Pelagic elasmobranch diversity and abundance in the Western Indian Ocean: an analysis of long-term trends from research and fisheries longline data.

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Abstract: Increasing fishing pressure in the open ocean worldwide over recent decades has affected the abundance level of large pelagic fishes. This impact concerns the target species such as tuna and swordfish as well as accessory species (bycatch) in capture. Among these bycatch species suffering the effect of always sophisticated open ocean fisheries (purse seine and longline), pelagic shark populations have likely declined. The decline level is difficult to estimate due the quality of data considered in the analysis and pessimistic values are published to increase concerns for their conservation. Often sharks data reported in fishermen logbooks and observer reports are characterised by under-reporting and as corollary over-reporting of some shark species and misidentification or misuse of generic words.

In this study we analysed shark capture (by taxa or group of taxa) dataseries collected in the Indian Ocean from 1961 to 2009 in the frame of both longline scientific cruises and the longline observer program based in La Réunion. The trend in time of the pelagic elasmobranch (sharks and rays) diversity is analysed according to a spatial stratification with respect to biogeographic province, distance from the coast and vertical habitat. Our data demonstrate decreased species richness during recent decades; however probable misidentifications for some taxa during early years of research could introduce biases in the observed pattern.. Decrease in nominal CPUE and mean weight of individuals are also demonstrated for major pelagic shark taxa. The current status of the shark community in the studied region is discussed.

INTRODUCTION

Pelagic elasmobranch species (sharks, rays and chimaeras) are diverse group, which plays an important role in the pelagic ecosystems (Compagno, 1990). Most of pelagic elasmobranch are opportunistic predators situated at the top of trophic pyramid producing strong impact on other species (Cortes, 1999, Kitchell et al., 2002, Olson, Watters, 2003).

Current level of human fisheries impact on the elasmobranch community (both by target efforts and as by-catch) apparently exceed sustainability threshold resulting in erosion of elasmobranch diversity and abundance (Stevens et al., 2000, Dulvy et al., 2008).

However robust dataseries with long-term coverage and sufficient specific precision, which are necessary for evaluation of the elasmobrach status, are extremely rare for the region. Diversity and abundance of pelagic elasmobranch in the open Indian Ocean are poorly known despite long history of research and more than 60 years of commercial exploitation by large-scale tuna fisheries. Most of knowledge originates from early summaries of J. L. B. Smith (1965), works of Bass et al. (1973, 1975a, b, c, d) and comprehensive synthesises of Compagno widely available through FAO publications (Compagno, 1984a, b, c, 2001).

Works described elasmobranch community of the open ocean are rare (Sivasubramaniam, 1963, 1969). Plenty of information is available as grey literature through working papers of the regional fisheries management organization – IOTC[1] and its predecessor IPTP[2]. However data on shark occurrences and distribution are often inaccurate (Moore et al., 2007) due to lack of good identification sheets in the past, taxonomic revisions (e.g. Marshall et al., 2009), focus of research programs on other species and lack of proper experience of the samplers.

Here we analyse shark diversity, distribution and trend in abundance using data obtained in long-term research programme started back in second half of the last century in combination with recent and ongoing data collected in the region.

DATA AND METHODS

Elasmobranch capture[3] (by species or higher of taxa) dataseries in the Indian Ocean were developed from the pelagic longlining data collected by YugNIRO[4] in 1961-1989 in research cruises SIOTLLRP[5] and by IRD[6] during 2001-2010 in research cruises and through observer program based in La Réunion (IRD SEALOR[7] database) (Table 1, Fig. 1).

Historical and recent data collection programmes are segregated by temporal gap 1990-2000 and are also subjected to gradual changes in the fishing gear and fishing strategy.

Gears and fishing strategy

[1] Indian Ocean Tuna Commission (IOTC), Victoria, Seychelles www.iotc.org
[2] Indo-Pacific Tuna Development and Management Programme (IPTP) operated in 1982-1995 with headquarters in Colombo, Sri Lanka (Kambona, Marashi, 1996). IPTP documents are available through IOTC.
[3] Here as a capture we consider any interaction of longline gear with elasmobranches: catch, entanglement, or escapement with taxa recording.
[4] Southern Scientific Research Institute of Marine Fisheries and Oceanography (YugNIRO), Kerch, Ukraine
[5] SIOTLLRP – Soviet Indian Ocean Tuna Longline Research Program.
[6] Institut de recherche pour le développement (IRD)
[7] SEALOR Database of SEA-going observer surveys monitoring the local pelagic LOngline fishery based in La Reunion (Bach *et al.*, 2008).

SIOTLLRP. Standard multifilament Japanese-type pelagic longline deployed either as regular (5 hooks between floats) or ‘deep’ (10-17 hooks between floats) gear within depth range 50-450 m was used during all period of research. In some cruises targeted sharks over the shelf or oceanic shoals shallow longlines (2-6 hooks between floats) were deployed within depth range 15-75 m. All branchlines of 20-21 m length in total were equipped with ‘tuna’ hooks (Fig. 2) attached to wire leaders 1.8-2.0 mm in diameter and 3-4 m in length. Total number of hooks deployed in one set varied from 15 to 1156, mean 469 hooks.

