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Characteristics of Fiji's small-scale ray fishery and its relevance to food security

Kerstin Glaus [a,*,1], Rusila Savou [a,2], Juerg M. Brunnschweiler [b,3]

[a] School of Agriculture, Geography, Environment, Ocean and Natural Sciences, SAGEONS, The University of the South Pacific, Laucala Campus, Suva, Fiji
[b] Independent Researcher, Gladbachstrasse 60, Zurich 8044, Switzerland

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ABSTRACT

Sharks and rays are a relevant component of Fiji's small-scale fishery. However, existing data are skewed towards sharks, leaving fishery activities for rays less understood. To document species-specific catch numbers, sex, and age-classes of captured rays, the Suva fish market on Fiji's main island Viti Levu was surveyed for one year from January 2022 to January 2023. Among the 192 individual rays recorded in Suva, five species were visually identified: maskray (*Neotrygon sp.*), spotted eagle ray (*Aetobatus ocellatus*), pink whipray (*Pateobatis fai*), Oceania fantail ray (*Taeniura lessoni*), and porcupine ray (*Urogymnus asperrimus*). DNA barcoding did not provide unequivocal species confirmation. The maskray and spotted eagle ray were the most captured and traded species. To further characterize the fishery and to capture the relevance of rays to food security, 84 fishers and market vendors were interviewed in coastal communities and at local fish markets. The interviews revealed that 70.4% of the interviewees caught rays, of which 60% reported to spear them. Rays were considered a moderately important resource but were particularly relevant to food security as substitute for bony fish. Given the life histories and global declines of many ray species, explicitly considering rays in management arrangements for coastal fisheries and enhancing compliance and enforcement of existing regulations, is vital to safeguard Fiji's coastal ray populations. Overall, these findings provide baseline information for monitoring Fiji's small-scale ray fishery.

1. Introduction

Small-scale fisheries (SSF) play a critical role in supporting food security, providing employment opportunities, and maintaining cultural and social connections within communities [1,2]. In times of increasingly depleted coastal ecosystems, where SSF are common on a global scale [3,4], only limited data on SSF are available [5,6]. Also, official statistics and national accounts are often lacking, which hinders the efficient management of coastal fisheries' resources.

Elasmobranchs (sharks and rays) are threatened by overfishing [7–9], causing diversity deficits in reef shark and ray assemblages [10]. In tropical coastal waters, SSF frequently target or opportunistically capture sharks and rays [11–14], which can be vital to the fishery resource base [15–17]. Considering their K-selected life-history [18], SSF can significantly affect coastal shark and ray populations [8]. Hence, understanding the role of elasmobranchs in SSF is crucial for their conservation [19]. Generally, sharks have received more attention, while rays have been underrepresented in scientific efforts [20,21], although five out of the seven most threatened elasmobranch families are rays [22].

Fiji's 60 elasmobranch species [23–25], have traditionally held high cultural relevance [26–28] and are frequently caught by artisanal and subsistence fishers throughout the country [29,30]. Available data suggests that sharks are typically caught opportunistically in mixed-species reef fisheries that use gillnets, spears, lines, and drumlines [29]. Several threatened species, including scalloped hammerhead (*Sphyrna lewini*), tiger (*Galeocerdo cuvier*), silvertip (*Carcharhinus albimarginatus*) and bull sharks (*C. leucas*), are affected. Sharks, particularly juveniles, are occasionally sold at fish markets and while their economic importance has presumably declined following the shark fin export ban

* Corresponding author.
E-mail address: kerstin.glaus@usp.ac.fj (K. Glaus).
1 0000-0001-9985-2243
2 0009-0005-9080-0486
3 0000-0002-9901-3279

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[31], the use of shark meat as a substitute for bony fish remains evident. Less is known about rays. Rays have been ceremonial and chiefly food among indigenous Fijian communities [28,32] and the maskray (as *Neotrygon kuhlii*), spotted eagle ray (*Aetobatus ocellatus*) and pink whipray (*Pateobatis fai*) are considered delicacies. Also, the maskray has been the most common ray sold at fish markets [33]. However, the exact catch numbers, species composition and biological characteristics are undocumented. Also, various ray species have undergone taxonomic revisions [32,34,35] and to date, only the bottlenose wedgefish (*Rhynchobatus australiae*) is unequivocally confirmed genetically among ray species in Fiji [29]. Without accurate species identifications, the value of catch data and specific information on species is questionable. Hence, genetic methods, such as mitochondrial DNA Cytochrome Oxidase subunit 1 (COI) barcoding for species identification is necessary for definitive in-country confirmation [36].

