIS bait boats, from 1969 to 1977, reaching the conclusion that there is a synchronous recruitment of young yellowfin in Dakar, Abidjan and Pointe Noire areas (Cayré *et al.* 1988). One of the first works that analyzes the influence of LOGs in the tropical tuna fishery is in Ariz *et al.* 1992. In this work it´s concluded that the recent development of the artificial log fishery allows a significant increase in the global fishing efficiency of purse seiners associated with a change in fishing patterns. The yield per recruit calculation presently conducted combining skipjack, yellowfin and bigeye suggests that this new fishery increases the global Y/R of the fisheries, despite the significant numbers of small yellowfin and bigeye taken. Other works such as Pallares and Pianet in 2005, where they analyze the distribution of the catches of juvenile yellowfin and bigeye obtained by the purse-seine tuna fleet in the Atlantic Ocean from 1991 to 2003. Some considerations of certain areas and periods by type of association and its possible relationship with measures of spatio-temporal closure of fishing for objects in order to reduce the capture of juvenile bigeye (SCRS/2005/058).

The sampling system, during landing of the three species of tropical tunas (yellowfin, skipjack and bigeye) from the East Atlantic in the surface fleets (purse seiner and bait boat) has undergone various modifications and updates throughout its history. The current called multi-species sampling, replaced conventional sampling of lengths separately in the early 1990s. The main advance of the so-called multispecies sampling was to provide a good basis for developing a method for estimating the specific composition of the catches, and thus, correct the biases detected in the official declaration of skippers. Until its full implementation, this method presented various problems, which were detected in various meetings and working groups of the time (Statistics of juvenile tuna, multispecies 1987, preparatory meeting of the program in the year of Yellowfin 1988) and corrected in different documents (Pallarés *et al.* 1984; Pallarés, 1987; Fonteneau, 1992; Pallarés *et al.* 1994). The current multi-species sampling system, carried out on the European fleet of PS and BB, is one of the programs with the highest quality and coverage in the Atlantic Ocean.

The aim of this paper is to bring information to the understanding of the variation of juvenile catch by the purse seine fishery during the 1990-2019 period. This first exploration of the data focuses first on size distribution of the catch. Then, we describe the spatio-temporal pattern of juvenile proportion of sets independently of the catch size. Finally, we investigate the catch pattern focusing on the sets associated to a floating object.

## Material and Methods

*Proportion of juvenile in sets*

Data used for this analysis cover the 1990-2019 period for EU-FR and EU- SP tropical purse seine fisheries in the Atlantic Ocean. Size distributions were issued from length sampling in wells of purse seiner at landing (from the DFC program). Samples were strongly selected to ensure better representativeness of the composition. Thus, following criteria were applied to select samples:

- All set of the well shared the same school type
- Distance between set of the well should not exceed 500 km

Six periods of five years were defined to explore the entire time series: [1990 - 1994], ]1994 - 1999], ]1999 - 2004], ]2004 - 2009], ]2009 - 2014], ]2014 - 2019].

After the screening, 23423 samples were used to compute the mean size distribution by period of interest, 5-degree squares and/or months (**Table 1**). Mean location and fishing date of each sample were weighted by the weight of all sets in the well.

We defined juvenile as individuals of BET and YFT with a weight < 10 kg. We so determined for each species the length threshold corresponding to 10 kg from the official length-weight relationships of ICCAT (**Table 2**). Proportions of juveniles in sample were calculated as the proportion of individuals on the total individual of the same species only (not all species in the sample) with size inferior to these thresholds. As example, if in a sample of 500 fishes, 100 individuals of YFT were counted with 30 YFT <10kg. The proportion of YFT juvenile is 30%. The value so represents the proportion of YFT juveniles independently of the volume of the set. This could be seen as an indicator of concentration of juvenile in sets.

Finally, we averaged these proportions of juvenile by 5-years period and month for each species.

*Catch pattern*

Catch data sources is the ICCAT reporting data available online (www.iccat.int/fr/accesingdb.html).

We only focused the investigation of the catch on sets associated to a floating object as they are dominated by juveniles. We average catches by month or by period and 5-degree square for the mapping depending on the needs.

**Results**

***General pattern***

Length distribution of school types differed similarly for the two species of interest. Thus, in school associated with floating object catches were almost composed of juveniles (**Figure 1**). In freeschool, size distribution was bimodal, with a first mode characterized by juveniles and a second one of the large reproducers. Intermediate sizes are less present in the sets of the purse seine fishery. As a consequence, the proportion of juveniles in FOB were very high (87 % on average) compared to FSC (37% on average).

***Temporal pattern***

In 30 years, the mean proportion of juveniles in sets varied in the fishery. Juvenile proportion of BET decreased from 82% to 68% between 1990 and 2015 whereas, in the same time, juvenile proportions for YFT increased from 40% to more than 70% (**Figure 2**). Since 2016, proportions of both species have decreased. But this general pattern differed for each school type.

The general pattern of % of individuals, with less10 kg in samples and caught on FOB, increases over the study period (**Figure 3**). The % of YFT's juveniles increases rapidly in the first years of the fishery, going from less than 75% to around 95% in the period 2004-2009. Subsequently, it drops to around 90% in the two following periods of 2009-2014 and 2014-2019. Regarding the % of BET juveniles in samples, the trend is similar to observation for YFT but with a lesser intensity. The % of presence of BET is even higher than YFT, ranging from around 90% in the first years of the fishery to more than 95% in the 2004-2009 period. Subsequently, this % of juveniles drops slightly to 90% in the last two periods.

The mean % of individuals under 10 kg in samples captured by freeschool was oscillating for both species throughout all periods and the variance of this % in each period is very wide (**Figure 3**). In YFT, the mean % represented only 12.5 % in the first period from 1989 to 1994, to increase around 30% for the period 1999-2000. Subsequently, it drops to 25% and 12% in the periods 2004-2009 and 2009-2014 respectively. In the last period, from 2014 to 2019, this % increased to a value greater than 35% in the samplings. In BET, the mean % of individuals under 10 kg, started with around 55 % in the period 1989-1994 and increased to around 60% in the period 1999-2004. Subsequently, the mean % drops to 30% and 49% in the periods 2004-2009 and 2009-2014 respectively. In the last exploitation period, 2014-2019, the mean % reached 60% in the samplings and its variance was the widest of the global data series.

The proportion of juveniles in sets had different monthly patterns according to the association type more than the species (**Figure 4**). Regarding FOB fishing, the summer months, June, July and August, showed a lower % of presence of individuals under 10 kg in samples with mean values around 80 %. By other hand, the months with a higher % of individuals less than 10 kg are clearly the months of November, December, January, February and March for both species with values close to 95% of presence.

Regarding the FSC fishing, the proportion of juveniles increased all along the year in the sets with an intermediate peak in spring for BET and summer for YFT. The lowest values were found in February - March. BET proportions were very similar to the YFT ones but with a higher value of 20%. Moreover, these patterns are similar for all periods but with an offset, the recent period presenting higher proportion than older one on average.