Sampling platforms and general sampling methodology are presented in Romanov et al. (2006). Longline operations within 20-120°E, 26°N-45°S were used in this analysis.

Most of the operations used ‘day’ longline sets targeting tuna: deployment before dawn, usually between 03.00-06.00 local time and retrieval from the noon (12.00-13.00) till late afternoon or evening. Few longlines (2.5%) were set as ‘night sets’ i.e. before sunset (between 16.00-20.00 local time) and retrieved in the morning next day. Soaking time (calculated here from the start of setting to the end of hauling) is varied from 2h 10 min to 38h 50 min (mean 11h 52 min) (Table 1).

Small pelagic fish were used both as primary bait (i.e. bait occupied 90-100% of hooks in one set) and as secondary bait (occupied less than 10% of hooks in one set) (Table 2). Small carangids, clupeids and scombrids used most frequently. Squid was used in less than 1% of operations.

IRD. Monofilament longline (both mainline and branchlines) was used for sampling. Three types of hooks: tuna, circle and J-hook (Fig. 2) were attached directly to monofilament leader 3 mm in diameter without wire leaders. Longlines were deployed in variable configurations (both within sets and between sets). However most commonly used configuration was 6-7 hooks between floats (Bach et al., 2010). Estimated hook fishing depth range varies from 10 m to about 180 m, however the average of maximum fishing depth recorded (depth measured in the middle of a basket) is about 80 m. Total number of hooks deployed in one set varied from 450 to 1440, mean 1216 hooks. Majority of operation were performed as ‘night shallow sets’ targeted swordfish with lightsteaks attached to the leader in various combinations (Table 1A). Primary bait was squid (*Loligo* spp.)(99% of operations) but chub mackerel (*Scomber japonicus*) occasionally used during squid shortage periods.

In both periods of sampling all marine animals interacted with longline (caught, damaged by predators, escaped, entangled) were recorded, identified to lower possible taxon by scientific crew (SIOTLLRP, IRD) or by observer (IRD). Hook position within basket was recorded whatever possible for further estimate of the depth of catch. In majority of IRD operations instrumented longlines equipped with time-depth recorders and hook timers were used. Animals hauled onboard were measured and weighted; sex was recorded. Whatever possible photographs of fish caught were taken using film (SIOTLLRP) or digital (IRD) photo camera.

<u>Taxonomy and identification.</u>

Shark identification was performed using best references available during each particular period of sampling. However sources used are varied in taxonomic precision, keys and illustrations quality. Smiths (1965) and locally developed manuals was primary reference material during 1960-s and early 1970s. It was supplemented and gradually replaced by book of Pinchuk (1972) used till mid-1980. During late 1980 and for the recent period FAO sheets (Compagno, 1984a, b, c, 2001) becomes main reference. Currently IRD observers widely used manual of Chapman et al. (2006). It is recognized that latter guide as well as guides used in 1960s and 1970s are not comprehensive and could be source of the identification mistakes.

During database developments field data were carefully screened for validity of the names used. Invalid taxa were replaced by valid synonyms or in case of uncertainty degraded to higher taxonomic levels. Photographs collected during the cruises were used for verification of species whatever possible. Data collected during early years (1961-1965) were discarded due non-recording of sharks or low precision in the identification.

<u>Data processing</u>

Data were pooled into 5 biogeographic areas: Gulf of Aden – North Arabian Sea (1), western monsoon province (2), Mozambique Channel (3), eastern monsoon province (4) and southern Indian Ocean (5). Temporal stratification was set on the decadal level to decrease effect of spatially and temporarily non-balanced sampling. Habitat stratification were based on 6 strata in relation with ocean depth and distance form topographic features: ‘shallow’ waters (< 200 m), ‘coastal’ beyond shelf (< 50 miles offshore), ‘mid-oceanic’ waters to 200-mile border (except seamounts), tops of ‘seamounts’, shoals, waters around seamounts, high seas.

Biodiversity indexes (Chao’s species richness, Shannon’s, and Simpson’s) and species accumulation curves (sample-based rarefaction curves) were calculated with 100 randomization runs using EstimatesS 8.2.0 software (Colwell, 2009)

Here we introduce an index, which we used as indicator of the taxonomic precision of field data: index of **Taxonomic Uncertainty (TU)**. It is calculated as percentage of the taxa recorded at level higher than species to all taxa reported. In the ideal case (all species precisely identified) this index is equal to **0**. Such index allows quick and easy estimation of the data suitability for biodiversity studies at high level of precision.

RESULTS AND DISCUSSION

Diversity indexes and taxonomic uncertainty. A total of 46 elasmobranch species / taxa were recorded in the catch of pelagic longlines in the Indian ocean. Taxonomic uncertainty (TU) of data is reached 30%, with **nine** taxa recorded at the genus level, **four** at the level of family and **one** was infraclass (Table 3). Most diverse group was pelagic sharks represented by 28 species, where family Carcharinidae dominates by 15 species of the *Carcharhinus* genus and by two monospecific genera *Galeocerdo* and *Prionace*.

