Analysing the bycatch taxonomic structure changes from observers data on board Spanish purse seiners in the Indian Ocean

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1. Introduction

Latitudinal species richness gradients affecting marine species richness have been good described since 19 century (Gray, 2001). In this line there is a global latitudinal taxonomic structure, where the species-genus ratio or genus-family ratio are maximum in the equator (Krug et al., 2008). The climatic stability of the tropical seas has been proposed as the main mechanism explaining this pattern of species diversity (Gray, 2001). Thus, the taxonomic structure should be similar within of a latitudinal range for a temporal series. In spite of the supposed stability of the tropical regions, two processes can disturb marine ecosystems: industrial fishing and climate change.

Industrial fishing has been proposed as an important anthropic factor that can influence the ecosystem by altering species diversity (Gewin, 2004). On the other hand, the planet is currently experiencing global warming (Oreskes, 2004), which could alter the specific composition of ecosystems and thus be reflected in fishing catches (Cheung et al., 2013). In this context, it is important to monitor the composition of catches from tropical regions in search of changes in taxonomic composition.

The main aim of the present study was to test the taxonomic structure pattern of Spanish purse seine (PS) bycatch from Indian Ocean in the last 15 years, we do not expected any change in the time series.

2. Material and Methods

The Spanish Institute of Oceanography (IEO) observers on board commercial purse seiner freezer vessels follows a scientific program, implementing the EU Fishing Data Collection Program (PNDB) (Parliament and Council Regulation (EU) No 2017/1004 of 17 May 2017). The data collection and processing methodology is common for the

Atlantic and Indian oceans (Ariz *et al*. 2010) and involves three research bodies of the European Union: Institut de Recherche pour le Développement (IRD, France), Centro Tecnológico en Investigación Marina y Alimentaria (AZTI-Tecnalia, Spain) and Instituto Español de Oceanografía (IEO, Spain). Sample forms from this observer program can be downloaded from ICCAT website https://www.iccat.int/Documents/SCRS/Manual/CH4/Annex%201%20to%20Chapter%204.zip.

The main aim of the scientific observer program is obtaining direct information on catches and discards of target and bycatch species (e.g. catch and bycatch species, number of individuals, size, and other biological data). In the present study, we used data recorded by IEO from 2003 to 2018 from the above-mentioned program.

Due to the piracy intensification problem the observer on board program was disrupted between 2010 and 2014 both years inclusive. On the other hand, the observation effort is not the same per year, since it depends on multiple variables such as the availability of ships. According to Magurran (1989) the sampling effort to determine the number of species observed. For this reason we expected a correlation between the number of species and the number of sets. In this context, we standardized the number of species expected according to the number of sets.

We analysed the taxonomic structure changes from observer data on board Spanish purse seiners in the Indian Ocean using two different approaches. In a first step, a qualitative multivariate analysis was applied using the Jaccard index to generate the similarity matrix with 55 species after eliminating the species that appeared every year and the species that appeared only in a specific year. A simple linkage cluster analysis was performed, followed by a one-way ANOSIM test with 99999 permutations for significant differences between groups (Clarke, 1993).

In second step, we standardized the number of species in function to the number of observed sets, and finally the number of standardized species is correlated with time. Moreover, we used the Pearson correlation between the number of sets and species, genera and families.

3. Results

At least 88 different species have been bycatched from Spanish PS. The **Table 1** showed the number of species and taxonomic structure, and observed sets per year.

We observed a significant correlation between the number of sets per year and the number of species (r= 0.758; P= 0.007) and genera (r= 0.706; P= 0.015). Thereby, the number of observed sets affected to the number of species and the taxonomic structure. However, we do not observe correlation between the number of sets per year and the number of families (r= 0.466; P= 0.148). The variability in the number of families observed is very low (between 17 and 23 families per year). Thus, for example, the greatest number of families were observed in the years 2004 and 2016. These years correspond to one year below the average set observed and the year with the maximum set observed, respectively. Similarly, the years with the least number of species are 2003 and 2018. These years correspond to the year with the minimum number of sets observed, and one year above the average number of sets observed, respectively. Therefore, the number of families observed is not related to the number of sets observed.

