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FIJI RIDGE TO REEF PROJECT

ACTIVITY 1.1.1.2: VANUA O VOTUA SHARK AND RAY SURVEY REPORT

AUGUST 2019

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Front cover photo: A scalloped hammerhead shark (*Sphyrna lewini*) is released back into the Ba Estuary after measurements. **Photo credit:** Tom Vierus.

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LIST OF ACRONYMS AND ABBREVIATIONS

CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
GEF	Global Environment Facility
IAS	The Institute of Applied Sciences
IUCN	International Union for Conservation of Nature
LMMA	Locally Managed Marine Area
R2R	Ridge to Reef
SDG14	Sustainable Development Goal 14 on Oceans
UNDP	United Nations Development Program
USP	The University of the South Pacific

EXECUTIVE SUMMARY

The demarcation of a potential shark and ray nursery area in the Ba Estuary was prepared in accordance with Activity 1.1.1.2 of the Global Environment Facility (GEF) funded Fijian Government's Ridge to Reef (R2R) project, implemented by the United Nations Development Programme (UNDP) and the Ministry of Waterways and Environment. One of the project's objectives is to effectively manage priority water catchments on Viti Levu and Vanua Levu, the two main islands of Fiji by addressing vital environmental issues through the enhancement of Locally Managed Marine Areas (LMMA) and affording greater protection of threatened marine species.

As part of this component of the Fiji R2R project, fishery-independent surveys of elasmobranch fauna were undertaken in the Ba Estuary in Viti Levu by the University of the South Pacific's School of Marine Studies and the Institute of Applied Sciences over a period of 113 days from December 2015 to July 2019 and were comprised of 361 bottom-set gillnet and longline deployments at multiple sites in the estuary.

Key findings encompassed the discovery of four shark and two ray species in the surveys, with the scalloped hammerhead shark (*Sphyrna lewini*; N = 97) and blacktip shark (*Carcharhinus limbatus*; N = 89) being the most common. Three further elasmobranch species were observed sporadically, but not captured in the surveys. Of these nine species, one was listed as Critically Endangered, two were listed as Endangered, four as Vulnerable and two as Near Threatened on the International Union for the Conservation of Nature (IUCN) Red List. Increased elasmobranch abundance and an elevated proportion of neonates occurred from November to February, most likely the birthing season for the encountered species. Further, a critical area with high catch of juveniles in the center of the estuary was demarcated and recommended as highest priority area for management.

Given the alarming declines of populations of sharks and rays globally and the resulting importance of the protection of essential habitats, this report suggests that the Ba Estuary is likely a valuable target for elasmobranch conservation. In particular, an LMMA with spatio-temporal fishing closures or restrictions covering the months and locations of highest shark and ray abundance is recommended. It is further recommended to harmonize local management measures with the involved stakeholders and communities and to extend and continue scientific research and bycatch monitoring in the area as part of a sustainable coastal development strategy.

1. INTRODUCTION

1.1 General Relevance

Sharks and rays are facing significant reductions in population sizes in recent times, making it a necessity to better understand their biology and ecology. Multiple human-driven factors like habitat loss, fishing pressure and climate change are threatening a large amount of the more than 1,250 recorded elasmobranch species (Dulvy et al., 2014, 2017; Ferretti et al., 2010). Typically occupying important trophic positions in marine food webs, sharks contribute to the regulation of multiple other species and are often considered "keystone species" for the functioning of marine ecosystems (Bornatowski et al., 2014; Heithaus et al., 2008; Heupel et al., 2014). When used sustainably, they can play a vital role for food security of coastal populations and carry non-consumption value for tourism development (Gallagher and Hammerschlag, 2011; Simpfendorfer and Dulvy, 2017).

In particular due to low annual reproductive output, late age of sexual maturity, slow growth rates and long life spans, rigorous efforts are required to effectively manage populations of sharks and rays (Dulvy et al., 2014, 2017; Ferretti et al., 2010; Heithaus et al., 2008). Sharks and rays are targeted in a wide range of fisheries for multiple products including meat, fins, gills and teeth. Incidental catches (bycatch) are also frequent, including in artisanal fisheries.

Conservation efforts for elasmobranchs require a clear understanding of the ecological processes they support and depend on. Given the complex movement ecology of many sharks and rays, data on the spatio-temporal distribution of critical life-history stages are especially needed. Many species exhibit philopatry, whereby individuals often return to or remain in specific locations for mating, parturition and maturation, making certain areas essential for population survival (Chapman et al., 2015; Hueter et al., 2005; Tillett et al., 2012).

Elasmobranch species which exhibit philopatry within coastal embayments and estuaries are subject to a plethora of threats both natural and anthropogenic. Estuaries in particular face heavy pressures, such as fishing, an increase in coastal development, declining water quality and habitat loss owing to their close proximity to human populations (Lotze et al., 2006). It has been suggested that several shark species use estuaries as nursery areas. Such areas can offer a steady source of food and protection from predators to juvenile cohorts (Froeschke et al., 2010; Heupel and Simpfendorfer, 2011). By definition, sharks visit such nursery areas repeatedly across years, spend a significant amount of time in these areas and inhabit them at higher densities than surrounding areas (Heupel et al., 2007). They are hence considered critical habitats and their identification is key to understanding elasmobranch ecology and improving current management approaches, in particular in countries with large tropical coastlines that are home to many elasmobranch species.

To support the identification of a critical habitat and potential nursery area in the Ba Estuary, Fiji Islands, this report compiles the results from fishery-independent surveys. The results serve as the basis for the demarcation of areas critical for protection within the Ba Estuary and for coastal management recommendations with special emphasis on potential LMMAs.

1.2 Sharks and Rays in Fiji

Over 40 coastal and pelagic species of elasmobranchs have been documented in Fiji waters with a quarter of these listed on the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the Convention on Migratory Species of Wild Animals (Sykes et al., 2018). Fishing pressures are mostly exerted by small-scale artisanal fisheries both offshore and inshore. Elasmobranchs are partially targeted directly for the high value of shark products, such as fins, gills and teeth, but also occur frequently as bycatch (Glaus et al., 2015, 2019a). An analysis of elasmobranchs caught in Fiji waters by offshore fishing fleets between 2011 and 2014 recorded a total of twenty-seven species, half of which were categorized as threatened in the IUCN Red List (Piovano and Gilman, 2017). Essential fish habitats for sharks have been identified in Fiji waters with potential nursery areas for bull sharks located in the Rewa, Navua, Sigatoka and Ba Rivers and for the endangered scalloped hammerhead sharks in the Rewa and Ba Estuary (Glaus et al., 2019b; Marie et al., 2017; Vierus et al., 2018). The utilization of Fijian riverine systems by sharks could be the result of a lack of other large river systems in the South Pacific. The nearest large river system is located in the Hawaiian archipelago almost 5000 kilometers away to the Northeast and to the West, New Caledonia at a distance of 1200 kilometers.

1.3 USP Shark Research in Fiji

The Shark Research Program was initiated by the University of the South Pacific's (USP) School of Marine Studies in 2014 with the primary goals to inform the management of the scalloped hammerhead shark fisheries in Fiji under CITES regulations and to investigate the population dynamics and structure of Fiji's bull sharks. A key objective of the project was to enhance conservation and management efforts by identifying priority populations and critical habitats in Fiji (https://www.usp.ac.fj/index.php?id=21104; accessed 2019-08). Subsequent research by the USP School of Marine Studies showed that the Rewa Delta serves as an aggregation area for scalloped hammerhead sharks (Brown et al., 2016). A follow-up study by Marie et al. (2017) confirmed this by capturing a total of 952 individuals during the period from September 2014 to March 2016 using bottom-set gill nets. A study by Glaus et al. (2019b) documented the spatio-temporal distribution of bull sharks in the Rewa, Sigatoka, and Navua Rivers. Fisheries-independent surveys captured 172 young bull sharks from January 2016 to April 2018 in the three of the largest riverine systems in Fiji, indicating that these areas provide essential habitat for newly born bull sharks. Genetic studies into scalloped hammerhead shark populations suggest connectivity between young individuals from the Rewa Delta and the Ba Estuary, potentially by migrating males which mate with females at both sites. With regard to population structure, the Ba Estuary was found to be utilized by at least two distinct populations of scalloped hammerhead shark which likely are from regions separated by a considerable distance (Marie et al., forthcoming). In this context of shark research at USP's School of Marine Studies with the goal of gathering information to effectively manage local populations, Vierus et al. (2018) commenced fishery-independent surveys in the Ba Estuary, followed by A. Paris (this report).

1.4 Shark Legislation and Policy

Despite various fragmented laws that deal with the establishment of shark protection zones, prohibitions on the trade of shark-related products, provisions on the treatment of sharks through the Fisheries Act 1941, the Offshore Fisheries Management Decree 2012 and the Endangered and Protected Species Act 2002, evidence-based and effective shark and ray conservation regulations have yet to be adopted (Sloan, 2019). The Endangered and Protected Species (Amendment) Act 2017 was formalized to amend the Endangered and Protected Species Act 2002 and regulates the trade of all species listed in Appendix I, II and III of CITES as well as local species that are considered to be nationally threatened. The Endangered and Protected Species (Amendment) Act 2017 has included twelve new species to the number of protected elasmobranchs. The Fiji Customs (Prohibited Imports and Exports) Regulations 1986 Schedule 1 also bans the import/export of shark fins. Legislation and policy regulating the exploitation of sharks in Fiji is also determined by the Western Central Pacific Fisheries Commission's Conservation and Management Measures first introduced in 2007 and revised in 2014. The management measures deal with the non-retention of dead sharks, release of live sharks unharmed, introduction of mitigation measures, and annual reporting of shark numbers caught by national fleets in annual reports to the Commission. An overview of elasmobranch species in the Ba Estuary with national and international obligations is provided in the Appendix A2.

