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Species composition and richness of the pelagic ecosystem based on EU PS observer data in the Western Indian Ocean

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ABSTRACT

Since beginnings of 50's, the tuna purse seine fishery has been extended in the Atlantic and Indian Oceans. Observer programs by PNDB (National Base Data Plan) has been carried out since 2003, with the aim to study the number and composition of discards. Moreover, changes produced in the Indian Ocean in the biodiversity patterns and trophic levels in tuna discards and accessories species as consequence of the increase use of FADs were observed.

The analysis suggested that richness and biodiversity has increased since 2003 until 2006 which may be linked to the use of FADs in the purse seine fisheries. The fishes were the species group where the biodiversity was most increased. However, changes in biodiversity patterns were observed since 2007, probably due to the piracy problems, which caused a decrease in the effort as a consequence of the movement of part of fleet to the Atlantic Ocean. The relation between the surface temperature SST and the number of sets was also studied, as well as the correlation between the specie richness of the different by-catch species groups.

1. INTRODUCTION

The fishery of the principal canning tunas has increased continuously since 1950, reaching the level of 4 million tons in 1999 and around 4.5 million tons in 2005. Within this tuna species group the tropical tuna species (yellowfin – *Thunnus albacares*, bigeye- *Thunnus obesus*, and skipjack – *Katsomonus pelamis*) has acquired special relevance since they are considered the most productive species. The tropical tunas are distributed in all Oceans in the tropical and subtropical area. These species are characterized to be considered epipelagic species that live between 15-30ºC in tropical and subtropical waters (ICCAT, 2009). For example, the catches of tropical tunas have reached 4.2 million tons in 2005 (2.2 in the Western and Central Pacific, 1.1 in the Indian Ocean, 0.6 in the eastern Pacific, and 0.3 in the Atlantic). Although the longline fleet started the fishery of these resources around 1950, is with the developing of the purse seiner fishery around 1970 when tropical tuna fisheries catches increased until the current levels. Actually, purse seine catches represent 70 percent of all tuna catches (Miyake *et al*. 2010).

Global fishing pressure in the last decades has caused an increase in the catches as well as by-catch of associated species, which thus may affect the biodiversity of the pelagic ecosystem. Different scientific committees are developing by-catch reduction methods to reduce this problem (Gilman & Lundin, 2008), without being affected by economic or political interests, and are encouraging the increase of observer coverage to allow the application of conservation and management measures. According to some authors, this has mainly affect animals in high trophic levels like tunas and vulnerable species like sharks, billfishes, turtles, etc (Pauly *et al*. 1998); since most of the fishing pressure has deployed to most valuable high trophic species. Some of those high trophic species such as sharks are considered vulnerable species due to their long life cycles, late maturity, slow growth and low fecundity (Murua et al., 2009; Arrizabalga *et al*. 2011).

The negative consequences of by-catch are the death of marine animals but also the gear damage, lost fishing time, lost of income and the safety concerns for fishermen (Hall, 1996). Furthermore, discards can disturb the ecosystem by transferring biomass between water layers (Hill and Wasseber, 2000), causing anoxia as consequence of the accumulation of biomass and also affecting the normal flow of nutrients and matter (ICES, 1995; Dayton *et al*. 1995). Moreover, the most indirect impact to consider are the changes that can be produced in the ecosystem due to high mortality induced in the whole community of the ecosystem, causing that the space currently occupied by tunas (more energetic and bigger animals), would be replaced by other species with lower trophic level (Essington *et al*. 2006). This concept was defined like “fishing down the food web” (Pauly *et al*. 1998) and was used the marine trophic index (MTI) to measure the healthy and stability of the marine ecosystem, in this case, the decline in the abundance of marine fishes (Jeffrey *et al*. 2004). Thus, the knowledge of the biodiversity patterns and the environmental conditions related to them is essential to understand the effect of fishing on the behaviour and state of the by-catch species caught in the purse seine fisheries.

Therefore, the main objective of this work is to study the impact of the purse seine fisheries in the richness and biodiversity patterns of the pelagic ecosystem as well as the changes produced in the trophic levels in tuna discards and by-catch species groups in the Indian Ocean. For that purpose, information on tuna discards and by-catch species collected by observers on tropical tuna purse seine fishery in the Indian oceans is used.

3. MATERIAL AND METHODS

In this study, the definition that best represents the term by-catch has been adapted by FAO (1999) and Kelleher (2005) and described by Amandé *et al*. 2010:

• **Bycatch**: all non-targeted species and small or damaged target tuna species that are not marketed as canned tuna. The by-catch may be divided in:

a) **by-products** that are kept to be consumed on board

b) **discards** that are rejected at sea, dead or alive.

3.1. Study area

The Indian Ocean is an important area of tuna fisheries for their special biological and climatological characteristics, due to the existence of upwelling zones in the areas of Somali (Tomczak and Godfrey, 1994; Fonteneau, 2003).

The study area was between the meridians 20º-80ºE (75º E in the Western Indian Ocean), the parallel 45ºS and the continent. The Indian Ocean was divided by different areas or ZET areas (Pianet *et al.* 2000).

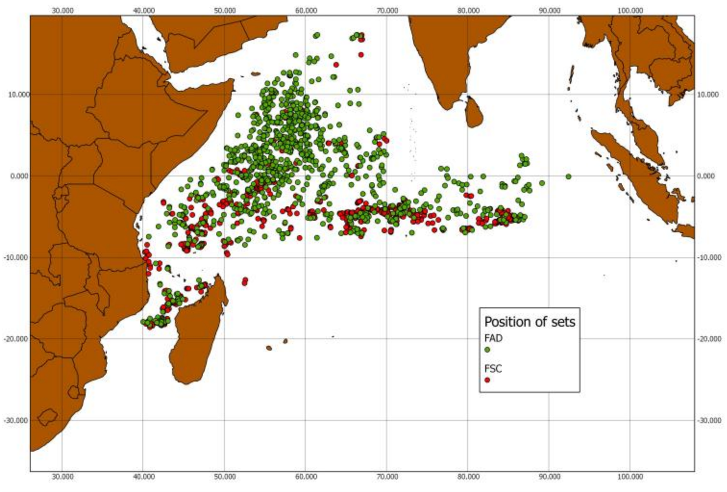


Figure 1. Spatial distribution of sets in the Indian Ocean

Since 2003, the EU in support to its Common Fishery Policy established a mandatory sampling observer sampling program for the collection of data in the fisheries sector (Amandé *et al*. 2008) under the EU Data Collection Regulations (EC) (EU DCR 2004/1634). One of the objectives of this sampling program is to estimate the discards of by catch species in EU fisheries (González *et al*. 2007). This program was complemented with data collected by observers who participated in the moratoria on floating objects carried out from 15th of November 1998 until 15th of January 1999 (Arrizabalaga *et al*. 2001).

IEO, AZTI and IRD use a common format of database (Obstuna) and are developing a new program (Observe) (Amandé *et al*. 2008) that will allow in the future maintain a global database to realize common analysis.