Required knowledge extends beyond reliable species identification and catch compositions to encompass a more profound understanding of Fiji's ray fishery. In Fiji, the dependence on marine resources for food security is generally substantial [37,38]. Hence, it is pivotal to recognize the degree to which rays contribute to food security, and the interdependence of economic and socio-cultural factors in Fiji's SSF.

This study presents the results from surveying Fiji's primary fish market in Suva for rays and interviewing local fishers and market vendors. The objectives were to (1) describe the species composition, sex-, size- and age structure of landed rays; (2) confirm visual species identification through DNA barcoding; (3) assess the importance of rays to food security; and (4) document fisher's perceptions associated with rays. The findings provide a baseline for future stock assessments, enabling tracking of changes in Fiji's ray fishery over time.

2. Materials and methods

2.1. Study area

The fish market survey was conducted in Suva, Fiji's capital on the main island Viti Levu. In-person interviews were carried out with locals from coastal villages on Viti Levu, Vanua Levu, Kadavu, Beqa, Koro and the Yasawa Islands; fishers and vendors were interviewed at fish markets in Suva, Sigatoka, Nadi, Lautoka and Ba on Viti Levu, and in Labasa and Savusavu on Vanua Levu (Fig. 1).

2.2. Suva fish market survey

The Suva fish market, Fiji's largest fish market, was visited one to three times per week between January 2022 and January 2023 to identify ray species, evaluate species-specific catch numbers, sex composition, seasonal variations in landings, size distribution, and associated sale prices. Prior to any data collection, the objectives of the survey were explained and verbal consent for performing measurements and collecting tissue samples was obtained from market vendors. In view of the significant economic value of the market day to fishers and the crucial role of trust in the local context, minimal intervention was preferred during the survey. Consequently, recording of certain information was selectively waived to prevent disruption of sale activities. Species, fishing gear, catch location, size, sex, and sale price were recorded whenever possible [39]. Species were identified using