Table 1. Number of species and taxonomic structure, and observed sets per year.

Year	Family	Genus	Species	Sets	Species/Family
2003	17	25	28	66	1.65
2004	23	39	50	158	2.17
2005	18	29	40	185	2.22
2006	21	32	43	153	2.048
2007	21	37	54	232	2.57
2008	21	31	46	124	2.19
2009	18	23	24	71	1.33
2015	21	34	50	217	2.38
2016	23	36	51	322	2.22
2017	18	28	37	154	2.056
2018	17	32	42	233	2.47

The cluster analysis revealed that the years with fewer sets (2003 and 2009) are the most different ones, due to the smaller number of species found. The rest of the years form two groups 2004-2008 and 2015-2018 (**Figure 1**). The one-way ANOSIM test reveals a significant difference between the two groups with P = 0.00828.

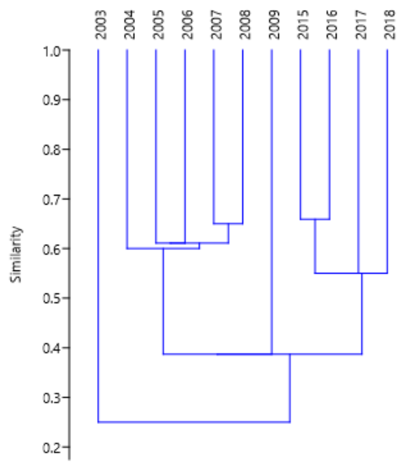

Figure 1. Similarity cluster in function to the Jaccard index.

We standardized the number of species in function to the number of observed sets (**Table 2**). Thus the linear function to define the species in function to the number of sets is: Number of species= 25.455+ Sets*0.097 (R^2= 0.575; P= 0.007)

Table 2. Number of species and taxonomic structure, and observed sets per year.

Year	Species	Sets	Species Standardized (SS)	SS/Family
2003	28	66	31,857	1,87394118
2004	50	158	40,781	1,77308696
2005	40	185	43,4	2,41111111
2006	43	153	40,296	1,91885714
2007	54	232	47,959	2,2837619
2008	46	124	37,483	1,78490476
2009	24	71	32,342	1,79677778
2015	50	217	46,504	2,21447619
2016	51	322	56,689	2,46473913
2017	37	154	40,393	2,24405556
2018	42	233	48,056	2,82682353

We observed a significant temporal trend between the standardized ratio and time (r= 0.662; P= 0.026).

4. Discussion

Our results indicate two different periods 2004-2008 versus 2015-2018. Baez et al. (2018) showed the list of fish species recorded by the tropical Spanish purse seiners operating in the Atlantic Ocean. Thus, during the period of study the authors observed a change in fish species recorded. This change could be due to an improvement in the quality of the data (improvements in observer training on species identification) or changes in the fishing strategy. In this context, the Spanish purse seiners fleet fishing from Indian Ocean have experimented a deep change in the fishing strategy increasing significantly the sets on Fishing Aggregating Devices (FADs) (Figure 2).

Thus, in the second period (2015-2018) species such as *Euthynnus affinis* and *Caranx lugubris* appear, which may be due to the increase in sets to FADs (Figure 3). On the other hand, the disappearance in the second period of billfishes (Figure 3) such as *Kajikia audax* or *Tetrapturus angustirostris* could be an effect of the decrease of their populations. However, none of these issues explain the increase in the species / family ratio for the fisheries area. According to our results, the current pattern is compatible with a change of the taxonomic structure due to climatic change, because there is an increase in the species / family ratio.

We concluded that during the period of study there is an increment in the number of species recorded and increase to the species / family ratio. Therefore, we deduce that there has been a change in the structure of the pelagic ecosystem of the Indian Ocean in recent years. We have not found a unique explanation to explains these changes (changes in fishing technique, overfishing, or global warming), perhaps because there is more than one factor interacting.