As a preliminary work, for the correct analysis of the data, data compiled in the database were depurated.

After correcting the database, 5 tables were obtained from the database with the necessary information to carry out the analysis of this study: "Activite, CapTuna, CapFauna, TailleTuna and TailleFauna". "Activite" table contains information about the campaign, sets, year, type and time of the set, latitude and longitude, ZET areas, quarter of year, and surface temperature. "CapTuna" table contains data about the sets, tuna catches, species captured, estimated weight, utilization of the catches and the weight of tuna discards. "CapFauna" table contains information about the accessories species catch, their number or estimated weight. "TailleTuna" and "TailleFauna" contains data about the size measurement of the (FL) for landed tunas, tuna discards, and accessories species. Moreover, includes information about the sex of the species when available.

3. 2. Analysis

The by-catch species groups were categorized as Billfishes, Sharks, Rays, Fishes, Turtles, and Cetaceans. The latter group was not included in all cases due to lack of data. To estimate the biodiversity and species richness of total tuna discards and by-catch of large species groups the data was stratified by year (1998 and 1999, period corresponding to the moratorium, and between 2003 and 2009); the fishing mode as FSC (Free School) and FAD (Fish Aggregation Device); quarters defined as Q1 (Jan-Mar), Q2 (April-June), Q3 (Jul-Sep) and Q4 (Oct-Dic); and the ZET sampling areas were defined by Pianet *et al*. 2000.

The number and distribution of sets was obtained calculating the number of sets by fishing mode in each stratum (area, quarter, year, type of set).

To analyze the biodiversity of the pelagic ecosystem (tuna species and by-catch specie groups) two methods were used: the Species Richness and the Shannon Index (Khan, 2006).

The Species Richness (S) is the number of species present in an ecosystem. In this study, it was calculated from number of species of each group and for each stratum for tuna discards and by-catch specie groups.

The Shannon Index is a Diversity indices used to measure Diversity in categorical data. The index is calculated as:

H = the Shannon diversity index
Pi = fraction of the entire population made up of species i
S = numbers of species encountered
Σ = sum from species 1 to species S

$$H' = -\sum_{i=1}^{S}(p_i \ln p_i)$$

The value of the index can vary from 1.5 (low species richness and evenness) to 3.5 (high species evenness and richness).

The Shannon index for each main group was calculated using the number of individuals of each species group. For those species that only catch in weight was available, the number of the individuals was estimated using the mean weight of this species in the whole trip. The Shannon index was calculated for each stratum.

The influence of environmental factors in the presence of species was evaluated through the relation between surface temperature and the number of sets where each specie groups appears using the diagrams of dispersion. This indicates the temperature range and preference of the various groups of species.

Non-parametric Spearman correlation was used to measure the correlation between the richness of different species group. Spearman correlation was estimated using the R program provided that the different species groups were not normally distributed.

4. RESULTS

4.1. Data coverage and distribution of sets by strata

In total, a total of 2093 sets were observed being 989 FAD sets from which 444 of these FAD sets were observed in the South of Somali area.

	Nº of Sets				
Year	**FSC**	**FAD**	**IND**	**Total general**	**Coverage%**
1998	291	376	72	739	35.3
1999	285	58	41	384	18.3
2003	50	48	-	98	4.7
2004	37	36	1	74	3.5
2005	110	69	1	180	8.6
2006	59	106	14	179	8.5
2007	64	158	13	235	11.2
2008	57	105	2	164	7.8
2009	7	33	-	40	1.9
Total general	**960**	**989**	**144**	**2093**	**100**

Table 1. Data coverage and distribution of sets in the Indian Ocean

The coverage of the observed data (Figure 2) for the period between 1998 and 1999, corresponding to the moratorium, exceeded the 10% coverage; while during the period of DCR, the coverage increased slowly until 2007 to decrease in 2008 and again in 2009 due to piracy problems in Indian Ocean waters.

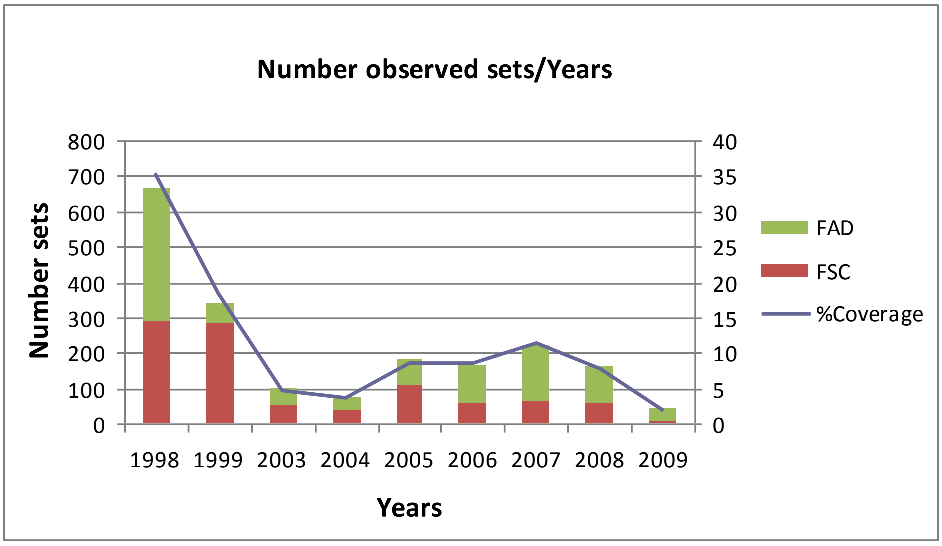


Figure 2. Number of sets by years and % of coverage

During the moratorium a total of 1010 sets were observed, from which 576 were FSC sets and 434 FAD sets. During the DCR program, a total of 939 sets were observed, being 384 FSC sets and 555 FAD sets.

Observing the distribution of sets by quarters (Figure 3), from a total of 1949 sets, 1017 sets were done in the last quarter (52%), being 630 of them FAD sets and 387 FSC sets. The total number of two types of sets was not so different (989 in FAD and 960 in FSC), but their seasonal distribution was different which a clear predominance of FAD fishing in the last quarter of the year.