***Spatial pattern***

Spatial patterns of juvenile proportion in sets are quite similar all along the study period (1990-2019). Therefore, only the last 5-year period (2014 – 2019) is presented in this paper. The highest concentration of juveniles of BET in sets is located in three main areas whatever the school association: In waters around Cape Verde Islands, on the continental shelf along all Gulf of Guinea and in an offshore ocean zone off Gabon´s coast (**Figure 5**). The highest concentration of juveniles of YFT is similar to BET: The continental shelf along the Gulf of Guinea and in an offshore ocean zone off Gabon´s coast.

However, there was a marked spatial discrepancy in the homogeneity of juvenile proportion in sets according to school types. The proportion of juvenile remained high in the whole fishing ground in FOB (around 80% on average) whereas it was more heterogeneous in FSC. Thus, the FSC caught in the central area of the fishing ground contained almost no juveniles. This pattern was consistent month after month (not shown here).

**Figure 6 and 7** shows the spatial distribution of juvenile proportion in FOB by months of the entire study period proposed for both species. As a general pattern, we can observe a varied and patchy behavior over the months. The continental shelf is the most important zone of distribution in both species. Only those months where concentrations of <10 kg were more abundant for both species are analyzed, as mentioned above in **Figure 3.**

For BET, the months of January, February, March, November and December were important (**Figure 3**). In January, the continental shelf along the Gulf of Guinea, the coastal strip of Gabon and an area offshore in oceanic waters off Gabon are shown to be more important (**Figure 6**). During the month of February, the continental coastal strip from Sierra Leone to Gabon was the most important. In March, the offshore zone of Senegal and waters around Cape Verde are shown to be more important. Finally, in November and December, the highest % is observed in the continental coastal strip from Senegal´s coast to Gabon´s coast.

In figure 3, for YFT, the months of January, February, March, April, October, November and December were important. In January, along continental coastal strip from Senegal to Gabon is the most important place of concentration of the juveniles of this species (**Figure 7**). In February, the coastal zone off Sierra Leone-Liberia coast and coastal area of Gabon as the most important during this month. In March, again the coastal zone of Senegal, Sierra Leone, Liberia and Cape Verde, in addition to another oceanic area offshore in front Gabon zone as the most important. In April, coastal zones of Senegal and Cape Verde and as well as, another offshore oceanic zone in front Gabon and Angola are the most important for this species. In October, November and December, the pattern is very similar, the coastal zone from Senegal to Sierra Leone-Liberia, as well as a wide offshore equatorial zone parallel to -5º South are important during these months.

***Pattern of catch on floating object***

**Figures 8 and 9** show a historical view of the mean catches on FOB of BET and YFT, in sectors of 5 x 5 degrees and each of the periods proposed in this work. In a global vision, of each period, the observed pattern is very similar for both species, although with important differences in the volume of catches in the different grids. Regarding the extent of the fishing ground, catches on FOB were centralized offshore of the Ivory Coast and Liberia.Then, year after year the fishing ground was extended in the north/east and south.

Regarding the average catch of BET, the first period considered between 1991 and 1994, presents the coastal zone of the Gulf of Guinea, in the parallel 0º-5º N, with the most abundant catches for the species, of the entire historical series (**Figure 8**). In subsequent periods, the same geographical patterns are observed for the catch of BET as in the first period, but with volumes of catches much lower than the first period.

Regarding the YFT catches, the same main coastal strip, along the parallel 0º-5ºN of the Gulf of Guinea presents the highest captures of the species during the first period (**Figure 9**). The following periods show geographic patterns of catches similar to the first one but with much lower levels of catches. In this species, the grid in front of Cabo López in Gabon, presents the highest and most important catches in all the periods considered in this work.

Mean monthly catches on FOB oscillated from the south of the fishing ground in winter to the north in summer (**Figures 10 and 11**). Thus, previously identified areas of highest catch were used only part of the year.

**Discussion**

Studies on the monthly geographic distribution of juvenile yellowfin and bigeye are not very numerous. We would like to mention previous studies of the spatio-temporal distribution of the catches of small YFT in Atlantic east in the works of Postel, 1969 and Zharov, 1967; In other works, such as Champagnat 1974, a partial migration model is presented, on the young yellowfin along the slope of the continental shelf, from the Ivory Coast to Mauritania, confirming the presence of YFT juveniles in coastal areas. Larger studies, for the period 1979-1983, observe monthly geographic distributions of juveniles in coastal areas, in offshore areas along the equator and west of Liberia. With important catches in Cabo López from May to September, off Liberia in November-December and in the interior of the Gulf of Guinea in January (F.X. Bard, P. Cayré and T. Diouf, in Fonteneau and Marcille, 1991). Regards previous studies on the geographical distribution of the monthly catches (1979 to 1983) of juvenile bigeye mention a distribution very similar to that of the young YFT, with some peculiarities. Young bigeye is found throughout the year in the equatorial zone, and seasonally, with significant concentrations in Cabo López from April to September, off the coast of Liberia from November to February and in the zone between 5ºN and 10ºN off Sierra Leone between April and May, and / or September and November (F.X. Bard, P. Cayré and T. Diouf, in Fonteneau and Marcille, 1991).

In this paper, spatio-temporal variations of the juvenile proportions in sets were observed for BET and YFT caught in the purse seine fishery during the period 1990-2019. From this preliminary study, several spatial areas seem to have major importance for the catch of the juveniles and then confirm the most important places of young mentioned by other authors too. Cape Verde, all the offshore coast until the Gulf of Guinea (From Senegal, Liberia, and Ivory Coast and Ghana) and Cape Lopez in Gabon represented the major places both in terms of catch but also in terms of proportion of juveniles in sets independently of the catch size.

In addition, we raised a temporary pattern in the use of each of these areas. The south of the fishing ground (Cape Lopez) was fished during winter months and the north during summer months (Cape Verde, Senegal y Mauritania) and that could be related to the existence of a thermal front that stabilizes in summer between 20º and 21º N (Cayré and Diouf, 1986). Offshore coastal zone and Gulf of Guinea were fished almost all along the year.

Another important point raised by this data exploration is that seasonal variation in the proportion of juveniles in sets seems to confirm the existence of diverse recruitment in different areas of the Atlantic Ocean. Sometimes occurring synchronously and also the existence of sedentary behaviors in YFT and BET juveniles in certain areas. The last 30 years, the general increase of proportion of juveniles for YFT by sets and in catch is most probably due to the shift in strategy of the purse seine fishery toward FOB. This result confirms again the increasing pressure on this component of the stock (Ariz *et al.* 1992). Thus, the highest acceleration in the proportion was observed between the 1995-1999 periods and the 2000-2004 periods, which coincided with the development of GPS technology in the fishery (Davies et al. 2014). We could hypothesize the massive use of connected DFAD led to a shift of the fishing effort toward FOB dominated by juveniles.

However, we could wonder what can explain the quasi-disappearance of larger individuals in the FOB sets. Did the attractiveness of FAD change according to change in material and their structure? Did fishing impact the size distribution of the stock in BET and YFT? It seems, from our observations, that the shift area or the extent of the fishing ground could not explain this variation alone. Indeed, the most productive areas for juveniles were already fished in the 90s.