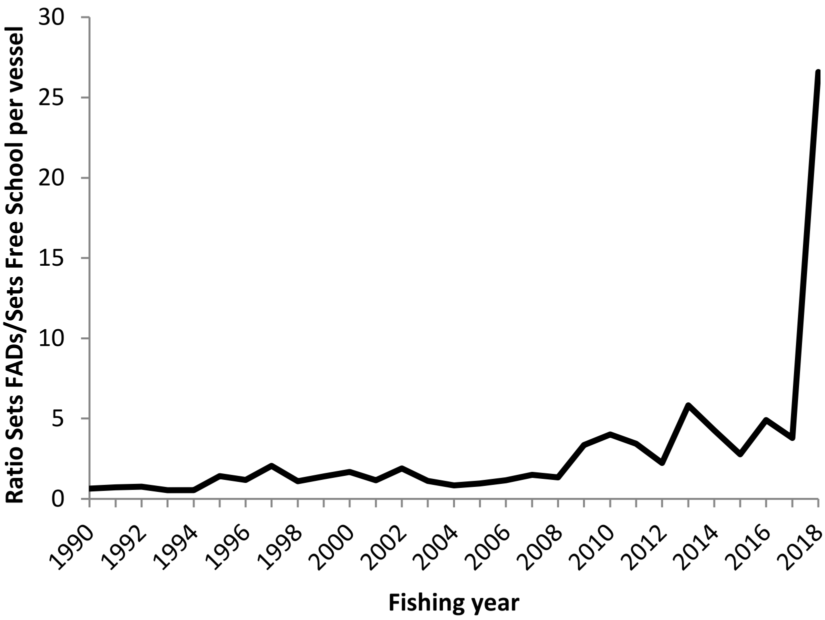

Figure 2. Trend in the fishing system used by Spanish fleet per fishing year. We plotted the ratio between the number of sets on FADs per vessel per year by the number of sets on Free schools per vessel per year. In recent years, there has been a significant increase in the proportion of FADs sets.

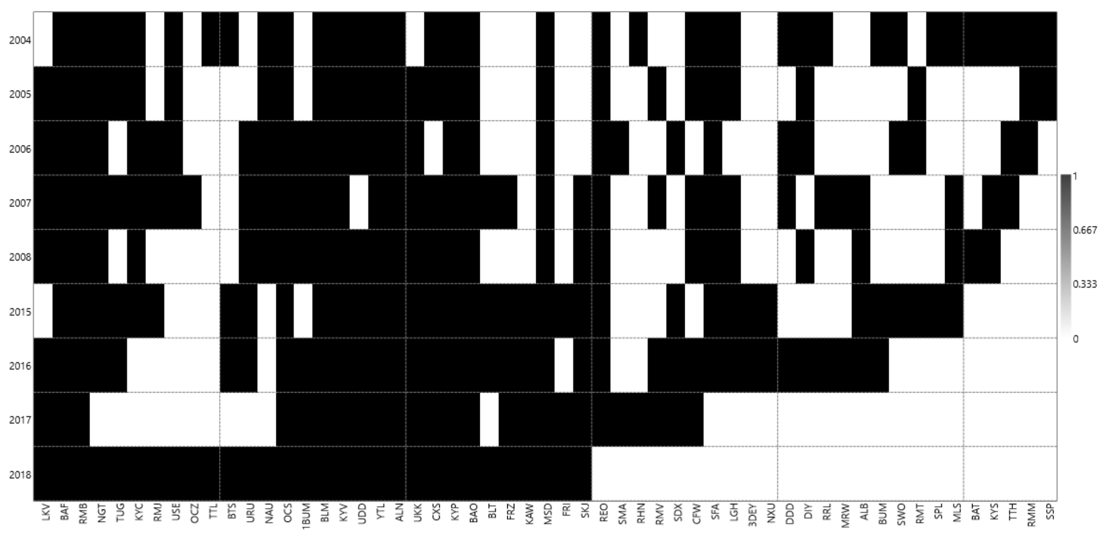

Figure 3. Species by-cached per year.

