diversity

MDPI

Article

Elasmobranch Diversity at Reunion Island (Western Indian Ocean) and Catches by Recreational Fishers and a Shark Control Program

S. Jaquemet [1,*], N. Oury [1,2], T. Poirout [1], J. Gadenne [3], H. Magalon [1,2,4] and A. Gauthier [3]

[1] Université de La Réunion, UMR Entropie (Université de La Réunion-IRD-CNRS-Ifremer-Université de la Nouvelle-Calédonie), 97400 Saint-Denis, Ile de La Réunion, France
[2] Laboratoire Cogitamus, 75000 Paris, France
[3] GIP Centre Sécurité Requin, 97460 Saint-Leu, Ile de La Réunion, France
[4] Laboratoire d'Excellence Corail, 66860 Perpignan, France
* Correspondence: sebastien.jaquemet@univ-reunion.fr

Abstract: Elasmobranchs are declining worldwide due to overfishing. In developing countries and island states in tropical regions, small-scale and recreational fisheries can significantly impact the dynamics of neritic species. We investigated elasmobranch diversity at Reunion Island, a marine biodiversity hotspot in the Western Indian Ocean. Combining information from the literature, catches from the local shark control program, results from a survey of local recreational fishing, and through barcoding of some specimens, we updated the list of elasmobranchs to 65 species. However, uncertainties remain about the actual presence of some species, such as the three sawfish species. Results highlight the disappearance of most coral reef-associated species, as already suspected. Results also suggest that local populations of scalloped hammerhead shark (*Sphyrna lewini*) and bottlenose wedgefish (*Rhynchobatus australiae*) seem healthy, in contrast with their decline in the region. For some species, such as bull sharks (*Carcharhinus leucas*) and scalloped hammerhead sharks, Reunion Island is a site of reproduction, and as such, the species are exploited at both juvenile and adult stages, which likely increases their vulnerability. In the context of global elasmobranch decline, it is urgent to clarify the conservation status and evaluate the degree of isolation of local populations to identify research and conservation priorities.

Keywords: chondrichthyans; cartilaginous fish; sharks; batoids; coral reef; Indian Ocean; conservation; overexploitation

check for updates

Citation: Jaquemet, S.; Oury, N.; Poirout, T.; Gadenne, J.; Magalon, H.; Gauthier, A. Elasmobranch Diversity at Reunion Island (Western Indian Ocean) and Catches by Recreational Fishers and a Shark Control Program. *Diversity* **2023**, *15*, 768. https://doi.org/10.3390/d15060768

Academic Editor: José Luis García-Marín

Received: 17 May 2023
Revised: 9 June 2023
Accepted: 9 June 2023
Published: 12 June 2023

1. Introduction

Human activities have affected coastal ecosystems for centuries and have greatly impacted marine biodiversity at all levels of organisation [1–4]. Among human activities, fishing is the primary cause of decline in marine ecosystems [5–7]. Consequently, many populations of large, slow-growing, predatory species have declined in abundance, and the number of endangered species is currently growing [8,9]. As large-bodied animals, these species play important roles in the top-down control of biomass in food webs through direct predation and indirect risk avoidance behaviour, but also in nutrient cycling, scavenging, or connecting distant ecosystems [10–12]. The decline of these species can lead to changes in the stability and productivity of marine ecosystems and a loss of goods and services for human society [13].

Chondrichthyans are one of the first major marine fish lineages for which extinction risk has been determined for the entire clade, with recent estimates suggesting that one-third of them are threatened with extinction globally [9]. Among chondrichthyans, elasmobranchs (sharks, skates, and rays) are the most impacted by human activities [14,15]. On a global scale, elasmobranchs are mostly caught by industrial fisheries, but the impact of small-scale and recreational fisheries is not negligible in coastal areas, particularly in developing countries [16–18]. As a consequence, it was recently shown that nearly two-thirds of coral reef-associated shark and ray species are threatened with extinction, mostly due to overfishing [7]. In coastal areas, sharks and rays are also caught as by-catch [19,20], and some shark species are specifically targeted in shark control programs in ecosystems where they interact with ocean users [21].

Reunion Island is a tropical oceanic island located in the southwest Indian Ocean that belongs to a marine biodiversity hotspot [22]. Although its coastal ecosystems are limited in size by the geomorphology and age of the island [23], it boasts a particularly rich marine biodiversity [24–27], with a total of 1143 marine fish species recorded from a total of 182 families [28]. Among these recorded species, Wickel and co-authors [28] listed 63 species of elasmobranchs and included 15 new species when compared to previous records [26,29,30], suggesting that the diversity of elasmobranch species around the island remains uncertain and could be underestimated. A recent study based on environmental DNA conducted in austral summer concluded that Reunion Island is a regional hotspot of elasmobranch diversity, which may play a significant role during the life cycle of endangered species such as the scalloped hammerhead shark *Sphyrna lewini* [31]. This study also pointed out the absence of coral reef-associated sharks in the samples, likely a consequence of the local overexploitation of these species. This theory is in agreement with observations from local artisanal fisheries, which led to a prefectorial decree protecting five reef-associated shark species since 2015, namely silvertip sharks, *Carcharhinus albimarginatus*; grey reef sharks, *Carcharhinus amblyrhynchos*; white-tip reef sharks, *Triaenodon obesus*; blacktip reef sharks, *Carcharhinus melanopterus;* and tawny nurse sharks, *Nebrius ferrugineus*.

Although shark bites have occurred since the colonisation of the island during the 17th century, the risk was deemed acceptable until a spate of attacks on ocean users along the west coast of the island after 2011 [32]. Before that year, virtually no study was conducted on elasmobranchs in Reunion Island except for a general census of species in marine biodiversity assessments [26,29]. After 2014, a shark control program was implemented on the west coast of the island to catch bull (*Carcharhinus leucas*) and tiger (*Galeocerdo cuvier*) sharks, the two species responsible for the series of bites [33]. Elasmobranchs are also traditionally exploited from the shore by recreational fishers, though the real impact of this activity on these species is unknown. The aim of the study was to combine different sources of information to improve our knowledge on the diversity of elasmobranchs present in Reunion Island, identify the species most commonly caught by recreational fishers in the coastal ecosystem as well as by the shark control program, and thus provide new information on the spatial and temporal dynamics of some of these species.

2. Material and Methods

2.1. Species Richness and Status of Conservation

A review of the diversity of species in the waters of Reunion Island was conducted based on published lists of species [26,28–30], the records of eDNA surveys of elasmobranchs conducted in 2019 around the island [31], a survey of the recreational fishing activity (see recreational fishing activity section), records of the catches of the shark control program [33], and the molecular identification of samples of various origins (recreational fishers, control programs, customs, etc.). Previous lists of fish species [26,28–30] mostly concentrated on coastal areas, especially coral reefs, on data from the artisanal and longline fisheries operating in the Economic Exclusive Zone of Reunion Island, and on occasional scientific surveys. As the taxonomy is in constant evolution, we used the World Register of Marine Species (WoRMS, www.marinespecies.org, accessed on 30 April 2023) to confront the different records of species and to establish an updated list of species of elasmobranchs for Reunion Island (last visit on the 15th of April 2023). The status of conservation of different species was updated based on the IUCN red list of species (www.iucnredlist.org, accessed on 30 April 2023). Since there is no regional or local red list for elasmobranchs to our knowledge, the global conservation status was considered, even if it could be biased for some species for which the local abundance could differ from the global pattern.