Species accumulation curves calculated using all types of stratification shows that minimum sample size for assessing pelagic elasmobranch biodiversity should be at least 200-250 LL sets (asymptote of the curve), (Fig. 3). All temporal and spatial strata chosen, except dataset for 2000-2010, correspond to the minimum sample size criteria.

Number of species varied from 30 to 40 in 1960-80-s declining to 22 in 2000-s. All diversity indices demonstrate lowest values in 2000-s (Fig. 4). However insufficient number of observations in 2000-s (see species accumulation curves, Fig. 3A) and alternative fishing strategy (night sets) prevailed for recent period might be important source of distortion.

Data obtained in the longline experiments in Seychelles (Gamblin et al., 2007) shows that most shark species are caught in greater numbers at night than during the day. Therefore potential effect of the fishing strategy on diversity and abundance estimates seems to be minor and apparently rather positive than negative. New analysis is currently underway with increased spatial and data coverage for the recent period (effort is surpassed minimum threshold of data representativeness equal to 200 sets) will bring more precision in diversity indexes for recent years.

Western monsoon province and southern Indian Ocean demonstrate highest species richness (Fig. 4). This index was at the lower (but equal) level for other areas, except eastern Indian Ocean, which demonstrate lowest diversity. Low diversity in the eastern Indian Ocean was not expected and has no clear explication except low number of sets at the seamounts or oceanic shoals.

Continental slope water and tops of seamounts inhabits by most diverse communities. Mid-oceanic region (50-200 miles from shore) are poorest habitat.

Relative abundance. Elasmobranch abundance (in terms of nominal pooled CPUE) is varied between 6.8 to 15.8 individuals per 1000 hooks in YugNIRO cruises, 11.9 individuals in average. This index is decreased by 2000-s threefold (to 4.5 individuals per 1000 hooks)(Table 1). Apparently fishing pressure could be the main reason of this trend but switch to monofilament gears, changes in fishing strategy and spatially unbalanced sampling might be important variables, which potential effects are unknown.

Monofilament leaders and potential effect on diversity and abundance estimates. Monofilament gears are considered as a potential option to minimize shark bycatch and facilitate escapement of alive sharks or their release (Ward et al., 2008). Consequently increased shark escape rate will affect diversity estimates by minimizing sample size and distorting species composition. However catchability and ability to retain the fish by longlines should be considered in combination of all parts of terminal gear: hooks, leaders, baits, and other parts of branchline.

Several experiments with two leader types (wire vs. mono) demonstrate controversial results; half of them show higher bycatch level of sharks for monofilament leaders (Branstetter, Musick, 1993, Yokota et al., 2006). Benefit of monofilament leaders is not evident and such conclusions (such as Ward et al., 2008) are based on non-significant differences or very small sample sizes with less than 20 individuals caught. Moreover, higher escapement rate is not a synonym of higher survival and conservation.

Escapement and release. Logically higher shark escapement rate for monofilament leaders is supposed to exploit natural ability of sharks to bite off. Except teeth sharks have no natural means to cut the line. Therefore position of hook in the shark body should not impede to the contact of the leader and teeth. Such hooking positions is usually corresponds to the hooking in the fish body areas with high probabilities of lethal injures (such as stomach and gills). Survival rate of the sharks escaped from LL gears is never studies and still unknown.

Introduction of the circle hooks in the longline fisheries was proposed as measure to decrease gut and gill hooking and increase percentage of jaw hooked fish (Kerstetter, Graves, 2006; Serafy et al., 2009). Our field data (Romanov, 2010) shows that percentage of jaw-hooked fish on circle hooks is 1.33 times higher than for tuna hooks and 4 folds higher than for J-

hooks. Similarly cumulative percentage of gill and gut hooked fish on circle hook is two-times lower than for tuna hook and 3.8 times lower than for J-hooks.
Jaw hooking of sharks will increase retention ability of LL eliminating leader contact with teeth usually observed for gut and gill hooked sharks. Hence combination of monofilament leader with circle hooks can increase longline catchability for sharks and their retention rate but minimize risk of lethal injures.

Is this gear is more beneficial for sharks than others? Are sharks will be able to survive after hours of soaking on the branchline? There is no answer for most shark species. However Campana (2009) showed that all jaw-hooked and released blue shark are survived, while sharks swallowed hook will most probably die.

Longliners data analyzed here for 2000-2010 demonstrate increasing percentage of the circle hooks use by fishermen at Reunion Island. Some of the vessels (Bach et al., 2010) completely eliminate other types of hooks from routine usage. But some monitored vessels (Alan Sharp, 2010 pers. comm.) adopt alternative strategy using 100% of J-hooks even if they use mixed hook composition earlier. Such opposite variability in the gear configuration of the fishing fleet is very difficult to monitor and account in the data bias estimates. One could expect that increased use of circle hooks should increase shark CPUE and produce better species coverage. However, as we demonstrate earlier this was not the case.