At this point, this preliminary study enabled description of the general pattern and brought several new trails to better understand the juvenile dynamic in the purse seine fishery. However, all hypotheses highlighted in this work have to be confirmed with proper statistical analyses accounting for spatial and temporal correlation. In particular, define more finely the area of interest regarding the juvenile's abundance all over the year should be a great interest in helping the stocks management of BET and YFT. As instance clustering analyses to identify the catch hotspots of juveniles as it was initiated by IRD for the BET juveniles (Deledda *et al.* 2018) is a good starting point.

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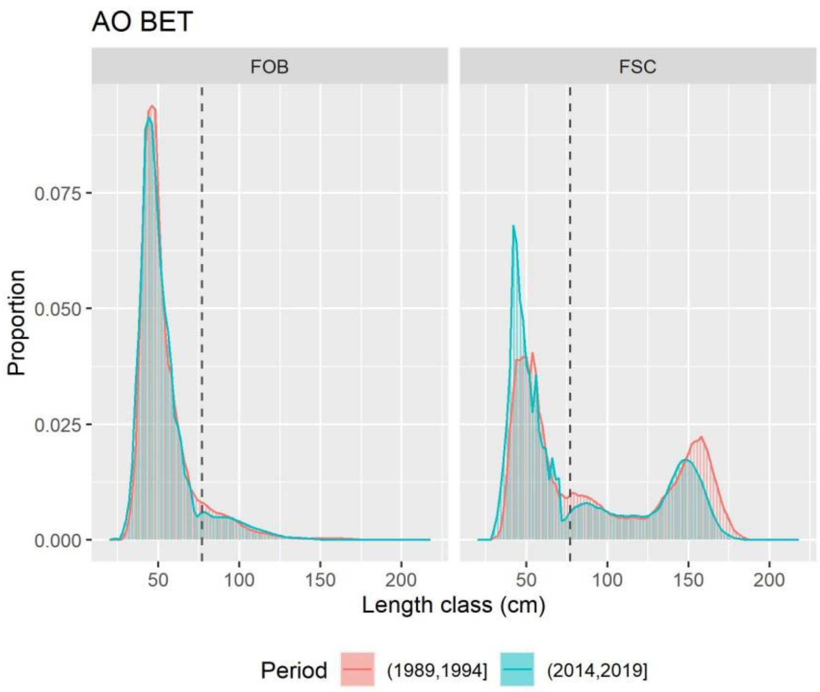
**Table 1.** Number of well samples by period, school type for EU-FR and EU-SP.

| ***Fleet*** | ***Species*** | ***School type*** | ***Period*** | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | ***[1990 - 1994]*** | ***]1994 - 1999]*** | ***]1999 - 2004]*** | ***]2004 - 2009]*** | ***]2009 - 2014]*** | ***]2014 - 2019]*** |
| EU-FR | YFT | FOB | 1291 | 1251 | 665 | 238 | 498 | 559 |
| EU-SP | YFT | FOB | 929 | 833 | 849 | 1043 | 1395 | 891 |
| EU-FR | YFT | FSC | 1417 | 1373 | 1204 | 722 | 582 | 654 |
| EU-SP | YFT | FSC | 832 | 716 | 844 | 979 | 966 | 894 |
| | | | 4469 | 4173 | 3562 | 2982 | 3441 | 2998 |
| EU-FR | BET | FOB | 1156 | 1145 | 588 | 207 | 428 | 497 |
| EU-SP | BET | FOB | 847 | 828 | 813 | 982 | 1340 | 852 |
| EU-FR | BET | FSC | 467 | 469 | 499 | 440 | 273 | 333 |
| EU-SP | BET | FSC | 183 | 198 | 562 | 835 | 810 | 661 |
| | | | 2653 | 2640 | 2462 | 2464 | 2851 | 2343 |

**Table 2.** Length-weight relationship and length at 10 kg for BET and YFT.

| ***Species*** | ***a*** | ***b*** | ***Length at 10 kg (cm)*** | ***Reference*** |
|---|---|---|---|---|
| Bigeye tuna (BET) | $2.396 . 10^{-5}$ | 2.9974 | 77 | Parks *et al.* (1982) |
| Yellowfin tuna (YFT) | $2.153 . 10^{-5}$ | 2.9760 | 80 | Caverivière (1976) |



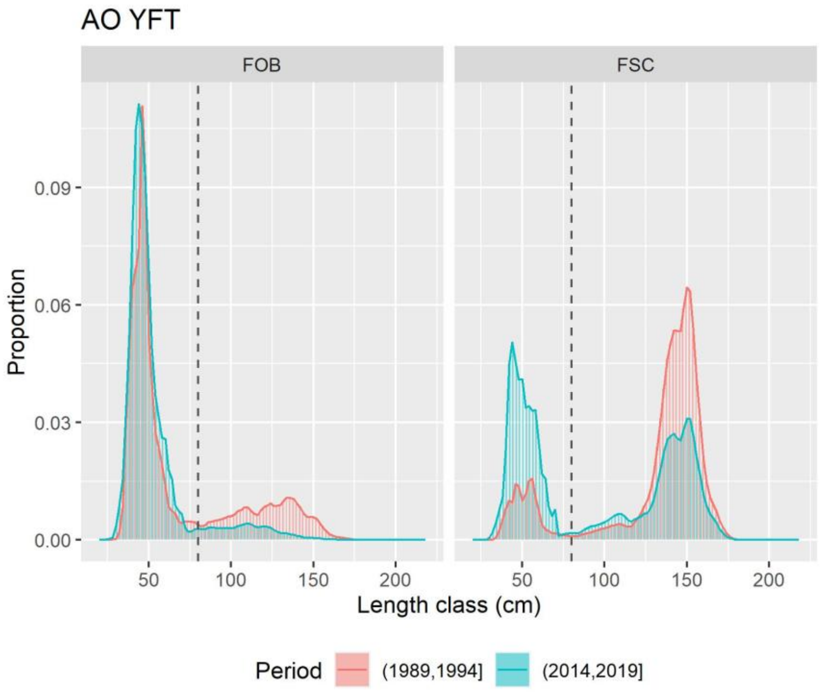




**Figure 1.** Mean length distribution for BET and YFT by school types for two periods overall fishing ground in AO. Dashed lines represent the maximum juvenile length.

