Seamounts and tuna fisheries: tuna hotspots or fishermen habits?

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SEAMOUNTS AND TUNA FISHERIES: TUNA HOTSPOTS OR FISHERMEN HABITS?

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SUMMARY

An objective method to identify and assess seamount aggregation of tuna schools is presented. The method combines statistical selection of active seamounts based on fleets fishing time and spatial point pattern analysis. The characteristics of the tuna catches for the 5 seamounts selected by this method in the Atlantic Ocean are briefly commented on the period 1999-2010 for the French and Spanish purse seine and baitboat fleets. Catches by km^{-2} are higher in the seamounts vicinity for both fleets. Species composition changes increasing big eye tunas proportion in catches and decreasing yellow fin and skipjack tunas proportion. Size frequency distributions show that smaller individuals are more frequent in the seamounts vicinity. However these patterns can vary between the seamounts considered.

RÉSUMÉ

Ce document présente une méthode objective visant à identifier et à évaluer les regroupements des bancs de thons autour des monts sous-marins. La méthode associe la sélection statistique des monts sous-marins actifs sur la base d'une analyse du temps de pêche de la flottille et du schéma de points spatiaux. Le document analyse brièvement les caractéristiques des prises de thonidés pour cinq monts sous-marins sélectionnés par cette méthode dans l'océan Atlantique au titre de la période 1999-2010 pour les flottilles de senneurs et de canneurs français et espagnols. Les prises par km^2 sont plus élevées à proximité des monts sous-marins pour les deux flottilles. La composition spécifique change et la proportion des thons obèses augmente dans les captures alors que celle des albacores et des listaos se réduit. Les distributions des fréquences des tailles montrent que les spécimens plus petits sont plus fréquents à proximité des monts sous-marins. Toutefois, ces schémas peuvent varier en fonction des monts sous-marins considérés.

RESUMEN

Se presenta un método objetivo para identificar y evaluar las congregaciones de bancos de túnidos en torno a montes marinos. El método combina la selección estadística de montes marinos activos basada en análisis del tiempo de pesca de las flotas y de patrones de puntos espaciales. Se comentan brevemente las características de las capturas de túnidos de 5 montes marinos seleccionados con este método en el océano Atlántico durante el periodo 1999-2010 para las flotas rancesas y española de cerco y cebo vivo. Las capturas por km^2 son mayores en la vecindad de los montes marinos para ambas flotas. Hay cambios en la composición por especies ya que aumenta la proporción de patudo en las capturas y desciende la proporción de rabil y listado. Las distribuciones de frecuencias de tallas muestran que en la proximidad de los montes marinos son más frecuentes los individuos más pequeños. Sin embargo, estos patrones pueden variar entre los diferentes montes marinos considerados.

KEYWORDS

Fishery sciences, seamounts, geographical distribution, spatial point pattern, Thunnus albacares, Katsuwonus pelamis, Thunnus obesus

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1. Introduction

Seamounts are, in a broad sense, "any geographically isolated topographic feature on the seafloor taller than 100 m, including ones whose summit regions may temporarily emerge above sea level, but not including features that are located on continental shelves or that are part of other major landmasses" (Staudigel *et al.*, 2010). Recently, seamounts have attracted attention to the scientific community Pitcher *et al.* (2008). Seamounts seem to favour aggregates of marine predators (tunas, dolphins, seabirds) in their vicinity (Morato *et al.* 2008], Chapter 10A; Pitcher *et al.* 2008). They have been identified as hotspots of pelagic biodiversity in the open ocean (Morato *et al.,* 2010). For local fishery, seamounts were found to either enhance or reduce tuna catch in their vicinity (Pacific Ocean, Morato *et al.* 2010), Atlantic Ocean, Fonteneau 1991). Worldwide fishery studies show that catches of seamount species seem to have peaked in the early 1990s and many appear vulnerable (Chapter 18, Pitcher *et al.* 2008). Consequently fishing around seamounts raises management questions but ask first (1) an objective identification of seamount effectively fished and (2) a good assessment of their fishery characteristics around them.

The present paper studies the tuna catches by the French and Spanish tuna fleets from 1999 to 2010 in the vicinity of the seamounts in the Atlantic Ocean. We introduce an objective method to identify "productive" or "active" seamounts (i.e., seamounts fished extensively). Then spatial point process statistics is used to quantify aggregative properties of tuna schools in the vicinity of the active seamounts. Following Fonteneau [1991] active seamounts are finally characterized by fishery data.

2. Materials and Methods

2.1 Fishery data

French and Spanish purse seine fishing activities have been monitored by the *Institut de Recherche pour le D´eveloppement (IRD)* and the *Instituto Español de Oceanografía (IEO)* in the Atlantic and the Indian Ocean since 1981 through the collection of logbook, well maps, and records of unloading and transhipment. In a first step, total catches declared in the logbooks were adjusted to the landings at the trip level. In a second step, species composition for the three principal market tunas was corrected through size-species samples collected at unloading Pianet (1999). In this study, we use fishing sets location and fishing composition between 1999 and 2010 for the French and Spanish purse seine and baitboat fleet targeting tuna in Atlantic Ocean.

2.2 Seamounts data

Two main global estimates of seamount abundances are available. Based on measurements originating with satellite altimetry, the SeaAroundUs database (SAU[7] hereafter) (Morato and Pauly, 2004) and the Global Seamount Database (GSD[8] hereafter) (Kim and Wessel, 2011) give global estimate of seamount abundances worldwide.

Seamounts were first selected geographically on the area defined by spatial extension of the fishing sets between 1999 and 2010. Seamounts referenced twice in the GSD and SAU database were discarded from the second database. Then seamounts were selected according to their depth extracted from the ETOPO1 digital elevation model (Amante and Eakins, 2009). The depth interval used was 0 to 1,000 m depth, resulting of a set of 325 seamounts. According to the literature in the same area 1,000 m depth is a threshold for seamounts influence on pelagic communities Fonteneau (1991).