1.5 The Ba Estuary

The Ba River Delta (Figure 1) is located on the Northwestern or leeward side of Fiji's largest island Viti Levu and supports one of the country's largest contiguous stands of mangroves with a total area of approximately 400 square kilometers, of which the majority is located on the large river mouths (Secretariat of the Pacific Regional Environment Programme, 2007). The study site encompasses an area of approximately 29 square kilometres with a depth range from one meter along the fringes of the mangroves to five meters along the seaward boundary where the inshore mud and sand flats drop off to the continental shelf. The western most boundary lies along Natogo creek which flows into the Karavi Bay and the eastern most end is bound by Bulu creek, a distance of approximately thirteen kilometers. The average distance from the land-sea interface to the drop off is two kilometers and include a diverse array of habitats such as mangroves, shorelines, estuaries, lagoons and reefs. The substrate comprises of bare rock, mud and sand, which supports a variety of seagrass including *Halophila ovalis* and algal beds dominated by *Dictyota* species. The Ba Estuary has been documented as supporting a high fish diversity and a high crustacean and mollusk productivity (Sykes et al., 2018). Daily temperature readings throughout this study found the average sea surface temperature to be at 28 degree Celsius with a range from 25 degrees Celsius in the month of August to 32 degrees Celsius in the month of February.

The site lies within the boundaries of the *Vanua o Votua Qoliqoli*, a type of customary fishing ground (Sloan and Chand, 2016), and is predominantly utilized by villagers of the three communities that lie on the banks of the Ba River closer to the river mouth, namely Votua, Nawaqarua and Natutu. The villagers employ a variety of small-scale extractive methods which include gillnetting, beach seining, hand-lining and foraging for crabs.

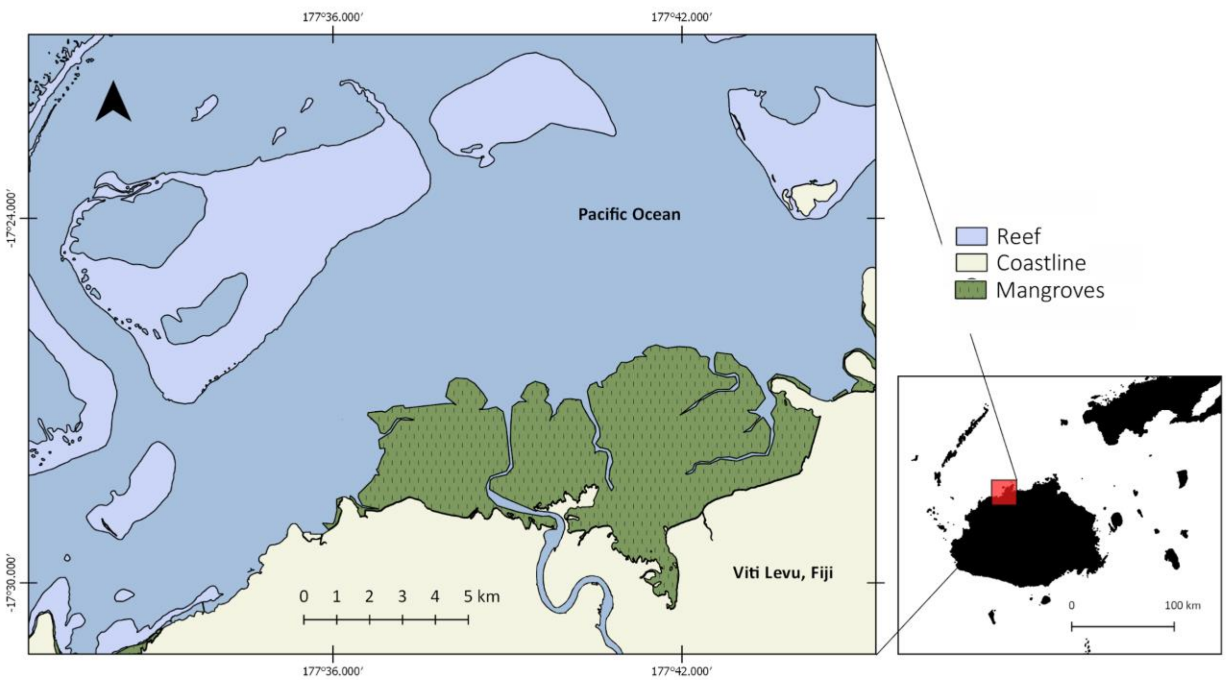

Figure 1. Map of the Ba Estuary in north-western Viti Levu, Fiji Islands. Adapted from Vierus et al. (2018).

1.6 Aims

The aim of this report is to demarcate a possible elasmobranch (sharks and rays) conservation area for the Ba Estuary.

Objectives:

- Investigate and quantify the distribution and abundance of elasmobranch species in the Ba Estuary.

- Identify and demarcate potentially important shark and ray nursery areas and appropriate conservation tools for enhanced protected LMMA according to IUCN protected area category VI.

2. METHODOLOGY

2.1 Sampling Methods

Fishery-independent surveys were undertaken over a period of 113 days from December 2015 to July 2019 and were comprised of 361 bottom-set gillnet and longline deployments across the estuary. The sampling area was selected on the advice of local fishermen and a pilot study by one of the authors (T. Vierus). Sampling times were between 5pm and 2am. Up to two gillnets (100 m length and 3 m width, ~10 cm mesh size) were deployed simultaneously with a soak time of 1–6 hrs. To minimize animal stress and mortality, gillnets were regularly checked in intervals of 15–25 min. When feasible, a longline (75 m) with 27 hooks was additionally deployed. Distance between gangions attached to the floater line varied from 2.4 to 2.8 m. Gangion length ranged between 0.6 and 3 m, with the last 0.5 m consisting of 1.5 mm steel wire and a baited 13″ circle hook. A Garmin e-trex 20 model GPS was utilized to record site locations. See Appendix A1 for composition of bycatch.

2.2 Shark Handling

Captured individuals were freed, processed and released back into the water on the opposite end of the boat. Processing involved recording species when possible, sex, umbilical scar condition and total length. The umbilical scar condition was categorized based on the degree of healing; open, semi-healed, healed. Open and semi-healed umbilical scars are characteristic for the neonate period with a duration of approximately 15 days until healed. Healed scars are indicative of an age more than 15 days and these specimens are classified as young-of-the-year (Duncan and Holland, 2006).

3. RESULTS

3.1 Catch Composition

Between December 2015 and July 2019, a total of 361 deployments (330 gillnet and 31 longline) were conducted totaling 587 hours of fishing distributed across seasons (Figure 2A). Total elasmobranch catch per unit effort (CPUE) was 0.38 per hour. CPUE was highest from

November to February and April to June (Table 1; but note the comparably small number of effort in April, May, July and August shown in Figure 2A).

Table 1. Elasmobranch CPUE in 1/hour, aggregated by month.

Month	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov	Dec
Mean CPUE	0.49	0.46	0.22	0.46	0.67	0.40	0.12	0.23	0.12	0.19	0.47	0.60

The fishery-independent survey led to the capture of 207 sharks consisting of four shark species (Table 2): scalloped hammerhead shark (*Sphyrna lewini*; N = 97), blacktip shark (*Carcharhinus limbatus*; N = 89), great hammerhead shark (*Sphyrna mokarran*; N = 14), bull shark (*Carcharhinus leucas*; N = 7), and 18 rays consisting of two ray species (Table 2): ocellated eagle ray (*Aetobatus ocellatus*; N = 13), and pink whipray (*Pateobatus fai*; N = 5). Sporadic, not survey-related observations in the Ba Estuary of one of the authors (A. Paris) documented the occurrence of at least one more shark species: tawny nurse shark (*Nebrius ferrugineus*; N = 2); and two more ray species: reef manta ray (*Manta alfredi*; N = 8) and bottlenose wedgefish (*Rhynchobatus australiae*; N = 2). Individuals were either identified by genetic analysis, as for many of the four captured shark species (see Vierus et al., 2018) but could not be undertaken for all individuals. The remaining individuals were identified visually (see Appendix A4 for photos).

3.2. Biological Shark Data

The two most common elasmobranch species encountered during the fishery-independent survey were the scalloped hammerhead shark *S. lewini* (N = 97) and the blacktip shark *C. limbatus* (N = 89). With mean sizes of 51.6 cm and 66.1 cm, respectively (Table 2), captured sharks were either neonate or young-of-the-year. The great hammerhead individuals encountered during this study (*S. mokarran,* N = 14) exhibited a mean length of 76.5 cm, whereas the seven bull sharks (*C. leucas*) measured a mean length of 88.1 cm. The male: female ratio of the blacktip shark and the scalloped hammerhead shark was about 1:1, while female great hammerheads outnumbered males with a male to female ratio of 0.4:1 (but note the small sample). Overall, 69% of successful umbilical scar assessments of captured sharks demonstrated open or semi-healed scars, indicating recent birth for the majority of those individuals. The proportion of open umbilical scars was especially high from November to February (Figure 2BC).