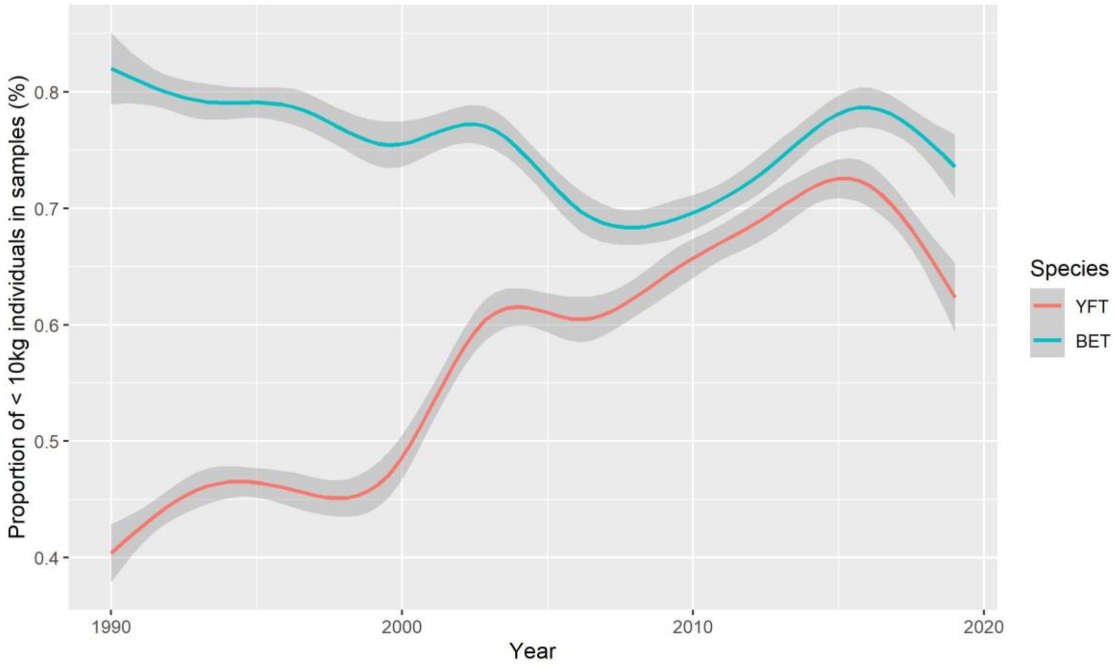



**Figure 2.** Fitted proportion of < 10 kg individuals in samples along years for YFT and BET (gam model, N = 37038).

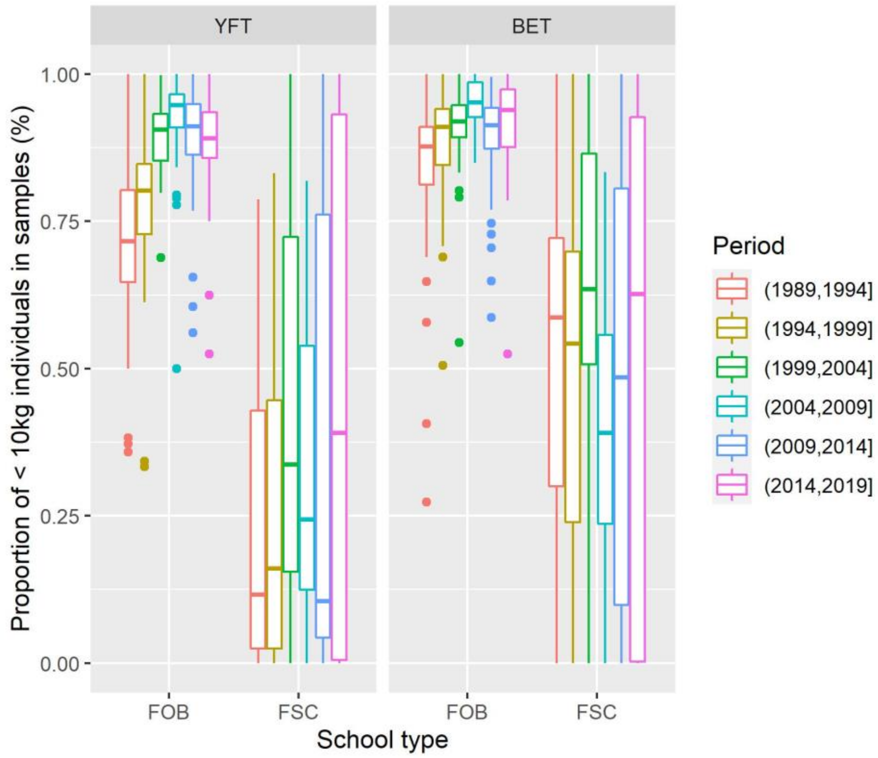



**Figure 3.** Mean proportion of <10 kg individuals in catches by species and fishing mode and 5 years step periods (N = 829).

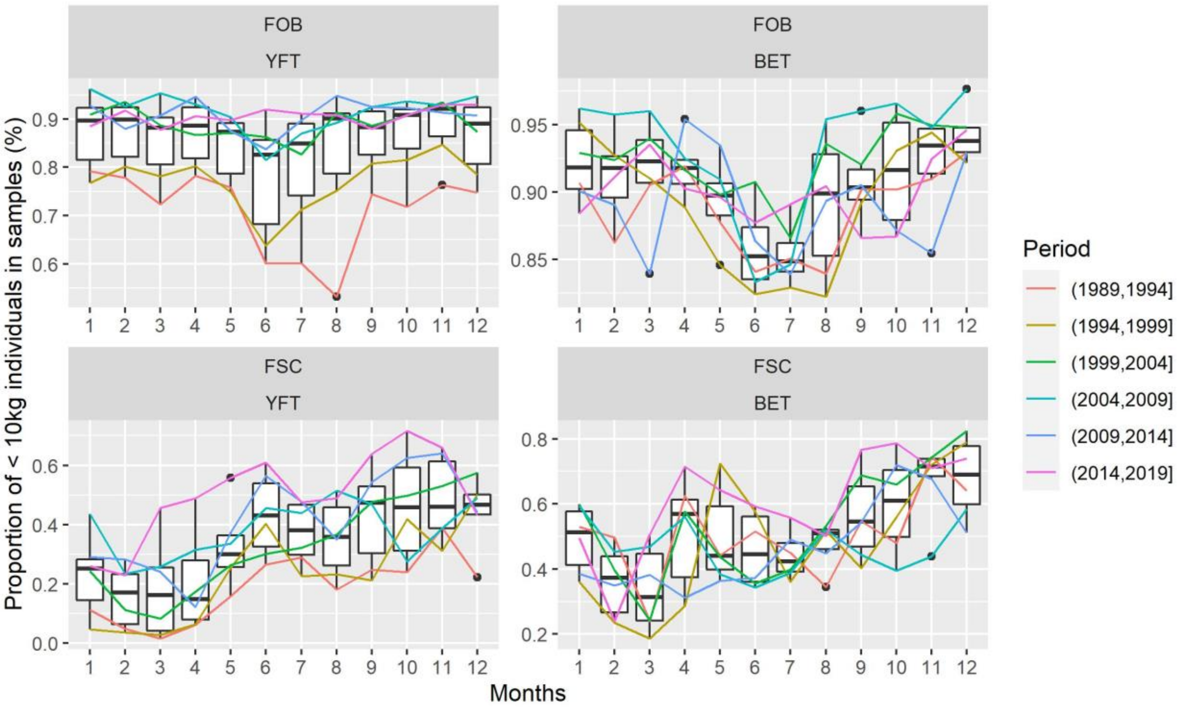



**Figure 4.** Mean proportion in samples by species and fishing mode all over the fishing ground in the Atlantic Ocean (N = 288). Boxplots represent the distribution accounting for all periods.