2.3 Active seamounts selection

Active (or productive seamounts in a fishery sense) seamounts were identified according to the time spent fishing in their vicinity. 10 time fishing by km by year were calculated in discus of increasing radii from 10 km to 100 km (by 10 km step) centered on each seamount. The seamounts with no fishing time in the ten discuss are seamounts with no fishing activities in a radius of 100 km over 12 years. These 181 seamounts were defined inactive. The 144 remaining seamounts were grouped according to the time fishing on each discus using a clustering analysis. Distance between the seamounts time fishing series were computed using Euclidean distance. Following Merigot *et al.* (2010), to assess which of the clustering methods preserves most faithfully the initial

[7] https//www.seaaroundus.org
[8] http://www.soest.hawaii.edu/PT/SMTS

distance matrix, we compute the 2-norm matrix norm on 7 clustering algorithms (Ward method, single and complete linkages, unweighted pair group method using arithmetic averages [UPGMA], weighted pair group method using arithmetic averages, weighted pair group method using centroids and unweighted pair group method using centroids). The ultrametric matrix obtained with the UPGMA algorithm was the closest to the distance matrix between pairs of density values for each seamount (not shown). The dendrogram of the fishing time for the seamounts was consequently computed using the UPGMA algorithm. The estimation of the optimal number of clusters was using the Gap statistics (Tibshirani *et al.* 2001).

2.4 Tuna schools spatial properties around seamount

From the active seamounts selected previously the spatial properties of the fishing sets distribution were investigated in order (1) to identify if tuna schools form aggregates around seamounts and (2) the spatial extent of such aggregative properties. Spatial distribution of items (here tuna schools) is conveniently analyzed using point process statistics (Cressie, 1991). Spatial point patterns are subject to first and second-order effects. First-order effects refer to systematic variations in intensity over space, like a response to environmental gradient in our case. Second-order effects refer to interactions between points, which involve any biological mechanism promoting active spacing or clustering behaviour, such as competition or social behaviour. To investigate first-order and second-order processes, respectively, we used (1) point process modelling and (2) point pattern analysis.

a) Point process models were fitted to the fishing sets distribution according to 6 hypotheses (Baddeley and Turner, 2005, Baddeley, 2010):
   - Hypothesis 1: complete spatial randomness (CSR) where tuna schools distributes following an homogeneous spatial Poisson process.
   - hypothesis 21: tuna schools spatial distribution follows an inhomogeneous Poisson model with an intensity that is log-linear in the Cartesian coordinates of the schools.
   - hypothesis 22: tuna schools spatial distribution follows an inhomogeneous Poisson model with an intensity that is log-quadratic in the Cartesian coordinates of the schools.
   - hypothesis 3: tuna schools spatial distribution follows an inhomogeneous Poisson model with an intensity function that depends on the distance to the seamount.
   - hypothesis 41: hypotheses 21 and 3 (tuna schools follow an inhomogeneous Poisson model with an intensity that is log-linear in the Cartesian coordinates of the schools and that depends on the distance to the seamount).
   - hypothesis 42: hypotheses 22 and 3 (tuna schools follow an inhomogeneous Poisson model with an intensity that is log-quadratic in the Cartesian coordinates of the schools and that depends on the distance to the seamount).

b) A derivated method of the K(r) function Ripley (1977), the inhomogeneous version of the L-function (Besag's transformation of Ripley's K-function (Besag 1977) was used to detect interactions (aggregation or inhibition) in our points patterns (the simply of tuna schools locations within the vicinity of a seamount) Baddeley *et al.* (2000).

2.5 Seamounts fisheries characteristics

The fisheries activities around seamounts are described using time fishing, total catches, number of sets (for purse seine only), number of positive sets (with catches, purse seine only), catches by sets and species composition for the three main species: yellowfin tuna, skipjack tuna and big-eye tuna.

3. Results

3.1 Active seamounts selection

The clustering and the fishing time around seamounts are represented using a heat map plot of the dataset ([Eisen *et al.,* 1998). A heat map is a graphical representation of data where the values of a variable on a two dimensional map are repre- sented by squares with colour gradients, and variables (here fishing time) are ordered according to the dendrogram defined by the hierarchical clustering. The results of this analysis are presented in **Figure 1**. In our dataset, the second cutoff in the Gap statistics was 5 clusters. Between 1999 and 2012, the median of the fishing time for the 5 clusters (see **Figure 1**) on a 100 km discus were 33 h.km^{-2} (cluster 1), 269 33 h.km^{-2} (cluster 2), 1196 33 h.km^{-2} (cluster 3), 1666 hours fishing 33 h.km^{-2} (cluster 4) and 3958 33 h.km^{-2} (cluster 5). The seamounts of the cluster 1 were considered not enough active for our study, and discarded from the database. Six seamounts were identified active from our procedure for the Atlantic (5 seamounts) and Indian Ocean (1 seamount, not discussed here). Seamounts are presented in the **Figure 2**. The data available for the five seamounts located in Atlantic Ocean are:

- Seamount 1: 226 set locations, 26 well samples.
- Seamount 2: 9222 set locations, 832 well samples.
- Seamount 3: 2477 set locations, 510 well samples.
- Seamount 4: 1743 set locations, 329 well samples.
- Seamount 5: 1369 set locations, 519 well samples.

3.2 Tuna schools spatial properties around seamount

The results of the spatial point process analyses are illustrated by the **Figure 3**. The L-function for the hypothesis 1 (complete spatial randomness) gives an idea of the influence radius of the seamounts on tuna school aggregates: the estimated L-function is above the envelope from 0 to 15 km and then below. Tuna schools are more aggregated than a random process from 0 to 15 km and then over dispersed. This distance is about 15 km for the 5 active seamounts (not shown).

The best point process model for all the tuna schools around the 5 seamounts is the inhomogeneous Poisson model with an intensity that is log-quadratic in the Cartesian coordinates of the schools and that depends on the distance to the seamount (hypothesis 42, lower AIC for the 5 seamounts, see **Table 1**).

3.3 Seamounts fisheries characteristics

Inter-annual and seasonal variabilities of the time spent fishing around the seamounts are presented in the **Figure 4 and 5**. The main pattern is an increasing fishing activities around the first 20 km near the seamounts. The seamount 1 is not fully used during the 1999-2010 period and not considered representative in this study: it is discarded from the analysis. Seamount 5 is only fished by the purse seine fleet. The area in the vicinity of this seamount is fully fished but in 2001 and 2009. But the area in the first 10 km is still fished. The area next to seamounts 2, 3 and 4 are both fished by purse seine and baitboats. Seamount 2 is dominated by the baitboats fishing. The seasonality is pronounced but different between the seamounts (**Figure 5**).