Table 2. Overview of elasmobranch species caught in the Ba Estuary and information on sex, length and umbilical scar condition for those where measurement was possible.

Species	N	Sex		Length				Umbilical scar condition		
		male	female	mean	SD	min.	max.	open	semi-healed	healed
S. lewini	97	50	47	51.6	4.9	37	61.8	26	31	40
C. limbatus	89	45	43	66.1	3.5	54.3	76.4	60	17	10
S. mokarran	14	4	9	76.5	3	72.3	81.5	-	4	9
C. leucas	7	3	4	88.1	12	81	115	5	1	1
A. ocellatus	13	2	3	49.6	13.9	29	62	-	-	2
P. fai	5	0	4	103.3	23.6	85	130	-	-	3

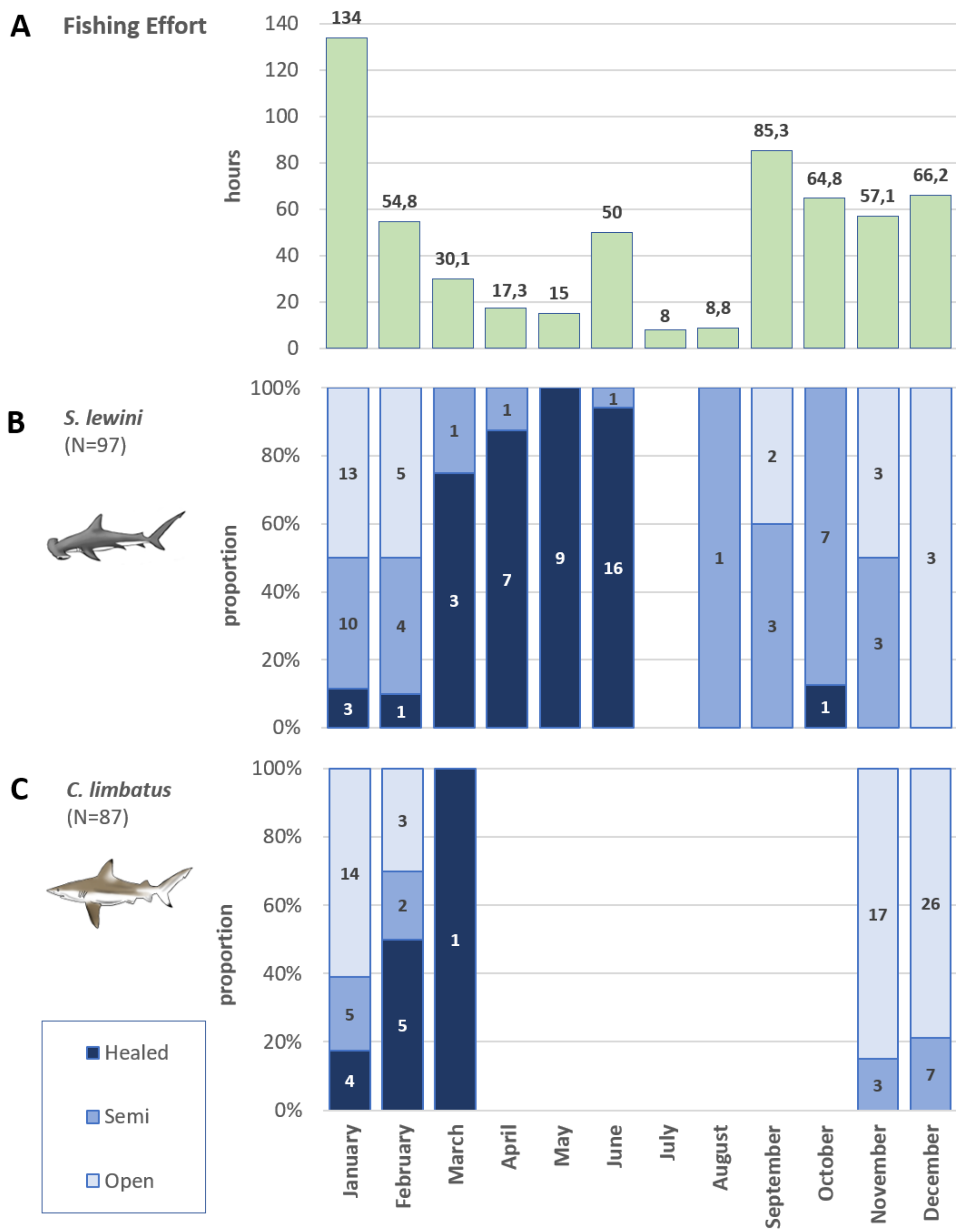

Figure 2. Pooled monthly fishing effort (A) and umbilical scar condition (open: light blue; semi-healed: blue, closed: dark blue) for the two most frequently caught species (B) *S. lewini* (scars identified in N = 97 individuals), and (C) *C. limbatus* (scars identified in N = 87 individuals).

3.3 Spatial Distribution of Elasmobranchs

Analyzing total elasmobranch CPUE spatially (as CPUE per grid cell of 1.3 km²; see Figure 3) revealed high abundance particularly in the center area of the Ba Estuary close to the river mouth, extending along the coast to the West.

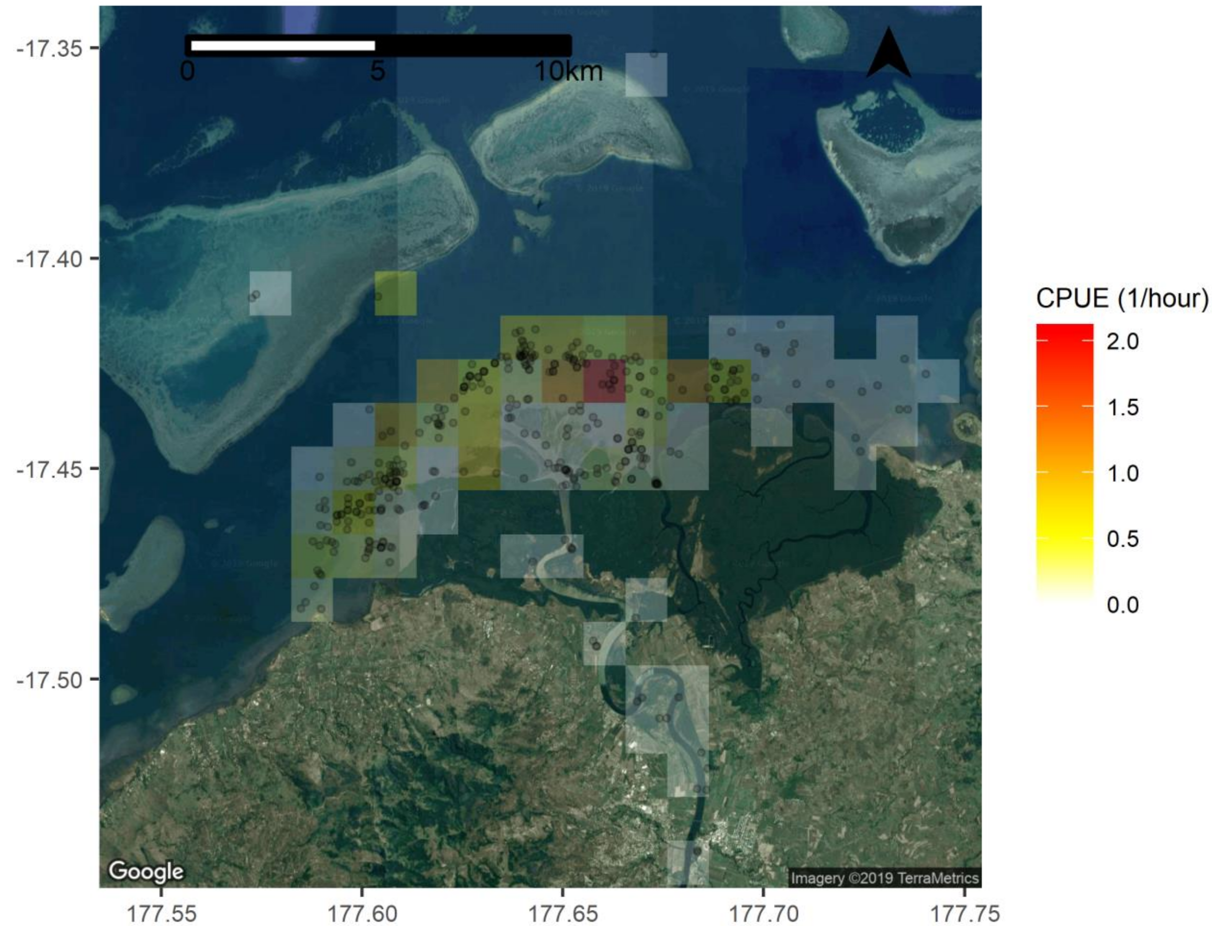

Figure 3. Spatial distribution of elasmobranchs (all shark and ray species pooled). One point represents one sampling deployment. Coloring intensity of a grid cell reflects CPUE for all sampling deployments within the cell (approximately 1.3 km²). No grid cells are shown for areas where no surveying occurred. Axis labels are coordinates in decimal degrees.