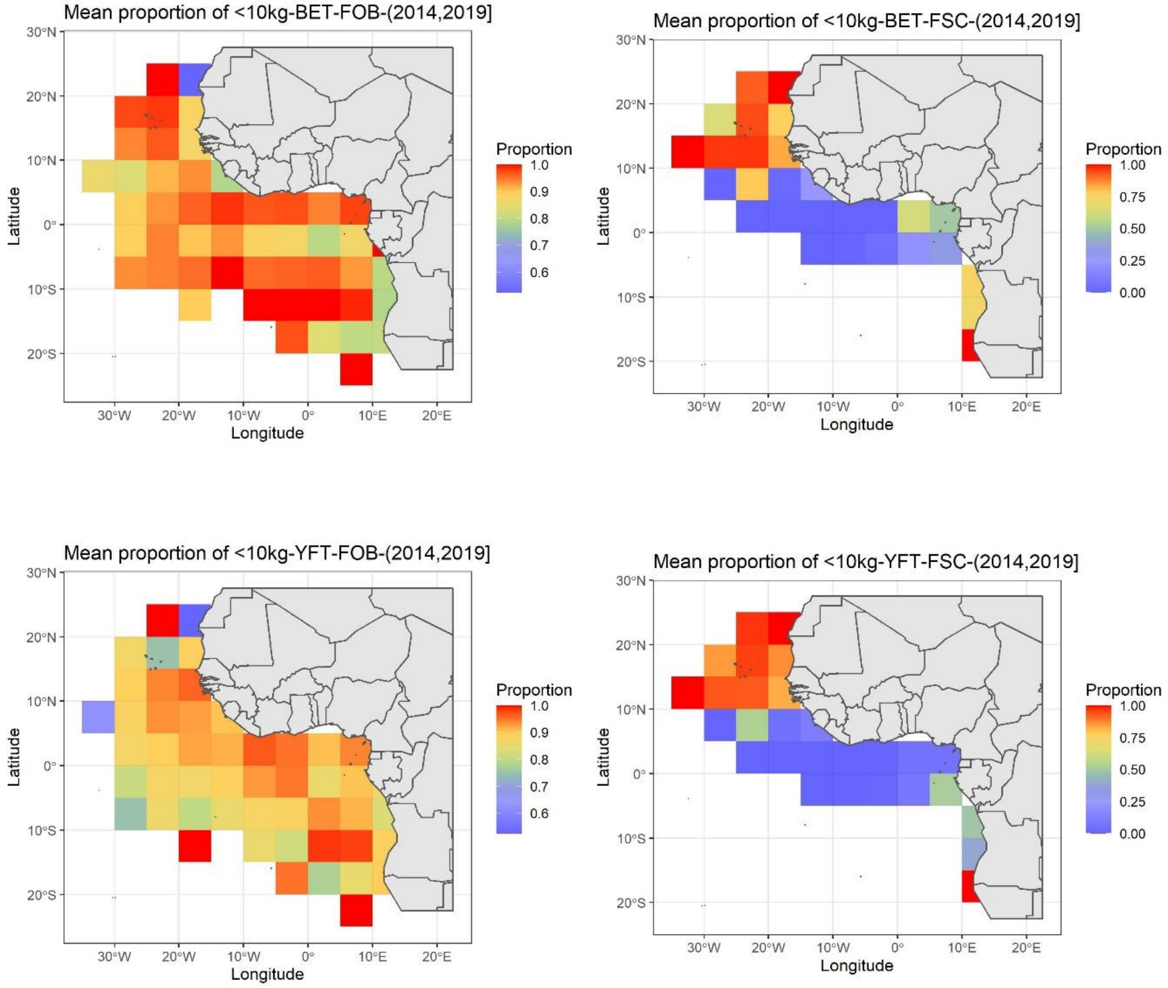



**Figure 5.** Mean proportion of <10 kg major tunas in samples (BET: top panels, YFT: bottom panels) by school types (FOB: left panels and FSC:right panels) by 5 degree squares for the period 2014-2019.

