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Review

The sharks and rays of the Solomon Islands: a synthesis of their biological diversity, values and conservation status

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Abstract. Sharks and rays are facing increasing anthropogenic pressure globally, including in the Pacific. However, data on their status and biodiversity are lacking for many Pacific Large Ocean Island States. This study aimed to construct a species checklist for the sharks and rays occurring in the Solomon Islands, review the human interactions with these species, and present a synthesis of their conservation status. Given the paucity of available data, a wide range of data sources were used including fisheries data, citizen science, and ethnobiological studies. Results were validated through a review process involving expert informants. Fifty sharks and rays were identified from the Solomon Islands, of which 20 are assessed as Vulnerable or Endangered on the IUCN Red List, 10 in the Convention on International Trade in Endangered Species, and 11 in the Convention for Migratory Species. The checklist also presents an eastwards range extension for the Endangered dwarf sawfish *Pristis clavata*. Fishing appears to be the main impact, though impacts from habitat loss and degradation are possible. This study provides a systematic synthesis and review of the biological diversity, uses, and cultural significance of Solomon Islands sharks and rays, and describes a process for assembling species checklists and reviews in data-poor contexts. However, this synthesis is based on limited information and a complete assessment of shark and ray status in the Solomon Islands will require primary fieldwork.

Additional keywords: biodiversity, citizen science, conservation management, extinction risk, legislation, population decline, predator

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Introduction

Sharks and rays are facing increasing pressure with widespread population declines, and up to one-quarter of shark and ray species are threatened with extinction (Dulvy *et al.* 2014; Davidson *et al.* 2016). Declines have also been reported in the waters of the Large Ocean Island States of the Pacific (Nadon *et al.* 2012; Clarke *et al.* 2013), the countries and territories of the western and central Pacific that have very small land masses relative to the size of their marine estates. However, information on sharks and rays is lacking for many of these Pacific states and territories, especially for coastal and deep-water species (Juncker *et al.* 2006; Clua and Planes 2014). This lack of information is a significant impediment to developing sustainable fishing and conservation policies across the region (Lack and Meere 2009). Although documentation of elasmobranch fauna is poor, the south-west Pacific countries and the Coral Triangle are renowned for their biological diversity (Allen 2008), including sharks and rays. New research has led to recent discoveries of new shark and ray species in these waters (Famhi and White 2015), range expansions, and rediscoveries of species thought to be locally extinct (White *et al.* 2015). Nevertheless, the shark and ray faunas of many locations in the region are yet to be assessed.

The Solomon Islands lies within the Coral Triangle and is the south-west Pacific's second largest archipelago (Sabetian 2002). Situated between 5 and 12°S, and between 152 and 170°E (Fig. 1), the Solomon Islands consist of six large islands, 30 small islands, and ~962 islets, atolls and cays within 1.34 million km^2 of ocean (Richards *et al.* 1994). The country has one of the world's highest per capita rates of seafood consumption, indicating a very high dependence on marine resources. The Solomon Islands' population has almost doubled since 1990, amplifying pressure on marine resources for food security and livelihoods. Additionally, while sustainable fishing practices have carried on for centuries in the Solomon Islands, the development of market economies since the 1970s has changed fishing priorities from subsistence-focused to income-focused activities, changing the nature of domestic fisheries (Doyle *et al.* 2012). As the global decline of shark populations has gained international attention, conservation concerns have also been

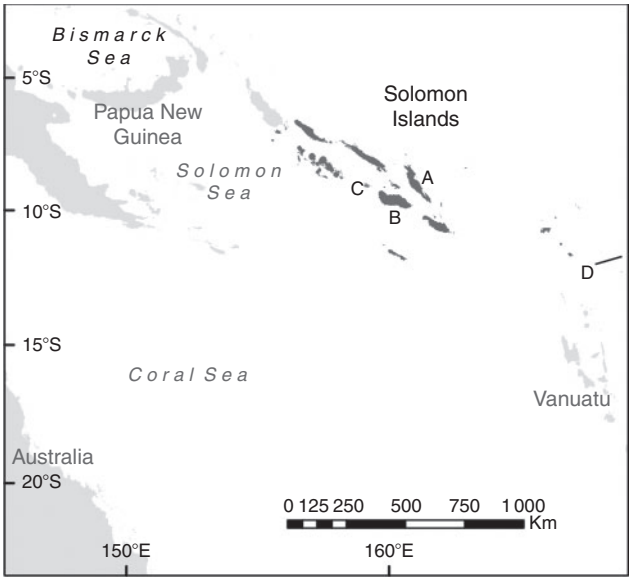

Fig. 1. Location of Solomon Islands in relation to Australia, Papua New Guinea, and surrounding nations in the Pacific Ocean. A, Malaita; B, Guadalcanal; C, Russell Islands; D, Anuta. Map created in ArcGIS 10.2.1.

raised by the Solomon Islands Government. On 4 December 2013, the national Government issued a statement of intent to create a National Plan of Action (NPOA) for sustainable use of shark resources in the Solomon Islands (MECDM and MFMR 2013). However, there is currently little scientific information on the diversity and status of Solomon Islands' sharks and rays, information that is needed for the development and implementation of an NPOA (Lack and Meere 2009). The present study used a systematic desktop literature review coupled with searches of museum records and databases, as well as citizen science to produce a synthesis of the biodiversity and conservation status of sharks and rays in the Solomon Islands. The review includes an overview of fisheries interactions and the role of sharks and rays in Solomon Islands society, and describes a process for assembling a biodiversity checklist and conservation synthesis in data-poor contexts.