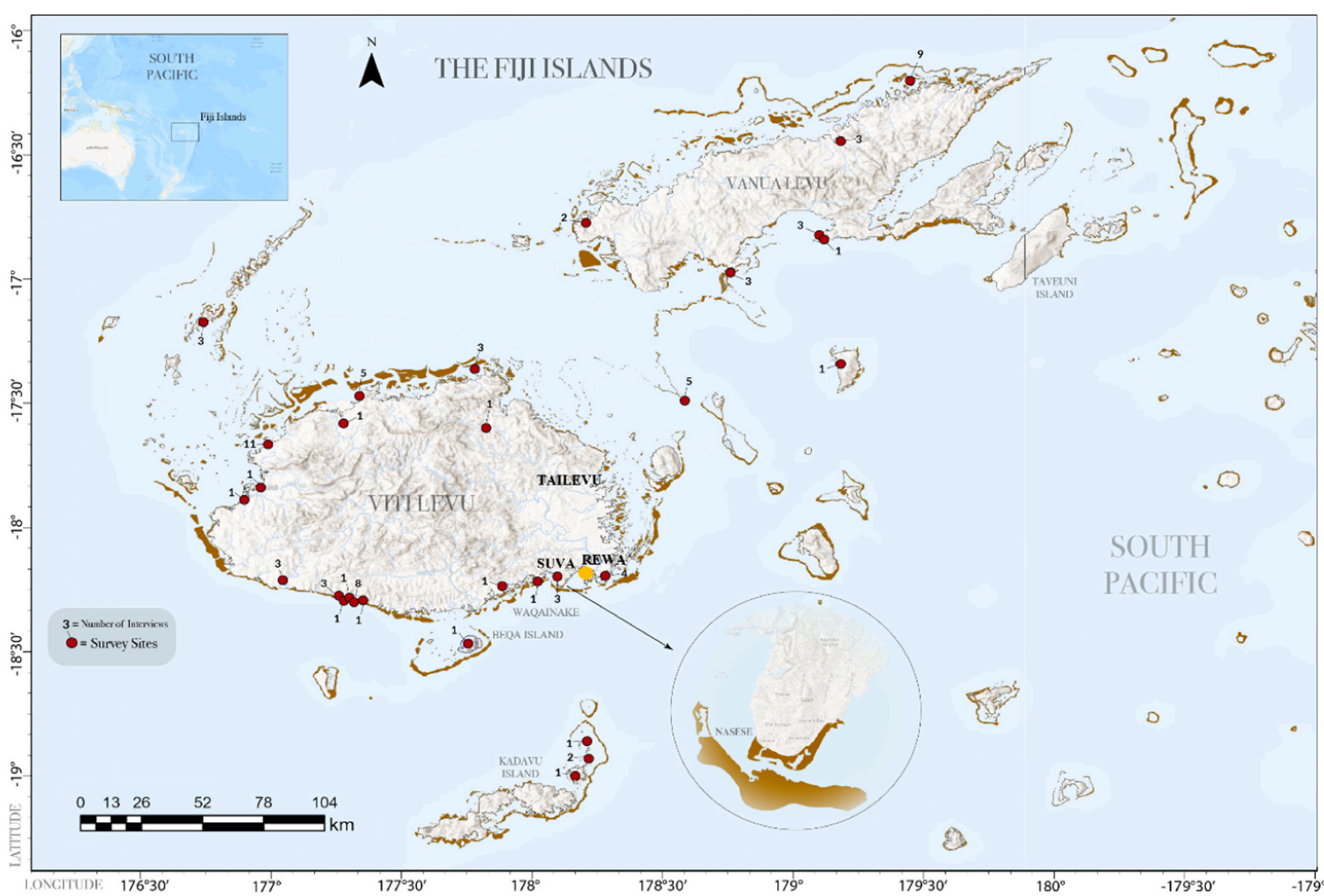

Fig. 1. The Fiji Islands in the South Pacific. Red dots mark locations where interviews were conducted (or respondents originated from) between January and December 2022, including the number of interviews per site. The Suva fish market (yellow dot) was monitored from January 2022 to January 2023. Tailevu, Rewa, Waqainake, Beqa, Kadavu and Nasese are catch sites of rays traded at the Suva fish market.

identification keys from Daley [40] and Last *et al.* [41]. Collected tissue samples (fin clips, 1 cm^2) were stored in 95% ethanol and kept in a freezer at – 20° C until DNA extraction. At the market, rays were measured by disc width (DW) with a tape measure. The disc of most rays encompasses the combined head, trunk and enlarged pectoral fins [41]. DW is defined as the maximum distance between the wingtips, and measurements were recorded to the nearest centimeter along the horizontal axis on the dorsal side [42]. The sex of rays was determined based on absence of claspers in female specimens and the presence of clasper in male specimens, which are visible from an early stage of development on the inside edge of the pelvic fins [43,44]. No rays were purchased from fishers or vendors to avoid any inadvertent incentives or demand.

2.3. Fish market data analysis

Market survey data were initially written manually onto data sampling sheets, then transferred to a Microsoft Excel sheet and imported into R statistical software using the tidyverse library [45]. In R, data were checked for errors, missing values, and inconsistencies. Descriptive statistics such as ray median and mean DW, standard deviations from size measurements, and frequency distributions of individuals per species sold per month were calculated and visualized. Analyses on size distributions and sex ratios were only performed for species for which sample sizes were $n > 30$. To ensure the validity and reliability of the information, a random sample comprising 10% of the dataset was selected for a manual double-check of the data entry process. Any discrepancies identified were resolved through cross-referencing the original notes.

2.4. DNA COI barcoding

The mitochondrial DNA COI gene is one of the most widely used gene markers for species identification [46]. DNA was extracted with the Qiagen Blood and Tissue Kit, following standard protocols (Qiagen Inc., Valencia, California, USA). A 652-bp fragment from the 5' region of the COI was PCR amplified using FishF2 (5′-35'TCGACTAATCATAAAGATATCGGCAC3'), FishF2N (5'ATCTTTGGTGCATGAGCAGGAATAGT3'), and FishR2 (5′ACTTCAGGGTGACCGAAGAAGAATCAGAA3′) primers [47]. PCR products were sequenced at Microsynth, Switzerland (www.microsynth.com). Resulting sequences were identified by using the Identification Engine at the Barcode of Life Data System (BOLD) [48] and by BLAST [49].