Catches around seamounts are higher by km^{-2} between 0 to 20 km than after 20 km (**Figure 6**) for purse seine and baitboat fleets. The catches map (**Figure 7**) show clearly that catches are not more important in the vicinity of seamounts, but more concentrated. For the purse seine sets, the proportion of the positive set is close to 1: the probability to catch a tuna school is high. Set numbers and catches by positive set are higher by km^{-2} in the vicinity of seamounts: purse seine fleet effort is consequently higher near seamounts and lead to more catches by set.

The composition of the main species fished is presented in the **Figure 8** (purse seine fleet) and **Figure 9** (baitboat fleet). For the purse seine catches in the vicinity of the seamounts 3, 4 and 5, skipjack and yellowfin proportions goes down and the big eye proportion goes up. The range of these changes is seamount dependent. The seamounts 2 shows the same kind of variation for big eye and yellowfin tuna proportion but the proportion of skipjack remain high, mainly because seamount 2 is more fished by the baitboat fleet. **Figure 9** shows variation in species composition depending to the seamount distance for the seamount 2 only: samples for the other seamounts are only localized in the first 10 km of their summits. The species composition of the seamount 2 shows variations for big eye and skipjack tunas (big eye replacing skipjack near the seamount). Proportion of yellow fin is low in this case in the first 30 km.

Species Size frequency distributions taken from the well samples pooled in two categories (samples taken between 0 and 20 km and 20 to 100 km from the seamounts) are presented in **Figure 10**. The noisy shapes of the size frequency distribution of the seamount 2 is due to the small number of samples (n=26) and will be not discussed here. For yellow fin tuna, large individuals (size ¿ 1000 cm) are very rare in the first 20 km near the seamounts. Smaller individuals are more frequent for the seamounts 5 and slightly more frequent for the seamounts 3. For the seamount 4, there isn't any difference for the smaller individuals. For skipjack tunas, smaller individuals are more frequent near the seamount. For big eye tunas, the modes of the size frequency distribution are similar, but larger individuals are more frequent near the seamount: the distribution is slightly skewed to the right around 500 cm for the seamounts 4 and 5.

4. Discussion

Seamounts selected by our rather objective and extensive analysis (objective in the use of a statistical classification of fishing time around seamounts without any knowledge of the fishermen habit and extensive in the use of the world coverage seamounts database) are well in accordance with the most productive seamounts identified by Fonteneau (1991): our seamounts 2, 3 and 5 correspond to the seamounts 1, 11 and 20 in the Fonteneau (1991) study. The spatial point process analysis of the tuna schools locations give a radius of seamount influence of about 15 km, a value near the 6 nm found by Fonteneau (1991) and the 10 km found by Morato *et al.* (2010).

Seamounts concentrate tuna schools in a small area well located in space, where in turn purse seine and baitboat fleet concentrate their fishing effort. Consequently catches by km^{-2} in these areas are higher in the vicinity of seamounts. Species compositions show an increasing in big eye in the catches. Size frequency distributions show that smaller individuals are caught near the seamounts, but with a variability associated to the seamount.

5. Conclusions

The seamounts identified as active in this study aggregate tuna schools in their vicinity, a fact well known by the fishermen Fonteneau (1991), which in turn tend to concentrate their fishing activities in these areas. Catches by km^{-2} are high in the first 20 km near the seamount. Species compositions change in favor to bigeye tuna and fishes caught are generally smaller in the vicinity of the seamount. But these patterns vary with the seamounts. Future works will (1) improve these patterns characterization by statistical modelling (using glm) and (2) will integrate possible environmental factors to explain these patterns (primary production).

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Table 1. Point process model results and test. AIC: Akaike information criterion. AOV: analysis of deviance.

Hypotheses	*AIC*	*p-value*	*Test*	*AOV*	*Schools nb*	*Diggle Cressie Loosmore and Ford test results*			*Seamount number*
						Value	*Rank*	*p-value*	
Hyp 1	-960.58		CSR		126	2.73E-03	1	1.96E-02	sm 1
Hyp 21	-961.06	1.06e-01	1 vs 2	4.48	126	2.70E-03	1	1.96E-02	sm 1
Hyp 22	-1216.42	2.18e-55	1 vs 3	265.85	126	5.64E-04	1	1.96E-02	sm 1
Hyp 3	-1374.64	1.76e-92	1 vs 4	416.06	126	4.37E-04	6	1.18E-01	sm 1
Hyp 41	-1443.00	1.54e-105	4 vs 5	488.43	126	7.14E-04	1	1.96E-02	sm 1
Hyp 42	-1592.24	8.87e-136	5 vs 6	643.66	126	5.24E-04	35	6.86E-01	sm 1
Hyp 1	-41672.23		CSR		3102	4.04E-05	1	1.96E-02	sm 2
Hyp 21	-41813.29	3.17e-32	1 vs 2	145.06	3102	3.67E-05	1	1.96E-02	sm 2
Hyp 22	-42638.89	6.06e-180	2 vs 3	831.60	3102	7.73E-06	1	1.96E-02	sm 2
Hyp 3	-42134.96	4.50e-103	1 vs 4	464.73	3102	1.80E-05	1	1.96E-02	sm 2
Hyp 41	-42318.06	5.86e-141	4 vs 5	651.83	3102	1.37E-05	1	1.96E-02	sm 2
Hyp 42	-42821.97	9.10e-248	5 vs 6	1161.74	3102	3.22E-06	1	1.96E-02	sm 2
Hyp 1	-8266.23		CSR		772	1.61E-03	1	1.96E-02	sm 3
Hyp 21	-8265.17	2.31e-01	1 vs 2	2.93	772	1.60E-03	1	1.96E-02	sm 3
Hyp 22	-9999.73	0.00e+00	1 vs 3	1743.50	772	2.27E-04	1	1.96E-02	sm 3
Hyp 3	-11222.75	0.00e+00	1 vs 4	2958.52	772	4.42E-04	1	1.96E-02	sm 3
Hyp 41	-11223.77	0.00e+00	4 vs 5	2963.54	772	4.35E-04	1	1.96E-02	sm 3
Hyp 42	-12247.66	0.00e+00	5 vs 6	3993.42	772	3.52E-04	1	1.96E-02	sm 3
Hyp 1	-11129.23		CSR		984	2.48E-03	1	1.96E-02	sm 4
Hyp 21	-11128.19	2.28e-01	1 vs 2	2.95	984	2.48E-03	1	1.96E-02	sm 4
Hyp 22	-14096.31	0.00e+00	1 vs 3	2977.07	984	3.76E-04	1	1.96E-02	sm 4
Hyp 3	-15997.71	0.00e+00	1 vs 4	4870.47	984	7.73E-04	1	1.96E-02	sm 4
Hyp 41	-16138.46	0.00e+00	4 vs 5	5015.23	984	8.53E-04	2	3.92E-02	sm 4
Hyp 42	-17450.60	0.00e+00	5 vs 6	6333.36	984	4.34E-04	2	3.92E-02	sm 4
Hyp 1	-2396.88		CSR		277	4.02E-04	1	1.96E-02	sm 5
Hyp 21	-2398.73	5.37e-02	1 vs 2	5.85	277	3.89E-04	1	1.96E-02	sm 5
Hyp 22	-2642.08	4.21e-53	1 vs 3	255.20	277	5.84E-05	1	1.96E-02	sm 5
Hyp 3	-2678.99	9.55e-64	1 vs 4	284.11	277	6.15E-05	1	1.96E-02	sm 5
Hyp 41	-2685.25	1.64e-63	4 vs 5	294.37	277	5.91E-05	2	3.92E-02	sm 5
Hyp 42	-2727.60	5.64e-71	5 vs 6	342.72	277	4.52E-05	1	1.96E-02	sm 5