Methods

Multiple methods were used to locate information sources regarding the Solomon Islands' shark and ray diversity and fisheries interactions, and to validate the species checklist. The primary search was conducted using online publication and data repositories of the United Nations Food and Agriculture Organisation (FAO) Fisheries, the Secretariat of the Pacific Community (SPC), and the Western and Central Pacific Fisheries Commission (WCPFC). Searches aimed to retrieve data and information about fisheries status and management specific to Solomon Islands fisheries. To locate additional information, a secondary search was conducted using the Web of Science™ and ScienceDirect™ databases with search terms including 'Solomon Islands', 'sharks', 'rays', 'fisheries', and 'shark finning'. Recognising that much information may exist as unpublished data and reports, a third search was conducted using Google Scholar™ using the same search terms, with the addition of the terms 'culture' and 'tradition'. Bibliographies from the acquired literature were analysed to locate additional sources. The 'Status of Coral Reefs of the Pacific and Outlook' (Chin *et al.* 2011) was used as a primary reference point regarding the status and use of coral reef resources, as well as existing management. The lack of published academic literature on elasmobranchs in the Solomon Islands prompted the need to acquire information from anthropological records and to pursue targeted enquiries through professional networks to source additional information. Once an initial species checklist was compiled, museum collection databases and the parasitological database http://tapewormdb.uconn.edu/ (accessed 31 March 2017) were searched to identify additional records from curated taxonomic collections that sourced sharks and rays and their parasites from the Solomon Islands.

The checklist (Table S1, available as Supplementary Material to this paper) includes the information source(s) that state a species' occurrence in the Solomon Islands, and records details of any taxonomic issues and uncertainties in species identification. A conservative approach was taken and if a species' occurrence in the Solomon Islands could not be confirmed, it was noted in the checklist but not counted as a valid species. The draft checklist was then sent to fisheries and marine specialists in the Solomon Islands for validation. These contacts included staff from the Solomon Islands Ministry of Fisheries and Marine Resources (MFMR), Ministry of Environment, Climate Change, Disaster Management and Meteorology (MECDM), the NGOs WorldFish and the Nature Conservancy, dive centres and resorts, and independent researchers. Specific efforts were made to ascertain the presence of species suspected to occur in the Solomon Islands but which were previously unrecorded, with informants (particularly SCUBA divers) asked to provide photographs or evidence of the presence of these species. Once comments and further data were received from in-country informants, the checklist was updated and all species checked against current taxonomic classification. The confidence of a species' occurrence in the Solomon Islands was then qualitatively categorised as (1) Unlikely, (2) Plausible, (3) Likely, (4) Confirmed or (5) Provisionally Confirmed pending taxonomic clarification, according to the criteria in Table 1. These confidence rankings were also explicitly stated in the species checklist (Table S1). Lastly, the conservation status of each species was included by adding the International Union for the Conservation of Nature (IUCN) Red List assessment for each species, as well as listings for species appearing in Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and Convention on the Conservation of Migratory Species of Wild Animals (CMS) appendices.

Results

Few data were available on Solomon Islands' sharks and rays from peer-reviewed scientific literature, and most of the data sources identified were grey literature and unpublished data (Table S1). Of the published peer-reviewed literature, several publications were ethnobiological and anthropological studies that provided valuable records of species presence, but also provided information about the cultural significance of sharks and rays to Solomon Islander communities. These data provide

Table 1. Descriptions of confidence rankings applied to data for species' occurrence in the Solomon Islands

Confidence category	Description
Unlikely	Records limited to a single source AND occurrence is outside the species' expected range OR habitat tolerances and contradicts biogeographic patterns AND/OR species is easily misidentified OR absent from other records and observations where it would otherwise be expected.
Plausible	Records limited to a single general reference OR occurrence is within range and environmental envelope; however, species is easily confused with other similar species.
Likely	Records from one or two sources; species is widely distributed throughout the region AND occurrence is within range and environmental envelope AND species easily identifiable.
Confirmed	Occurrence reported in two or more published sources OR reported from museum record/curated scientific database/checklist/taxonomic collection with expert verification OR photographic record AND occurrence is within expected range and environmental envelope AND species is easily identifiable OR identification verified by expert.
Provisionally confirmed (pending taxonomic clarification)	Species occurrence provisionally confirmed; however, taxonomic issues mean that the species needs further attention to resolve potential issues to identify species, separate cryptic species or remove invalid species.

important social and cultural context to the conservation and management issues facing Solomon Islands' sharks and rays, and provide key data needed to address NPOA components that focus on social and cultural values. In-country informants also provided novel information sources including footage from a National Geographic documentary, a locally produced species checklist from a dive centre for local dive sites, and photographs of a sawfish rostrum collected in the 1960s.