2.2. Shark Control Program

A shark control program was implemented in 2014 on the west coast of Reunion Island, close to areas where nautical activities occur, in order to regulate the population of bull and tiger sharks. Fishing gear was deployed less than 2 km from the shore, between 10 m and 50 m of depth. As the fishing program was implemented in close vicinity of a Marine Protected Area (MPA), the use of traditional shark fishing gear was undesirable due to the high risk of by-catch, including several threatened elasmobranch species. In these conditions, a specific fishing gear, the SMART (Shark Management Alert in Real Time) drumline, was specifically developed for this shark control program to facilitate the rapid release of non-targeted species and hence limit the overall impact of the fishing program on marine biodiversity. A traditional drumline was modified by the addition of a GPS buoy connected to the Iridium satellite. When a fish is hooked, it triggers a magnet that allows the GPS buoy to emit a signal, the "Catch-A-Live" system. This real-time alert system of this SMART drumline informs the fisherman on duty within just a few minutes after a fish is hooked, enabling rapid intervention that ensures a very high survival and release rate of non-targeted species. In addition, due to the rapid handling of the fish after its catch, this fishing gear allows fishers to tag and measure the specimens before their release and also provides a very accurate (<5 min) timing of the capture [33]. To compare the catch composition, its seasonal variability, and the size of the animals with the catches of recreational fishers along the coast, data from the fishing operations of the shark control program were extracted from the database for the same time period as the survey on Facebook, between January 2016 and December 2021.

2.3. Recreational Fishing Activity

Between January 2016 and December 2021, four private groups of local recreational fishers with 3300 to 19,700 members were surveyed on social media (Facebook). These groups were visited daily, and whenever information and/or photos of elasmobranch catches were published, they were recorded with as much information as possible on the species, location, time of catch, size (estimated total length), weight and sex of the specimens. In addition, the author of the post was contacted to collect additional information on the catch, whether the individual was released or kept, the main purpose of the fishing activity and possibly to collect biological samples to complete a bank of samples at Reunion Island University. These data remain an underestimation of the total catches, as not all fishers will be registered on the surveyed social media sites or will always post their catches.

2.4. Species Molecular Identification of Specimens

A total of 63 samples of elasmobranchs from various sources, such as recreational and artisanal fishers or sanitary authorities (French Food and Drug Administration), with no clear information on the species identification, were barcoded. All samples were from local origins, with no doubt about the possible importation of seafood. Total genomic DNA of all 63 samples was individually extracted using the Qiagen DNeasy Blood and Tissue Kit (Qiagen, Hilden, Germany), following the manufacturer's instructions. In order to identify the species associated with the studied samples, the complete mitochondrial cytochrome oxidase c subunit I (COI) was amplified using the fish-specific primer cocktails C_FishF1t1/C_FishR1t1 [34], as in Oury and coauthors [35]. Sequences were checked for quality and edited using Geneious 8.1.2 [36]. Species identification of the samples was performed by comparing sequences to DNA records on the Barcode of Life Data System (BOLD, [37]) and BLAST identification system (https://blast.ncbi.nlm.nih.gov/Blast.cgi, accessed on 15 February 2023). A ~98% sequence similarity match was considered reliable for species identification [38].

2.5. Data Analyses

For seasonal analyses, seasons were defined as "Summer" between January and April, "Cooling" between May and June, "Winter" between July and October and "Warming" between November and December following a ten-year survey of sea-surface temperature in Reunion Island [39].

For the main species, the size distribution of the individuals caught in the shark control program and by recreational fishers over the studied period was compared to the normal distribution using Shapiro–Wilk tests and between them using a Kolmogorov–Smirnov test. For species with a sufficient number of records ($n > 30$), monthly trends in catches were studied based on the data from social media. For each species, the monthly catches were represented as percentages of annual catches, with the hypothesis that the catches are representative of the relative abundance of the species over time.

3. Results

3.1. Elasmobranch Diversity and Status of Conservation

The comparison of the different lists of elasmobranchs established over the last 25 years in Reunion Island showed an increase in the number of species recorded (Table 1), but uncertainties remain about the presence of some species locally. With the recent progress of molecular taxonomy, some species have changed classification (family, genus), which contributes to these uncertainties about the specific diversity. As an example, the stingray *Dasyatis thetidis* was present in published lists of species, but this species was synonymised with *Bathytoshia lata* according to WoRMS.

Two species are of particular interest: the bottlenose wedgefish (*Rhynchobatus australiae*) and the dusky shark (*Carcharhinus obscurus*), which have not been recorded in Reunion Island to date to the best of our knowledge. For the dusky shark, one unidentified shark sample provided by a recreational fisherman was barcoded as *C. obscurus* with a similarity of 99.9%. In the shark control program, two specimens were caught by fishers in 2016 and 2018 and identified as dusky sharks, though not firmly confirmed. For the wedgefish, several sources of recent information suggest that there was a likely misidentification of the species in the past. The species is regularly caught in the shark-control program as a non-targeted species and, as such, is always released. However, in several instances, photographs were taken by fishers and confirmed the identification of the bottlenose wedgefish based on the pattern of white spots on the body and especially the presence of three white spots aligned over the pectoral marking [40]. In addition, on some occasions, samples were collected ($n = 12$) before release, and these samples were barcoded. In all cases, the molecular identification was *R. australiae* (99.8–100% similarity), and none of them was associated with *R. djiddensis*, while the species was present in all official lists of fish of Reunion Island until now. The longnose spurdog (*Squalus blainvillei*) was only mentioned in one report (Table 1), and its distribution in Eastern Africa and the Western Indian Ocean, including on Mauritius Island according to WoRMS, suggests that its presence in Reunion Island is highly plausible, though not firmly confirmed. Considering these different additions and the corrections to the list of elasmobranchs of Reunion Island, the number of species is now estimated at 65 in Reunion Island waters, including 50 species of sharks and 15 species of batoids (Table 1).

Of these 65 species, only four are data deficient (DD) for their global status of conservation. Nine of the sixty-one remaining species are critically endangered (CR), thirteen endangered (EN), twenty vulnerable (VU), eleven near threatened (NT), and only eight are least concern (LC). Species with an unfavourable conservation status are present in all habitats.

Table 1. Updated list of shark and batoid species in Reunion Island waters with their habitats, status of conservation on the IUCN red list (CR: critically endangered, DD: data deficient, EN: endangered, LC: least concerned, NT: near threatened, VU: vulnerable), total number of catches (N ind) and total richness of species per season (W: winter, Wa: warming, S: summer, Co: cooling), mean size of the catches (total length TL in cm or disc length DL in cm ± standard error (se)) by the shark control program and the recreational fishing and comparison with previously published lists of species and number of reads in the eDNA survey conducted in coastal ecosystems of the island up to 50 m in depth (Mariani et al. 2021). x: presence of the species in the list.

	Present Study (*n* = 65)		Letourneur et al. 2004 (*n* = 37)	Fricke et al. 2009 (*n* = 39)	Kizska et al. 2009 (*n* = 48)	Wickel et al. 2020 (*n* = 64)	IUCN Red List		Shark Control Program			Recreational Fishing			Mariani et al. 2021
	Family (Number of Species)	Species					Habitat	Status of Conservation	N ind	Mean TL/DL (se)	Season	N ind	Mean TL/DL (se)	Season	Number of Reads
SHARKS (*N* = 50)	Alopiidae (*n* = 3)	*Alopias pelagicus*				x	Neritic/oceanic	EN							
		Alopias superciliosus	x	x	x	x	Neritic/oceanic	VU				1		Co	
		Alopias vulpinus	x	x	x	x	Neritic/oceanic	VU							
	Carcharhinidae (*n* = 18)	*Carcharhinus albimarginatus*	x	x	x	x	Neritic/deep benthic	VU	4	177 (47)	W, Wa				
		Carcharhinus amblyrhynchos	*C. wheeleri*	x	x	x	Neritic	EN	2	158 (19)	W				
		Carcharhinus brachyurus				x	Neritic/oceanic	VU	9	245 (8)	W				
		Carcharhinus brevipinna	x	x	x	x	Neritic	VU							
		Carcharhinus falciformis		x	x	x	Neritic/oceanic/ deep Benthic	DD							15,679
		Carcharhinus humani				x	Neritic	DD							
		Carcharhinus leucas		x	x	x	Wetland/neritic/ supratidal	VU	107	247 (5)	S, Co, W, Wa	73	102 (8)	S, Co, W, Wa	228,385
		Carcharhinus limbatus	x	x	x	x	Neritic/oceanic	VU							
		Carcharhinus longimanus	x	x	x	x	Neritic/oceanic	CR							
		Carcharhinus melanopterus	x	x	x	x	Neritic/intertidal	VU							
		Carcharhinus obscurus					Neritic/oceanic		2 ?		W, Wa	1		W	