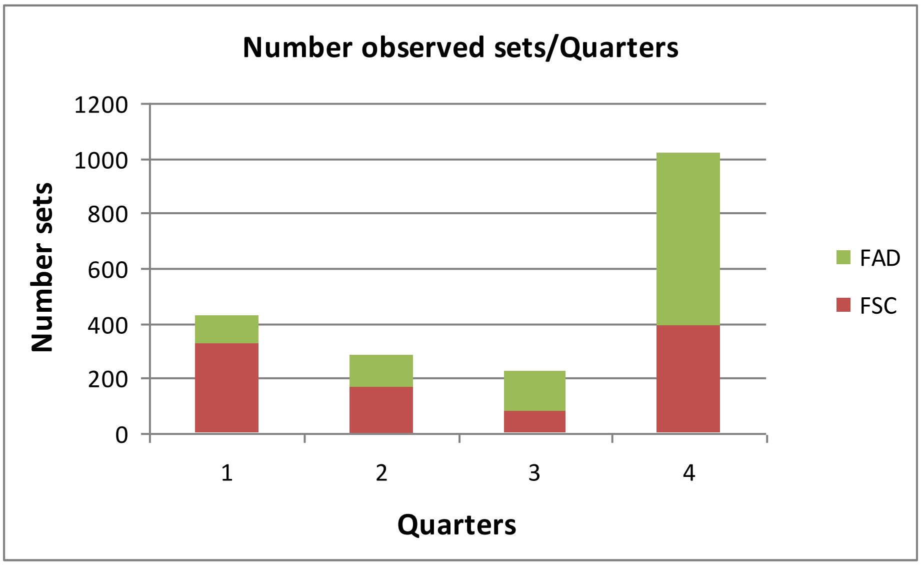


Figure 3.Number of observed set by quarters

The spatial distribution of the number of sets is observed in Figure 4. Higher number of sets was observed in South Somali followed by NW Seychelles, SE Seychelles, West Indonesie, Maldives-Chagos, Canal de Mozambique, North Somali, Arabian Sea, and South Indian Ocean, being the FAD fishing mode more predominant in the North areas and FSC sets in the South areas.

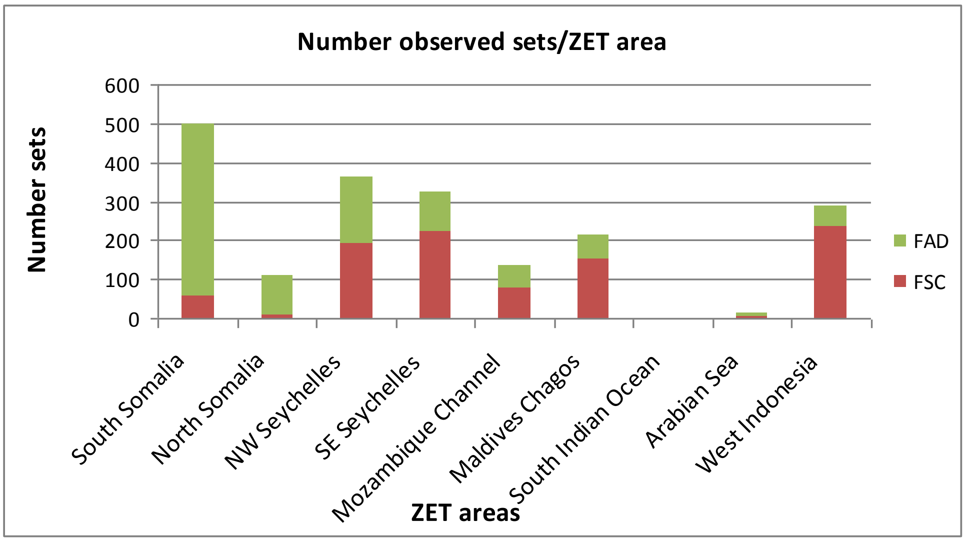
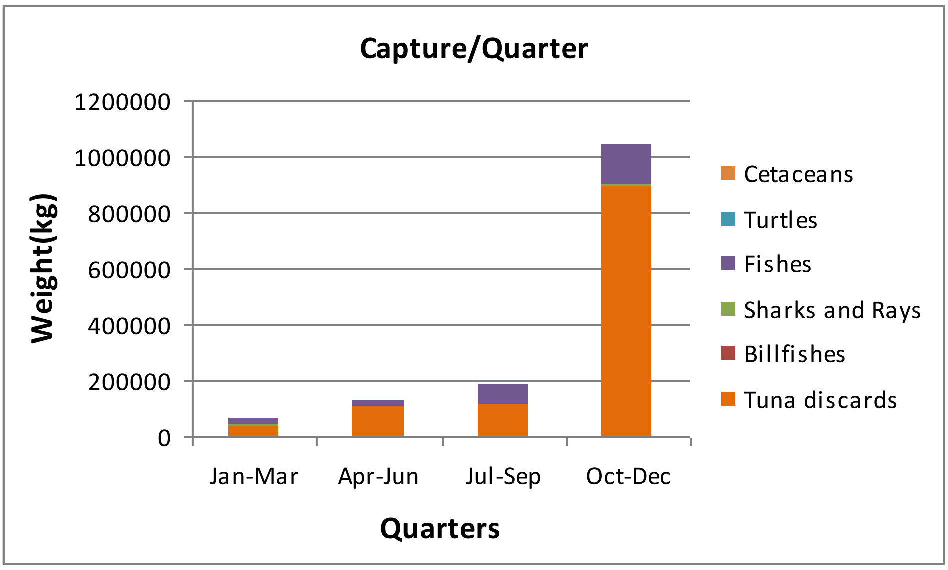


Figure 4. Number of observed sets by ZET areas

With regard to the by catch species, a total of 266 tons of associated species which corresponds to 73797 animals (associated individuals) observed, mainly distributed in the last quarter of year and in the Somali area (Figure 5 and 6).



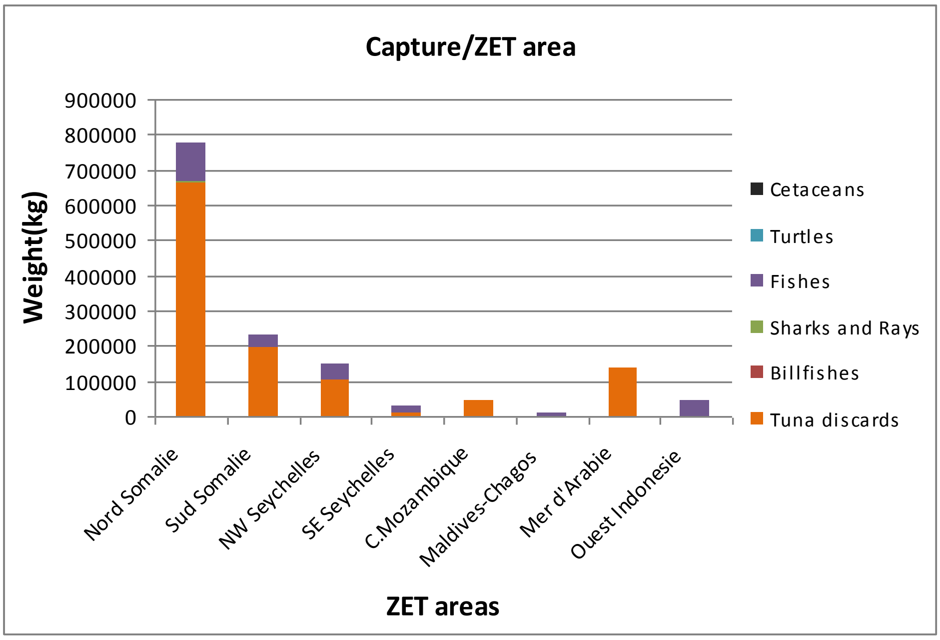


Figure 5-6. Estimated weight in kg of tuna discards and associated species by Quarters and ZET areas

4.2. Biodiversity

4.2.1. Richness

The Species Richness observed in purse seine catches over the period analyzed showed high values during the moratorium. Then the species richness increased from 2003 to 2007, when it began to remain stable (Figure 7). With regard to the seasonality of this index, the last quarter of the year increased progressively until 2008, when it started to decrease (Figure 8). The third and fourth quarter of year showed the highest values between 2006 and 2008. Moreover, since 2006 the first quarter has shown an increasing trend.