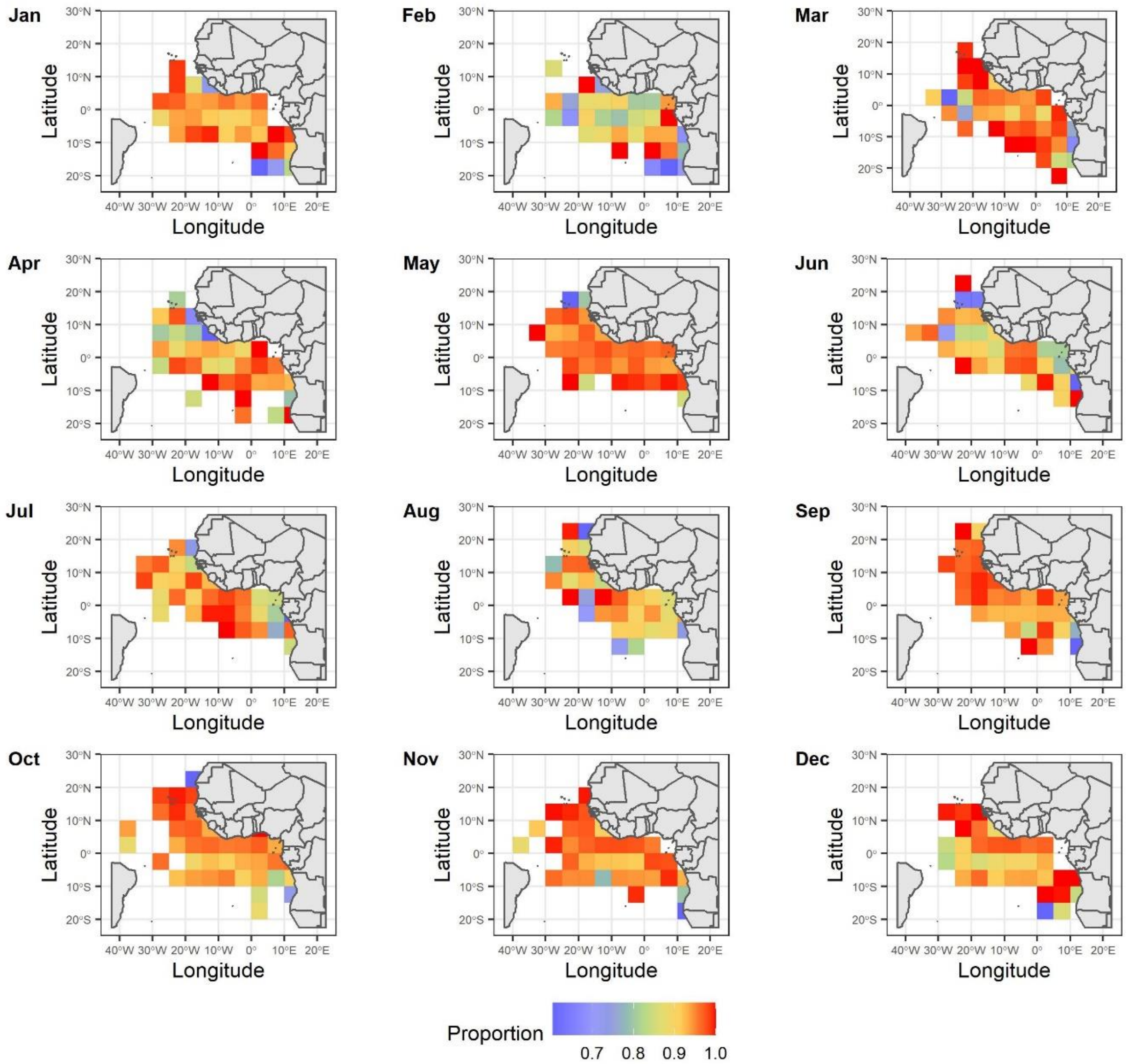



**Figure 6:** Monthly mean proportion of <10 kg BET in samples on FOB by 5 degree squares over the period 1990-2019 for the EU-FR and EU-SP fleet.

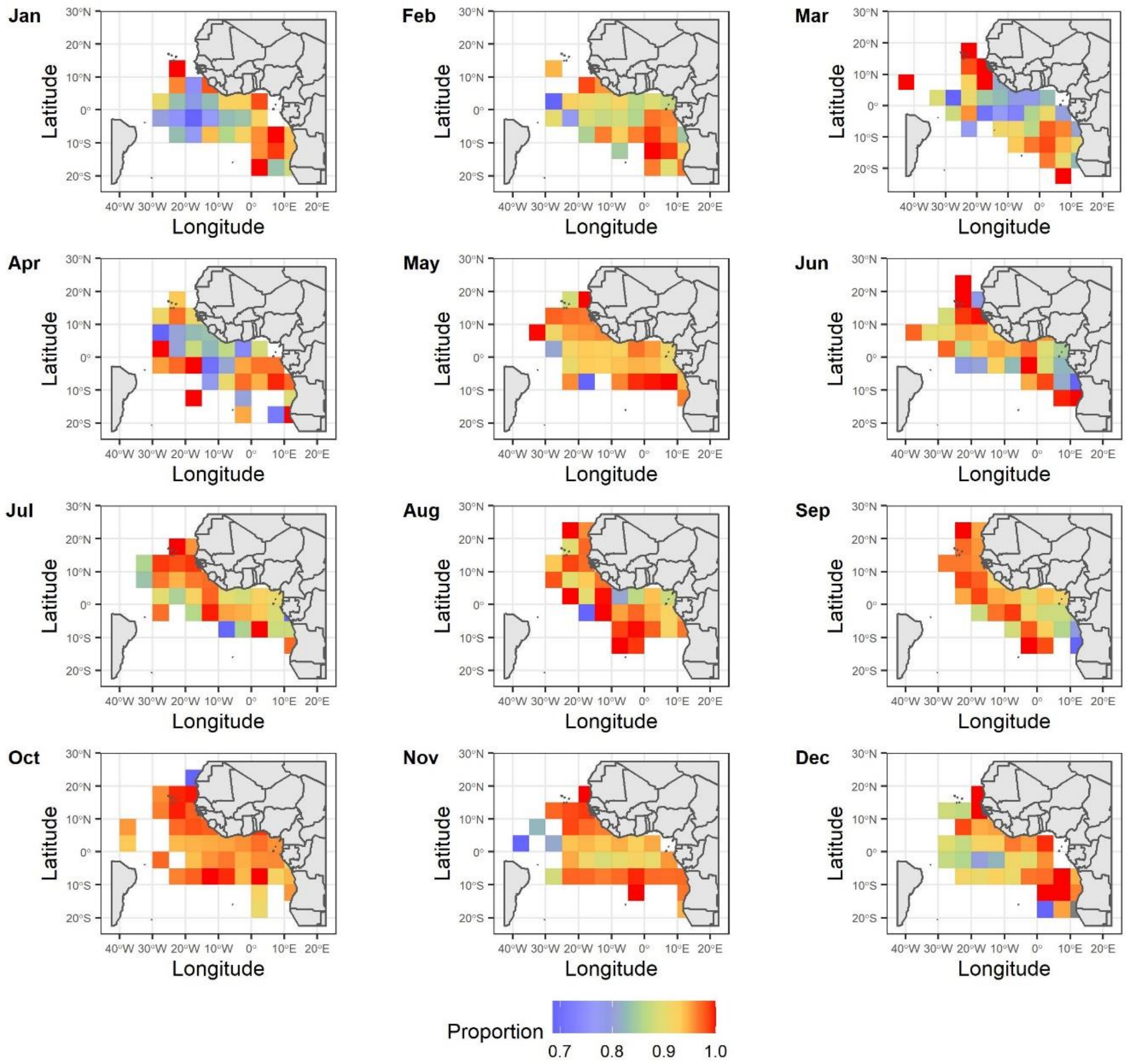



**Figure 7.** Monthly mean proportion of <10 kg YFT in samples on FOB by 5-degree squares over the period 1990-2019 for the EU-FR and EU-SP fleet.