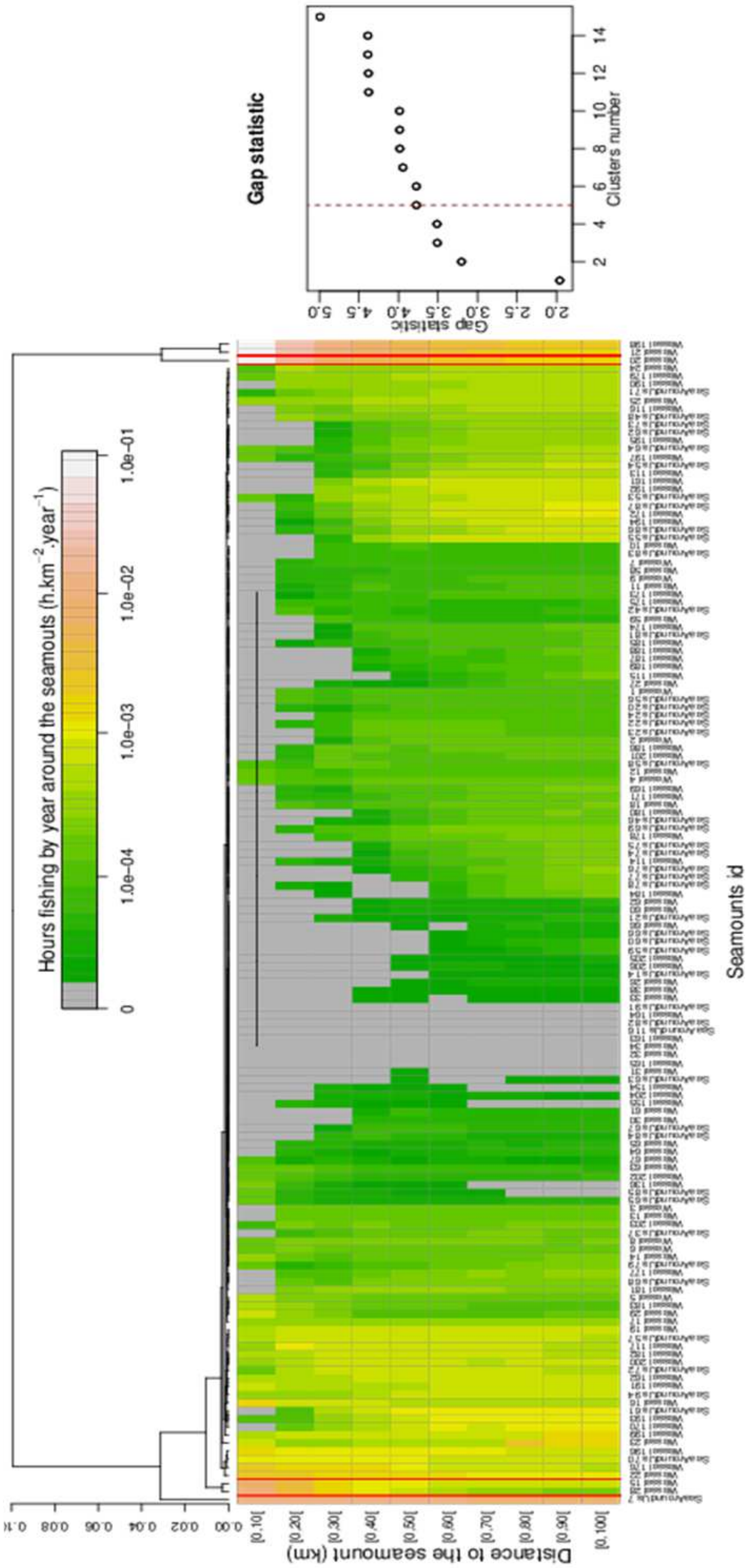

Figure 1. Cluster analysis of the fishing time around the seamounts. The heatmap shows the fishing time values (log 10 transformed) by Seamounts id (SeaAroundUs refer to the SAU database and Wessel to the GSD database) and distance class, ordered according to the dendogram (algorithm UPGMA on Euclidean distance). The plot gives the Gap statistic and the number of clusters. The optimal cluster number chosen in our analysis is underlined by the dashed red line (5 in our case). The corresponding groups are reported on the heatmap separated by the red lines.