Table 1. *Cont.*

	Present Study (*n* = 65)		Letourneur et al. 2004 (*n* = 37)	Fricke et al. 2009 (*n* = 39)	Kizska et al. 2009 (*n* = 48)	Wickel et al. 2020 (*n* = 64)	IUCN Red List		Shark Control Program			Recreational Fishing			Mariani et al. 2021
	Family (Number of Species)	Species					Habitat	Status of Conservation	N ind	Mean TL/DL (se)	Season	N ind	Mean TL/DL (se)	Season	Number of Reads
Sharks (*N* = 50)	Carcharhinidae (*n* = 18)	*Carcharhinus plumbeus*	x	x	x	x	Neritic/deep benthic	EN	4	150 (17)	S, W	2		Co	
		Carcharhinus sorrah	x	x	x	x	Neritic	NT							
		Galeocerdo cuvier	x	x	x	x	Neritic/oceanic	NT	349	290 (3)	S, Co, W, Wa	9	202 (34)	S, Co, W, Wa	979,818
		Loxodon macrorhinus		x	x	x	Neritic	NT	37	82 (2)	S, Co, W, Wa	39		S, Co, W, Wa	22
		Negaprion acutidens			x	x	Neritic/intertidal	EN							
		Prionace glauca	x	x	x	x	Neritic/oceanic	NT							
		Triaenodon obesus	x	x	x	x	Neritic	VU				1	55	W	
	Centrophoridae (*n* = 3)	*Centrophorus moluccensis*	x	x	x	x	Deep benthic	VU				2		S, W	
		Deania profundorum				x	Deep benthic	NT							
		Deania quadrispinosa				x	Deep benthic	VU							
	Dalatiidae (*n* = 2)	*Euprotomicrus bispinatus*	x	x	x	x	Oceanic	LC							
		Isistius brasiliensis				x	Oceanic	LC							
	Ginglymostomatidae (*n* = 1)	*Nebrius ferrugineus*	x	x	x	x	Neritic	VU	12	271 (11)	S, Co, W, Wa	2		S, W	
	Hexanchidae (*n* = 4)	*Heptranchias perlo*	x	x	x	x	Neritic/oceanic/deep Benthic	NT							
		Hexanchus griseus	x		x	x	Deep benthic	NT							
		Hexanchus nakamurai	*H. vitulus*	x	*H. vitulus*	x	Oceanic/deep benthic	NT							
		Notorynchus cepedianus	x		x	x	Neritic/deep benthic	VU							

Table 1. *Cont.*

	Present Study (*n* = 65)		Letourneur et al. 2004 (*n* = 37)	Fricke et al. 2009 (*n* = 39)	Kizska et al. 2009 (*n* = 48)	Wickel et al. 2020 (*n* = 64)	IUCN Red List		Shark Control Program			Recreational Fishing			Mariani et al. 2021
	Family (Number of Species)	Species					Habitat	Status of Conservation	N ind	Mean TL/DL (se)	Season	N ind	Mean TL/DL (se)	Season	Number of Reads
Sharks (*N* = 50)	Lamnidae (*n* = 3)	*Carcharodon carcharias*	x	x	x	x	Neritic/oceanic	VU							
		Isurus oxyrinchus	x	x	x	x	Oceanic	EN	1	313	W	1	200	Co	
		Isurus paucus			x	x	Oceanic	EN							
	Odontaspididae (*n* = 1)	*Carcharias taurus*			x	x	Neritic/deep benthic	CR							
	Pseudocarchariidae (*n* = 1)	*Pseudcarcharias kamoharai*			x	x	Oceanic	LC							
	Rhincodontidae (*n* = 1)	*Rhincodon typus*	x	x	x	x	Neritic/oceanic	EN							
	Somniosidae (*n* = 3)	*Centroscymnus owstonii*				x	Oceanic/deep benthic	VU							
		Centroselachus crepidater	*Centroscymnus crepidater*	x	x	x	Deep benthic	NT							
		Zameus squamulosus				x	Oceanic/deep benthic	LC							
	Sphyrnidae (*n* = 3)	*Sphyrna lewini*	?		x	x	Neritic/oceanic	CR	81	233 (6)	S, Co, W, Wa	120	51 (2)	S, Co, W, Wa	1,220,474
		Sphyrna mokarran	x	x	x	x	Neritic/oceanic	CR							
		Sphyrna zygaena	?			x	Neritic/oceanic	VU	5	225 (26)	W	1		W	5058
	Squalidae (*n* = 4)	*Cirrhigaleus asper*	*Squalus asper*	x	x	x	Deep benthic	DD							
		Squalus blainville			x		Neritic/deep benthic	DD							
		Squalus megalops	x	x	x	x	Neritic/deep benthic	LC				4		S	
		Squalus mitsikurii			x	x	Deep benthic	EN							

Table 1. *Cont.*

	Present Study (n = 65)		Letourneur et al. 2004 (n = 37)	Fricke et al. 2009 (n = 39)	Kizska et al. 2009 (n = 48)	Wickel et al. 2020 (n = 64)	IUCN Red List		Shark Control Program			Recreational Fishing			Mariani et al. 2021
	Family (Number of Species)	Species					Habitat	Status of Conservation	N ind	Mean TL/DL (se)	Season	N ind	Mean TL/DL (se)	Season	Number of Reads
SHARKS (N = 50)	Stegostomatidae (n = 1)	*Stegostoma tigrinum*			x	x	Neritic/oceanic	EN							213,431
	Triakidae (n = 2)	*Mustelus mosis*		x	x	x	Neritic/deep benthic	NT	3	100 (15)	S, W	35	88 (10)	S, Co, W	
		Mustelus palumbes				x	Neritic/deep benthic	LC							
BATOIDS (N = 15)	Dasyatidae (n = 6)	*Bathytoshia lata*	*Dasyatis thetidis*	*Dasyatis thetidis*	*Dasyatis thetidis*	x	Neritic/deep benthic	VU	33	151 (27)	S, Co, W, Wa	20		S, Co, W, Wa	
		Dasyatis chrysonota	*Dasyatis pastinaca*			x	Neritic	NT							
		Neotrygon caeruleopunctata				x	Neritic/intertidal	LC							
		Pateobatis fai				x	Neritic	VU				9		S, Co, W	
		Pteroplatytrygon violacea	*Dasyatis violacea*			x	Oceanic	LC							225,925
		Taeniurops meyeni	*Taeniura meyeni*	x	x	x	Neritic/deep benthic	VU	98	119 (4)	S, Co, W, Wa	44	97 (6)	S, Co, W, Wa	347,215
	Mobulidae (n = 1)	*Mobula birostris*	*Manta birostris*	x	*Manta birostris*	x	Neritic/oceanic	EN							
	Mobulidae (n = 1)	*Mobula tarapacana*		x		x	Neritic/oceanic	EN							
	Myliobatidae (n = 2)	*Aetobatus ocellatus*				x	Neritic/oceanic	VU	10	116 (5)	S, W, Wa	5		S, Co, W, Wa	
		Myliobatis aquila	x	x	x	x	Neritic/oceanic	CR							