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Annex 1. Checklist of bycatch species

FAMILY	GENUS	SCIENTIFIC LABEL	FAOCODE
Belonidae	*Ablennes*	*Ablennes hians*	BAF
Pomacentridae	*Abudefduf*	*Abudefduf vaigiensis*	DDD
Scombridae	*Acanthocybium*	*Acanthocybium solandri*	WAH
Aetobatidae	*Aetobatus*	*Aetobatus narinari*	MAE
Monachanthidae	*Aluterus*	*Aluterus monoceros*	ALM
Monachanthidae	*Aluterus*	*Aluterus scriptus*	ALN
Scombridae	*Auxis*	*Auxis rochei*	BLT
Scombridae	*Auxis*	*Auxis spp*	FRZ
Scombridae	*Auxis*	*Auxis thazard*	FRI
Balistidae		*Balistidae*	TRI
Belonidae		*Belonidae*	BEN
Bramidae		*Bramidae*	BRZ
Balistidae	*Canthidermis*	*Canthidermis maculata*	CNT
Carangidae		*Carangidae*	CGX
Carangidae	*Carangoides*	*Carangoides orthogrammus*	NGT
Carangidae	*Caranx*	*Caranx crysos*	RUB
Carangidae	*Caranx*	*Caranx lugubris*	NXU
Carangidae	*Caranx*	*Caranx sexfasciatus*	CXS
Carcharhinidae		*Carcharhinidae spp*	RSK
Carcharhiniformes		*Carcharhiniformes*	CVX
Carcharhiniformes		*Carcharhiniformes*	CVX
Carcharhinidae	*Carcharhinus*	*Carcharhinus falciformis*	FAL
Carcharhinidae	*Carcharhinus*	*Carcharhinus longimanus*	OCS
Carcharhinidae	*Carcharhinus*	*Carcharhinus obscurus*	DUS
Cheloniidae	*Caretta*	*Caretta caretta*	TTL
Cheloniidae	*Chelonia*	*Chelonia mydas*	TUG
Coryphaenidae	*Coryphaena*	*Coryphaena equiselis*	CFW
Coryphaenidae	*Coryphaena*	*Coryphaena hippurus*	DOL
Coryphaenidae		*Coryphaenidae*	DOX
Nomeidae	*Cubiceps*	*Cubiceps spp*	CUP
Dasyatidae		*Dasyatidae*	STT
Carangidae	*Decapterus*	*Decapterus macarellus*	MSD
Carangidae	*Decapterus*	*Decapterus spp*	SDX
Dermochelyidae	*Dermochelys*	*Dermochelys coriacea*	DKK
Diodontidae	*Diodon*	*Diodon eydouxii*	3DEY
Diodontidae	*Diodon*	*Diodon hystrix*	DIY
Diodontidae		*Diodontidae*	DIO
Echeneidae		*Echeneidae*	ECN
Carangidae	*Elagatis*	*Elagatis bipinnulata*	RRU
Ephippidae		*Ephippidae*	SPA
Cheloniidae	*Eretmochelys*	*Eretmochelys imbricata*	TTH
Scombridae	*Euthynnus*	*Euthynnus affinis*	KAW
Exocoetidae		*Exocoetidae*	FLY