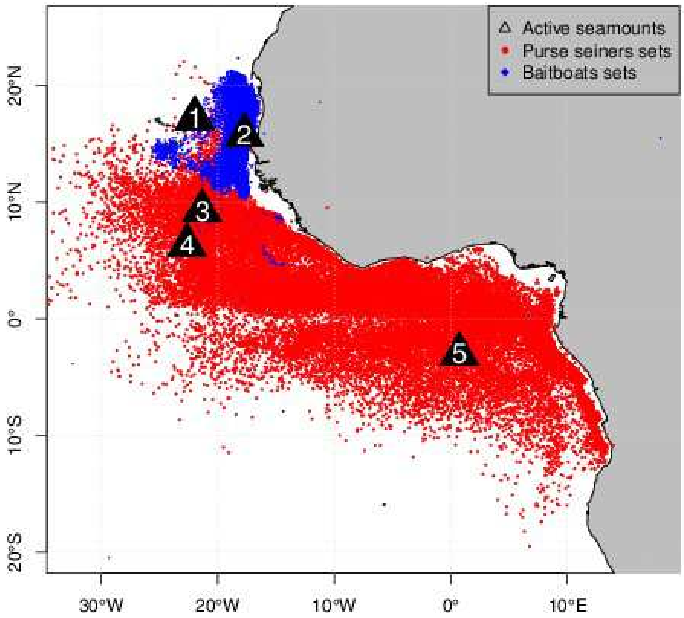

Figure 2. Locations of the 5 active seamounts and the fisheries dataset used in this study (1999-2010).

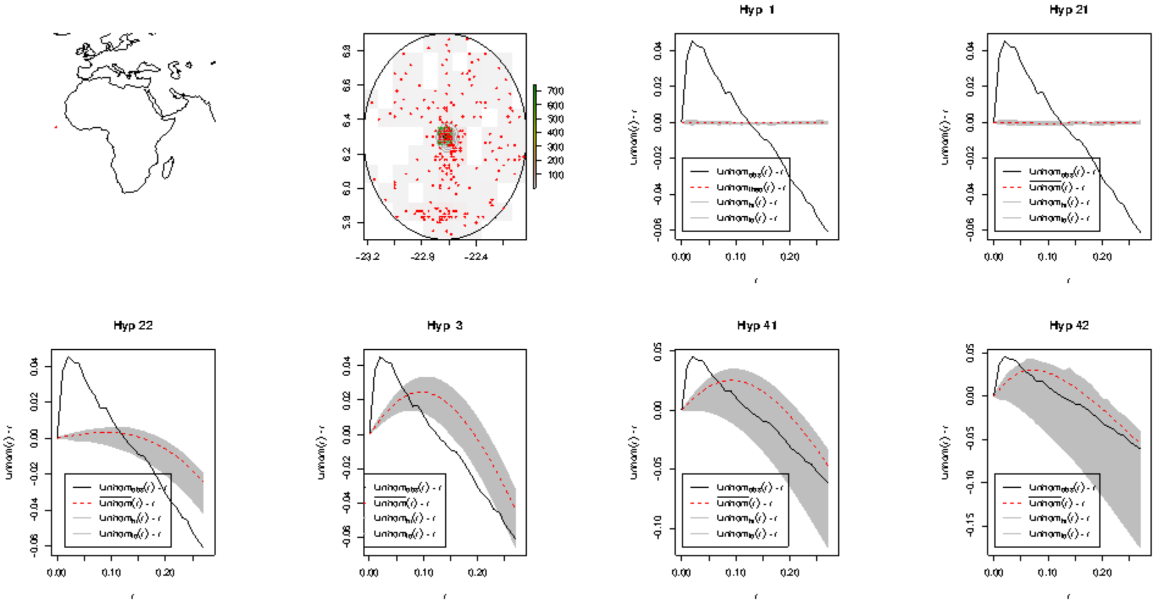

Figure 3. Spatial point pattern analysis of the tuna schools distribution around the seamount 4. Upper panels from left to right: location of the seamount, locations of the tuna schools (red point) with density map, inhomogeneous L-function for the point process model 1, inhomogeneous L-function for the point process model 21. Lower panels from left to right: inhomogeneous L-function for the point process model 22, 3, 41 and 42. Inhomogeneous L-functions are given for observed point process (black line), the simulated corresponding model (red dashed line) and its envelope (maximum and minimum values for the simulated L-function for each value of r). For the L-function in x-axis is given the distance between points (in degrees) and in y-axis the corresponding value of the L-function. If the L-function estimated from the tuna schools data lies outside the typical range of value of the envelope, then the point process observed is more aggregated (above the envelope) or over dispersed (below the envelope) than the modeled point process.