Spatial CPUE data was used to designate a highest priority area which could be recommended as target area for management interventions. Figure 4 shows the minimum rectangle which includes all grid cells with elasmobranch CPUE ≥ 1 from Figure 3. Its size is approximately 18.2 km² and it is described by the following coordinates in decimal degree: longitude 177.6136 to 177.6864 and latitude -17.4344 to -17.4136.

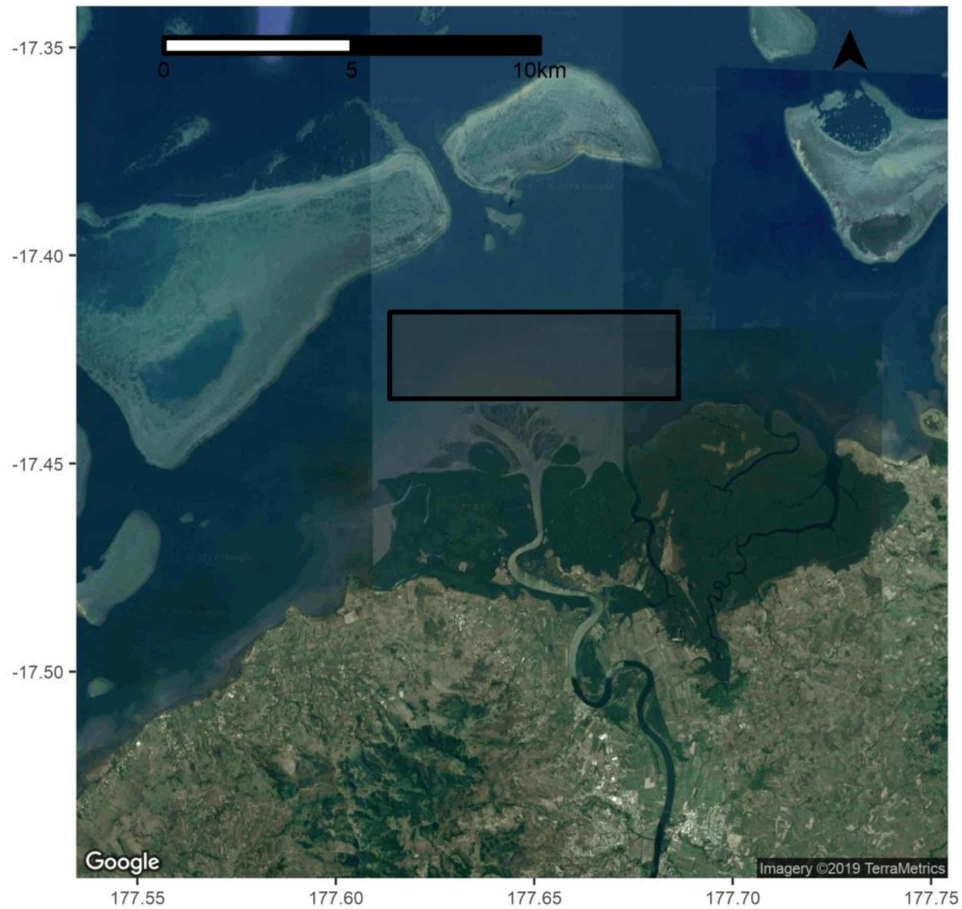

Figure 4. Highest-priority area recommended for elasmobranch conservation and management based on spatial abundance data from the fishery-independent survey. Axis labels are coordinates in decimal degrees.

4. DISCUSSION

4.1 Elasmobranchs of the Ba Estuary

The study evaluated the catch composition of a fishery-independent survey of elasmobranch species in the Ba Estuary and calculated corresponding total CPUE which was 0.38 per hour. Increased abundance of elasmobranchs was observed from November to February (Table 1) when focussing on those months with considerable sampling effort (Figure 2A). These months also tended to be the months with a high proportion of recently born sharks (open or semi-healed umbilical scar). Spatial CPUE data demarcated an area with elevated elasmobranch occurrence in the center of the estuary (Figure 4), consistent with results from a subset of the data previously reported by (Vierus et al., 2018). The following paragraphs discuss further details on abundance, age and spatio-temporal trends for the five most commonly encountered elasmobranch species in the Ba Estuary, based on the available data.

Sphyrna lewini

Scalloped Hammerhead Shark (*qio ulutuki, qio mataitaliga*)

Scalloped hammerhead sharks were found to be the most abundant elasmobranch species in the Ba Estuary, accounting for 43% of all elasmobranch individuals caught (Table 2). The average size of individuals was 51.6 ± 4.9 cm (Table 2), which suggests an approximate age of two weeks as per estimations made for individuals in the Rewa Delta (Marie et al., 2017). Scalloped hammerhead sharks were caught throughout the year and across years with a high percentage of open and semi-healed umbilical scars observed from September to February indicative of a birthing period during these months. A higher proportion of healed scar condition of captured sharks from the months of March to June (Figure 2) suggests the species tends to remain in or return to the estuary for at least several months after birth. The results are similar to findings from the Rewa Delta (Marie et al., 2017) and indicate that both are likely to represent important birthing and nursery areas for this species.

Carcharhinus limbatus

Blacktip Shark (*qio, qio mokomoko, qio tokiloa*)

Blacktip sharks were the second most abundant species representing 40% of all elasmobranch captures in the Ba Estuary (Table 2). A more clearly defined parturition window is observed for the blacktip sharks during the months of November to February. A small fraction of healed scar captures during the months of January to March coupled with the absence of the species from April to October suggests that individuals leave the estuary soon after birth (Figure 2). Observations align well with studies in the Southeastern United States where blacktip sharks were found to leave their nursery area within three months after birth (Castro, 1996).

Sphyrna mokarran

Great Hammerhead Shark (*qio ulutuki, qio mataitaliga*)

Great hammerhead shark abundance was low compared to the two previous shark species, with only 14 captures during all 361 deployments. All individuals with identifiable umbilical scars exhibited either a semi-healed or healed condition. There is scant scientific data on neonates of the species worldwide. However, young-of-the-year with a length range of 64 – 89 cm (Table 2) have been observed to use coastal areas in the Gulf of Mexico during warmer months (Hueter and Tyminski, 2007). A similar size range was documented in the Ba Estuary in this study (72 – 81 cm), suggesting usage at least as a secondary nursery area by this species.

Carcharhinus leucas

Bull Shark (*qio, qio bulubulu, qio qa, qio ni uciwai*)

All seven captures of bull sharks took place near the main Ba River mouth during the month of January 2017 (Appendix A3). The month was observed to have a high percentage of rainy days and strong river currents with a large volume of discharge into the estuary. High precipitation and the consequent large volume of freshwater discharge into the estuary may have caused the temporary migration of bull sharks from riverine to estuarine areas. Bull sharks are known to utilize riverine systems as parturition sites and nursery grounds, and studies have documented the presence of juvenile in Fiji's main river systems, including the Ba River (Cardeñosa et al., 2017; Glaus et al., 2019b; Vierus et al., 2018). For example, Vierus et al. (2018) reported three juvenile bull sharks caught in gillnets by local fishermen in the Ba River several kilometers upstream in Ba River. All individual bull shark captures had either an open or semi-healed umbilical scar condition with an average size of 88.1 ± 12 cm (Table 2) which indicates the utilization of the area as a likely primary nursery.

Aetobatus ocellatus

Ocellated Eagle Ray (*vai lilili, vai beka, vai tonotono*)

Ocellated eagle rays were captured throughout the year in the Ba Estuary with a high percentage of juveniles caught during the months of January and October (Appendix A3). Ocellated eagle ray populations in Queensland, Australia and French Polynesia were also found throughout the year in coastal environments (Berthe, 2017; Schluessel et al., 2010). Previous studies in those locations indicate that current is the main physical parameter that determined distribution in coastal environments with the species preferring foraging in areas with low current. Indeed, most captures of the species were in the coastal embayment to the West of the river mouth, an area with low currents further away from the main river mouth.

4.2 Elasmobranch Philopatry

Several shark species have been shown to exhibit philopatric behavior, i.e., throughout their lives, they return to the same region (regional philopatry) or birth ground (natal philopatry) to give birth to their pups (Chapman et al., 2015). Newborn and juvenile hammerhead and blacktip sharks have been captured consistently in the bay with anecdotal evidence placing their existence in the Ba Estuary as long as local fishermen could remember (Vierus et al., 2018).

The consistent sightings, captures, mean lengths and umbilical scar conditions of these sharks and the scientific studies that took place in the area as well as in the broader region strongly indicate that the Ba Estuary serves first as a birthing ground and then as a subsequent nursery area for young sharks. As rather shallow, sheltered and highly biologically productive environments, bay habitats offer protection from larger sharks and/or offer ample food opportunities for individuals in the first months of their lives (Heupel et al., 2007).

The most dominant elasmobranch species in the Ba Estuary were the scalloped hammerhead shark (*S. lewini*), the blacktip shark (*C. limbatus*) and the great hammerhead shark (*S. mokarran*), all of which have been shown to exhibit regional philopatry in other places (Chapman et al., 2015; Guttridge et al., 2017). This behavior should spark strong effort by researchers and policy-makers to identify and subsequently protect these areas that play a vital part in the sharks' lifecycle. Similarly, bull sharks (*C. leucas*), which were captured near the Ba River mouth and previously observed more upstream, also exhibit regional philopatry (Tillett et al., 2012). Potentially, adult females utilize the Ba River year after year to give birth to their offspring before returning into deeper waters.