Table 1. *Cont.*

	Present Study (*n* = 65)		Letourneur et al. 2004 (*n* = 37)	Fricke et al. 2009 (*n* = 39)	Kizska et al. 2009 (*n* = 48)	Wickel et al. 2020 (*n* = 64)	IUCN Red List		Shark Control Program			Recreational Fishing			Mariani et al. 2021
	Family (Number of Species)	Species					Habitat	Status of Conservation	N ind	Mean TL/DL (se)	Season	N ind	Mean TL/DL (se)	Season	Number of Reads
BATOIDS (*N* = 15)	Pristidae (*n* = 3)	*Pristis pectinata*	x	x	x	x	Neritic/intertidal	CR							
		Pristis pristis	*Pristis microdon*	x	*Pristis microdon*	x	Wetland/neritic/intertidal	CR							
		Pristis zijsron				x	Neritic/intertidal	CR							
	Rhinidae (*n* = 1)	*Rhynchobatus australiae*	*R. djiddensis*	*R. djiddensis*	*R. djiddensis*	*R. djiddensis*	Neritic	CR	51	191 (5)	S, Co, W, Wa	30	182 (8)	S, Co, W, Wa	476,221
	Torpedinidae (*n* = 1)	*Torpedo fuscomaculata*		x	x	x	Neritic/intertidal/deep benthic	DD				3		S, Co, Wa	
Unidentified specimens										61			18		
Total number of individuals										869			420		
Total number of individuals in summer (S)										302			201		
Total number of individuals in winter (W)										249			110		
Total number of individuals during transition periods (C, Wa)										218			109		
Species richness										17			20		
Species richness in summer (S)										11			14		
Species richness in winter (W)										17			15		
Species richness during transition periods (C, Wa)										11			14		

3.2. Composition and Size Distribution of the Catches

Catches of elasmobranchs occurred all around Reunion Island, but they were more numerous on the west coast of the island, as that is the location of the shark control program (Figure 1). During the study period (January 2016–December 2021), more than twice as many elasmobranchs were caught within the shark control program (n = 869) compared to the catches recorded in the recreational fishing survey (n = 420), but the species richness was nearly the same (n = 20 for recreational fishing, n = 17 for the shark control program, Table 1). In addition, the catch composition was very similar in these two fishing activities. Over the 65 species of elasmobranchs listed, 24 were recorded in the total catches of the shark control program and recreational fishing, which in fact represents nearly half (48.9%) of all elasmobranch species when we remove all the species with a deep-benthic and/or an oceanic habitat (16 species).

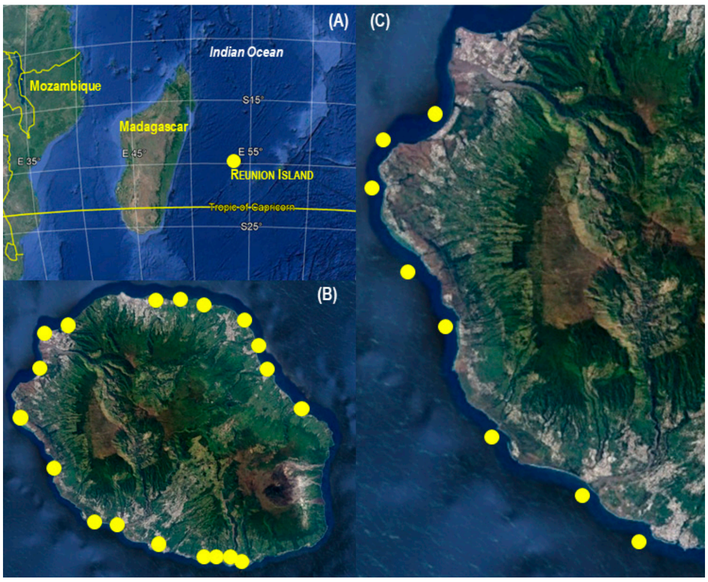

Figure 1. Location of Reunion Island in the Western Indian Ocean (**A**) and location of the fishing sites all around the island for recreational fishing (**B**) and on the west coast of the island for the shark control program (**C**). *Source: Google maps*.

Overall, more sharks were caught than batoids in both the shark control program and recreational fishing. The shark richness was higher in the shark control program, while the batoid richness was higher in recreational fishing. In the shark control program, both targeted species, bull sharks (*C. leucas*) and tiger sharks (*G. cuvier*), dominated the catches. *Taeniurops meyeni*, *S. lewini*, and *R. australiae* were the main by-catch. *Sphyrna lewini*, *C. leucas, T. meyeni, G. cuvier*, and *R. australiae* were the main catches by recreational fishers.

Although the catch composition had high similarities between both fishing activities, the sizes of the individuals were very different for a given species (Table 1, Figures 2 and 3). In the shark control program, the size distribution was not significantly different from normality for the bottlenose wedgefish (W = 0.973, p = 0.3304) only (all other species $p < 0.05$). In recreational fishing, the round ribbontail ray (W = 0.842, p = 0.107) and the tiger shark (W = 0.93, p = 0.612) had size distributions not different from the normality.

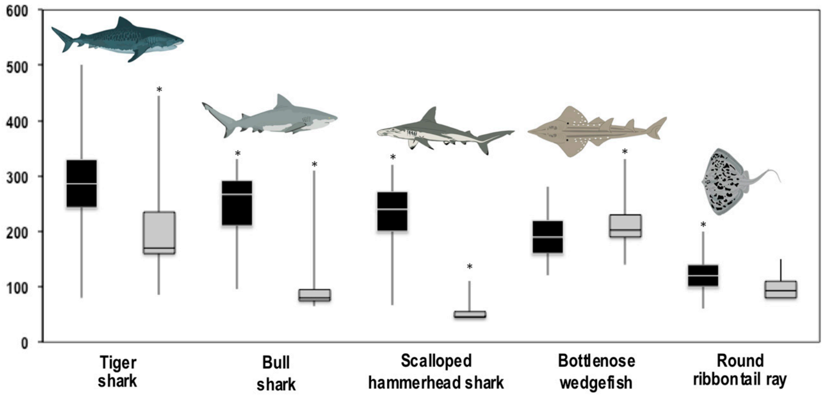

Figure 2. Box plot of the size distribution of the catches of tiger shark *Galeocerdo cuvier*, bull shark *Carcharhinus leucas*, scalloped hammerhead shark *Sphyrna lewini*, bottlenose wedgefish *Rhynchobatus australiae,* and round ribbontail ray *Taeniurops meyeni* in the shark control program in black and recreational fishing in grey. Medians, first, and third quartiles of the size distribution are represented. *: Significant difference from the normal distribution.

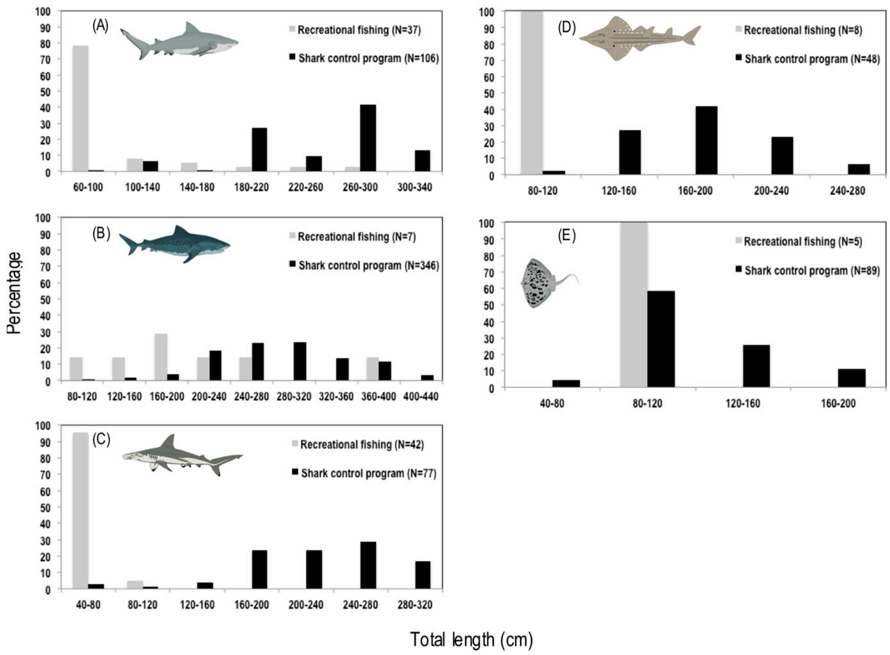

Figure 3. Size distribution of the catches of bull shark *Carcharhinus leucas* (**A**), tiger shark *Galeocerdo cuvier* (**B**), scalloped hammerhead shark *Sphyrna lewini* (**C**), bottlenose wedgefish *Rhynchobatus australiae* (**D**), round ribbontail ray *Taeniurops meyeni* (**E**) in recreational fishing and the shark control program.