Status and diversity of Solomon Islands' sharks and rays

The state of knowledge about shark and ray populations in the Solomon Islands is poor and comprehensive scientific surveys to document shark and ray diversity and population trends have not been completed. Due to this large knowledge gap, information was compiled from a diverse range of sources spanning anthropological records and ethnobiological research, natural science journal articles, grey literature and fishery improvement plans. Further information on elasmobranch diversity was also sourced from fisheries records, unpublished data, in-country informants and museum records (Akimichi 1978; Richards *et al.* 1994; Foale 1998; Juncker *et al.* 2006; Lack and Meere 2009; Gillett 2010; Banks 2014). Collectively, these sources documented 50 elasmobranch species in the Solomon Islands (Table 2), which included 43 confirmed or provisionally confirmed species and seven species that are likely to occur, given their distributions and available information (Table 1). These 50 species include 32 sharks and 18 rays. No chimaeras were listed. An additional seven species have reports indicating their presence in the Solomon Islands; however, these accounts were limited by taxonomic confusion, or lacked the taxonomic and spatial resolution needed to confirm a species' presence. As such, four of these seven species are listed as Plausible (Table 2), and the remaining three are listed as Unlikely. The complete annotated checklist is available at Table S1 and from www.sharksearch-indopacific.org (accessed 21 July 2017). In-country informants also provided a photograph of a sawfish rostrum obtained from a fisherman in the Russell Islands in the Central Solomon Islands in the 1960s (Fig. 2). Examination of the rostral teeth by two independent experts revealed that the rostrum belonged to a dwarf sawfish (*Pristis clavata*), a record that extends the species' range eastwards from Papua New Guinea into the Solomon Islands. Globally, the dwarf sawfish is one of the most threatened species of sharks and rays (Dulvy *et al.* 2014).

In the absence of more detailed conservation assessments for sharks and rays in the Solomon Islands, global conservation assessments for each identified species were used as a preliminary indicator of the conservation status of each species. The IUCN Red List of Threatened Species follows a globally accepted assessment process and ranks species as Data Deficient (DD), Least Concern (LC), Near Threatened with extinction (NT), Vulnerable to extinction (VU), Endangered (EN), Critically Endangered (CR), Extinct in the Wild (EW), and Extinct (EX). Forty-five of the 50 species recorded in this literature review have been assessed against the IUCN Red List criteria (Table 3). In all, 28% of shark species and 44% of ray species recorded here are listed as Vulnerable to extinction. Three species are listed as Endangered (whale shark, scalloped hammerhead and dwarf sawfish). At this time, no species categorised as Critically Endangered, Extinct in the Wild, or Extinct have been documented in the Solomon Islands.

Most shark species assessed as Near Threatened and Vulnerable to extinction under the IUCN Red List criteria are members of the family Carcharhinidae, and most ray species with the same listings are members of the Dasyatidae. Nine of the 14 carcharhinid sharks are listed with Near Threatened status by the IUCN, three are listed as Vulnerable, and two are Data Deficient. Of the nine dasyatid rays, two species are Data Deficient, three are Least Concern, one is Near Threatened, and three are Vulnerable. It should be recognised that these categorisations are based on global-scale IUCN assessments, with very few evaluations of regional status.

Several species are also listed under the CITES and CMS conventions (Table 3) and these listings are additional proxy indicators of conservation concern. Twelve species are listed in CITES appendices (CITES 2017), and 13 species appear in appendices of the CMS (2017). There is a high degree of overlap between these listings, with 11 species being listed under both conventions, and all but one of these species are considered to be threatened species under the IUCN Red List (Table 3). This extensive overlap between independent assessments suggests that there are valid conservation concerns for these species.

Table 2. Species of sharks and rays reported from Solomon Islands

Table is organised by Family, Genus, Species, and includes global IUCN Red List™ conservation status if listed (IUCN 2017). Asterisks denote species with 'plausible' confidence ranking. IUCN Global categories: DD, Data Deficient; LC, Least Concern; NT, Near Threatened with extinction; VU, Vulnerable to extinction; EN, Endangered; CR, Critically Endangered