4.3 Critical Elasmobranch Areas

Over the course of 113 sampling days spread out over almost three years and encompassing all twelve months, a total of 225 sharks and rays were captured (207 and 18, respectively). It is highly probable that the Ba Estuary plays a critical role in the early-life stages of at least four of the occurring sharks (scalloped and great hammerhead, blacktip, and bull shark). While individuals have been caught throughout the sampling area, the highest CPUE was recorded around the center and center-Westward section of the study area (Figure 3). This subsection of the estuary can with moderate-to-high confidence already be recommended for intensified management. Importantly, local fishermen utilizing gillnets are common in the Ba Estuary and fishing grounds overlap with these areas of highest abundance (T. Vierus and A. Paris, personal observation and communication). A full ban of fishing activities within the bay is neither enforceable nor sensible with regards to the needs and customs of local stakeholders. A recommended approach of meeting demands of local communities as well as decreasing the currently exerted fishing pressure on elasmobranch species is thus recommended as the way forward.

Although further research and an extension of the sampling effort and area is highly advisable, a highest-priority area for an immediate conservation initiative based on the available data (see Figure 4) was demarcated. However, before an implementation of a managed area of any kind, it should be ensured that all stakeholders' costs and benefits are acknowledged and taken into account. A recent Environment Impact Assessment study for a mining operation in the study area noted only one species of shark, the white tip shark (*Triaenodon obesus*) and no rays. It must also be noted that prior to completing this report, USP-IAS was informed that a mining lease exists for a large portion of the area studied, although the lease area for mining operations was not shared with the authors at the time of finalizing this report, which further emphasizes the need for a more diplomatic, multi-stakeholder approach for conservation of elasmobranch populations in the Ba Estuary.

The demarcation of the priority 2 area follows the rationale to extend the highest-priority area towards the river mouth and mangroves. The reasons for selecting this area are (i) repeated elasmobranch catches (although at lower CPUEs, see Figure 3) including all catches of bull sharks (*C. leucas*) in this study, (ii) close proximity to the highest-priority area with highest catch rates and (iii) the generally high productivity and diversity of near-shore areas, estuarine mixing zones and mangrove habitats which are likely essential to species at higher trophic levels like elasmobranchs. Indeed, the nearshore mangroves and mudflats of the Ba Estuary have been attested to be high fish diversity and crustacean and mollusc productivity areas (Sykes et al., 2018, p. 50). The size of the priority 2 area was matched to the size of the highest-priority area and is also approximately 18.2 km² and described by the following coordinates in decimal degree: longitude 177.6136 to 177.6864 and latitude to -17.4552 to -17.4344.

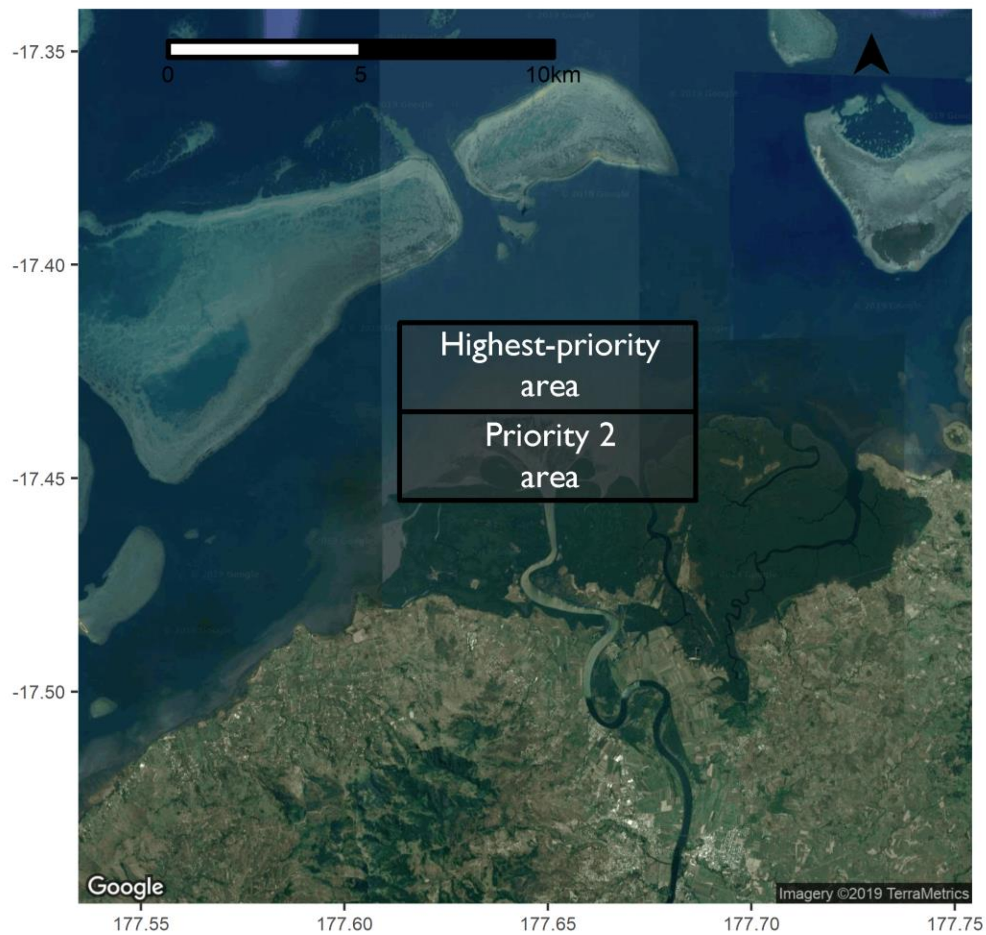

Figure 5: Highest-priority and priority 2 area for elasmobranch conservation in the Ba Estuary.

4.4 Elasmobranch Conservation

Fiji had made 17 SDG14 voluntary commitments at the 2017 United Nations Ocean Conference in New York, including the protection of all shark and ray habitats in Fijian waters under the Sustainable Development Goal 14 (https://oceanconference.un.org/commitments/?id=19999; accessed 2019-08). Considering the rapid decline of elasmobranch populations throughout the world (Dulvy et al., 2014, 2017; Ferretti et al., 2010) and their ecological importance for marine ecosystems (Bornatowski et al., 2014; Heithaus et al., 2008; Heupel et al., 2014) as well as economic potential (Gallagher and Hammerschlag, 2011; Simpfendorfer and Dulvy, 2017), a better management approach for shark and ray populations is urgently needed.

Fiji is home to at least 40 species of sharks and rays (Sykes et al., 2018) and has a responsibility to ensure their long-term survival. Recently published research suggest Fiji may be a hotspot within the Pacific with likely the largest hammerhead shark nursery situated in the Rewa Estuary, Fiji's major riverine system (Marie et al., 2017). While more studies should focus on identifying potential areas of conservation interest for threatened species, the available data for the Ba Estuary highlights the importance of improved management approaches for the area. In 2016, approximately 150 licensed boats were fishing the *Qoliqoli Votua* (customary fishing grounds) and most of them utilized gillnets, a technique which yielded the highest amount of shark bycatch (Vierus, personal communication, 2016). This number will likely be higher now and is projected to increase in the future, exacerbating the fishing pressure on all fish species within the bay, including sharks and rays.

Both hammerhead shark species (*S. lewini* and *S. mokarran*) frequently encountered and captured in the Ba Estuary are classified as Endangered on the Red List of Threatened Species (IUCN, 2019). The blacktip shark (*C. limbatus*), the second most abundant shark during the sampling period, and the bull shark (*C. leucas*) are listed as Near Threatened. Four of the sporadically documented species are listed as Vulnerable; the ocellated eagle ray (*Aetobatus ocellatus*), the pink whipray (*Pateobatus fai*), the reef manta (*Manta alfredi*) and the tawny nurse shark *(Nebrius ferrugineus*). Of particular significance is the Critically Endangered bottlenose wedgefish (*Rhychobatus australiae*) which was encountered on two occasions. All listings (see Appendix A2) highlight the urgency of protecting the shark and ray species. The current high fishing pressure leads to unsustainable catch rates, which by far exceed the natural capability of these predators to reproduce quick enough and maintain healthy populations.

4.5 Management Implications and Recommendations

Ownership of the seabed and overlying waters throughout Fiji remains with the state. However, the Fisheries Act recognizes traditional fishing rights within *qoliqoli* boundaries by customary landowners (Clarke and Jupiter, 2010). The *Vanua o Votua Qoliqoli* Resource Management Committee is comprised of representatives from each village whose management decisions require authorization from the *bose vanua*. The resource management committee makes broad decisions over regulations for the *qoliqoli* and ultimately the decision to impose customary management of the Ba Estuary will be theirs. Marine management initiatives in the *Qoliqoli Votua* have been implemented through the Fiji LMMA network with institutional support from the *Votua Yaubula* Management Support Team governing the management of these LMMA's and "no-take zones" at the community level. Management actions can involve bans on certain types of fishing gear, on the harvesting of certain species and seasonal closures (Mills et al., 2011).