Overall, the size of the individuals caught from the shore by recreational fishers was significantly smaller than the individuals caught within the shark control program (Kolmogorov–Smirnov $p < 0.05$ for all comparisons). For the bottlenose wedgefish and the round ribbontail ray, the low number of measured individuals in recreational fishing prevented any robust conclusion on the size distribution, yet all individuals caught by recreational fishers were smaller than the size at maturity for both species (Figure 2). Similarly, for scalloped hammerhead sharks, only individuals smaller than 100 cm were recorded in recreational fishing, while the shark control program mostly caught individuals larger than 160 cm. Interestingly, for the two species targeted by the shark control program, both small and large individuals were caught from the shore and within the shark control program, though smaller individuals were clearly more abundant in catches along the shore and larger individuals further offshore where the SMART drumlines are deployed (Table 1, Figure 3).

3.3. Seasonal Variations in the Catches

Both in recreational fishing and the shark control program, sharks and batoids were caught during all seasons. While this diversity of catches was nearly the same all year round in recreational fishing, it was higher in winter for the shark control program. Eight species were caught regardless of the season, among which the five most abundant were in the catches (*C. leucas*, *G. cuvier*, *T. meyeni*, *S. lewini*, and *R. australiae)*. Six species of sharks of neritic and oceanic habitats were exclusively caught in winter, while only *Squalus megalops*, a neritic-deep habitat species, was exclusively caught in summer (Table 1). In all cases, the number of individuals was low, which limited the conclusion about the seasonal dynamics of these species. Interestingly, one species, the smooth hammerhead shark *Sphyrna zygaena*, was only caught in the winter in both recreational fishing and the shark control program. The low number of individuals also prevented strong conclusions.

In recreational fishing, there was a clear seasonal pattern in catches for both bull sharks and scalloped hammerhead sharks, which were higher between December and February during the warming and summer months (Figure 4A). This seasonal pattern was also observed in catches of the round ribbontail ray, though it was not as marked as in the former species. Finally, no seasonal pattern was observed in catches of the bottlenose wedgefish (Figure 4B).

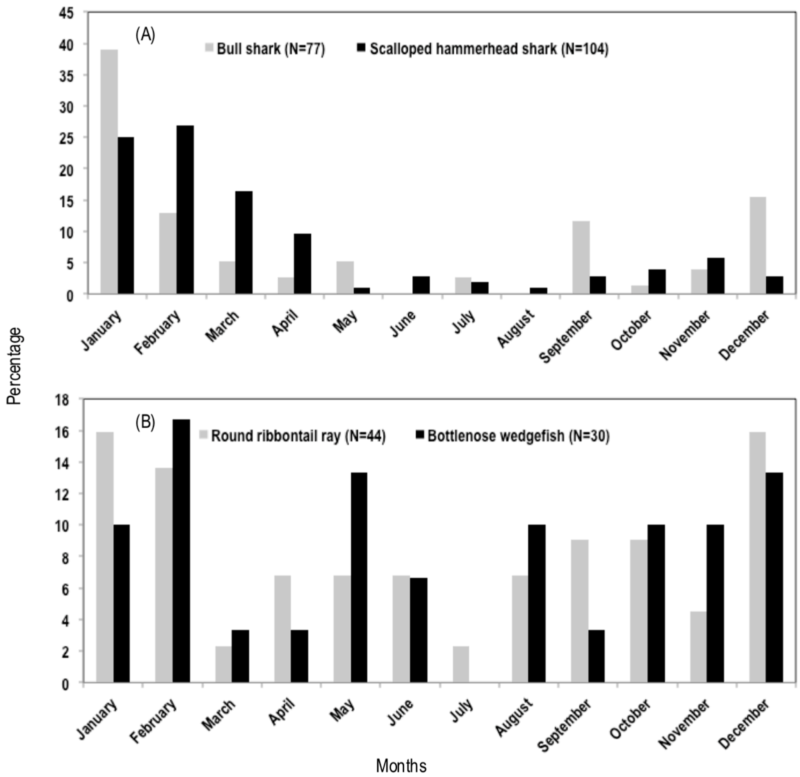

Figure 4. Percentage of total catches of bull sharks *Carcharhinus* leucas and scalloped hammerhead sharks *Sphyrna lewini* (**A**) and round ribbontail ray *Taeniurops meyeni* and bottlenose wedgefish *Rhynchobatus australiae* (**B**) per month in recreational fishing.

4. Discussion

4.1. Elasmobranch Richness in Reunion Island and Species Conservation Status

Combining different sources of information allowed for updating the list of elasmobranch species in Reunion Island. The number of species is now evaluated at 65, with 50 species of sharks and 15 species of batoids, though uncertainties remain on the taxonomic identification and the real presence of some species. Similarly, a recent assessment of the marine biodiversity of the Western Indian Ocean estimated 264 sharks and rays [41], which is more than the 188 species recorded in an earlier review [42]. This difference in the number of species highlights that accurately evaluating the marine biodiversity of a region is challenging, even though it is fundamental to supporting effective fisheries management and implementing efficient conservation plans for threatened species. This increase in species diversity does not necessarily imply healthy populations, as suggested by the overall status of conservation for most species. The species present in Reunion Island could represent one-quarter of the total diversity of elasmobranchs in the Western Indian Ocean, which is relevant considering the small size, young age, and position of the island. Yet this is in agreement with the high diversity of fish already underlined for the island [26,28], and the fact that the island is part of a marine biodiversity hotspot [22]. This number is close to the 61 elasmobranch species documented for neighbouring Mauritius [30], an island slightly smaller but older than Reunion Island, with a larger coral reef ecosystem, and belonging to the same biodiversity hotspot.

Dusky sharks (*Carcharhinus obscurus*) and bottlenose wedgefish (*Rhynchobatus australiae*) were not recorded in Reunion Island in previously published lists of fish [26,28–30]. For *C. obscurus*, the species was identified from one barcoded sample obtained from a recreational fisherman and two unconfirmed records from the shark control program. The species is present in Eastern Africa and Madagascar [30,43], but is not recorded in the Seychelles [30,44] or Mauritius [30,45]. Due to its ecology and distribution in the region, its presence in Reunion Island is plausible, but more investigation would help clarify it locally. All published lists of species in Reunion Island indicated the presence of the whitespotted wedgefish *Rhynchobatus djiddensis*, while according to our results, it is very likely that the only wedgefish species present in the coastal waters of Reunion Island is the bottlenose wedgefish *R. australiae*. In the artisanal catches of Mauritius, *R. djiddensis* is recorded [45], but based on the misidentification in Reunion Island, it will be useful to check their taxonomy. Wedgefishes are threatened globally [9] and catches in East Africa and the Western Indian Ocean are declining, which is considered an indicator of population reduction [46]. Therefore, it is necessary to clearly identify the species and define their distribution to accurately evaluate their threats and conservation status and to implement legislation that protects the proper species.