New analysis of increased dataset, including variables such night/day sets ratio and percentage of hook composition is a potential way to decrease uncertainty and bring robustness in the results obtained.

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Table 1. List of the data used in the present study. Sampling periods, areas and seasons, data stratification and origin are presented by fishing gear and research program

A. Data by source and sampling period

Data origin, sampling period	Data used, period	Sets	Hooks	Total soaking time (hours)	Mean soaking time (hours)	Individual fish observed	Individual sharks obsereved	Mean pooled shark CPUE ind./1000 hooks
SIOTLLRP, YugNIRO, 1961-1989	1966-1970	1089	405444	9677	10.2	14248	2928	7.2
	1971-1980	2403	1224428	27950	11.9	45159	19312	15.8
	1981-1989	1186	565448	15011	12.7	13711	3830	6.8
	Sub total	4678	2195320	52638	11.7	73118	26070	11.9
IRD, 2000-2010	2002-2010	190	186714	3368	19.0	6845	834	4.5
	Total	**4868**	**2382034**	**56006**	**12.0**	**79963**	**26904**	

B. Data by biogeographic region

	Area 1	593	190342	4026	7.7	7191	1593	8.4
	Area 2	2658	1322106	31831	12.4	47435	18842	14.3
	Area 3	317	145113	3703	12.2	4274	758	5.2
	Area 4	536	288961	6669	12.5	6209	2208	7.6
	Area 5	762	433125	9741	13.4	11753	3488	8.1
	Total	**4866**	**2379647**	**55969**	**12.0**	**76862**	**26889**	

Table 2.

Table 2. Bait (% of sets with particular bait) used in longline fishing operations during sampling

Sampling period	SIOTLLRP (1961-89)		IRD (2000-2010)***	
Bait group	Primary bait*	Secondary bait*	Primary bait	Secondary bait
Barracudas *Sphyraena* spp.	0.05	0.08		
Mackerel *Scomber* spp., *Rastrelliger* spp.	4.83	9.94	~2.0	100.0
Sauries *Scomberesox saurus, Cololabis saira*	2.40	1.00		
Clupeids *Sardina pilchardus*, *Sardinops* spp., other	20.97	20.80		
Scads, jack or horse mackerels (*Decapterus* spp., *Trachurus* spp., *Selar* spp.)	49.64	59.57		
Shark meat	0.81	3.09		
Other coastal or demersal fish	0.35	4.09		
Unknown bait (presumably small pelagic fish)	20.91	0.00		
Squid	0.05	1.42	~98.0	

* bait occupied 90-100% of hooks in one set
** occupied less than 10% of hooks in one set
*** preliminary estimates

Table 3. Elasmobranch species recorded in pelagic LL catches

Order, family, name	Alpha 3 code	Period 1961-1970	1971-1980	1981-1989	2002-2009
LAMNIFORMES					
Alopiidae					
Alopias pelagicus	PTH	+	+	+	+
Alopias superciliosus	BTH	+	+	+	+
Alopias vulpinus	ALV	+	+	+	+
Alopias spp	THR	+	+	+	+
Lamnidae					
Carcharodon carcharias	WSH	+			
Isurus oxyrinchus	SMA	+	+	+	+
Isurus paucus	LMA		+	+	+
Isurus spp	MAK	+	+	+	
Lamna nasus	POR		+	+	
Pseudocarchariidae					
Pseudocarcharias kamoharai	PSK		+	+	+
CARCHARINIFORMES					
Carcharhinidae					
Carcharhinus albimarginatus	ALS	+	+	+	+
Carcharhinus altimus	CCA	+			
Carcharhinus amblyrhynchoides	CCY		+		
Carcharhinus amblyrhynchos	AML		+	+	+
Carcharhinus brachyurus	BRO		+		
Carcharhinus brevipinna	CCB		+	+	
Carcharhinus falciformis	FAL	+	+	+	+
Carcharhinus galapagensis	CCG		+		
Carcharhinus leucas	CCE	+	+	+	
Carcharhinus limbatus	CCL	+	+	+	
Carcharhinus longimanus	OCS	+	+	+	+
Carcharhinus melanopterus	BLR	+	+	+	+
Carcharhinus obscurus	DUS	+	+	+	
Carcharhinus plumbeus	CCP	+	+	+	+
Carcharhinus sorrah	CCQ	+	+	+	
Carcharhinus spp	CWZ	+	+	+	
Carcharhinidae	RSK	+	+	+	
Galeocerdo cuvier	TIG	+	+	+	+
Prionace glauca	BSH	+	+	+	+
Sphyrnidae					
Sphyrna lewini	SPL	+	+	+	+
Sphyrna mokarran	SPK		+	+	+
Sphyrna zygaena	SPZ	+	+	+	
Sphyrna spp	SPN	+	+	+	+
HEXANCHIFORMES					
Hexanchidae					
Hexanchus griseus	SBL			+	
SQUALIFORMES					
Squalidae					
Squalus spp	DGZ		+		
Non-identified sharks	SKH	+	+	+	+
RAJIFORMES					