Common name	Family	Genus	Species	IUCN Global
Bigeye thresher shark	Alopiidae	*Alopias*	*superciliosus*	VU
Silvertip shark	Carcharhinidae	*Carcharhinus*	*albimarginatus*	NT
Grey reef shark	Carcharhinidae	*Carcharhinus*	*amblyrhynchos*	NT
Pigeye shark*	Carcharhinidae	*Carcharhinus*	*amboinensis*	DD
Nervous shark	Carcharhinidae	*Carcharhinus*	*cautus*	DD
Silky shark	Carcharhinidae	*Carcharhinus*	*falciformis*	NT
Bull shark*	Carcharhinidae	*Carcharhinus*	*leucas*	NT
Common blacktip shark	Carcharhinidae	*Carcharhinus*	*limbatus*	NT
Oceanic whitetip shark	Carcharhinidae	*Carcharhinus*	*longimanus*	VU
Blacktip reef shark	Carcharhinidae	*Carcharhinus*	*melanopterus*	NT
Sandbar shark	Carcharhinidae	*Carcharhinus*	*plumbeus*	VU
Spottail shark	Carcharhinidae	*Carcharhinus*	*sorrah*	NT
Tiger shark	Carcharhinidae	*Galeocerdo*	*cuvier*	NT
Sicklefin lemon shark	Carcharhinidae	*Negaprion*	*acutidens*	VU
Blue shark	Carcharhinidae	*Prionace*	*glauca*	NT
White-tip reef shark	Carcharhinidae	*Triaenodon*	*obesus*	NT
Smallfin gulper shark	Centrophoridae	*Centrophorus*	*moluccensis*	DD
Lanternshark	Etmopteridae	*Etmopterus*	sp.	
Tawny nurse shark	Ginglymostomatidae	*Nebrius*	*ferrugineus*	VU
Bigeyed sixgill shark	Hexanchidae	*Hexanchus*	*nakamurai*	DD
White shark	Lamnidae	*Carcharodon*	*carcharias*	VU
Shortfin mako shark	Lamnidae	*Isurus*	*oxyrinchus*	VU
Longfin mako shark	Lamnidae	*Isurus*	*paucus*	VU
Tassled wobbegong	Orectolobidae	*Eucrossorhinus*	*dasypogon*	NT
Whale shark	Rhincodontidae	*Rhincodon*	*typus*	EN
a catshark	Scyliorhinidae	*Apristurus*	sp.	
a catshark	Scyliorhinidae	*Galeus*	sp.	
Southern sleeper shark	Somniosidae	*Somniosus*	*antarcticus*	DD
Scalloped hammerhead	Sphyrinidae	*Sphyrna*	*lewini*	EN
Great hammerhead*	Sphyrnidae	*Sphyrna*	*mokkran*	EN
a spurdog	Squalidae	*Squalus*	cf. *nasutus*	DD
Zebra shark	Stegostomatidae	*Stegostoma*	*fasciatum*	VU
Solomon's houndshark	Triakidae	*Hemitriakis*	sp. A	
Longnose houndshark	Triakidae	*Iago*	*garricki*	LC
Solomon's smoothhound	Triakidae	*Mustelus*	sp. A	
Spotted eagle ray	Aetobatidae	*Aetobatus*	*ocellatus*	NT
Reticulate whipray	Dasyatidae	*Himantura*	*australis*	VU
Kuhl's maskray	Dasyatidae	*Neotrygon*	*kuhlii*	DD
Broad cowtail ray	Dasyatidae	*Pastinachus*	*ater*	DD
Pink whipray	Dasyatidae	*Pateobatis*	*fai*	LC
Pelagic stingray	Dasyatidae	*Pteroplatytrygon*	*violacea*	LC
Oceania fantail ray	Dasyatidae	*Taeniura*	*lessoni*	LC
Blotched stingray	Dasyatidae	*Taeniurops*	*meyeni*	VU
Porcupine ray	Dasyatidae	*Urogymnus*	*asperrimus*	VU
Mangrove whipray	Dasyatidae	*Urogymnus*	*granulatus*	NT
Giant guitarfish	Glaucostegidae	*Glaucostegus*	*typus*	VU
Sixgill stingray	Hexatrygonidae	*Hexatrygon*	*bickelii*	LC
Reef manta	Mobulidae	*Mobula*	*alfredi*	VU
Manta ray	Mobulidae	*Mobula*	*birostris*	VU
Devil ray	Mobulidae	*Mobula*	*tarapacana*	VU
Dwarf sawfish	Pristidae	*Pristis*	*clavata*	EN
Largetooth sawfish*	Pristidae	*Pristis*	*pristis*	CR
Whitespotted wedgefish	Rhynchobatidae	*Rhynchobatus*	*australiae*	VU
Giant torpedo ray	Torpedinidae	*Tetronarce*	*nobiliana*	DD

Fig. 2. Photograph of a dwarf sawfish rostrum supplied by an informant from the Solomon Islands. The rostrum was obtained in the Russell Islands in the central Solomon Islands during the 1960s.

Table 3. Species of sharks and rays found in the Solomon Islands listed on CITES Appendix I and/or II, on CMS Appendix I and/or II and IUCN Red List™ as Vulnerable or Endangered (IUCN 2017)

Asterisks denote species with 'plausible' confidence ranking. IUCN Global categories: NT, Near Threatened with extinction; VU, Vulnerable to extinction; EN, Endangered; CR, Critically Endangered

Common name	Family	Genus	Species	CITES Appendix	CMS Appendix	IUCN Global
Whale shark	Rhincodontidae	*Rhincodon*	*typus*	II	II	EN
Scalloped hammerhead	Sphyrnidae	*Sphyrna*	*lewini*	II	II	EN
Great hammerhead*	Sphyrnidae	*Sphyrna*	*mokarran*	II	II	EN
Bigeye thresher shark	Alopiidae	*Alopias*	*superciliosus*	II	II	VU
Oceanic whitetip shark	Carcharhinidae	*Carcharhinus*	*longimanus*	II		VU
Sandbar shark	Carcharhinidae	*Carcharhinus*	*plumbeus*			VU
Sicklefin lemon shark	Carcharhinidae	*Negaprion*	*acutidens*			VU
Tawny nurse shark	Ginglymostomatidae	*Nebrius*	*ferrugineus*			VU
White shark	Lamnidae	*Carcharodon*	*carcharias*	II	I, II	VU
Shortfin mako shark	Lamnidae	*Isurus*	*oxyrinchus*		II	VU
Longfin mako shark	Lamnidae	*Isurus*	*paucus*		II	VU
Zebra shark	Stegostomatidae	*Stegostoma*	*fasciatum*			VU
Silky shark	Carcharhinidae	*Carcharhinus*	*falciformis*	II	II	NT
Largetooth sawfish*	Pristidae	*Pristis*	*pristis*	I	I, II	CR
Dwarf sawfish	Pristidae	*Pristis*	*clavata*	I	I, II	EN
Reticulate whipray	Dasyatidae	*Himantura*	*uarnak*			VU
Blotched fantail ray	Dasyatidae	*Taeniurops*	*meyeni*			VU
Porcupine ray	Dasyatidae	*Urogymnus*	*asperrimus*			VU
Reef manta	Mobulidae	*Mobula*	*alfredi*	II	I, II	VU
Manta ray	Mobulidae	*Mobula*	*birostris*	II	I, II	VU
Devil ray	Mobulidae	*Mobula*	*tarapacana*	II	I, II	VU
Giant guitarfish	Glaucostegidae	*Glaucostegus*	*typus*			VU
Whitespotted wedgefish	Rhynchobatidae	*Rhynchobatus*	*australiae*			VU