When all species with a deep-benthic or oceanic habitat are removed, the analysis of the catches by recreational fishers and the shark control program reveals that nearly 50% of the shark and batoid species were caught during the study period. Five species, *C. leucas*, *G. cuvier*, *T. meyeni*, *S. lewini*, and *R. australiae*, dominated the catches. These species were all recorded in an eDNA survey around the island, with *C. leucas*, *G. cuvier*, and *S. lewini* being the three most frequently recorded species and having the highest eDNA read abundance [31]. Coral reef-associated species, such as *C. albimarginatus*, *C. amblyrhynchos*, *C. melanopterus*, and *T. obesus*, were notably absent from the catches of both recreational fishing and the shark control program, in agreement with the observations made in the recent eDNA survey of the elasmobranch diversity around the island [31] and in line with the prefectural decree protecting these species since 2015. The small size of the coral reef in Reunion Island has likely limited its natural abundance around the island, leading to a local intrinsic vulnerability. This result indicates that the populations of coral reef-associated species have significantly declined as a main consequence of overfishing and secondary to the degradation of their habitat, as observed on a global scale [7]. The isolation of the island, combined with the small home range and high site fidelity to the reef habitat of these species [12], limits the opportunities for outside individuals to replenish those lost, explaining the low abundance of coral reef-associated sharks locally while there is a ban on fishing. The absence of these species in catches is one of the major differences with the catch composition of the artisanal fisheries of Madagascar [17,43,47], Mauritius [45], or the Seychelles [44], where coral reef ecosystems are much more developed. Hammerhead sharks and wedgefish are present in the artisanal catches of these countries, such as in

Reunion Island. Among hammerhead sharks, both adults and young-of-the-year scalloped hammerhead sharks are particularly abundant in catches in Reunion Island, suggesting that the species could be locally abundant, as already noted by Mariani and coauthors [31]. The species has been assessed as critically endangered [48], and as such, the identification of a possible healthy population in Reunion Island is of significant importance for the conservation of the species. Similarly, in Reunion Island, mature individuals of *R. australiae* are abundant in the catches, while there is a decrease in the catches of the fisheries in the Western Indian Ocean [46], suggesting that Reunion Island could host a healthy population that should be protected.

An important aspect to consider when discussing the diversity of elasmobranch species present in Reunion Island is that there have been no official sightings around the island for many of these species, at least over the last 25 years, and their status remains uncertain. More prominent among these are blacktip reef sharks (*Carcharhinus melanopterus*), the three species of sawfish (*Pristis* spp.), sicklefin lemon sharks (*Negaprion acutidens*), or even zebra sharks (*Stegostoma trigrinum*) that have never been sighted but were only detected through eDNA analysis at one station [31]. Future studies should aim to validate the presence of these species in Reunion Island waters and investigate the vulnerability of local populations of elasmobranchs in Reunion Island.

4.2. Spatial and Temporal Dynamics of the Catches of Elasmobranchs in Reunion Island

Overall, catch composition from the shore in recreational fishing and in coastal habitats in the shark control program was very similar. Both fishing activities exploit primarily neritic and neritic/oceanic species, while deeper species were rare in the catches. The main difference was in the average size of the individuals, which was larger in the shark control program than in recreational fishing. This difference in the size distribution of the catches is partially related to hook size. In the shark control program, professional fishers target the largest individuals, which are considered the most dangerous for ocean users, while they tend to limit by-catches of vulnerable species that are usually smaller than bull and tiger sharks. As such, they mainly used medium-sized circle hooks (18/0). Along the shore, shallower waters naturally limit the presence of large individuals. In addition, recreational fishers use mostly hand fishing rods, which also limits the size of their catches, though some of them target large individuals successfully, as shown in the recreational fishing survey. However, the absence of an insular plateau along most of the coastline of Reunion Island favours the presence of large individuals and oceanic species nearshore, explaining the presence of small and some large individuals in catches from the shore. Catches of both small and large individuals suggest that some species are exploited at different life stages in the coastal habitats of Reunion Island, and this can increase their vulnerability to exploitation. This is particularly the case for bull sharks and scalloped hammerhead sharks, for which adults and young individuals are caught in abundance.

The diversity of elasmobranchs caught during the study period was higher in the winter. Seasonality in the catches per unit of effort of the shark control program was already observed for giant trevallys, stingrays, bull sharks, and bottlenose wedgefish, with a higher presence during the early winter period [49]. In the artisanal fishery in the southwest of Madagascar, a peak in the numbers of sharks landed was observed in June (early winter), but not in size or catch weight [43]. In recreational fishing, catches were higher in the summer, but the fishing effort was unknown. Two factors could explain this trend in the catches. First, recreational fishers favour the warm season to fish, especially during the summer holidays. Second, the catches of young-of-the-year bull and scalloped hammerhead sharks peaked during this season and represented more than 50% of the catches. For bull sharks, this seasonal peak in summer is in agreement with females giving birth at the end of the year in Reunion Island [50], and for scalloped hammerhead sharks, this suggests that the birth period would also be in summer in Reunion Island, as already shown in other locations [51,52]. This matching between the birth period and increase in catches suggests that this higher abundance in the summer months is real, though it cannot be balanced by the fishing effort. In addition, for both species, young-of-the-year are known to stay in nurseries during the first months of their life [53,54]. These nurseries are in coastal waters close to or in estuaries, where the turbidity is high and the water is shallow. This explains why the two species are heavily exploited during the summer months by recreational fishing, as their nurseries are typically where recreational fishers fish. Indeed, most of the catches are in the summer, during the rainy season, on the east coast of the island and at one specific location in the southwest of the island, close to a large river mouth. For both species, the catches of the shark control program seem to peak during the mating period, and the catches of recreational fishing seem to peak shortly after the period of parturition, suggesting that fishing activities could severely impact local populations. Moreover, Niella and coauthors [49] showed that the catches per unit of effort of bull sharks in the shark control program have significantly decreased over the last decade, which reinforces the idea that the fishing pressure has already impacted the local population. For the ribbontail ray, the seasonal pattern observed in the catches of recreational fishing may be related to a higher fishing effort in summer, though seasonality in the dynamics of the individuals is possible.

5. Conclusions

By combining different sources of information, this study updates the list of elasmobranchs in Reunion Island and highlights the high diversity of species relative to the age, size, and geomorphology of the island. Efforts are still needed to stabilise this list of species, as uncertainties remain concerning rare species. The status of conservation of these species seems very contrasted, with coral reef-associated species nearly locally extinct, whereas the critically endangered scalloped hammerhead shark seems to exhibit a rather healthy local population. Although the insular plateau is very limited in size, a spatial segregation between juveniles and adults was observed in catches from the shore and further offshore within the shark control program. This suggests the existence of coastal nurseries for some species, which is in agreement with the peak of catches for young-of-the-year bull sharks and scalloped hammerhead sharks in summer. Targeted surveys will be useful to explicitly identify key nursery areas where fishing pressures should be regulated. In the context of global declines in elasmobranch biodiversity worldwide, clarifying the conservation status and evaluating the degree of isolation of local populations are necessary to prioritise research and conservation priorities.

Author Contributions: Conceptualization, S.J.; data curation, S.J., N.O., T.P., J.G., H.M. and A.G.; formal analysis, S.J.; writing, S.J., N.O., T.P., J.G., H.M. and A.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partially funded by the DEAL-SEB Réunion (Eurraica Project Grant Number 2017/18). The shark control program is funded by the Préfecture de La Réunion, the Reunion Island Regional Council, the Reunion Island University, the TCO, CIVIS, CINOR communauté de communes, the municipalities of Saint-Paul, Trois-Bassins, Saint-Leu, Etang-Salé and Saint-Pierre.

Institutional Review Board Statement: All data are from the literature, interview, available on Facebook and fisher provided samples after independent catches.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data from barcoding will be made available on GenBank.