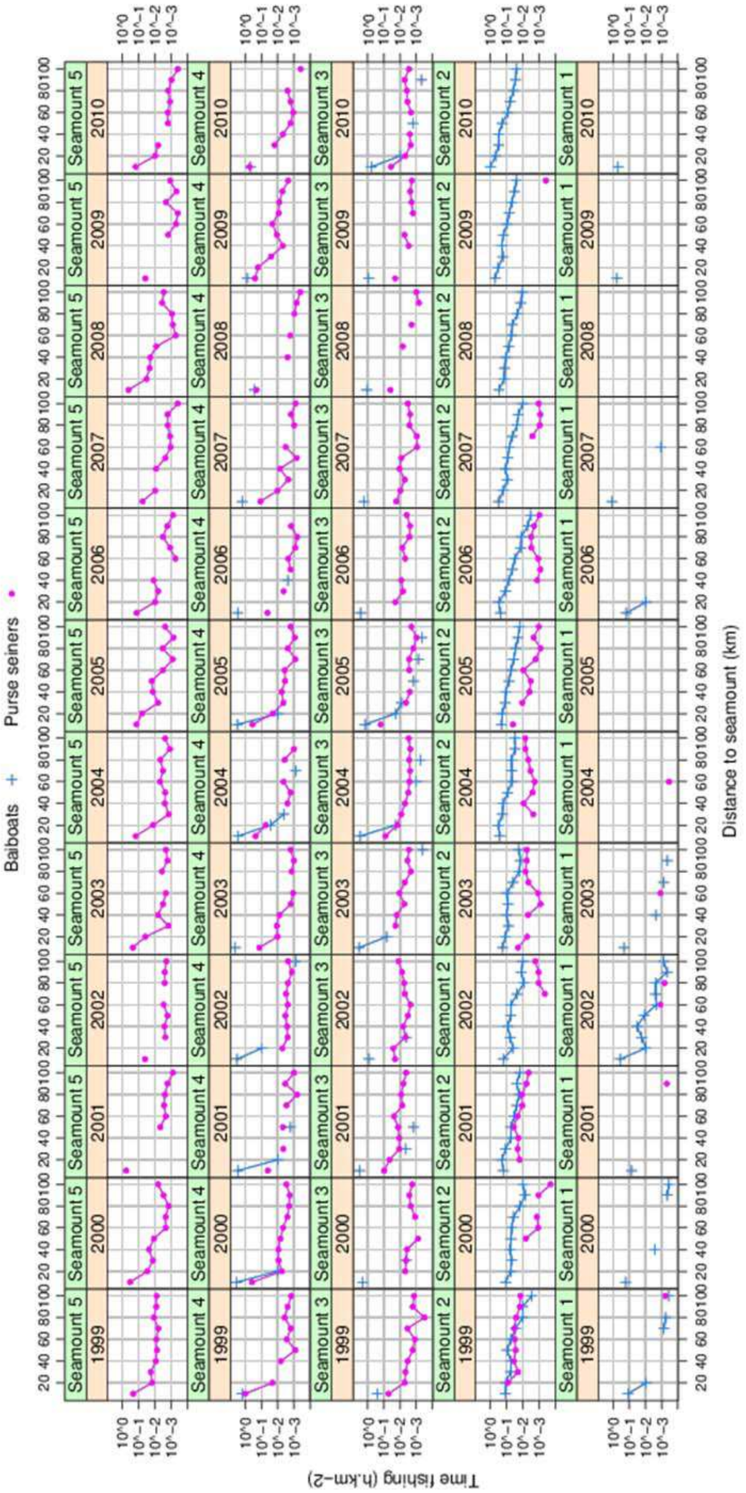

Figure 4. Interannual variability of the sum of time spent fishing by Km^2 in 1999-2010 (y-axis) against the distance to the seamounts by 10 km step until 100 km (x-axis) for the purse seine (pink dot) and the baitboat (blue cross) fleets. Each panel is associated with a seamount (green title) and a year (orange title).

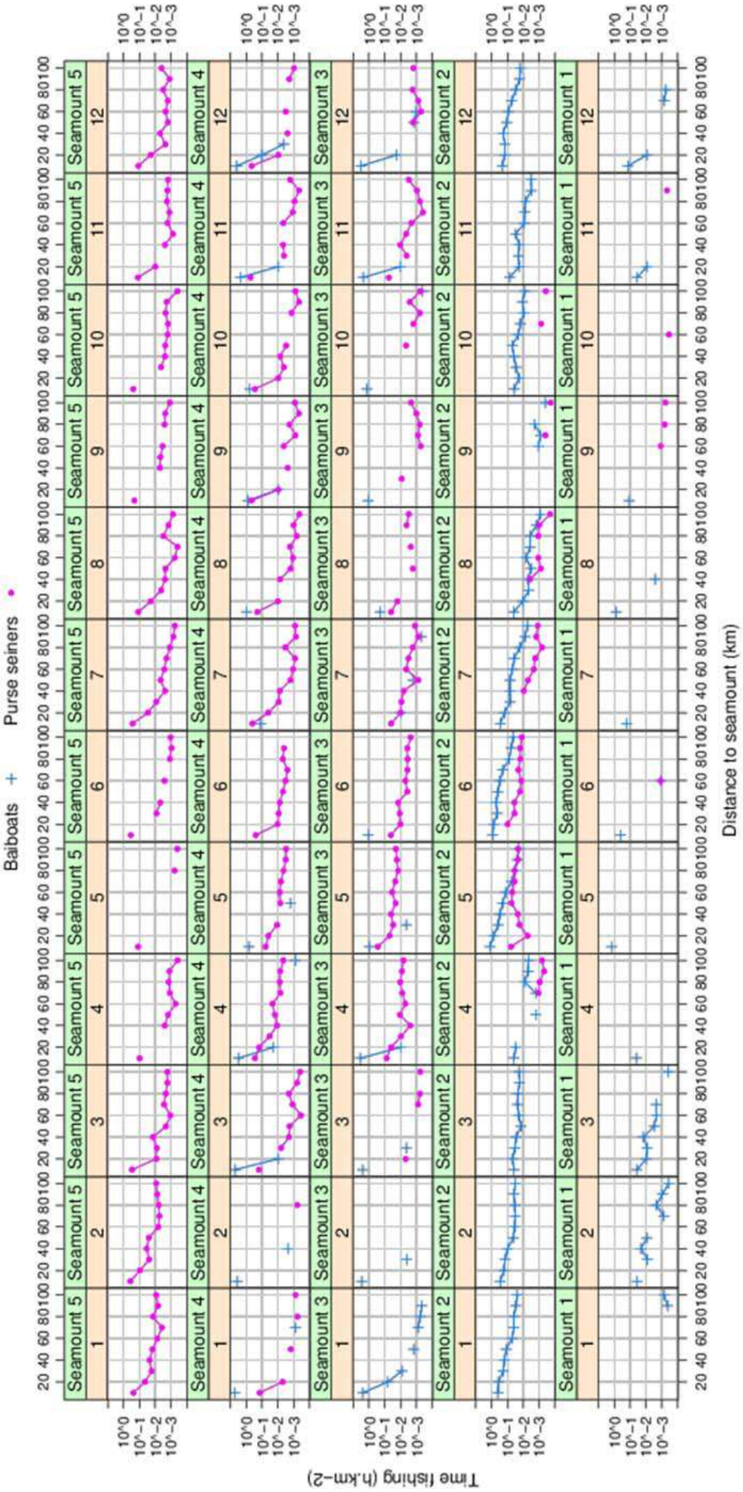

Figure 5. Seasonal variability of the sum of time spent fishing by km^{-2} in 1999-2010 (y-axis) against the distance to the seamounts by 10 km step until 100 km (x-axis) for the purse seiner (pink dot) and the baitboat (blue cross) fleets. Each panel is associated with a seamount (green title) and a month (orange title).