The areas with the highest number of species over years were South of Somali and NW Seychelles (Figure 9). By fishing mode, FAD sets showed more species over the study period than FSC sets (Figure 10).

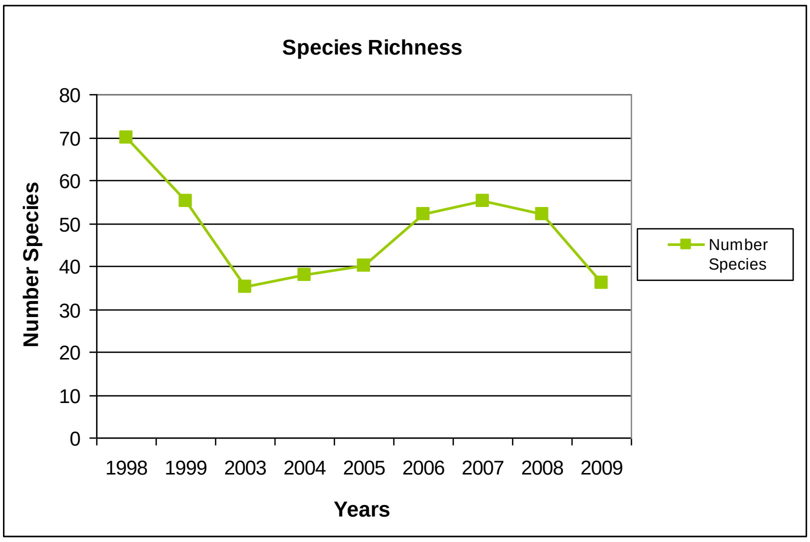


Figure 7. Specie Richness in Purse Seine catches by years

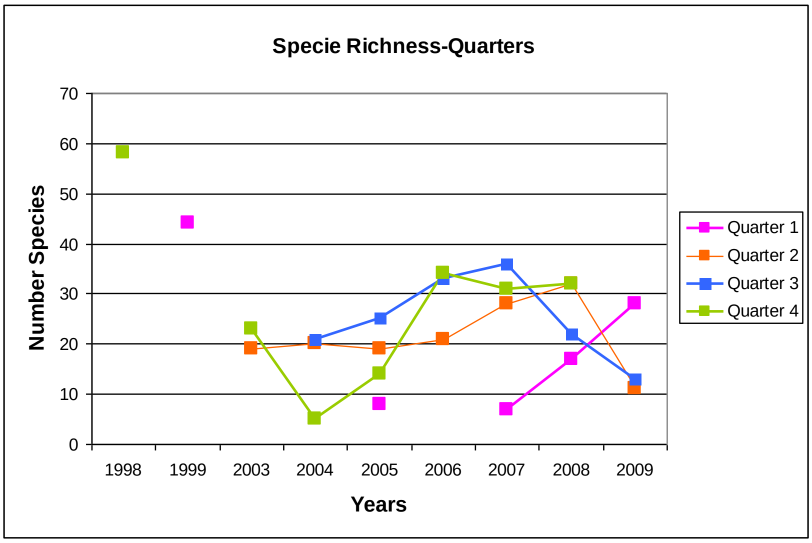


Figure 8. Specie Richness in Purse Seine catches by Quarters

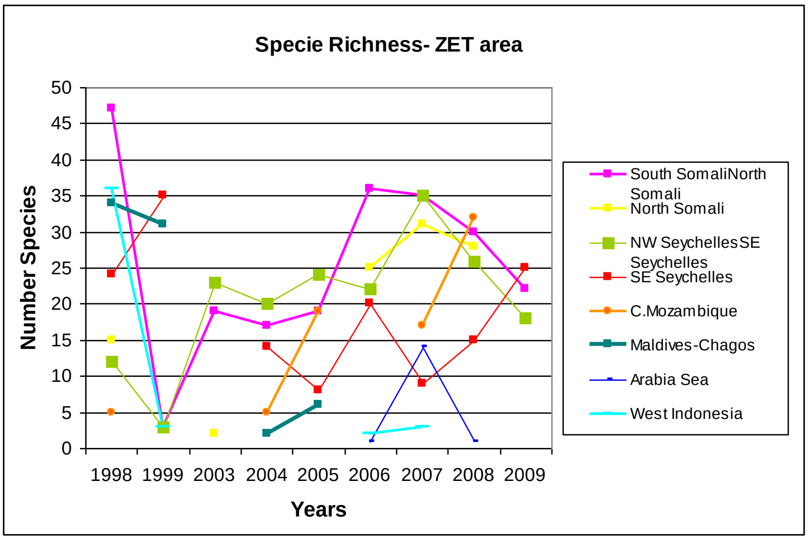


Figure 9. Specie Richness in Purse Seine catches by ZET area

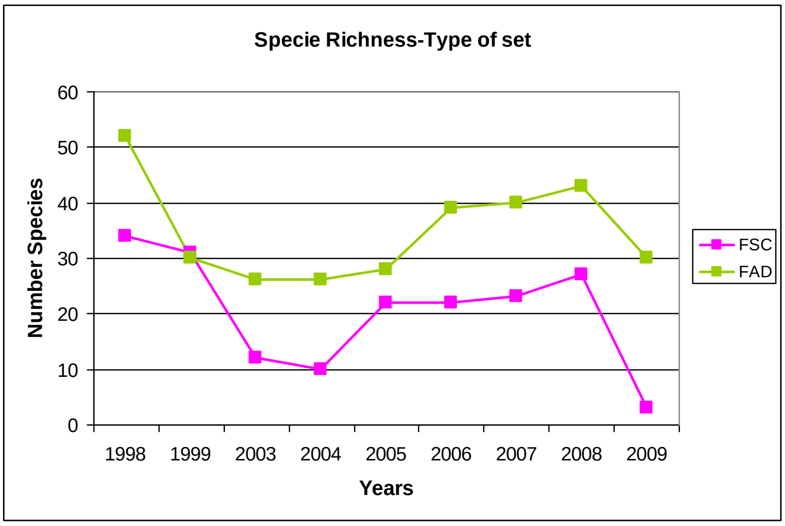


Figure 10.Specie Richness in Purse Seine catches by fishing mode

With regard to by-catch species groups, although the values of years 1998 and 1999 were the highest values in the series for all groups (Figure 11), the species richness of fishes and sharks showed the largest increase along the study period since 2004 (Figure 12). The third and fourth quarter of year showed the highest values between 2006 and 2008 (Figure 13) and South of Somali and NW Seychelles were the ZET areas with the higher number of associated species (Figure 14).