Acknowledgments: D. Guyomard and C. Perry initiated the shark control program. Grateful thanks to all professional fisher involved in the shark control program and to all recreational fishers that provided information and samples. J.F. Nativel provided additional samples collected within its own network of fisher. G. Chandelier provided the drawing of the species. We are grateful to the two anonymous reviewers who improved the manuscript with their comments.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

1. Jackson, J.B.C.; Kirby, M.X.; Berger, W.H.; Bjorndal, K.A.; Botsford, L.W.; Bourque, B.J.; Bradbury, R.H.; Cooke, R.; Erlandson, J.; Estes, J.A.; et al. Historical Overfishing and the Recent Collapse of Coastal Ecosystems. *Science* **2001**, *293*, 629–637. [CrossRef]
2. Estes, J.A.; Terborgh, J.; Brashares, J.S.; Power, M.E.; Berger, J.; Bond, W.J.; Carpenter, S.R.; Essington, T.E.; Holt, R.D.; Jackson, J.B.C.; et al. Trophic downgrading of Planet Earth. *Science* **2011**, *333*, 301–306. [CrossRef]
3. Halpern, B.S.; Frazier, M.; Afflerbach, J.; Lowndes, J.S.; Micheli, F.; O'Hara, C.; Scarborough, C.E.; Selkoe, K.A. Recent pace of change in human impact on the world's ocean. *Sci. Rep.* **2019**, *9*, 11609. [CrossRef]
4. O'Hara, C.; Frazier, M.; Halpern, B.S. At-risk marine biodiversity faces extensive, expanding, and intensifying human impacts. *Science* **2021**, *372*, 84–87. [CrossRef]
5. Crowder, L.B.; Hazen, E.L.; Avissar, N.; Bjorkland, R.K.; Latanich, C.; Ogburn, M.B. The Impacts of Fisheries on Marine Ecosystems and the Transition to Ecosystem-Based Management. *Annu. Rev. Ecol. Evol. Sys.* **2008**, *39*, 259–278. [CrossRef]
6. Halpern, B.S.; Walbridge, S.; Selkoe, K.A.; Kappel, C.V.; Micheli, F.; D'Agrosa, C.; Bruno, J.F.; Casey, K.S.; Ebert, C.; Fox, H.E.; et al. A Global Map of Human Impact on Marine Ecosystems. *Science* **2008**, *319*, 948–952. [CrossRef] [PubMed]
7. Sherman, C.S.; Simpfendorfer, C.A.; Pacoureau, N.; Matsushiba, J.H.; Yan, H.F.; Walls, R.H.L.; Rigby, C.L.; VanderWright, W.J.; Jabado, R.W.; Pollom, R.A.; et al. Half a century of rising extinction risk of coral reef sharks and rays. *Nat. Commun.* **2023**, *14*, 15. [CrossRef]
8. Lotze, H.K.; Worm, B. Historical baselines for large marine animals. *TREE* **2009**, *24*, 254–262. [CrossRef]
9. Dulvy, N.K.; Pacoureau, N.; Rigby, C.L.; Pollom, R.A.; Jabado, R.W.; Ebert, D.A.; Finucci, B.; Pollock, C.M.; Cheok, J.; Derrick, D.H.; et al. Overfishing drives over o-third of all sharks and rays toward a global extinction crisis. *Curr. Biol.* **2021**, *31*, 4773–4787. [CrossRef] [PubMed]
10. Heithaus, M.R.; Frid, A.; Wirsing, A.J.; Worm, B. Predicting ecological consequences of marine top predator declines. *TREE* **2008**, *23*, 202–210. [CrossRef] [PubMed]
11. Estes, J.A.; Heithaus, M.R.; McCauley, D.J.; Rasher, D.B.; Worm, B. Megafaunal impacts on structure and function of ocean ecosystems. *Annu. Rev. Environ. Resour.* **2016**, *41*, 83–116. [CrossRef]
12. Roff, G.; Doropoulos, C.; Rogers, A.; Bozec, Y.-M.; Krueck, N.C.; Aurellado, E.; Priest, M.; Birrell, C.; Mumby, P.J. The Ecological Role of Sharks on Coral Reefs. *TREE* **2016**, *31*, 395–407. [CrossRef] [PubMed]
13. Worm, B.; Barbier, E.B.; Beaumont, N.; Duffy, J.E.; Folke, C.; Halpern, B.S.; Jackson, J.B.C.; Lotze, H.K.; Micheli, F.; Palumbi, S.R.; et al. Impacts of biodiversity loss on ocean ecosystem services. *Science* **2006**, *314*, 787–790. [CrossRef]
14. Ferretti, F.; Worm, B.; Britten, G.L.; Heithaus, M.R.; Lotze, H.K. Patterns and ecosystem consequences of shark declines in the ocean. *Ecol. Lett.* **2010**, *13*, 1055–1071. [CrossRef] [PubMed]
15. Flowers, K.I.; Heithaus, M.R.; Papastamatiou, Y.P. Buried in the sand: Uncovering the ecological roles and importance of rays. *Fish Fish.* **2020**, *22*, 106–127. [CrossRef]
16. Bonfil, R. Overview of world elasmobranch fisheries. In *FAO Technical Paper*; FAO: Rome, Italy, 1994.
17. Robinson, L.; Sauer, W.H.H. A first description of the artisanal shark fishery in northern Madagascar: Implications for management. *Afr. J. Mar. Sci.* **2013**, *35*, 9–15. [CrossRef]
18. Oliver, S.; Braccini, M.; Newman, S.J.; Harvey, E.S. Global patterns in the bycatch of sharks and rays. *Mar. Policy* **2015**, *54*, 86–97. [CrossRef]
19. Stevens, J.D.; Bonfil, R.; Dulvy, N.K.; Walker, P. The effects of fishing on sharks, rays and chimaeras (Chondrichthyans), and the implications for marine ecosystems. *ICES J. Mar. Sci.* **2000**, *57*, 476–494. [CrossRef]
20. Musick, J.A.; Musick, S. Sharks (Special Topics C3). In *Review of the State of the World Marine Fishery Resources*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2000; Volume 569, pp. 245–254.
21. Dudley, S.F.J. A comparison of the shark control programs of New South Wales and Queensland (Australia) and KwaZulu-Natal (South Africa). *Ocean Coast.* **1997**, *34*, 1–27. [CrossRef]
22. Roberts, C.M.; McClean, C.J.; Veron, J.E.; Hawkins, J.P.; Allen, G.R.; McAllister, D.E.; Mittermeier, C.G.; Schueler, F.W.; Spalding, M.; Wells, F. Marine biodiversity hotspots and conservation priorities for tropical reefs. *Science* **2002**, *295*, 1280–1284. [CrossRef]
23. McDougall, I. The geochromology and evolution of the young volcanic island of Reunion, Indian Ocean. *Geochim. Cosmochim. Acta* **1970**, *35*, 261–288. [CrossRef]
24. Bourmaud, C.A.F.; Abouidane, A.; Boissier, P.; Leclere, L.; Mirault, E.; Pennober, G. Coastal and marine biodiversity of La Reunion. *Ind. J. Mar. Sci.* **2005**, *34*, 98–103.
25. Dulau-Drouot, V.; Boucaud, V.; Rota, B. Cetacean diversity off La Réunion Island (France). *J. Mar. Biol. Ass.* **2008**, *88*, 1263–1272. [CrossRef]
26. Frick, R.; Mulochau, T.; Durville, P.; Chabanet, P.; Tessier, E.; Letourneur, Y. Annotated checklist of the fish species (Pisces) of La Réunion, including a Red list of threatened and declining species. *Stutt. Beit. Natur. A* **2009**, *2*, 1–168.
27. Conand, C.; Ribes-Beaudemoulin, S.; Trentin, F.; Mulochau, T.; Boissin, E. Marine Biodiversity of La Reunion Island: Echinoderms. *WIO J. Mar. Sci.* **2018**, *17*, 111–124.
28. Wickel, J.; Fricke, R.; Durville, P.; Chabanet, P.; Dumestre, M.; Mulochau, T.; Pinault, M.; Tessier, E. Updated checklist of the fish species of Reunion Island. In *Évaluation de Statuts de Conservation Pour les Poisons Récifaux à la Réunion*; Dumestre, M., Wickel, J., Eds.; Marex/Deal 974: Saint-Denis, France, 2020.