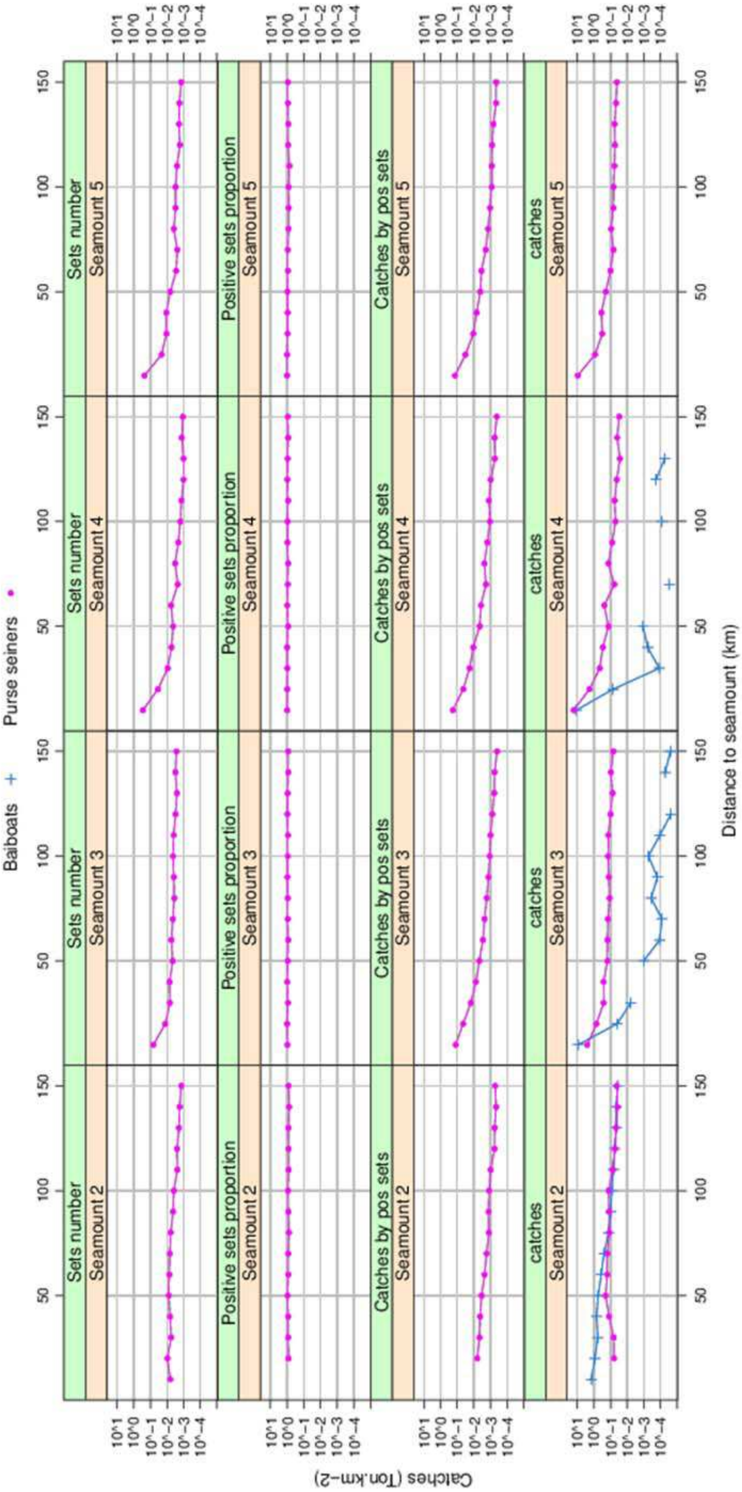

Figure 6. Fishing sets characteristics around seamountsSeasonal.

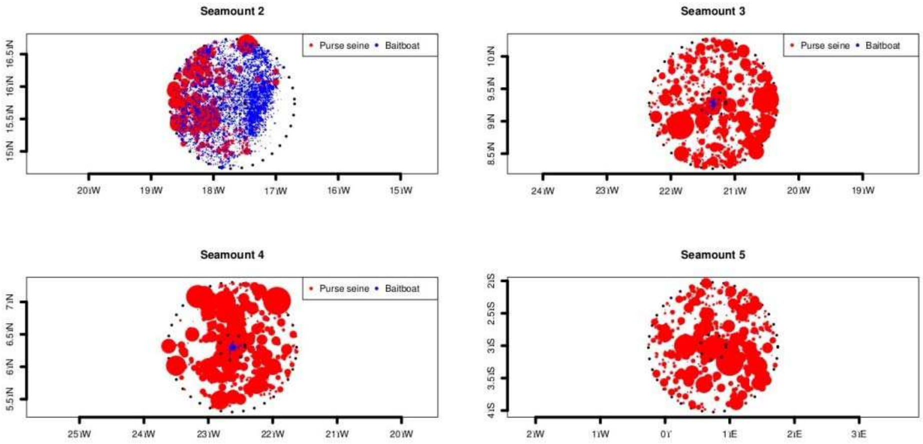

Figure 7. Tuna catches locations around active seamounts number 2 to 5 between 1999 to 2010 Circle radius is proportional to the catches.

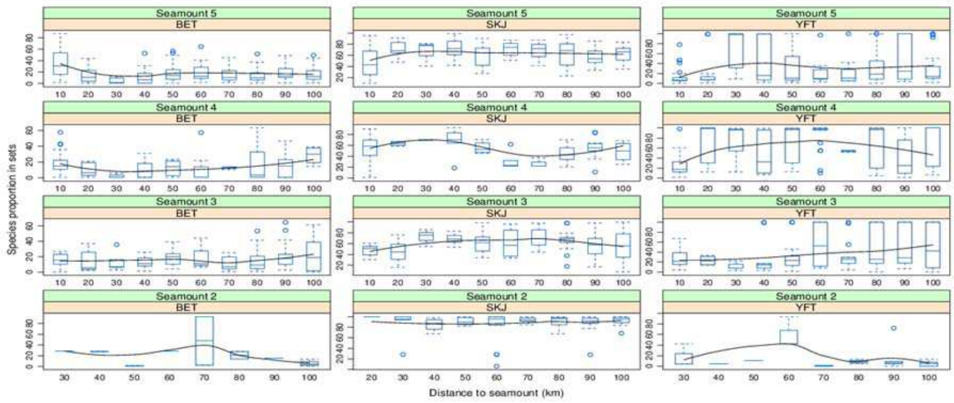

Figure 8. Proportion of the main tuna species (bigeye skipjack and yellowfin tuna) in the well samples around active seamounts number 2 to 5 for the purse seine fleet. Species proportions are presented with a boxplot for each 10 km step distance from the seamounts. The black line gives a LOESS fitting to the data with standard deviation (grey envelope) to underline the main trend.