Social and cultural dimensions of sharks and rays in coastal fisheries

Coastal fisheries in the Solomon Islands are diverse, as are the roles that sharks and rays play in these fisheries, the social and cultural values that communities have for sharks and rays, and the conservation ethos and management approaches of these different communities. Nevertheless, the practice of catching, processing, distributing and consuming marine organisms from local waters is a widespread and essential part of Solomon Islander life. With up to 90% of the Solomon Islands population living in rural coastal areas, subsistence fishing is a major source of food security. Gillett (2010) reported that over 80% of coastal catch in the Solomon Islands comes from the subsistence sector, estimated at 15 000 tonnes in 2007. The main target species of subsistence fisheries have traditionally been shallow-water estuarine and reef fishes, with the occasional sea turtle, shark,

and deep-water snapper taken for local consumption or sale (Skewes 1990). The shallow-water reef and estuarine fish fishery has provided a significant part of traditional diet for many centuries. The annual consumption of fish in 1992 was estimated at 45.5 kg person^{-1} in the city of Honiara alone, where 31% of households reportedly eat fresh fish daily (Crossland and Philipson 1993, p. 136.). Population growth has created resource scarcities, forcing some Solomon Islanders to find new sources of food (Roeger *et al.* 2016). While critical for food security, small-scale fisheries are also economically important. A 2011 survey found a mean economic yield of US$5173 year^{-1} respondent^{-1} for fisheries-based products harvested by Solomon Islanders. With fish contributing the greatest value to this total, the importance of fish to food security and local economies is clear (Albert *et al.* 2015). The income derived from these fisheries, including shark products, provides the means to purchase additional food (e.g. rice, tinned meat) and basic domestic necessities, and services such as education and health care.

Featured in the nation's coat of arms, sharks have traditionally held cultural importance in many areas of the Solomon Islands. They can be regarded as sacred gifts or embodiments of gods, and form offerings and 'first fruits' for deities, chiefs, families and special occasions (Thaman *et al.* 2010). The practice of shark calling has a long history in Melanesia for both 'taming' rituals and for hunting (Horton 1965). In Malaita, anthropologists have recorded shark taming rituals that involve sharks lying peacefully in shallow water with their heads resting on rocks breaking the surface while being hand-fed pig entrails. Anthropologists observing the ritual were told that the sharks were guardians and protectors (Cooper 1970, pp. 108–109). In a largely Christian nation, religion plays a role in daily life of Solomon Islanders. Of the ~96% who identify with a Christian religion, 11.7% are Seventh Day Adventist (CIA 2017). The beliefs of this religion prohibit trade and consumption of all shellfish, crustaceans, marine reptiles, cephalopods, marine mammals, sharks, and all fish without scales (Sabetian 2002), which in turn may influence how these communities use marine resources.

Nevertheless, the traditional symbolism and values associated with sharks and rays have begun to lose their significance in recent times. Lucrative international markets drive intense resource use across the Pacific (Cohen *et al.* 2015) and targeted shark fishing and finning is believed to occur in many small-scale fisheries throughout the Solomon Islands. On the island of Bellona, shark meat is not generally sold or eaten, but fins have been sold to Chinese merchants for US$6.30 kg^{-1} (Thaman *et al.* 2010). Perceptions and values of sharks are also changing. For example, the island of Anuta is well known for its approach to community-based management and sustainable resource use (Feinberg 2011). However, shark fishing has been documented and fishermen have been reported to have developed a sense of disdain towards sharks, and would not consider the depletion of local populations to be negative (Feinberg 2010).

Sharks and rays in Solomon Islands' fisheries

Fishing practices in the Solomon Islands have diversified. Before the 1970s, fishing was focused on satisfying local needs (Skewes 1990). A shift towards market economies has increased incentives to fish for monetary income, and both industrial commercial fishing offshore and coastal artisanal fishing have increased. At present, Solomon Islands' fisheries can be categorised into two main sectors: offshore industrial commercial fisheries, and coastal small-scale fisheries.

Offshore industrial fisheries

The interactions between sharks and fisheries in the Solomon Islands are best documented in offshore industrial tuna fisheries operating in the Solomon Islands Exclusive Economic Zone (EEZ). These fisheries target yellowfin, skipjack, bigeye, and albacore tuna, and the fishery is a major component of the national economy. Since the 1970s, the domestic commercial tuna fishery has grown to become one of the nation's largest employers; by the 1980s it accounted for 30–50% of the nation's total foreign exchange earnings (Anonymous 1992). However, the Solomon Islands also gains valuable foreign income from licence fees from foreign fishing vessels operating within the EEZ (Oreihaka 2001). These foreign fishing vessels are often member countries of the Western and Central Pacific Fisheries Commission (WCPFC), which oversees the management of highly migratory species in this region. The concentration of tuna fishing under WCPFC management is heavily focused in the waters directly east of Papua New Guinea and around the Solomon Islands for both the purse seining and longlining industries (Clarke *et al.* 2013).

While not necessarily targeted, sharks are often taken in offshore tuna fisheries throughout the Pacific (Clarke *et al.* 2013). Despite the connection between the high value of shark fins and shark mortality, sharks are often taken as by-catch or by-product, which creates challenges for effective management (Clarke *et al.* 2013). Prior to the 1980s, Solomon Islands tuna fisheries were dominated by pole-and-line fisheries, which had relatively little by-catch, but the shift to longline and purse seine fishing gear after this period has increased by-catch significantly (Sulu *et al.* 2000; Doyle *et al.* 2012). While there are limited official data specifically on shark by-catch in tuna fisheries in the Solomon Islands, the 'Sea Around Us' (SAU) database provides rough estimates of landings and unreported discards of several shark species caught by industrial fisheries operating in the Solomon Islands EEZ, including blue silky, oceanic whitetip, mako and thresher sharks. Using a combination of officially reported FAO data and estimated unreported catches and discards, as described by Zeller *et al.* (2016), the SAU data provide evidence of by-catch under-reporting (Doyle *et al.* 2012). Furthermore, cryptic mortality, where animals die even if released, could also increase mortality.