By fishing mode, both in tunas and associated species, FAD sets showed more species over the study period than FSC sets (Figure 15).

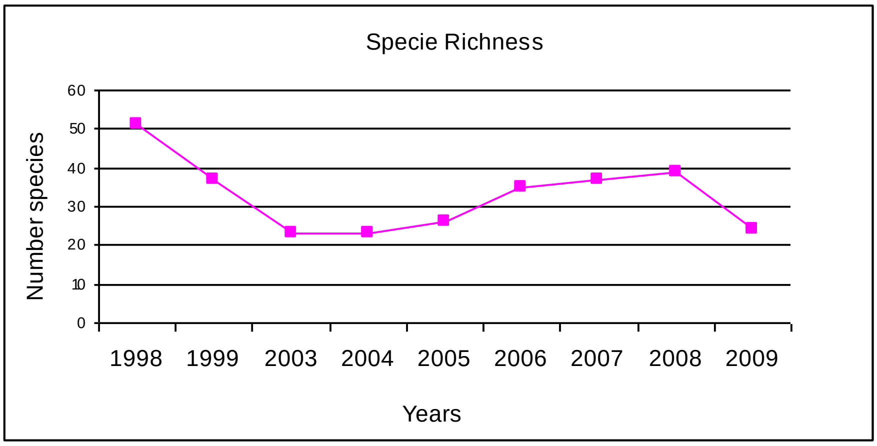


Figure 11.Specie Richness of associated species by years

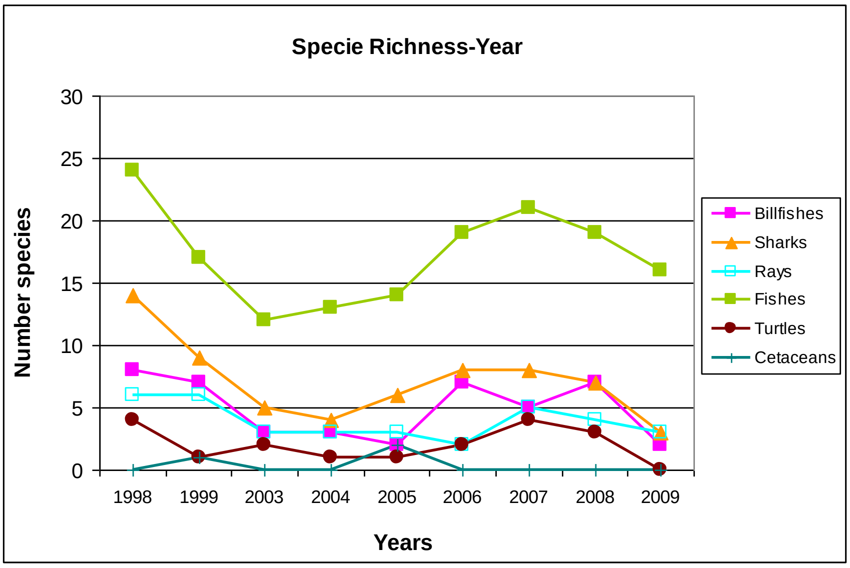


Figure 12.Specie Richness of associated species by years

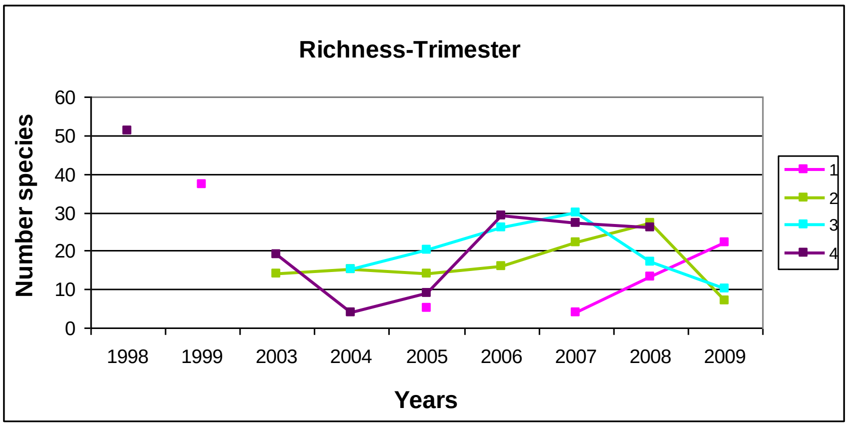


Figure 13. Specie Richness of associated species by Trimesters

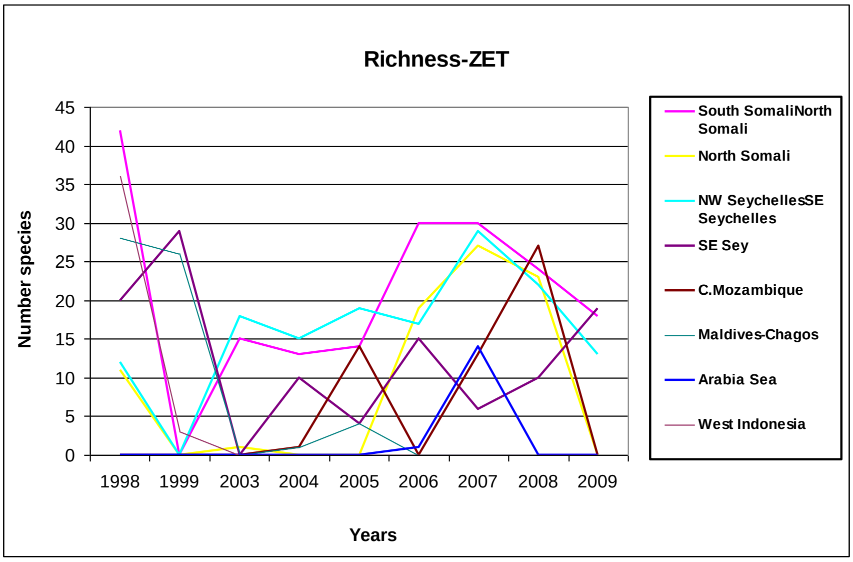


Figure 14. Specie Richness of associated species by ZET areas

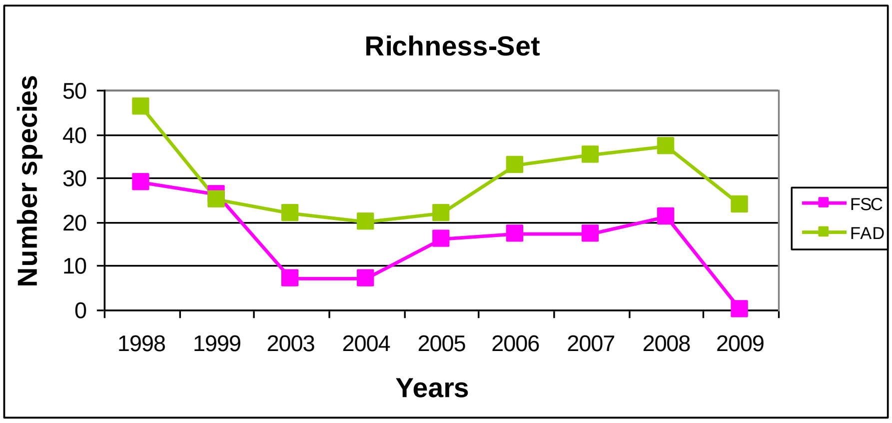


Figure 15. Specie Richness of associated species by fishing mode

4.2.2. Shannon Index

The Shannon index in the by-catch species groups increased in general since 2005 until 2008, and the highest values were observed in fishes and billfishes during the moratorium (Figure 16 and 17).