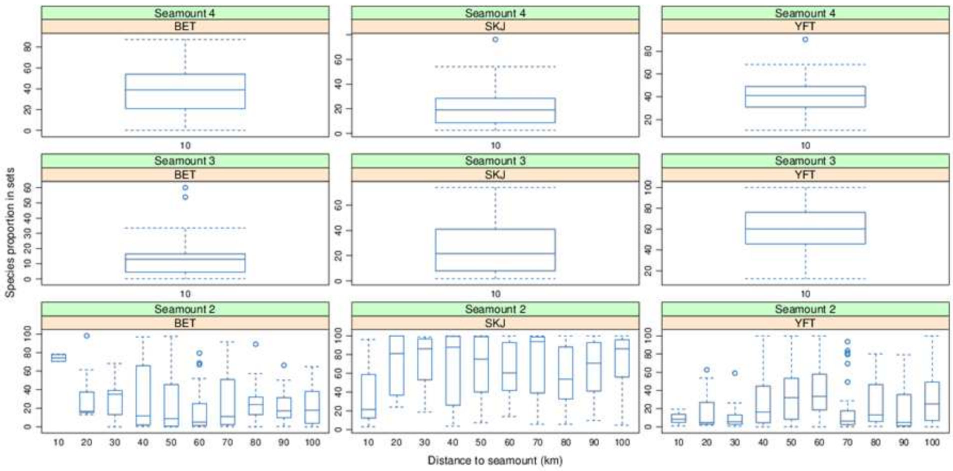

Figure 9. Proportion of the main tuna species (big eye, skipjack and yellow fin tuna) in the well samples around active seamounts number 2 to 5 for the baitboat fleet. Species proportions are presented with a boxplot for each 10 km step distance from the seamounts. The black line gives a LOESS fitting to the data with standard deviation (grey envelope) to underline the main trend.

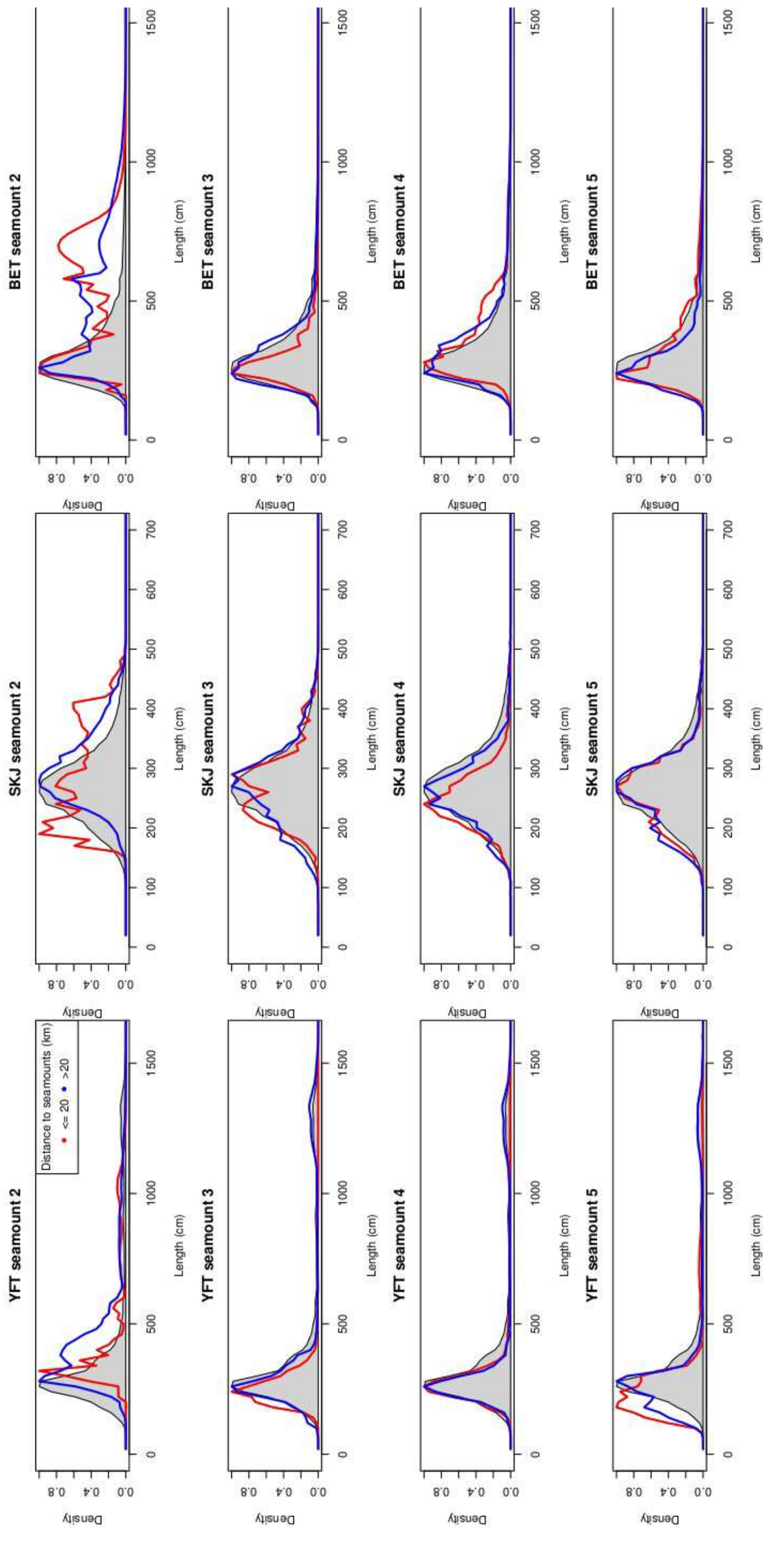

Figure 10. Size frequency distribution (total 1999-2010) for yellow fin tuna (YFT), bigeye tuna (BET) and skipjack tuna (SKJ). In red the size frequency of the well samples taken between 0 to 20 km of the seamount, and in blue between 20 and 100km. The size frequency for these species for the well samples taken in Atlantic Ocean is in grey.