The Ridge to Reef (R2R) project seeks to improve management efficacy of new and existing protected areas by taking into account the factors recognized by IUCN as needed for successful long-term *in situ* conservation. The 'Protected Area Category System' adopted by IUCN offers a global standard on how to define and record protected areas. Category VI serves the purpose of protecting ecosystems and utilizing natural resources sustainably, with an emphasis on the sustainable use of natural resources in order to minimize the risks to ecological sustainability but also recognize human needs. They are described as "generally large, with most of the area in a natural condition, where a proportion is under sustainable natural resource management and where low-level non-industrial use of natural resources compatible with nature conservation is seen as one of the main aims of the area" (Dudley et al., 2013). Fishermen operating in the Ba Estuary are fishing either with hand-lines or gillnets (T. Vierus and A. Paris, personal observation and communication) with gillnets in particular leading to a substantial amount of newborn and juvenile sharks as bycatch. Therefore, minimizing shark bycatch will require better management of gillnet usage within the shark hotspots of the estuary. Figure 4 outlines a highest-priority area that includes the hotspots of highest shark and ray abundance within the Ba Estuary given the collected data (see section 3.3), whereas Figure 5 additionally includes a priority 2 area (see section 4.3).

In accordance with the IUCN Category VI, we propose the following possibilities for the Ba Estuary with the aim of maintaining sustainable resource extraction while minimizing elasmobranch mortality. Note that the term "demarcated area" preferably refers to

(i) the highest-priority area *and* the priority 2 area *jointly* as shown in Figure 5, but may refer, with decreasing preference,

(ii) to the highest-priority area *alone*, or

(iii) the priority 2 area *alone*, in case the preferred area is compromised by stakeholder requirements or policy trade-offs.

Possibility 1: Partial ban on gillnet fishing in the demarcated area during the peak of the parturition period (November to February).

Possibility 2: Partial ban on gillnet fishing in the Ba Estuary during the peak of the parturition period (November to February).

Possibility 3: Complete ban on gillnet fishing in the demarcated area throughout the year.

Possibility 4: Complete ban on gillnet fishing in the Ba Estuary throughout the year.

The protection of the recently listed Critically Endangered bottlenose wedgefish (*Rhychobatus australiae*) will need immediate and intensive management actions. There have been few recorded sightings of the species and it is recommended that a gazetted no-go, no-take boundary be set up.

Generally, it is strongly recommended the precautionary principle be applied in the Ba Estuary with further complimentary scientific studies into remaining elasmobranch numbers, population dynamics, breeding success rates and potential threats in the area, including bycatch monitoring.

4.6 Potential Challenges and Issues

Initiatives such as and the Fiji LMMA network and the *Yaubula* Management Support Team are traditionally recognized but not legally binding. Both are participatory initiatives that focus on creating awareness and educating local communities on environmental issues, particularly on issues pertaining to marine conservation (Fiji Environmental Law Association and EDO NSW, 2016). Unique challenges are presented to the *Vanua o Votua Qoliqoli* resource committee working with these initiatives and with the involvement of other stakeholders such as the Provincial Office. The establishment of LMMAs in Fiji are considered to be a tool for integrated ocean management and not a final or universal solution (Govan et al., 2011). Simply safeguarding an area from one type of threat (e.g., overfishing) does not nullify other threats such as pollution or ecosystem degradation through extractive industries. Declaring an area as locally managed will inadvertently affect the local communities who rely on the Ba Estuary for subsistence. Therefore, the input of the traditional custodians of the area in the consultative process is vital. A transparent and inclusive process with all relevant stakeholders would provide the traditional fishing rights owners a clear understanding of changes and limitations created by the establishment of the LMMA, allowing for better monitoring and enforcement (Clarke and Jupiter, 2010). A management framework tailored to the specific requirements of the area should be based on scientific research, as presented here, and would subsequently improve the decision-making process more particularly on what specific activities to be regulated. Within the framework of the LMMA, honorary fish wardens need to be better equipped to effectively monitor illegal and unregulated fishing, poaching and bycatch. Fish wardens should also be trained on proper handling techniques as well as live release procedures.

Personal communication with members of the *Vanua o Votua Qoliqoli* committee has allowed for the formulation of a list of measures to aid in creating and maintaining a comprehensive management plan for elasmobranchs in the Ba Estuary. These include:

- The *Vanua o Votua Qoliqoli* resource committee need to be provided all relevant information in the vernacular, in order to make well-informed decisions pertaining to marine resource management.

- A paradigm shift is required among the wider local community that utilizes the Ba Estuary. One important part of that is a change in mindset, framed within the traditional structures that influence livelihoods in the community, the *vanua*, the government and the church. A change in narrative from one of degenerative resource use to one of regenerative resource management is crucial. This can foster compliance and behavioral change without drawing on ongoing external enforcement.

- A *Yaubula* Management Support Team must be reactivated immediately with representatives from all communities. Clear guidelines need to be developed such that participants and representatives of all groups within a community are involved, including youth and women, and understand what their roles are within this committee. One of the key objectives of the committee should be to facilitate education and awareness activities on issues pertaining to the marine environment. Additionally, education material needs to be made available to the committee.

- A common concern for the *Vanua o Votua Qoliqoli* committee are constraints in the ability to effectively enforce resource use regulations. Honorary fish wardens are limited by the lack of resources, with a patrol boat a necessity, those with boats often have to foot their own fuel bill when going on patrol, aside from this they also lack back monitoring equipment such as binoculars, torches and at times even phones. Clear and well understood procedures must also be agreed on between fish wardens, the Ministry of Fisheries and the Police in the event that poachers are encountered.

- An integrated approach to marine resource management is required. Environmental issues that occur in the wider catchment may inadvertently affect the lower reaches of the Ba River and the communities that rely on its resources for sustenance.

- A submission to government for the legal protection of critical priority shark ecological areas subject to community and stakeholder consultations.

5. CONCLUSION

Over the course of almost four years (December 2015 to July 2019) a total of 113 sampling days were undertaken in the Ba Estuary and river. The aim of the study was to investigate the occurrence and abundance of elasmobranchs in the area and gather baseline data regarding population characteristics. In total, 207 sharks and 18 rays were caught consisting of six different elasmobranch species (four and two, respectively). Two of the present shark species are listed as Endangered on IUCN's Red List of Threatened Species (scalloped and great hammerhead shark) and the remaining two sharks (bull and blacktip shark) and ray species (ocellated eagle ray and pink whipray) are listed as Vulnerable (IUCN, 2019). Three sporadically encountered species in the bay, the reef manta and the tawny nurse shark, are listed as Vulnerable and the bottlenose wedgefish (encountered on two occasions) as Critically Endangered. This conservation concern and high gillnet bycatch rates as well as almost constant availability of sharks on the Ba market (T. Vierus and A. Paris, personal observation) prompt for an urgent need of management implementations in the Ba region.

The Ba Delta is fished by at least 150 boats (Vierus et al., 2018) and although most local fishermen interviewed for this study denied they target sharks due to their low desirability as a food fish and low economical value (Vierus et al., 2018), a recent paper encompassing 211 interviews with Fijian fishermen in all provinces concluded a substantial amount of small-scale fishing pressure was driven by subsistence fishers (Glaus et al., 2019a). The fact that the shark catch consisted of predominantly newborn sharks according to umbilical scar condition (most likely less than two weeks old) indicates the importance of this area with a high probability that it serves as a parturition area and nursery ground. A nursery ground is defined by a higher mean density of neonate or young juvenile shark abundance than in surrounding areas, the utilization of the area over extended periods of time, and the repeated use over years (Heupel et al., 2007), whereas a parturition ground is an area where shark pups are born. Highest densities of newborn sharks were observed in the center part of the delta (Figure 3) during the summer months of November to February (Table 1), a time period that overlaps with data from the Rewa Delta (Marie et al., 2017), as well as from Australia (September to February; Miller et al., 2013). Based on this, we demarcated a highest-priority and priority 2 area for protection as well as respective timeframes for gillnet fishing closures.

In 2005, the Fiji Government made a declaration to effectively protect 30% of its inshore and offshore waters by 2020. In 2017, Fiji furthermore declared intentions to protect all ray and shark species and their habitats within Fijian waters at the UN Ocean Conference in New York. Having signaled this willingness, appropriate steps for collecting further evidence and improving management and conservation need to be undertaken.

Inshore environments typically support high biodiversity and productivity and provide important habitat for a number of shark species. Based on the data collected for this report, there is little doubt that the Ba Estuary serves as an important habitat for several elasmobranch species. While the exact function of the Ba area in regard to the lifecycle of the observed elasmobranchs remains to be scientifically investigated, a precautionary management approach dictates that LMMAs should be extended to the Ba Estuary to protect these animals. Current bycatch levels are high and additional external stressors, such as habitat destruction due to mining activities, threaten the health and continuous existence of the local shark and ray populations. Without adequate action, this may eventually lead to local extinction of the present species with potentially severe ecological consequences for the Ba River and estuary, but also for elasmobranch populations more globally.

This *Vanua o Votua* shark and ray report was prepared to demonstrate elasmobranch abundance, distribution and diversity in the Ba Estuary and to provide recommendations for their management. The GEF-UNDP funded Fijian Government's R2R project, implemented by the Ministry of Waterways and Environment, provides a unique opportunity to enhance LMMAs and afford greater protection of threatened marine species.