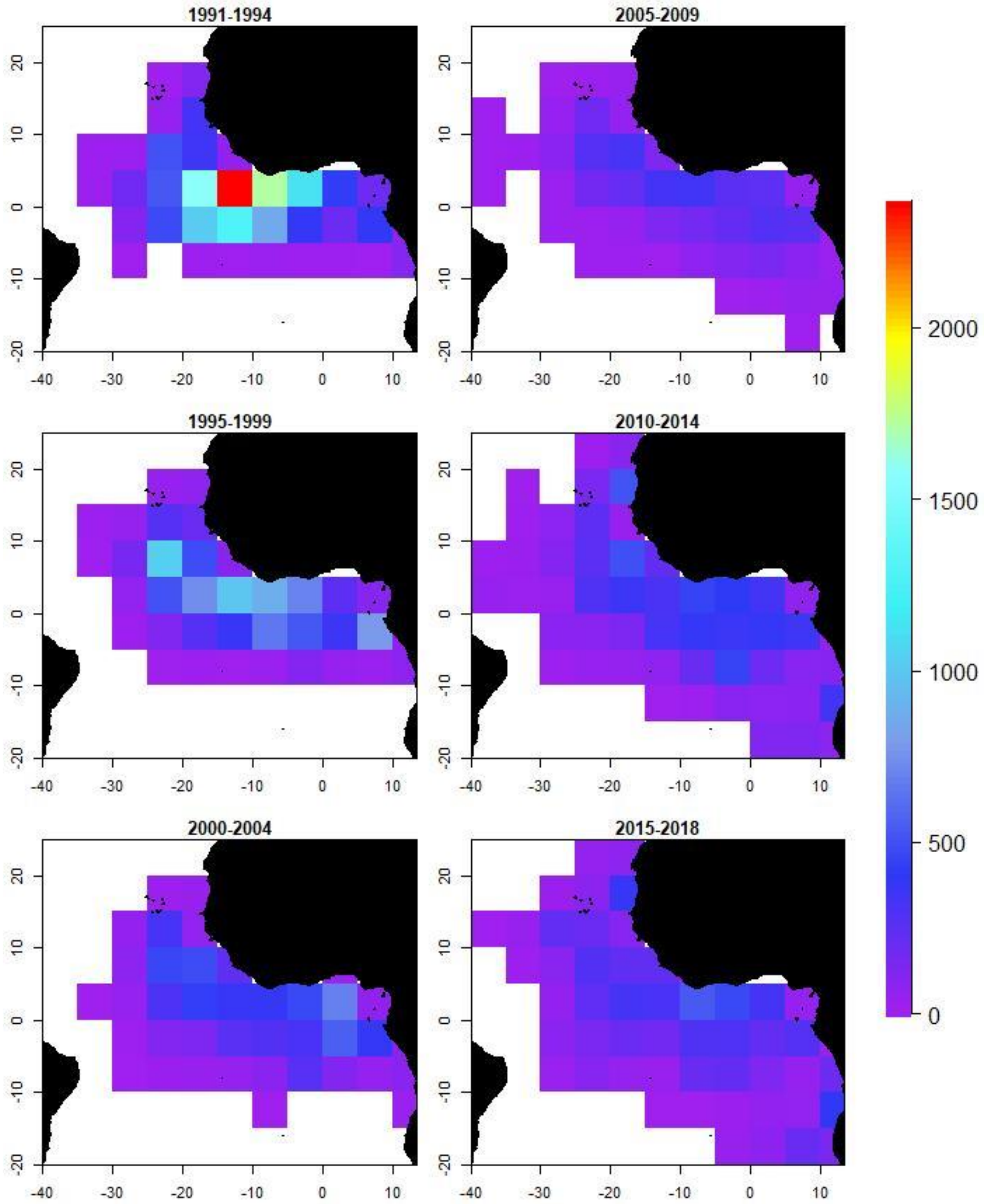



**Figure 8.** Average Catch (t) for BET on FOB by EU fleet during the 1991-2018 period.

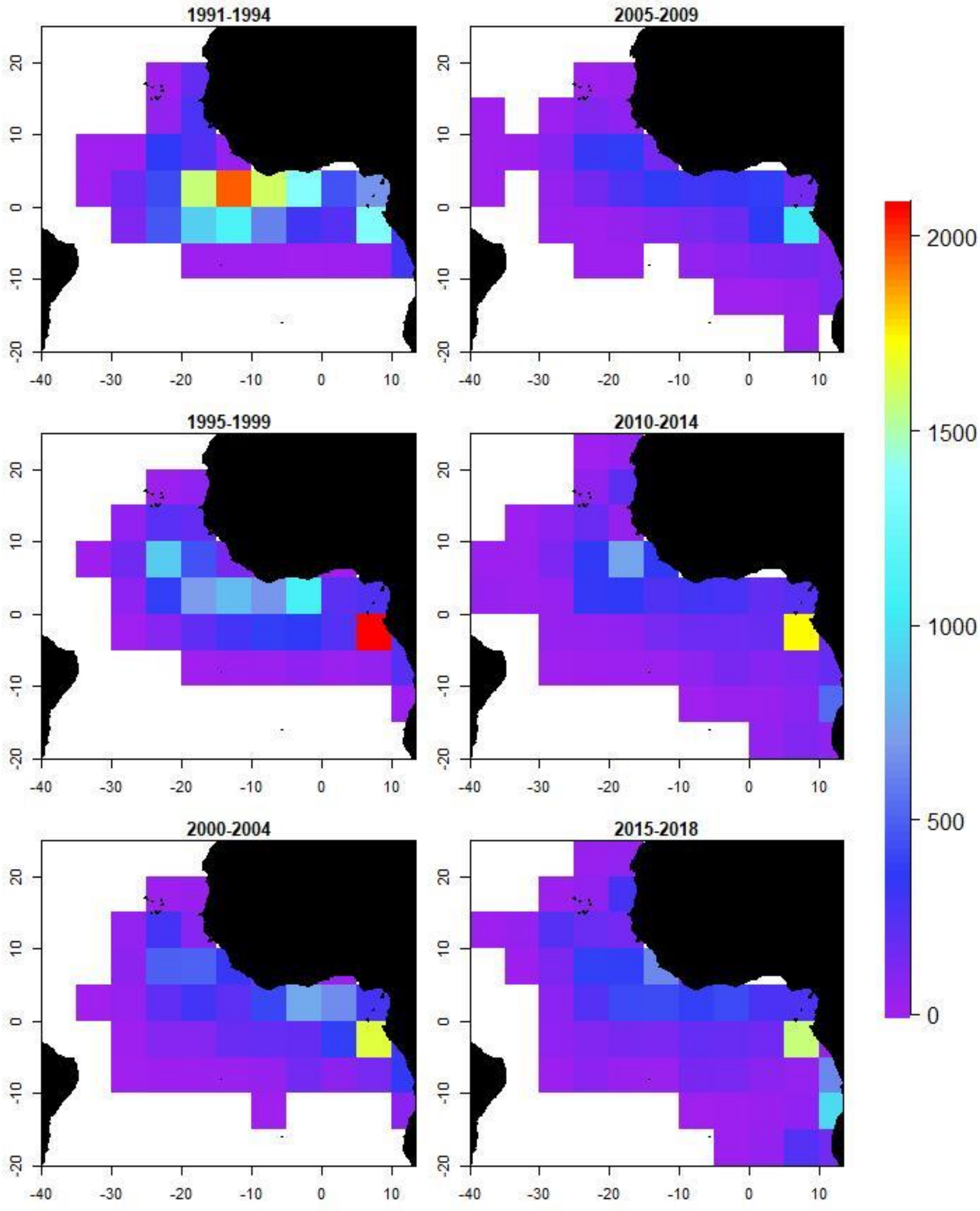



**Figure 9**. Average Catch (t) for YFT on FOB by EU fleet during the 1991-2018 period.