Istiophoridae	*Istiompax*	*Istiompax indica*	BLM
Istiophoridae		*Istiophoridae*	BIL
Istiophoridae	*Istiophorus*	*Istiophorus platypterus*	SFA
Lamnidae	*Isurus*	*Isurus oxyrinchus*	SMA
Istiophoridae	*Kajikia*	*Kajikia audax*	MLS
Scombridae	*Katsuwonus*	*Katsuwonus pelamis*	SKJ
Kyphosidae	*Kyphosus*	*Kyphosus cinerascens*	KYC
Kyphosidae	*Kyphosus*	*Kyphosus sectatrix*	KYS
Kyphosidae	*Kyphosus*	*Kyphosus spp*	KYP
Kyphosidae	*Kyphosus*	*Kyphosus vaigiensis*	KYV
Tetraodontidae	*Lagocephalus*	*Lagocephalus lagocephalus*	LGH
Lampridae	*Lampris*	*Lampris guttatus*	LAG
Cheloniidae	*Lepidochelys*	*Lepidochelys kempii*	LKY
Cheloniidae	*Lepidochelys*	*Lepidochelys olivacea*	LKV
Lobotidae	*Lobotes*	*Lobotes surinamensis*	LOB
Istiophoridae	*Makaira*	*Makaira mazara*	1BUM
Istiophoridae	*Makaira*	*Makaira nigricans*	BUM
Myliobatidae	*Manta*	*Manta birostris*	RMB
Myliobatidae	*Manta*	*Manta spp*	MNT
Molidae	*Masturus*	*Masturus lanceolatus*	MRW
Myliobatidae	*Mobula*	*Mobula japanica*	RMJ
Myliobatidae	*Mobula*	*Mobula mobular*	RMM
Myliobatidae	*Mobula*	*Mobula spp*	RMV
Myliobatidae	*Mobula*	*Mobula tarapacana*	RMT
Myliobatidae		*Mobulidae*	MAN
Molidae	*Mola*	*Mola mola*	MOX
Molidae		*Molidae*	3MOP
Monacanthidae		*Monacanthidae*	FFX
Carangidae	*Naucrates*	*Naucrates ductor*	NAU
Octopodidae	*Octopus*	*Octopus spp*	OCZ
Osteichthyes		*Osteichthyes*	MZZ
Echeneidae	*Phtheirichthys*	*Phtheirichthys lineatus*	HTL
Ephippidae	*Platax*	*Platax spp*	BAT
Ephippidae	*Platax*	*Platax teira*	BAO
Carcharhinidae	*Prionace*	*Prionace glauca*	BSH
Delpninidae	*Pseudorca*	*Pseudorca crassidens*	FAW
Dasyatidae	*Pteroplatytrygon*	*Pteroplatytrygon violacea*	PLS
		Rajiformes	SRX
		Rajiformes	SRX
Echeneidae	*Remora*	*Remora australis*	3RAU
Echeneidae	*Remora*	*Remora osteochir*	REZ
Echeneidae	*Remora*	*Remora remora*	REO
Echeneidae	*Remorina*	*Remorina albescens*	RRL
Rhincodontidae	*Rhincodon*	*Rhincodon typus*	RHN
Gempylidae	*Ruvettus*	*Ruvettus pretiosus*	OIL
Scombridae		*Scombridae*	MAX

Sphyraena barracuda		*Selachimorpha*	2REX
Carangidae	*Seriola*	*Seriola rivoliana*	YTL
Sphyraenidae	*Sphyraena*	*Sphyraena barracuda*	GBA
Sphyrnidae	*Sphyrna*	*Sphyrna lewini*	SPL
Sphyrnidae		*Sphyrnidae*	SPY
Testitudines		*Testitudines*	TTX
Tetraodontidae		*Tetraodontidae*	PUX
Istiophoridae	*Tetrapturus*	*Tetrapturus angustirostris*	SSP
Scombridae	*Thunnus*	*Thunnus alalunga*	ALB
Scombridae	*Thunnus*	*Thunnus albacares*	YFT
Scombridae	*Thunnus*	*Thunnus obesus*	BET
Belonidae	*Tylosurus*	*Tylosurus crocodilus*	BTS
Carangidae	*Uraspis*	*Uraspis helvola*	UDD
Carangidae	*Uraspis*	*Uraspis secunda*	USE
Carangidae	*Uraspis*	*Uraspis spp*	UKK
Carangidae	*Uraspis*	*Uraspis uraspis*	URU
Xiphiidae	*Xiphias*	*Xiphias gladius*	SWO
Zanclidae	*Zanclus*	*Zanclus cornutus*	ZAO