BIBLIOGRAPHY

Berthe, C. (2017). First ecological, biological and behavioral insights of the ocellated eagle ray Aetobatus ocellatus in French Polynesia.

Bornatowski, H., Navia, A.F., Braga, R.R., Abilhoa, V., and Corrêa, M.F.M. (2014). Ecological importance of sharks and rays in a structural foodweb analysis in southern Brazil. ICES Journal of Marine Science *71*, 1586–1592.

Brown, K.T., Seeto, J., Lal, M.M., and Miller, C.E. (2016). Discovery of an important aggregation area for endangered scalloped hammerhead sharks, Sphyrna lewini, in the Rewa River estuary, Fiji Islands. Pac. Conserv. Biol. *22*, 242–248.

Cardeñosa, D., Glaus, K.B.J., and Brunnschweiler, J.M. (2017). Occurrence of juvenile bull sharks (Carcharhinus leucas) in the Navua River in Fiji. Mar. Freshwater Res. *68*, 592–597.

Castro, J.I. (1996). Biology of the blacktip shark, Carcharhinus limbatus, off the southeastern United States. Bulletin of Marine Science *59*, 508–522.

Chapman, D.D., Feldheim, K.A., Papastamatiou, Y.P., and Hueter, R.E. (2015). There and Back Again: A Review of Residency and Return Migrations in Sharks, with Implications for Population Structure and Management. Annual Review of Marine Science *7*, 547–570.

Clarke, P., and Jupiter, S.D. (2010). Law, custom and community-based natural resource management in Kubulau District (Fiji). Environmental Conservation *37*, 98–106.

Dudley, N., Shadie, P., and Stolton, S. (2013). Guidelines for applying protected area management categories including IUCN WCPA best practice guidance on recognising protected areas and assigning management categories and governance types.

Dulvy, N.K., Fowler, S.L., Musick, J.A., Cavanagh, R.D., Kyne, P.M., Harrison, L.R., Carlson, J.K., Davidson, L.N., Fordham, S.V., Francis, M.P., et al. (2014). Extinction risk and conservation of the world's sharks and rays. ELife *3*, e00590.

Dulvy, N.K., Simpfendorfer, C.A., Davidson, L.N.K., Fordham, S.V., Bräutigam, A., Sant, G., and Welch, D.J. (2017). Challenges and Priorities in Shark and Ray Conservation. Curr. Biol. *27*, R565–R572.

Duncan, K.M., and Holland, K.N. (2006). Habitat use, growth rates and dispersal patterns of juvenile scalloped hammerhead sharks Sphyrna lewini in a nursery habitat. Marine Ecology Progress Series *312*, 211–221.

Ferretti, F., Worm, B., Britten, G.L., Heithaus, M.R., and Lotze, H.K. (2010). Patterns and ecosystem consequences of shark declines in the ocean. Ecology Letters *13*, 1055–1071.

Fiji Environmental Law Association, and EDO NSW (2016). Regulating Fiji's Coastal Fisheries. Policy and Law Discussion Paper. Fiji Environmental Law Association, Suva.

Froeschke, J., Stunz, G.W., and Wildhaber, M.L. (2010). Environmental influences on the occurrence of coastal sharks in estuarine waters. Marine Ecology Progress Series *407*, 279–292.

Gallagher, A.J., and Hammerschlag, N. (2011). Global shark currency: the distribution, frequency, and economic value of shark ecotourism. Current Issues in Tourism *14*, 797–812.

Glaus, K.B.J., Adrian-Kalchhauser, I., Burkhardt-Holm, P., White, W.T., and Brunnschweiler, J.M. (2015). Characteristics of the shark fisheries of Fiji. Scientific Reports *5*, 17556.

Glaus, K.B.J., Adrian-Kalchhauser, I., Piovano, S., Appleyard, S.A., Brunnschweiler, J.M., and Rico, C. (2019a). Fishing for profit or food? Socio-economic drivers and fishers' attitudes towards sharks in Fiji. Marine Policy *100*, 249–257.

Glaus, K.B.J., Brunnschweiler, J.M., Piovano, S., Mescam, G., Genter, F., Fluekiger, P., and Rico, C. (2019b). Essential waters: Young bull sharks in Fiji's largest riverine system. Ecology and Evolution *9*, 7574–7585.

Govan, H., Comley, J., Tan, W., Guilbeaux, M., and Vave, R. (2011). Recommendations from Ten Years of Monitoring under the LMMA Network's Learning Framework.

Guttridge, T.L., Van Zinnicq Bergmann, M.P.M., Bolte, C., Howey, L.A., Finger, J.S., Kessel, S.T., Brooks, J.L., Winram, W., Bond, M.E., Jordan, L.K.B., et al. (2017). Philopatry and Regional Connectivity of the Great Hammerhead Shark, Sphyrna mokarran in the U.S. and Bahamas. Front. Mar. Sci. *4*.

Heithaus, M.R., Frid, A., Wirsing, A.J., and Worm, B. (2008). Predicting ecological consequences of marine top predator declines. Trends Ecol. Evol. (Amst.) *23*, 202–210.

Heupel, M.R., and Simpfendorfer, C.A. (2011). Estuarine nursery areas provide a low-mortality environment for young bull sharks Carcharhinus leucas. Marine Ecology Progress Series *433*, 237–244.

Heupel, M.R., Carlson, J.K., and Simpfendorfer, C.A. (2007). Shark nursery areas: concepts, definition, characterization and assumptions. Marine Ecology Progress Series *337*, 287–297.

Heupel, M.R., Knip, D.M., Simpfendorfer, C.A., and Dulvy, N.K. (2014). Sizing up the ecological role of sharks as predators. Marine Ecology Progress Series *495*, 291–298.

Hueter, R., and Tyminski, J. (2007). Species-specific distribution and habitat characteristics of shark nurseries in Gulf of Mexico waters off peninsular Florida and Texas. In American Fisheries Society Symposium, (American Fisheries Society), p. 193.

Hueter, R., Heupel, M., Heist, E., and Keeney, D. (2005). Evidence of philopatry in sharks and implications for the management of shark fisheries. Journal of Northwest Atlantic Fishery Science *35*, 239–247.

IUCN (2019). The IUCN Red List of Threatened Species. Version 2019-2. http://www.iucnredlist.org.

Lotze, H.K., Lenihan, H.S., Bourque, B.J., Bradbury, R.H., Cooke, R.G., Kay, M.C., Kidwell, S.M., Kirby, M.X., Peterson, C.H., and Jackson, J.B.C. (2006). Depletion, degradation, and recovery potential of estuaries and coastal seas. Science *312*, 1806–1809.

Marie, A., Stockwell, B., and Rico, C. (forthcoming). Scalloped hammerhead shark (Sphyrna lewini) juveniles occurring in Fiji Islands' estuaries reveal multiple breeding populations in the South Pacific and signs of adaptive divergence among them.

Marie, A.D., Miller, C., Cawich, C., Piovano, S., and Rico, C. (2017). Fisheries-independent surveys identify critical habitats for young scalloped hammerhead sharks (Sphyrna lewini) in the Rewa Delta, Fiji. Sci Rep *7*, 1–12.

Miller, M.H., Carlson, J., Cooper, P., Kobayashi, D., Nammack, M., and Wilson, J. (2013). Status review report: scalloped hammerhead shark (Sphyrna lewini). Report to National Marine Fisheries Service, Office of Protected Resources. March 2013.131 Pp.

Mills, M., Jupiter, S.D., Pressey, R.L., Ban, N.C., and Comley, J. (2011). Incorporating Effectiveness of Community-Based Management in a National Marine Gap Analysis for Fiji. Conservation Biology *25*, 1155–1164.

Piovano, S., and Gilman, E. (2017). Elasmobranch captures in the Fijian pelagic longline fishery. Aquatic Conservation: Marine and Freshwater Ecosystems *27*, 381–393.

Schluessel, V., Broderick, D., Collin, S.P., and Ovenden, J.R. (2010). Evidence for extensive population structure in the white-spotted eagle ray within the Indo-Pacific inferred from mitochondrial gene sequences. Journal of Zoology *281*, 46–55.

Secretariat of the Pacific Regional Environment Programme (2007). Fiji. https://www.sprep.org/attachments/bem/Fiji_Country_Chapter.pdf.

Simpfendorfer, C.A., and Dulvy, N.K. (2017). Bright spots of sustainable shark fishing. Current Biology *27*, R97–R98.

Sloan, J. (2019). Marine Protected Areas in Fiji waters: The law and governance context requires careful consideration and transparent decision-making. Siwatibau and Sloan Ocean Law Bulletins. http://www.sas.com.fj/ocean-law-bulletins/marine-protected-areas-in-fiji-waters-the-law-and-governance-context-requires-careful-consideration-and-transparent-decision-making.

Sloan, J., and Chand, K. (2016). An analysis of property rights in the Fijian qoliqoli. Marine Policy *72*, 76–81.

Sykes, H., LeGrand, J., Davey, K., Kirmani, S., Mangubhau, S., Yakub, N., Wendt, H., Gauna, M., and Fernandes, L. (2018). Biophysically special, unique marine areas of Fiji. MACBIO (GIZ, IUCN, SPREP), Wildlife Conservation Society and Fiji's Protected Area Committee (PAC); Suva.