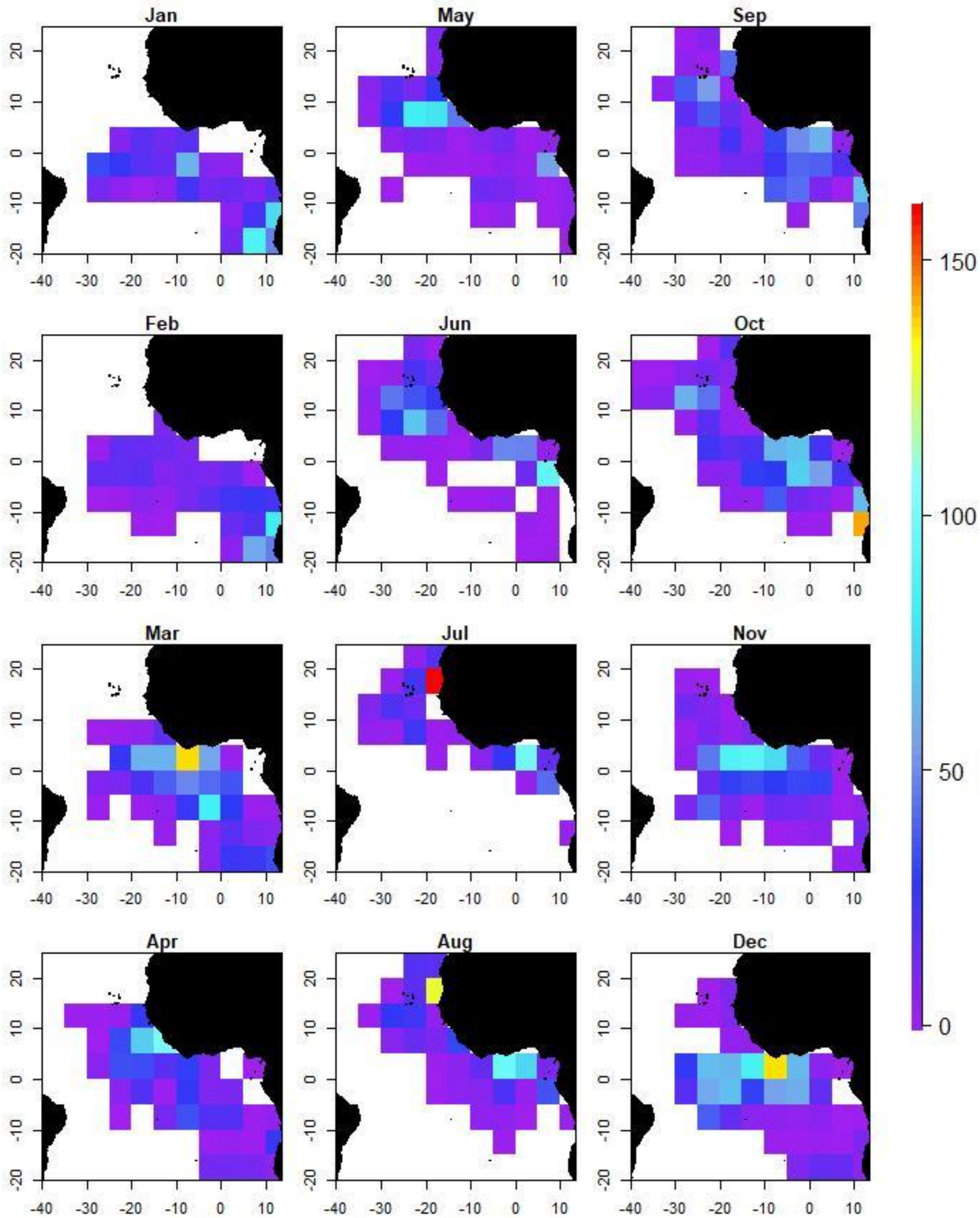



**Figure 10.** Monthly catches on FOB for BET by EU fleet between 2015 and 2019.

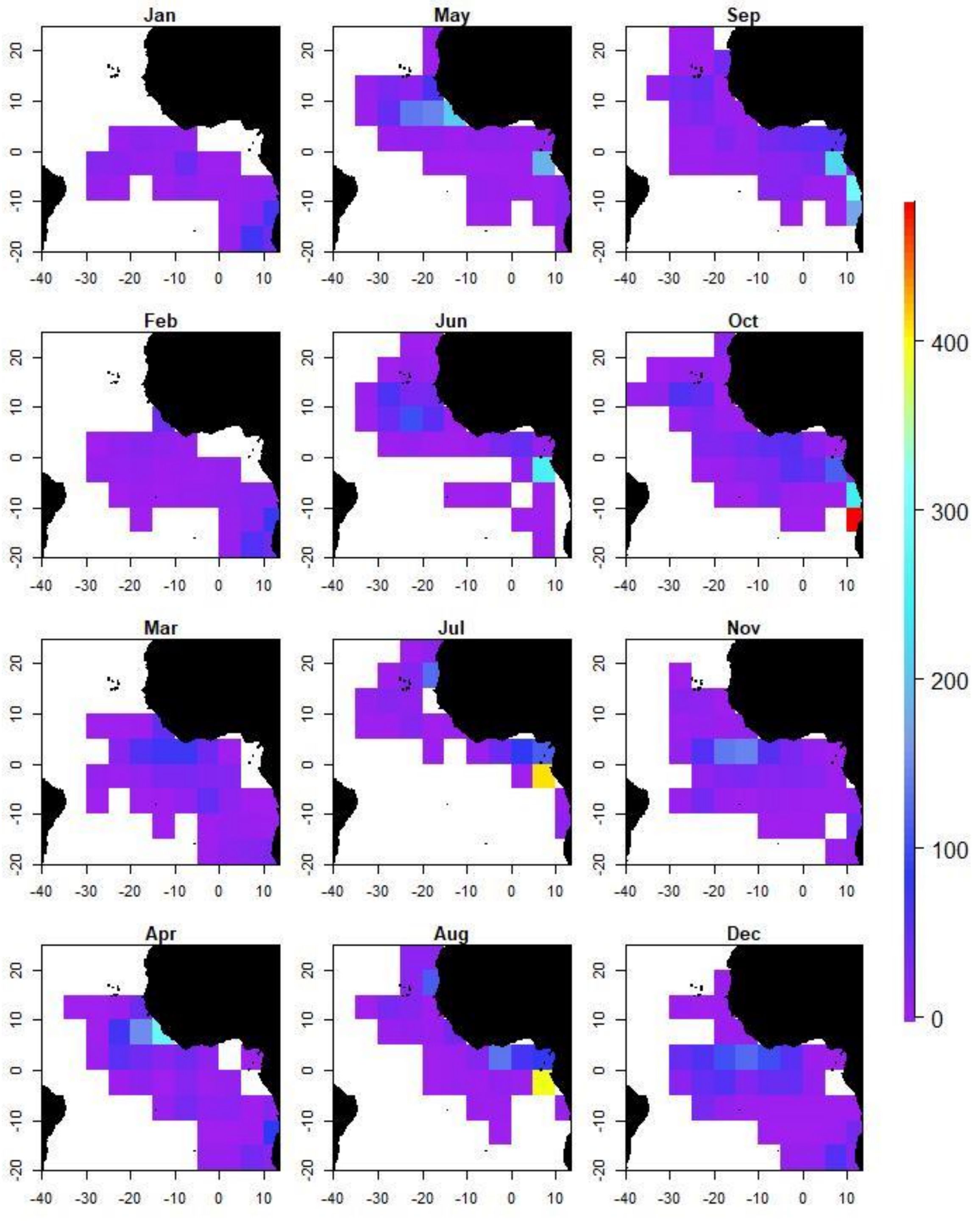



**Figure 11.** Monthly catches on FOB for YFT by EU fleet between 2015 and 2019.