Mobulidae					
Manta birostris	RMB	+	+		
Manta spp	MNT		+	+	
Mobula spp	RMV	+		+	+
Mobulidae	MAN		+		
Dasyatidae					
Pteroplatytrygon violacea	PLS	+	+	+	+
Dasyatis spp	STI		+	+	+
Taeniura lymma	RTY	+			
Dasyatidae	STT		+		
Rajidae					
Raja spp	SKA		+		
Rajidae	RAJ	+			
Number of species / taxa recorded	*46*	*30*	*40*	*34*	*22*
Total number of individuals	*26904*	*2928*	*19312*	*3830*	*834*
Taxonomic uncertainty	*30.0*	*26.6*	*30.0*	*26.4*	*22.7*

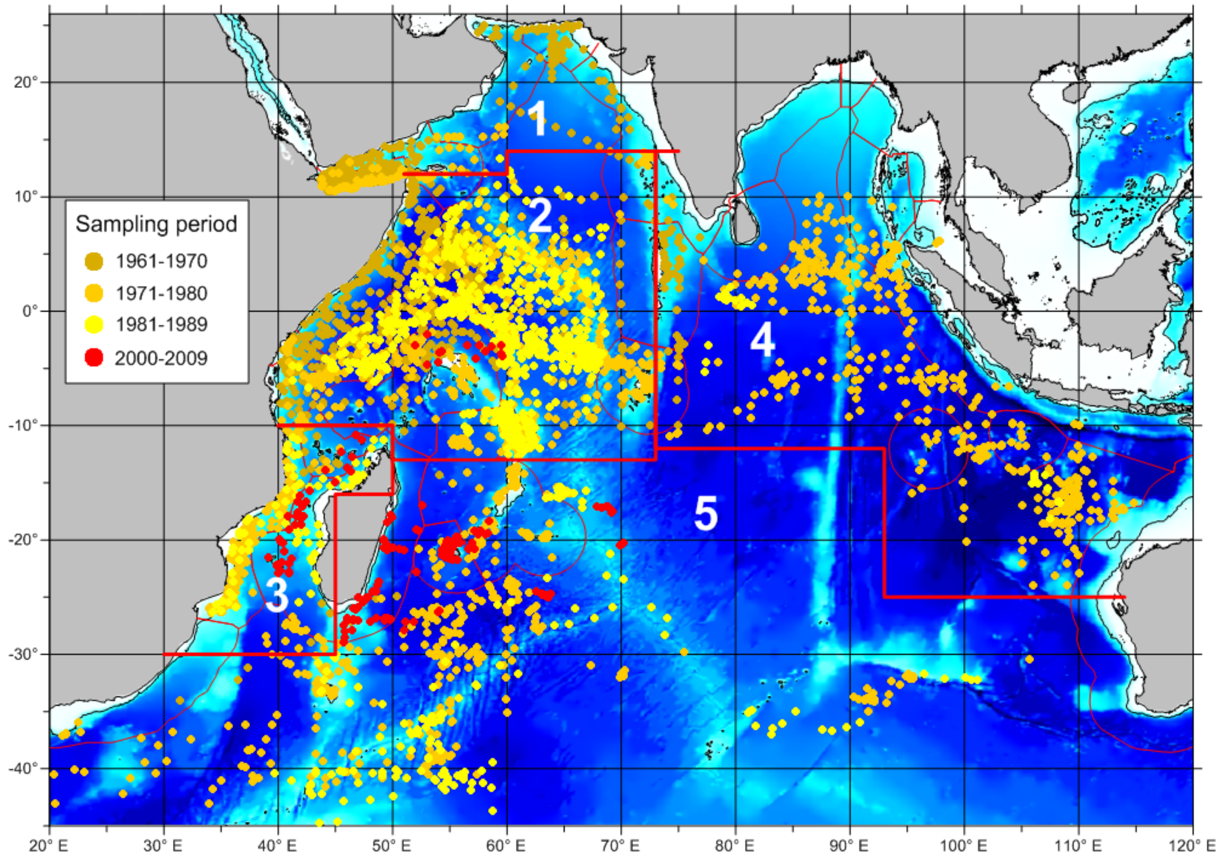


Fig. 1. Sampling area and sampling periods for data used.