While blue sharks (*Prionace glauca*) are reportedly the most common shark caught on longlines and purse seines in the Solomon Islands (Lack and Sant 2012), specific landings data by shark species and year could not be located for the fishery. SAU data estimate annual unreported blue shark discards at an average of 2445 tonnes annually from 2000 to 2014. Estimates for annual reported landings of silky shark (*Carcharhinus falciformis*) in the same period were 36.9 tonnes, while unreported discards were 347.5 tonnes. Average reported oceanic whitetip shark (*Carcharhinus longiamnus*) landings were 12.9 tonnes, with an unreported 121.2 tonnes of discards. Mako

sharks (*Isurus* spp.) averaged 92.5 tonnes reported landings and 249.7 tonnes unreported discards, while thresher sharks (*Alopias* spp.) averaged 23.4 tonnes reported landings and 22.5 tonnes unreported discards. With the exception of thresher sharks, the estimated tonnage of unreported discards greatly outweighs reported landings. While these trends provide some indication of shark catches in the absence of more reliable data, SAU data are compromised by issues such as upscaling and the quality and availability of source data. Likewise, while the WCPFC recognises by-catch issues with these species, the lack of data about interaction rates, compliance rates and postrelease survival from shark interactions specific to the Solomon Islands make it difficult to accurately estimate shark catch and mortality in the offshore tuna fishery.

The second major offshore fishery affecting sharks in Solomon Island waters was the targeted shark pelagic long-line fishery. Shark catches peaked in 1984–85 with an estimated 190 tonnes of mainly carcharhinid sharks. Exports from this catch included 2000 hides and 2 tonnes of shark fins (Richards *et al.* 1994). Deep-water gulper sharks were briefly targeted by deep-water long-liners from 1987 to 1992. Oil produced from the livers of this catch was exported exclusively to Japan, averaging 2.9 tonnes in 1989 and 7.7 tonnes in 1992 (Richards *et al.* 1994). By the year 2000, there were 201 licenced fishing vessels in Solomon Islands including 13 shark long-liners that specifically targeted sharks (Oreihaka 2001). By 2010 the total number of licenced vessels had more than doubled to 482, with 13 shark longlining vessels still in operation. Following a decision of the Ministry of Fisheries and Marine Resources to halt targeted commercial shark fishing in 2010, licenses for these vessels were not renewed (Lack and Sant 2012).

Coastal small-scale fisheries

Artisanal and subsistence fishers in the Solomon Islands use a wide range of gear to target a diverse array of species (Richards *et al.* 1994). Since the early 1800s, resources such as sea cucumbers and green snails have reached foreign markets from traders in the Solomon Islands, and these resources have remained important to small-scale artisanal fishermen (Skewes 1990; Chin *et al.* 2011). The most common fishing method used by artisanal and subsistence fishers is drop lining on local reefs, a non-selective method that can take sharks and other reef fish.

Sharks are also part of the traditional diet of some coastal communities; skin and meat of mainly carcharhinid sharks are consumed as food, especially in the Wagina area of Choiseul Province, where communities actively hunt shark for domestic consumption (Skewes 1990). In Marovo Lagoon, Western Province, shark fishing is conducted with heavy modern tackle (Hviding 1988). While data are limited, it seems likely that targeted shark fishing occurs in other communities, with the meat being consumed and fins sold for export (Juncker *et al.* 2006). As for many Pacific nations, collecting data from coastal fisheries is challenging and apart from specific datasets arising from specific projects, there are few long-term data on catch composition, fishing effort and landings. It is therefore unknown whether overfishing has occurred; however, there are indications that many fisheries have declined (Sabetian and Foale 2006; Roeger *et al.* 2016). The available information suggests that sharks taken in small-scale fisheries are usually species of *Carcharhinus*. Shark fin exports from the Solomon Islands are small and intermittent compared with those of other nations, with a reported 2 tonnes in 2001 and 3 tonnes in 2008 (FAO 2010), although FAO statistics on shark fin should be treated with caution (Clarke *et al.* 2006). While artisanal fishing is tremendously important throughout the nation, little information on these fisheries exists, and the take of sharks and rays in coastal fisheries requires urgent attention (Juncker *et al.* 2006; Clua and Planes 2014).