By ZET area, the index was higher in all species groups in NW and SE Seychelles and the index for fishes was higher in Mozambique Channel (Figure 18).

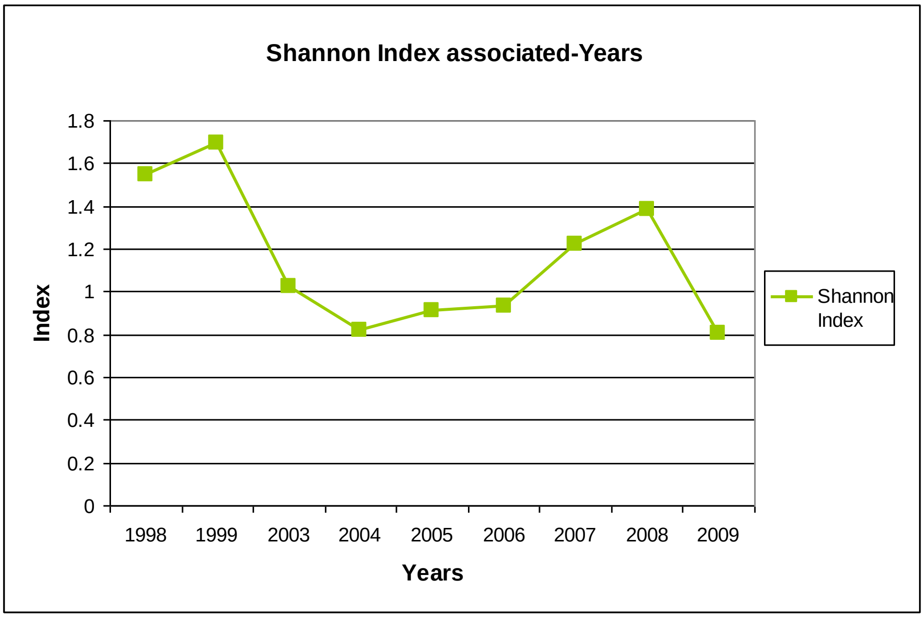


Figure 16. Shannon Index of associated species

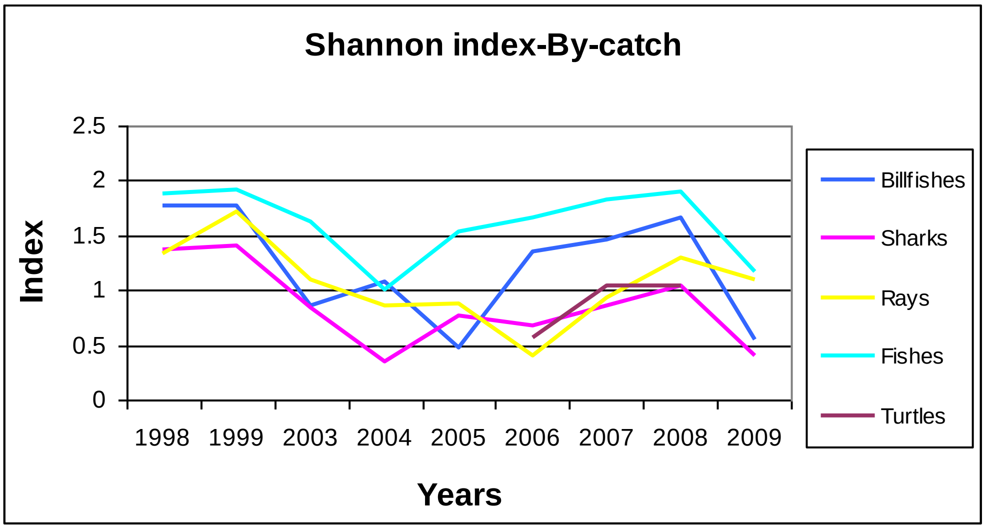


Figure 17. Shannon Index for associated species by years

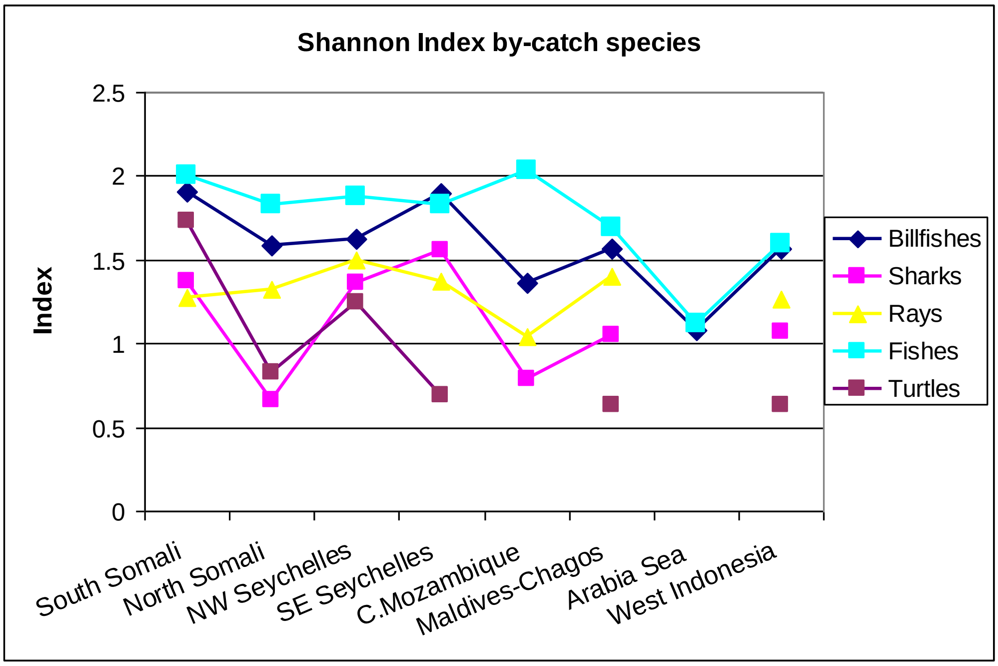


Figure 18. Shannon Index of associated species by ZET areas

4.4. SST- Specie Richness

The comparison between SST and the number of sets with presence of tuna and associated species catch indicate clearly that 94% of sets were done between 26ºC and 30ºC with a mode in the distribution around 28.5ºC in both cases (Figure 19).