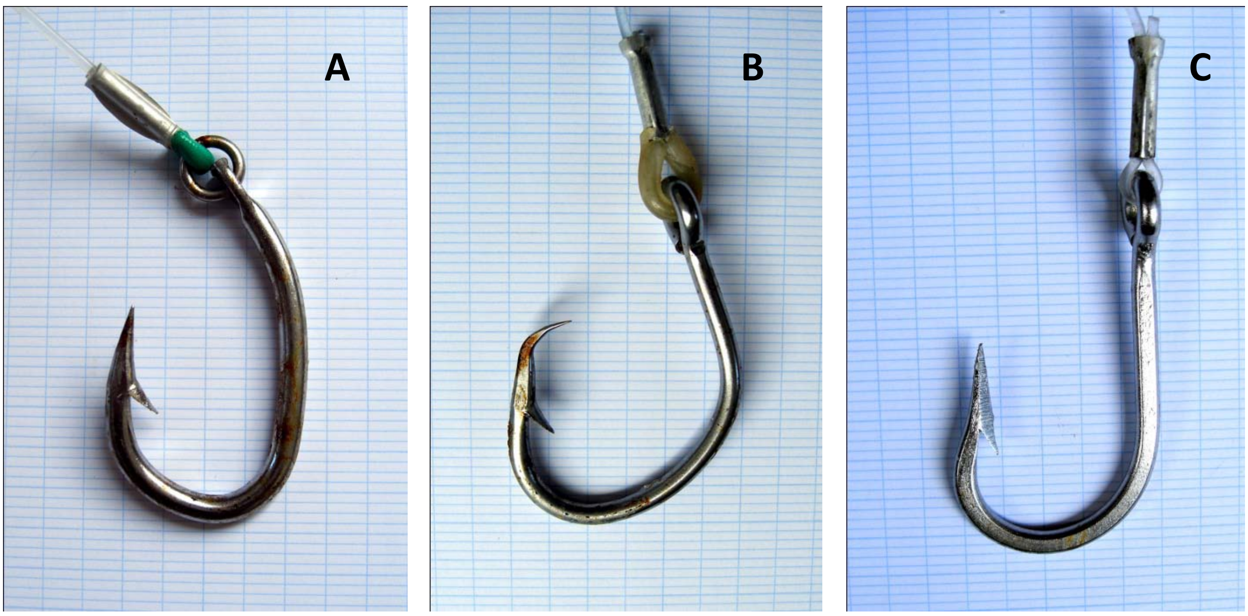


Fig. 2. Types of hooks used in the experimental and commercial fishing in this study: tuna hooks (A), circle hooks (B), and J-hooks (C)