Discussion

This systematic review presents a synthesis of the available information regarding the diversity of sharks and rays in the Solomon Islands, the fisheries interacting with them, and the current understanding of their conservation status. While this is an important first step, it is clear that information is limited – especially for coastal fisheries – and the data presented here should be treated as preliminary. Given these data limitations, the approach of using multiple searches that included online data repositories and grey literature, and across a wide variety of disciplines proved invaluable. Indeed, peer-reviewed scientific journals accounted for only 13 species records, with the remaining 37 species being uncovered from unpublished data including ethnobiographical work, museum and specimen databases (e.g. http://tapewormdb.uconn.edu/ accessed 31 March 2017) and unpublished data from research cruises (Table S1). Data verification and validation through a taxonomic expert, and ground-truthing with in-country partners, was also vital to ensuring the checklist's rigour. Taxonomic expertise enabled access to museum databases and resolved numerous taxonomic issues, while in-country specialists provided validation of species presence with their own records and data. In some cases, dive shop operators had decades' worth of accumulated knowledge that were used to validate data. For example, while the epaulette shark (*Hemiscyllium ocellatum*) is reported for the Solomon Islands in a regional synopsis, specific data cannot be located to confirm the species' presence, and a dive shop owner with decades of experience in the region confirmed the absence of the epaulette shark, suggesting that this historical museum record most likely has erroneous location information on the original label. These cases highlight the importance of validation processes and the need to be explicit about taxonomic uncertainty. Indeed, while the full annotated checklist includes 57 species, three of these (*H. ocellatum*, *Chiloscyllium indicum* and *Lamna nasus*) are suspected of being misidentifications due to biogeographical inconsistencies with the known range for these species (Table S1). In contrast, the reef manta (*Mobula alfredi*) is reported only from anecdotal data and, while its occurrence is likely, the record requires photographic verification to confirm its presence. Furthermore, the great hammerhead shark (*Sphyrna mokarran*) is reported from Papua New Guinea to the north and from New Caledonia in the south (Last and Stevens 2009). Given that hammerheads are known to make long-distance migrations (Hammerschlag *et al.* 2011), it seems plausible that the great hammerhead does occur in the Solomon Islands, but has either been unrecorded in fisheries, or, more likely, misidentified as the scalloped hammerhead.

Additionally, valid reports of the largetooth sawfish (*Pristis pristis*) have been documented in Bougainville in Papua New Guinea. Bougainville is part of an island chain in the northern Solomon Islands and thus, it is plausible for *P. pristis* to occur in the Solomon Islands as well. Resolving these issues would increase the rigour of the existing species list. Meanwhile, the current checklist provides a reference point that can be amended and changed as new information becomes available. Considering what is already known of the Solomon Islands' biodiversity as part of the Coral Triangle, it is highly likely that more species would be identified with primary research efforts in the country to investigate shark and ray diversity in the region.

These findings also highlight the importance of citizen science and local networks when working in data-poor contexts. There are numerous examples of successful citizen science approaches to record species occurrence and distribution, and to monitor shark populations (Davies *et al.* 2012; Dickinson *et al.* 2012; Chin 2014; Vianna *et al.* 2014). Given resource limitations and logistical constraints in surveying sharks and rays across the archipelago, citizen science could be a powerful tool in documenting the occurrence of sharks and rays in the Solomon Islands, and, indeed, across the Large Ocean Island States of the western and central Pacific. The power of citizen science can be further enhanced and focused with training from scientists with first-hand field experience in coastal communities of Solomon Islands.

The conservation status assessments presented for Solomon Islands sharks and rays should also be treated as preliminary data that require primary research to validate these assessments. The IUCN Red List provides an account of conservation status at a global scale, which may not reflect regional or local contexts, which is why regional assessments are often undertaken (e.g. Cavanagh *et al.* 2003). However, Red List assessments and listings on CITES and CMS do reflect the outcomes of systematic and comprehensive conservation assessments and, in the absence of other data, these assessments should be considered as preliminary indicators of at-risk sharks and rays in the Solomon Islands. Using this approach, 35% of shark and ray species in the Solomon Islands are listed as threatened with extinction. This finding suggests that further attention is needed to conduct local assessments for these species to ensure that current harvests are sustainable, and to identify which threatened species may require further action.

Another indirect indicator of shark and ray conservation status and outlook is to examine the state of fisheries interactions and of fisheries management. There are clear differences between large-scale, industrial offshore fisheries and small-scale coastal fisheries in the Solomon Islands, and both fisheries require separate management approaches (Pomeroy and Andrew 2011) to ensure sustainable catches of sharks and rays. For offshore fisheries, the most recent fisheries management arrangements lie in the Fisheries Improvement Project (FIP) for the Solomon Islands Longline Fishery. Adopted in 2014, the FIP aims to complete a series of 33 necessary 'milestones' by 2019, which includes the conservation of endangered, threatened, and protected species as well as the completion of a National Plan of Action for Sharks in the Solomon Islands (Banks 2014). Under the FIP, licensing rules will prevent the landing of oceanic whitetip, silky, hammerhead, and white sharks. The use of trace wires will be banned, and there will be a 5% fin-to-carcass ratio by weight in an attempt to prevent shark finning (Banks 2014). The weight of fins on board a fishing vessel must total no more than 5% the weight of shark on board (Lack and Meere 2009). The project aims to improve monitoring and reporting on species composition of all catch, including detailed information on everything retained and discarded in Solomon Islands waters. Many of the management actions require implementation through WCPFC as Conservation and Management Measures (CMM), as well as support from the Forum Fisheries Agency, Secretariat of the Pacific Community, and the Ministry of Fisheries and Marine Resources (Banks 2014). The WCPFC CMMs apply across all offshore tuna fisheries operating in Solomon Islands waters, and as one of the 32 members of the WCPFC, the Solomon Islands is required to uphold the regulations described in all CMMs. Between 2011 and 2013, the WCPFC introduced CMMs that prohibited the targeting, retention and processing of silky sharks, oceanic whitetip sharks and whale sharks. However, it is unclear to what degree CMMs are enforced within the Solomon Islands due to issues in monitoring and enforcement. Additionally, fishing vessels in the Convention area were not required to accept observers from the Regional Observers Program on-board until 2007 (WCPFC 2015), and it was not until 2011 that WCPFC members were required to submit catch data for sharks (Clarke *et al.* 2013). The large-scale use of longlining and purse seining in tuna fisheries can take significant amounts of sharks and rays, but robust species-level data on the total catch of sharks and rays in Solomon Island waters are not available. These issues mean that historical data on shark catch are lacking. Overall, while there are conservation and management frameworks in place for offshore fisheries, the complexity of these fisheries and shark movements, the lack of catch data, and the uncertainty in compliance and enforcement mean that it is unclear whether these new measures are sufficient to ensure the sustainability of shark catch into the future.