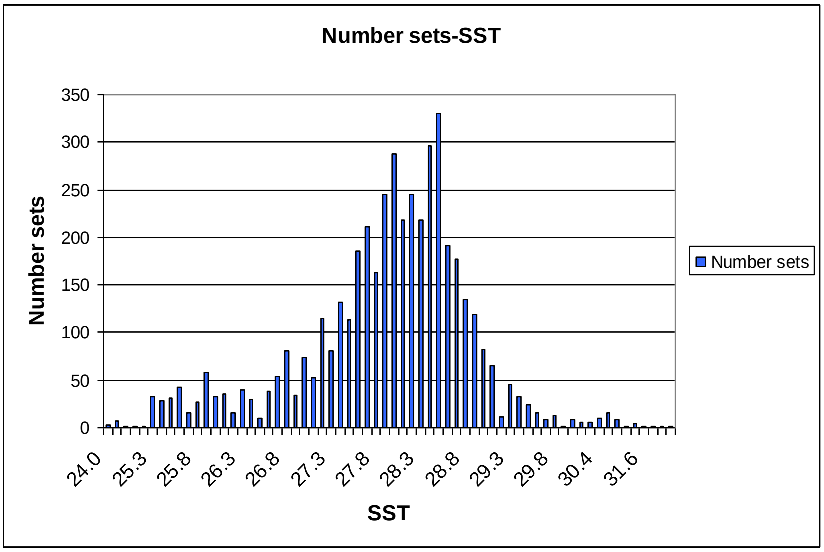


Figure 19.SST- Number of sets in purse seine tuna fishery.

For billfishes, shark and the group of other fishes, a higher number of species were caught within a temperature range between 28ºC and 29ºC (Figure 20 and 21).

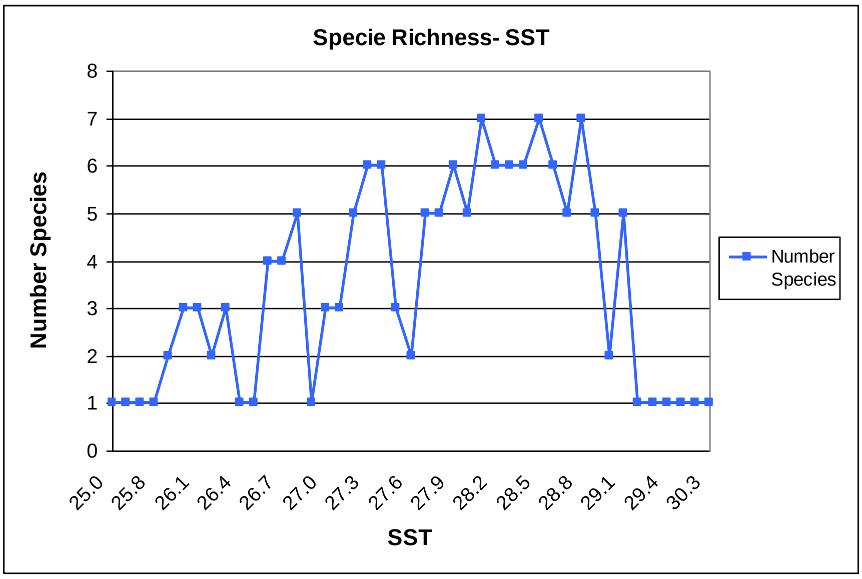


Figure 20.SST- Specie Richness in Billfishes

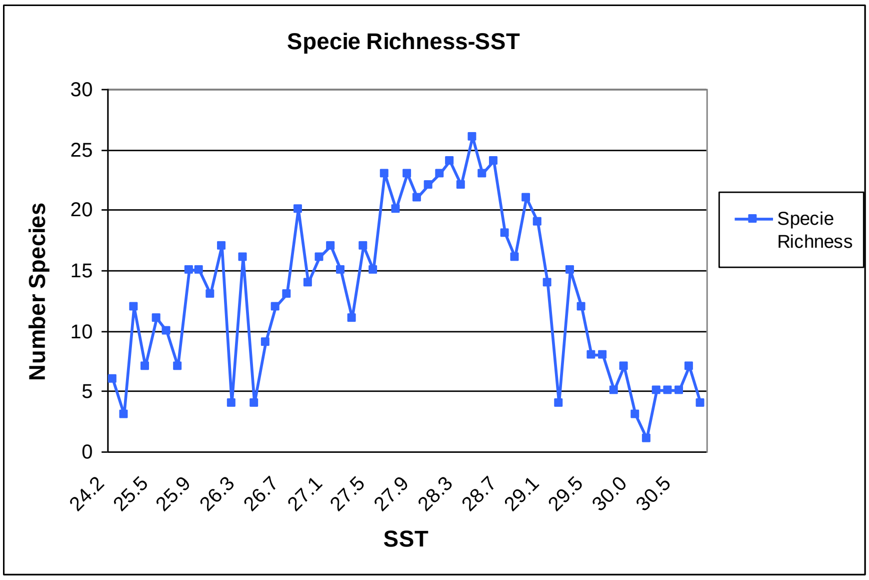


Figure 21.SST- Specie Richness in and Fishes

4.5. Co-occurrence of different group of species

Spearman correlation was used to relate the species richness between different species groups. The Spearman correlation (r) between the groups showed that the relation existed when the critical value of the table of r where > 0.666(table: r=0.05(2)9). The results showed that the higher correlations were found between billfishes and sharks, billfishes and fishes, billfishes and turtles, and shark and fishes. The relation between Tunas and the rest of groups was not significant (Figure 22 and Table 2).