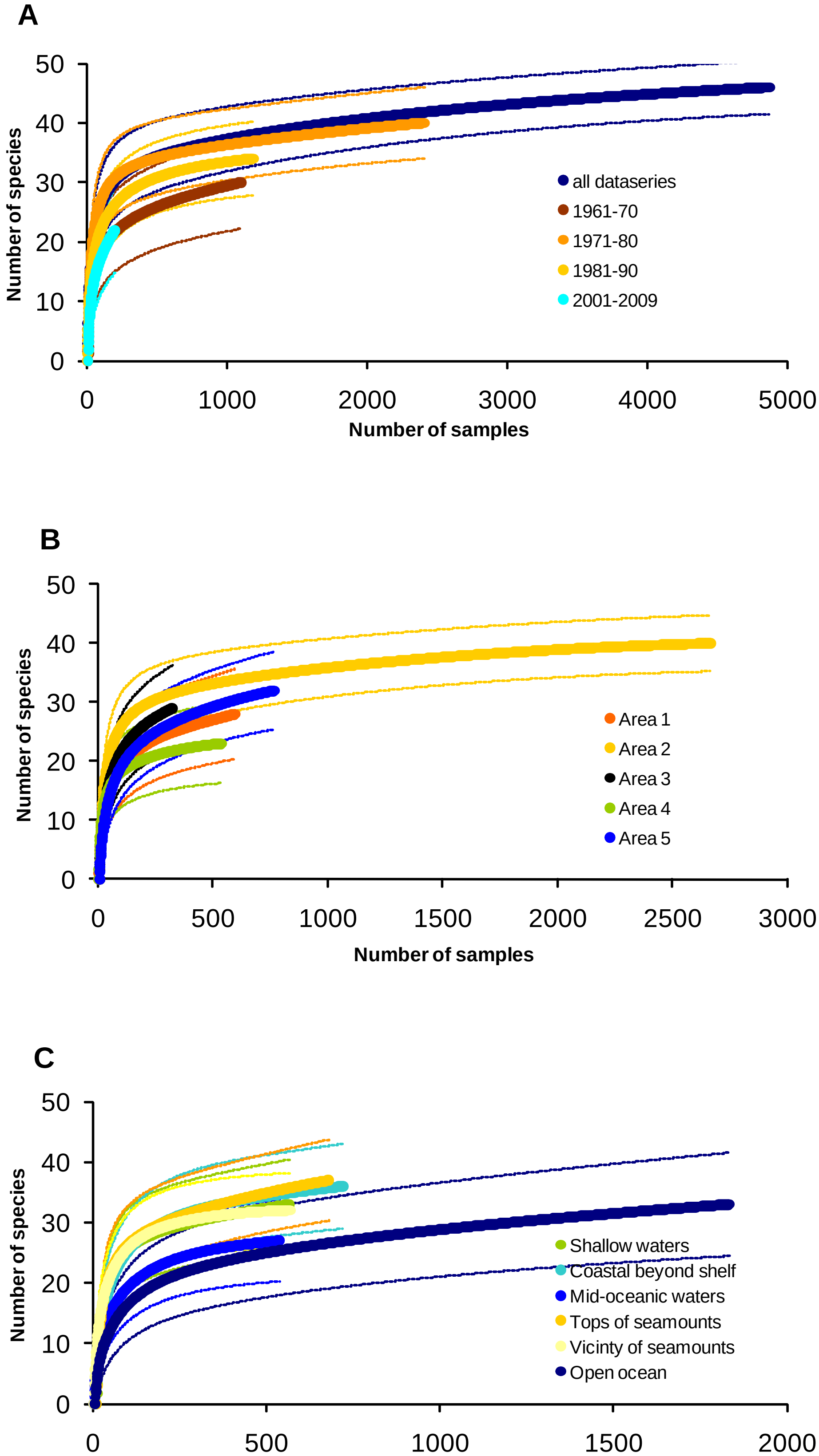


Fig. 3. Species rarefication curves with 95% confidence intervals by dataset and period (A), biogeographic area (B), and habitat (C)

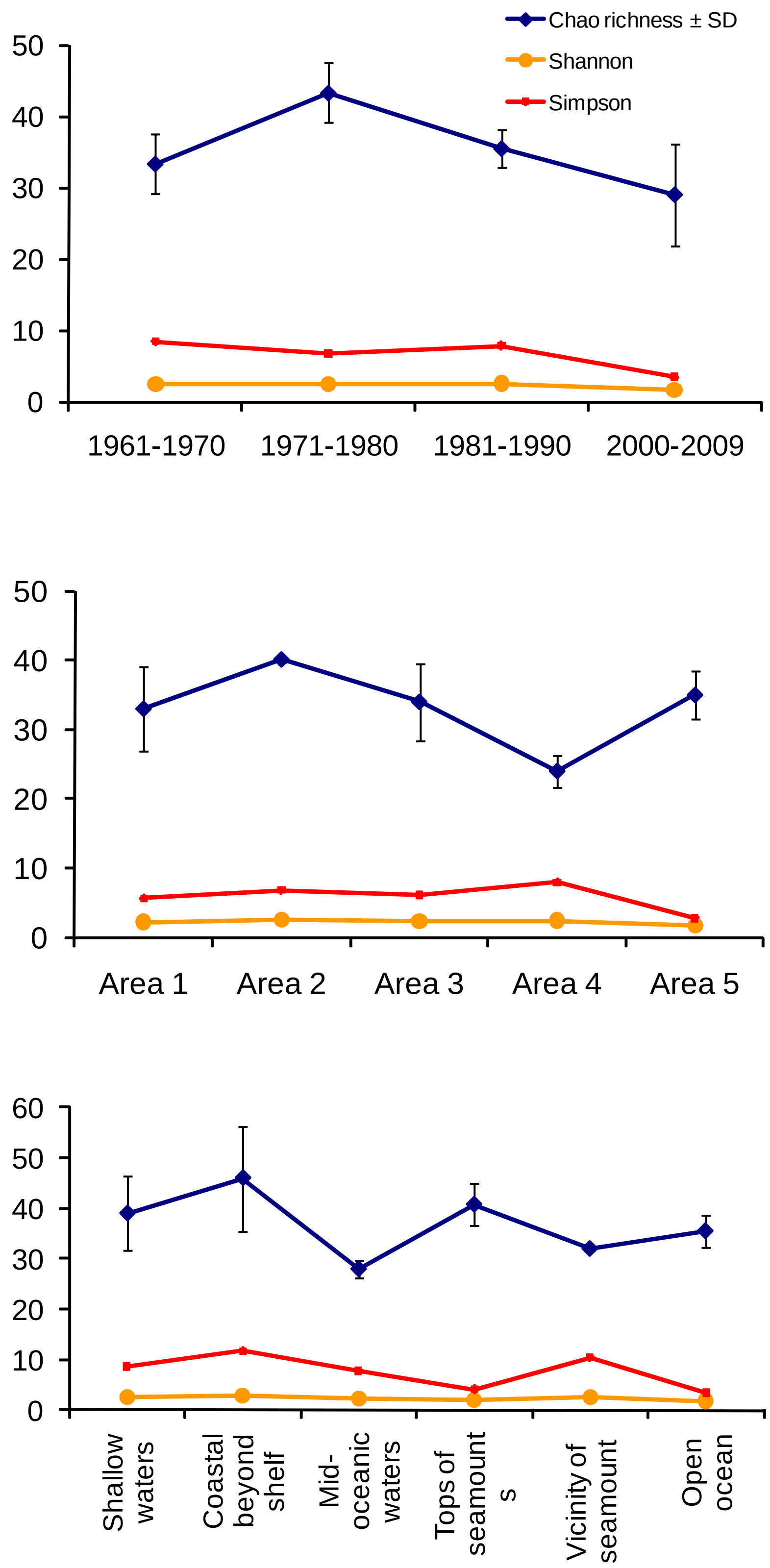
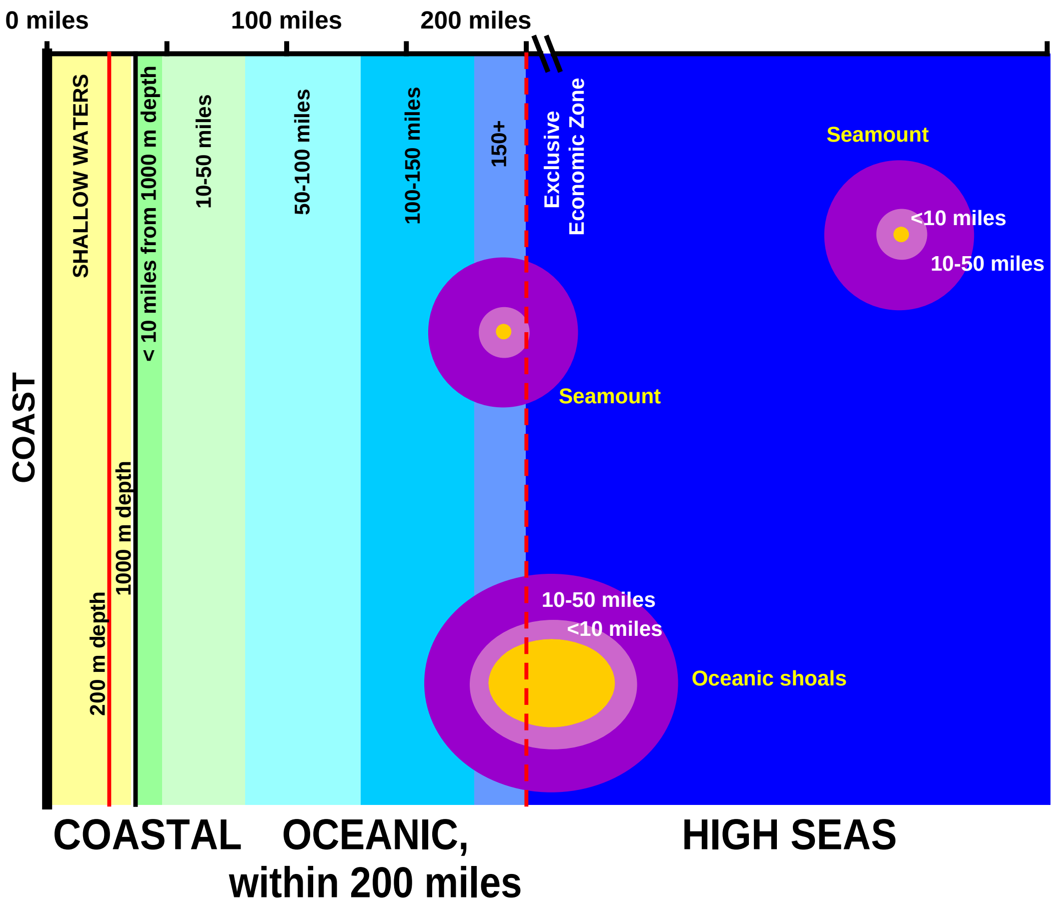