Tillett, B.J., Meekan, M.G., Field, I.C., Thorburn, D.C., and Ovenden, J.R. (2012). Evidence for reproductive philopatry in the bull shark Carcharhinus leucas. Journal of Fish Biology *80*, 2140–2158.

Vierus, T., Gehrig, S., Brunnschweiler, J.M., Glaus, K., Zimmer, M., Marie, A.D., and Rico, C. (2018). Discovery of a multispecies shark aggregation and parturition area in the Ba Estuary, Fiji Islands. Ecol Evol *8*, 7079–7093.

APPENDIX

A1. Bycatch

Table A1. Documentation of finfish and crustacean bycatch in the fishery-independent surveys

Scientific Name	Common Name	Local Name	N	Max. Length (cm)	Comments
Anguilla obscura	pacific shortfin eel	bonu/duna	4	80	found in Karavi Bay
Arothron hispidus	white-spotted puffer	vocea/sumusumu	7	30	found in oligohaline environments
Caranx ignobilis	giant trevally	dole/saqaloa	5	110	found in Karavi Bay
Caranx melampygus	blue trevally	saqaleka	9	35	found at main river mouth
Caranx papuensis	papuan trevally	saqa	1	27	found at main river mouth
Chanos chanos	milkfish	luya/yawa	13	30	found upstream
Echeneis naucrates	remora/suckerfish	bakewa	14	50	found along coasts and occasionally at river mouth
Eleostris melanosoma	broadhead sleeper	kurukoto	3	35	found along mangroves at low tide
Ellochelon vaigiensis	squaretail mullet	kava	5	35	found at river mouths
Elops hawaiiensis	banana fish	watowato	18	90	most often found in pairs in coastal waters
*Epinephalus coioides/malabaricus**	ornage spotted grouper	kalo	5	90	present in both coastal and riverine sites.
Epinephelus coeruleopunctatus	whitespot grouper	kawakawa	2	20	present in both coastal and riverine sites.
Gerres oyena	silver biddy	matu	3	12	found in coastal waters

Hemirhamphus far	garfish	busa	22	20	very common in BE
Herklotsichthys quadrimaculatus	herring	daniva	30	10	found by river mouth
Kuhlia rupestris	flagtail	ikadroka	10	15	found in riverine areas
Kulia marginata	flagtail	sakelo	5	10	found in riverine areas
Lactarius lactarius	milk trevally	jowa	34	35	common coastal species
Leiognathus equulus	common ponyfish	kaikai/sonisoni	387	15	very common, ubiquitous distribution in estuary
Gazza minuta	toothpony	kaikai/sonisoni	23	14	very common, ubiquitous distribution in estuary
Lethrinus harak	thumb-print emperor	kabatia	7	18	found on patch reef
Lethrinus nebulosus	spangled emperor	kawago	2	25	found on patch reef
Lutjanus argentimaculatus	mangrove red snapper	tiri damu	174	90	common along mangroves and up rivers.
Lutjanus bohar	two spot red snapper	bati damu	2	20	further from shore
Lutjanus rivulatus	maori snapper	damu ni cakau*	3	30	found on patch reef
Lutjanus russellii	russell's snapper	kake/kwake	2	18	found on patch reef
Megalops cyprinoides	oxeye herring	yavula	25	65	common after heavy rains
Megalaspis cordyla	finny scad	moli	2	17	found in coastal waters
Mesopristes kneri	orange-spotted terapon	reve	1	25	solitary specimen found at river mouth
Monodactylus argenteus	silver moony	tutu	242	15	at river mouth and coastal waters

Mugil cephalus	sea mullet	koto	4	50	found at main river mouth
Muraenesox cinereus	pike eel	ikasa	23	150	found in waters between 2-3 meters further from mangroves.
Planiliza melinoptera	otomebora mullet	molisa/lulu	8	12	found in freshwater
Plectorhinchus nigra	brown sweetlip	ikanivatu/drekeni	13	40	found along rocky bottoms in small schools
Polydactylus plebeius	threadfin	uculuka	11	35	found in salt/brackish water
Rastrelliger brachysoma	short mackerel	salala	6	12	found in schools
Rastrelliger kanagurta	indian mackerel	salala	12	14	found in schools
Scatophagus argus	spotted scat	vetakau/baba	9	23	found in rivers
Scomberoides lysan	leatherjacket	votonimoli	6	21	found in coastal waters
Scomberomorus commerson	spanish mackerel	walu	5	25	juveniles only present at river mouth
Siganus vermiculatus	Spinefoot rabbitfish	nuqa	6	13	found along mangroves
Sphyraena barracuda	great barracuda	ogo	17	105	found in schools further from shore
Sphyraena forsteri	Forster's seapike	silasila	12	50	found in schools further from shore
Sphyraena jello	yellowtail barracuda	ogo biudromo	8	95	found in pairs along coastal areas.
Terapon jarbua	crescent perch	qitawa	13	15	found in coastal waters
Trachinotus bailloni	black-spotted swallowtail	iribuli	2	16	found at river mouth
Trachinotus blochii	snubnose pompano	vilu	2	14	found at river mouth

Trichiurus lepturus	hairtail/beltfish	beleti	22	60	found up rivers
Tylosurus crocodilus	long tom/needlefish	saku	3	40	found in coastal areas.
Upeneus vittatus	yellow striped goatfish	ki/kiki	8	15	found at river mouth
Valamugil buchanani	blue tail mullet	kanace	19	27	large schools move up river and around mouth
Planiliza macrolepis	large-scale mullet	keteleka/lulu	4	12	found along mangroves
Platax orbicularis	batfish	jet/vuna	3	11	found along mangroves
Palaemon concinnus	mangrove prawn	moci	7	9	found just up river from river mouth
Scylla serrata	mangrove crab	qari	22	16	found in coastal waters
Carpilius maculatus	threespot reef crab	tavutolu	2	10	found in coastal waters
Penaeus monodon	Giant Tiger Prawn	ura	32	17	found in coastal waters
Thalamita crenata	Swimmer Crab	qarivatu	14	12	found in coastal waters

A2. Elasmobranch Species with National and International Obligations.

Table A2. Overview of elasmobranch species in the Ba Estuary with national and international obligations.

Scientific Name	Endangered and Protected Species Act 2002	Endangered and Protected Species (Amendment) Act 2017	CITES	Convention on Migratory Species of Wild Animals	IUCN Red List
Sphyrna lewini	×	✓	II	II	Endangered
Carcharhinus limbatus	×	×	×	×	Near Threatened
Sphyrna mokarran	×	✓	II	II	Endangered
Aetobatus ocellatus	×	×	×	×	Vulnerable
Manta alfredi	×	×	II	I/II	Vulnerable
Carcharhinus leucas	×	✓	×	×	Near Threatened
Pateobatus fai	×	×	×	×	Vulnerable
Nebrius ferrugineus	×	×	×	×	Vulnerable
Rhynchobatus australiae	×	×	II	II	Critically Endangered

A3. Species and Months Captured/Observed

Table 3. Captures per month for all shark and ray species caught during deployments (first six rows) or observed otherwise (last three rows).

Scientific Name	**N**	**Month Captured/Observed**
Sphyrna lewini	97	Jan(26) Feb(10) Mar(4) Apr(8) May(9) Jun(17) Aug(1) Sep(5) Oct(8) Nov(6) Dec(3)
Carcharhinus limbatus	89	Jan(23) Feb(10) Mar(1) Nov(20) Dec(33)
Sphyrna mokarran	14	Jan(4) Feb(5) Aug(1) Sep(2) Dec(1)
Aetobatus ocellatus	13	Jan(6) Mar(1) Jun(1) Jul(1) Oct(3) Nov(1)
Carcharhinus leucus	7	Jan(7)
Pateobatus fai	5	May(2) Jun(2) Sep(1) Oct(1)
Manta alfredi	8	Sep(8)
Nebrius ferrugineus	2	Jun(2)
Rhynchobatus australiae	2	Feb(2)

A4. Photographs of Visually Identified Species

This section provides photographic images for the species that were exclusively visually identified by researchers (no DNA barcoding). Images of reef manta rays (*Manta alfredi*) are missing.

Figure A1. Pink whiprays (*Pateobatis fai*) with severed tails in the Ba Estuary.
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Figure A2. A bottlenose wedgefish in the Ba Estuary (*Rhynchobatus australiae*).
© Lekima Copeland

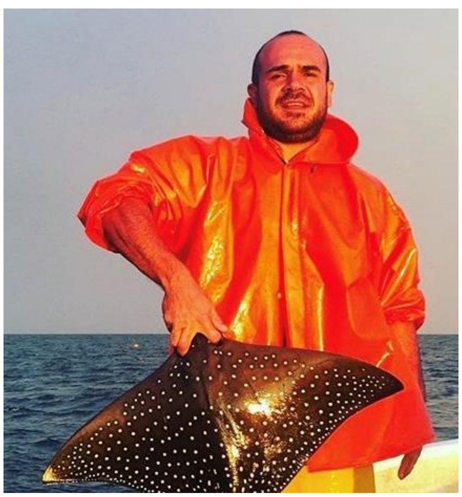

Figure A3. An ocellated eagle ray (*Aetobatus ocellatus*) in the Ba Estuary.
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Figure A4. Tawny nurse shark (*Nebrius ferrugineus*) in the Ba Estuary.
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