Group	Billfishes	Sharks	Rays	Fishes	Turtles	Tunas
Billfishes	-	0.897	0.671	0.811	0.757	0.688
Sharks	-	-	0.742	0.832	0.733	0.641
Rays	-	-	-	0.666	0.567	0.431
Fishes	-	-	-	-	0.754	0.551
Turtles	-	-	-	-	-	0.257

Table 2. Spearman correlation between groups in the Indian Ocean

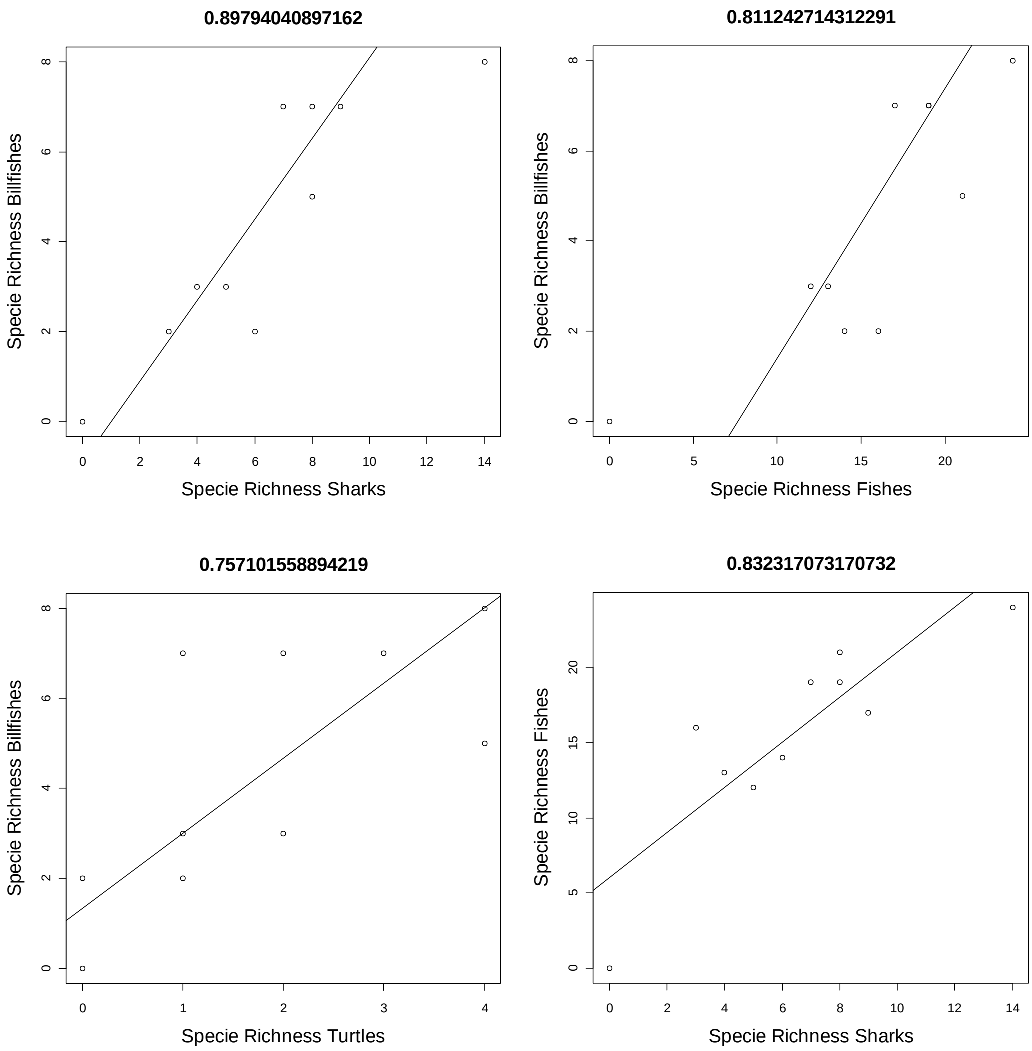


Figure 22(a-b-c-d). Spearman correlation between billfishes and sharks (a), billfishes and fishes (b), billfishes and turtles (c), and sharks and fishes (d) in the Indian Ocean.

5. DISCUSSION

This study is based on information collected by observers between 1998 and 2009 which allowed us to analyze the species richness and biodiversity patterns of tuna discards and by-catch associated species in the tropical tuna purse seine fishery in the Indian Ocean. The sampling coverage was different between years and area, being in some years/area very low which may affect the results of this study. For example, the differences founded between the numbers of sets by survey (i.e. moratoria vs. DCR) could be explained by the different sampling strategy. During moratorium (1998 and 1999) the number of observations was larger because most of the trips and vessels carried out an observer. Moreover, there are not observers trip since 2009/2010 in Indian Ocean due to piracy problems which may affect the time series of data to complete the study in this Ocean. Therefore, this study could be considered very preliminary due to the reasons explained above; however, it is planned that this study will be completed with observer data from IEO and IRD which will increase the sampling coverage to levels that would allow a comprehensive study for the biodiversity of the pelagic ecosystem and the effect and changes that the purse seine fishery produces on it.

The numbers of sets depending on the fishing mode were different. In the Indian Ocean the number of FAD sets operations was greater than the number of FSC sets. This can be explained because the Indian Ocean in general is more productive due to the various upwelling systems (Fauvel. *et al*. 2009) and, thus, the fishery is more directed to the use of FAD to catch the very productive skipjack tuna species. The number of sets during the last quarter is highest because it corresponds with the period of the year where FAD sets are more predominant.

Another important point to consider is the distribution of the sets. The FAD sets are distributed in the North area of the Indian Ocean. This is due to the “South Equatorial Current” that produces the displacement of the objects towards the west and north (Chassot *et al*. 2009). This movement occurs approximately between 0º-8º N in the Indian Ocean. The sampling zones where the numbers of FAD sets are higher coincide with the areas where the species richness increases. Amandé *et al*. (2008) observed similar results in relation to the major areas of FAD sets as well as major areas (Somali area) of bycatch in the Indian Ocean. However, the higher Shannon index in fishes was observed in Mozambique Channel an area that is not associated to the FAD fishing.

As expected, the Shannon Index showed the highest values during the moratorium in the Indian Ocean as there are much more number of sets observed. The fishes were the specie group that increased most over the time period studied, followed by billfishes between 2005 and 2008. The areas where the higher number of FAD sets were observed are the same areas where higher Shannon Index values were found, except for the fishes, where higher values were observed in the Mozambique Channel.

The Specie Richness in the Indian Ocean showed the highest values during the moratorium and in the last months of the year, mainly in fishes and sharks species groups. This can be explained by the higher number of observers, as well as FADs, during this period. For each stratum, values increased since 2006 until 2008. The areas where the highest numbers of species were found are the same as the areas where the number of FAD sets were more predominant.

These changes since 2006 until 2008 are due to the movement of the Indian Ocean fleet to the Atlantic Ocean as consequence of piracy, that produces a decrease in the catch species richness and the use of FAD sets, observing, therefore, notable changes in biodiversity patterns.

The results obtained about correlations in the Indian Ocean, showed that the highest relations were between billfishes and sharks, probably due to the same movement of these groups to find food, and between billfishes/sharks and fishes, due to the aggregating behaviour of fishes around FADs, that produces an attraction for the big pelagic predators.

The preliminary analysis of various biodiversity indices show that values increased in the groups and the areas sampled where FAD fishing mode is used, which is the expected pattern. Moreover, the various indices trend, if any trend was observed, showed an increasing patter which would not be expected due to the published theories about the Fishing Down the Web. However, these indices were affected by the small coverage and low number of set; therefore, they should be taken with caution. Nevertheless, it is expected to improve the sampling coverage and the analysis when the data of other observers programs from IEO and IRD is included. Thus, it is necessary to have more information to evaluate the changes in the pelagic ecosystem over time.

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