Fig. 4 Diversity indexes by dataset and period (A), biogeographic area (B), and habitat (C)

Appendix I

Data stratification by the oceanic zones

PR1		PR_D		
No	Clause	Code	Zone	Strata
1.	Distance from the coast < 100 miles AND depth < 1000 m	**1**	Coastal	'Shallow' waters
2.	Distance from the coast < 100 miles AND depth > 1000 m AND distance from 1000 m isobath 0-10 miles	**2**		'Coastal' beyond shelf
3.	Distance from the coast < 100 miles AND depth > 1000 m AND distance from 1000 m isobath 10-50 miles	**2**		
4.	Distance from the coast < 200 miles AND depth > 1000 m AND distance from 1000 m isobath 50-100 miles	**3**	Oceanic waters within 200 mile zones	'Mid-oceanic' waters
5.	Distance from the coast < 200 miles AND depth > 1000 m AND distance from 1000 m isobath 100-150 miles	**3**		
6.	Distance from the coast < 200 miles AND depth > 1000 m AND distance from 1000 m isobath 150-200 miles	**3**		
7.	Distance from the coast > 100 miles AND depth < 1000 m	**4**	Oceanic shoals, seamounts	Tops of 'seamounts', shoals,
8.	Distance from the coast > 100 miles AND depth > 1000 m AND distance from 1000 m isobath ≤ 10 miles	**5**		Waters around 'slopes of shoals' and seamounts
9.	Distance from the coast > 100 miles AND depth > 1000 m AND distance from 1000 m isobath 10-50 miles	**5**		
10.	Distance from the coast > 200 miles AND depth > 1000 m AND distance from 1000 m isobath > 50 miles	6	High seas	'High seas'


0 miles
100 miles
200 miles
COAST
SHALLOW WATERS
200 m depth
1000 m depth
< 10 miles from 1000 m depth
10-50 miles
50-100 miles
100-150 miles
150+
Exclusive Economic Zone
Seamount
<10 miles
10-50 miles
Seamount
10-50 miles
<10 miles
Oceanic shoals
COASTAL
OCEANIC, within 200 miles
HIGH SEAS