29. Letourneur, Y.; Chabanet, P.; Durville, P.; Taquet, M.; Tessier, E.; Parmentier, M.; Quéro, J.-C.; Pothin, K. An updated checklist of the marine fish fauna of Reunion Island, South-Western Indian Ocean. *Cybium* **2004**, *28*, 199–216.
30. Kiszka, J.J.; Jamon, A.; Wickel, J. *Les Requins dans les îles de l'océan Indien Occidental: Biodiversité, Distribution et Interactions Avec les Activités Humaines*; MAYSHARK: Mayotte, France, 2009.
31. Mariani, S.; Fernandez, C.; Baillie, C.; Magalon, H.; Jaquemet, S. Shark and ray diversity, abundance and temporal variation around an Indian Ocean Island, inferred by eDNA metabarcoding. *Conserv. Sci. Pract.* **2021**, *3*, e407. [CrossRef]
32. Lagabrielle, E.; Allibert, A.; Kiszka, J.J.; Loiseau, N.; Kilfoil, J.P.; Lemahieu, A. Environmental and anthropogenic factors affecting the increasing occurrence of shark-human interactions around a fast-developing Indian Ocean island. *Sci. Rep.* **2018**, *8*, 3676. [CrossRef] [PubMed]
33. Guyomard, D.; Perry, C.; Tournoux, P.-U.; Cliff, G.; Peddemors, V.; Jaquemet, S. An innovative fishing gear to enhance the release of non-target species in coastal shark-control programs: The SMART (shark management alert in real-time) drumline. *Fish. Res.* **2019**, *216*, 6–17. [CrossRef]
34. Ivanova, N.V.; Zemlak, T.S.; Hanner, R.H.; Hebert, P.D. Universal primer cocktails for fish DNA barcoding. *Mol. Ecol. Notes* **2007**, *7*, 544–548. [CrossRef]
35. Oury, N.; Jaquemet, S.; Simon, G.; Casalot, L.; Vangrevelynghe, G.; Landron, F.; Magalon, H. Forensic genetic identification of sharks involved in human attacks. *Foren. Sci. Int. Genet.* **2021**, *54*, 102558. [CrossRef]
36. Kearse, M.; Moir, R.; Wilson, A.; Stones-Havas, S.; Cheung, M.; Sturrock, S.; Buxton, S.; Cooper, A.; Markowitz, S.; Duran, C.; et al. Geneious Basic: An integrated and extendable desktop software platform for the organization and analysis of sequence data. *Bioinformatics* **2012**, *28*, 1647–1649. [CrossRef] [PubMed]
37. Ratnasingham, S.; Hebert, P.D. BOLD: The barcode of life data system. *Mol. Ecol. Notes* **2007**, *7*, 355–364. [CrossRef] [PubMed]
38. Barbuto, M.; Galimberti, A.; Ferri, E.; Labra, M.; Malandra, R.; Galli, P.; Casiraghi, M. DNA barcoding reveals fraudulent substitutions in shark seafood products: The Italian case of "palombo" (*Mustelus* spp.). *Food Res. Int.* **2010**, *43*, 376–381. [CrossRef]
39. Conand, F.; Marsac, F.; Tessier, E.; Conand, C. A ten-year period of daily sea surface temperature at a coastal station in Reunion Island, Indian Ocean (July 1993–April 2004): Patterns of variability and biological responses. *WIO J. Mar. Sci.* **2007**, *6*, 48222. [CrossRef]
40. Jabado, R.W. *Wedgefishes and Giant Guitarfishes: A Guide to Species Identification*; Wildlife Conservation Society: New York, NY, USA, 2019.
41. Bullock, R.; Ralph, G.; Stump, E.; Al Abdali, F.; Al Asfoor, J.; Al Buwaiqi, B.; Al Kindi, A.; Ambuali, A.; Birge, T.; Borsa, P.; et al. *The Conservation Status of Marine Biodiversity of the Western Indian Ocean*; IUCN: Gland, Switzerland, 2021; pp. vii + 32.
42. Kiszka, J.J.; Van Der Elst, R.P. Elasmobranchs, p366–386. In *Offshore Fisheries of the Southwest Indian Ocean: Their Status and the Impact on Vulnerable Species*; Van Der Elst, R.P., Everett, B.I., Eds.; Oceanographic Research Institute: Pechardwip, Bangladesh, 2015; Special Publication; Volume 10, p. 448.
43. McVean, A.R.; Walker, R.C.J.; Fanning, E. The traditional shark fisheries of southwest Madagascar: A study in the Toliara region. *Fish. Res.* **2006**, *82*, 280–289. [CrossRef]
44. Nevill, J.; Robinson, J.; Giroux, F.; Isidore, M. *Seychelles National Plan of Action for the Conservation and Management of Sharks*; Seychelles Fishing Authority: Victoria, Seychelles, 2007; 59p.
45. Poonian, C.N.S. A first assessment of elasmobranch catch in Mauritian artisanal fisheries using interview surveys. *Phelsuma* **2015**, *23*, 19–29.
46. Kyne, P.M.; Mauvis, A.G.; Ebert, D.A.; Jabado, R.W.; Rigby, C.L.; Dharmadi; Pollock, C.M.; Herman, K.B.; Cheok, J.; Simpfendorfer, C.A.; et al. The thin edge of the wedge: Extremely high extinction risk in wedgefishes and giant guitarfishes. *Aqua. Cons. Mar. Fresh. Ecos.* **2020**, *30*, 1337–1361. [CrossRef]
47. Humber, F.; Andrianmahaino, E.T.; Beriziny, T.; Botosoamananto, R.; Godley, B.J.; Gough, C.; Pedron, S.; Ramahery, V.; Broderick, A.C. Assessing the small-scale shark fishery of Madagascar through community-based monitoring and knowledge. *Fish. Res.* **2017**, *186*, 131–143. [CrossRef]
48. Rigby, C.L.; Dulvy, N.K.; Barreto, R.; Carlson, J.; Fernando, D.; Fordham, S.; Francis, M.P.; Herman, K.; Jabado, R.W.; Liu, K.M.; et al. Sphyrna lewini. In *The IUCN Red List of Threatened Species*; IUCN Red List: Cambridge, UK, 2019; p. eT3985A2918526.
49. Niella, Y.; Wiefels, A.; Almeida, U.; Jaquemet, S.; Lagabrielle, E.; Harcourt, R.; Peddemors, V.; Guyomard, D. Dynamics of marine predators off an oceanic island and implications for management of a preventative shark fishing program. *Mar. Biol.* **2021**, *168*, 42. [CrossRef]
50. Pirog, A.; Magalon, H.; Poirout, T.; Jaquemet, S. Reproductive biology, multiple paternity and polyandry of the bull shark *Carcharhinus leucas*. *J. Fish Biol.* **2019**, *95*, 1195–1206. [CrossRef] [PubMed]
51. Adams, D.H.; Paperno, R. Preliminary Assessment of a Nearshore Nursery Ground for the Scalloped Hammerhead off the Atlantic Coast of Florida. In *Shark Nursery Grounds of the Gulf of Mexico and the East Coast Waters of the United States*; McCandless, C.T., Kohler, N.E., Pratt, H.L., Eds.; Chapter: Preliminary Assessment of a Neashore Nursery Ground for the Scalloped Hammerhead off the Atlantic Coast of Florida; American Fisheries Society: New York, NY, USA, 2007; pp. 165–174.
52. Cuevas-Gómez, G.A.; Pérez-Jiménez, J.C.; Méndez-Loeza, I.; Carrera-Fernández, M.; Castillo-Géniz, J.L. Identification of a nursery area for the critically endangered hammerhead shark (Sphyrna lewini) amid intense fisheries in the southern Gulf of Mexico. *J. Fish Biol.* **2020**, *97*, 1087–1096. [CrossRef] [PubMed]

53. Werry, J.M.; Lee, S.Y.; Lemckert, C.J.; Otway, N.M. Natural or artificial? Habitat-use by the bull shark, *Carcharhinus leucas*. *PLoS ONE* **2012**, *7*, e49796. [CrossRef]
54. Zanella, I.; López-Garro, A.; Cure, K. Golfo Dulce: Critical habitat and nursery area for juvenile scalloped hammerhead sharks *Sphyrna lewini* in the Eastern Tropical Pacific Seascape. *Environ. Biol. Fishes* **2019**, *102*, 1291–1300. [CrossRef]