The Solomon Islands' coastal fisheries are similarly complex, and like many small-scale fisheries are extremely challenging to monitor and manage (Pomeroy and Andrew 2011). The lack of knowledge about coastal and inshore fishing compromises national-level management of shark resources, and demonstrates the need for research such as biodiversity surveys and population size estimates through catch surveys, life-history studies, and ecological risk assessments (Stobutzki *et al.* 2001; Harry *et al.* 2011). Without detailed studies such as these, it is uncertain how well global IUCN Red List assessments reflect the status of Solomon Islands elasmobranch populations, and complicates efforts to plan and prioritise further management.

In the meantime, future shark and ray management and conservation in coastal artisanal and subsistence fisheries will probably depend on forms of Customary Marine Tenure (CMT) or Locally Managed Marine Areas (LMMAs), which embody a set of understood rules and relationships over access to, and use of, fishing areas and resources between groups and communities (Hviding 1988; Jupiter *et al.* 2014). Estimates suggest that access to, and use of, over 90% of inshore coastal areas is controlled by these community-based arrangements (Albert *et al.* 2015), and formal governance arrangements exist to support CMT- and LMMA-based management. For example,

the Solomon Islands Locally Managed Marine Area Network facilitates comanagement relationships between local community managers, NGOs, research agencies, and the government, and the Solomon Islands Constitution acknowledges the importance of traditional management and ownership arrangements (Sulu *et al.* 2000). This recognition emphasises that successful management and conservation almost completely rely on the compliance and dedication of local communities. However, it should be recognised that LMMAs typically prioritise the regulation of nearshore waters, and the exclusiveness of fishing rights wanes with distance from the shore (Hviding 1988), so offshore activities such as shark fishing may not be managed by existing LMMAs. In these small-scale fisheries, shark and ray management will also need to be considered within approaches that focus on livelihoods and food security, not conservation-dominated narratives. In general, the concept of conservation and sustainability in Solomon Islands' coastal communities is often based in food security. For example, communities on Anuta Island actively pursue conservation and natural resource management, and it is understood that too many fish harvested in one year could mean too few the next, and sustainable management practise has been in place for decades (Feinberg 2010). Some areas, like Marovo Lagoon in the Western Province, have highly flexible CMT, which can adapt to local issues regarding subsistence and commercial use of fishing territories (Ruddle *et al.* 1992). In order to establish commercialised fishing within community-regulated territory, agreement must be met between all associated rights-holders. Widespread opposition to commercial fishing in communities with well established CMT has prevented the switch to large-scale fishing (Ruddle *et al.* 1992). These examples demonstrate the potential of participatory community-based approaches such as CMT and LMMAs to successful small-scale fisheries management in coastal communities (Jupiter *et al.* 2014; Cohen *et al.* 2015), and managing shark and ray catches should be integrated with these processes. Nevertheless, changing needs and aspirations concerning food security and livelihoods, and the potential for economic gain, may weaken the influence of CMT over the harvest of resources (Cohen *et al.* 2015) such as shark fins. Additionally, although CMT controls access to, and use of, resources, many managed areas were originally developed through social and cultural drivers rather than by conservation or sustainability ethics (Foale *et al.* 2011). Thus, future shark and ray management and conservation efforts in these small-scale fisheries should be based upon participatory processes that identify and explicitly consider social and cultural factors, as well as community-specific drivers, aspirations and needs.

Conclusions

This review provides an important first step to understanding the diversity, significance and preliminary status of sharks and rays. While more information is needed to comprehensively assess the status of sharks and rays in the Solomon Islands, this review provides vital background information to support development of policy instruments such as an NPOA, and meeting reporting requirements for agreements such as the Convention of Biological Diversity. While sharks appear to be culturally important to some Solomon Islanders, and are certainly taken in offshore and coastal fisheries, little is known of their diversity, their population status and trends, catches and values – especially in coastal fisheries – and of their contemporary significance and importance to local communities. Existing shark and ray management is focused on offshore fisheries, but is compromised by low observer coverage and uncertainty about the implementation of conservation measures. Participatory community-based approaches hold promise for coastal fisheries management, but need the involvement and commitment of many stakeholders, including government agencies. This review identifies several key knowledge gaps and priority actions that need to be addressed to assess and manage the Solomon Islands' sharks and rays, and recognises that field work is necessary to complete these actions. Priority actions include (1) obtaining better knowledge about catches in coastal fisheries, and the social, cultural and economic dimensions of these activities; (2) supporting and enhancing participatory monitoring and management processes for the Solomon Islands' coastal fisheries; (3) targeting research, including citizen science, to document the diversity of sharks and rays in the region; (4) explicitly considering sharks and rays in management arrangements and processes for coastal fisheries; (5) supporting and enhancing monitoring, compliance and enforcement of existing management of large-scale offshore fisheries; (6) preparing a localised risk assessment such as an ecological risk assessment for shark and rays; and (7) building capacity and understanding in the Solomon Islands about shark and ray management and conservation. In conjunction with the NPOA, these actions should be considered as focal areas to start discussions about developing a multidisciplinary, multiagency project to develop a feasible plan for documenting, monitoring, managing and conserving the shark and ray resources of the Solomon Islands into the long term.

Conflicts of interest

The authors declare no conflicts of interest.

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