2.4.1. Interviews with local fishers and vendors

Approval for in-person interviews was provided by the Pacific-European Union Marine Partnership Programme Team Leader, by the University of the South Pacific, and by Provincial Councils (see Acknowledgement). In-person interviews were conducted from January to December 2022. Information was gathered by means of semi-directive interviews [50–52] with fishers from 30 locations on Viti Levu, Vanua Levu, Kadavu, Beqa, Koro and the Yasawa Islands (Fig. 1). Two of the authors (KG, RS) visited most markets and all villages together. Fishers and vendors were interviewed on-site at fish markets and an opportunistic sampling procedure was applied. Opportunistic sampling is a type of non-probability sampling where interviewees are selected based on naturally occurring groups [53]. In the villages, verbal authorization and approval were obtained from each village headman (*Turaga-ni-Koro*) prior to the interviews. Upon arrival in each village, permission to interview fishers was requested from the respective headman and/or the head of clans (*Turaga-ni-Yavusa*). Headmen and/or head of clans were presented with a *sevusevu* (kava, *Piper methysticum*) as per traditional protocol [54]. Headmen and/or head of clans then designated active fishers that could be interviewed. Fishers were asked to participate in the interviews, and they did not receive incentives to partake. Participants were further informed about the main purpose of the survey, that the interview could take up to 30–60 minutes and were assured that all information would be kept confidential and, except for documentation of selected quotes, only data aggregates would be revealed for the purpose of the study. Fishers were interviewed at their convenience [55], typically in the village meeting halls or their homes. One of the authors (RS) is fluent in English and Bauan Fijian. English is an official language in Fiji and interviews were conducted in English and Bauan Fijian, a common dialect which is used throughout Fiji and known to indigenous Fijians [56].

Pre-categorized and open-ended questions were outlined in a questionnaire (Supplementary, S1). The questionnaire covered various topics including: i) the socio demographics of respondents; ii) ray catch numbers and catch trends; iii) ray catch sites; iv) fishing gear used to catch rays; v) relevance of rays for food security; vi) trade of rays; and vii) perceptions toward rays. Fishers were shown photographs of ray species reported from Fiji, including the oceanic and reef manta rays (*Mobula birostris*, *M. alfredi*) [57], and asked to point out the species they catch. To ensure that the data on ray catch numbers was as accurate as possible, the authors avoided offering guidance or suggestions to respondents, aiming to prevent any influence on their responses. Accordingly, fishers provided information on their ray catch rates as they saw fit, i.e., per trip, week, or month. Responses were noted by hand on the questionnaires as they were encountered, and no leading questions or *a priori* coding dictionary were used.

2.5. Interview data analysis

Responses were compiled, coded into themes, and counted. Thematic analysis was primarily used for analyzing quantitative interview data. Open-ended and descriptive qualitative responses were also transferred verbatim into a Microsoft Excel sheet. Codes were created based on the content of the responses; in some cases, axial coding was used to group responses with similar codes. For example, fishers were asked how relevant rays are to food security. Similar responses such as 'important', 'any fish is important', 'getting more important' and 'important for large families' were grouped as 'important'. Responses such as 'occasional and substitute' 'tasty food', and 'tasty and something to share' were grouped as 'moderately important'. Bootstrapping was applied to obtain confidence intervals regarding ray catch numbers reported by fishers. The dataset was structured to include annual, monthly, and weekly catch variables. Three separate data frames were created for each variable (Catch_Year, Catch_Month, Catch_Week). These data frames were then combined into a single dataframe named 'combined_catch'. The catch numbers were adjusted to provide uniformity: monthly values remained unchanged, annual values were divided by 12, and weekly values were multiplied by four. Descriptive statistics, including the mean and standard deviation, were computed for the combined catch data. Next, a bootstrap resampling method generating 100,000 bootstrap samples to estimate the mean catch was applied. The 95% confidence interval (CI) was calculated for the bootstrap mean across the data set. The central limit theorem was applied to calculate a normal CI. All data were stored and standardized in Microsoft Excel and analyzed and visualized in R using the tidyverse and ggplot2 packages [58], where needed.

3. Results

3.1. Suva fish market: species composition and DNA barcoding

A total of 192 specimens from five ray species were recorded on the Suva fish market (Fig. 2). DNA barcoding confirmed the spotted eagle ray (99.2% similarity) and the pink whipray (100% similarity). Closest matches for the maskray were Kuhl's maskray (97.8% similarity) and the Coral Sea maskray (*N. trigonoides*, 96.83% similarity). Samples from the *Taeniura* genus were genetically identified as bluespotted lagoon ray (*Taeniura lymma*, 100% similarity). However, sequences of its closely allied and Data Deficient congeneric species the Oceania fantail ray (*T. lessoni*) were not available on BOLD and BLAST at the time of writing.

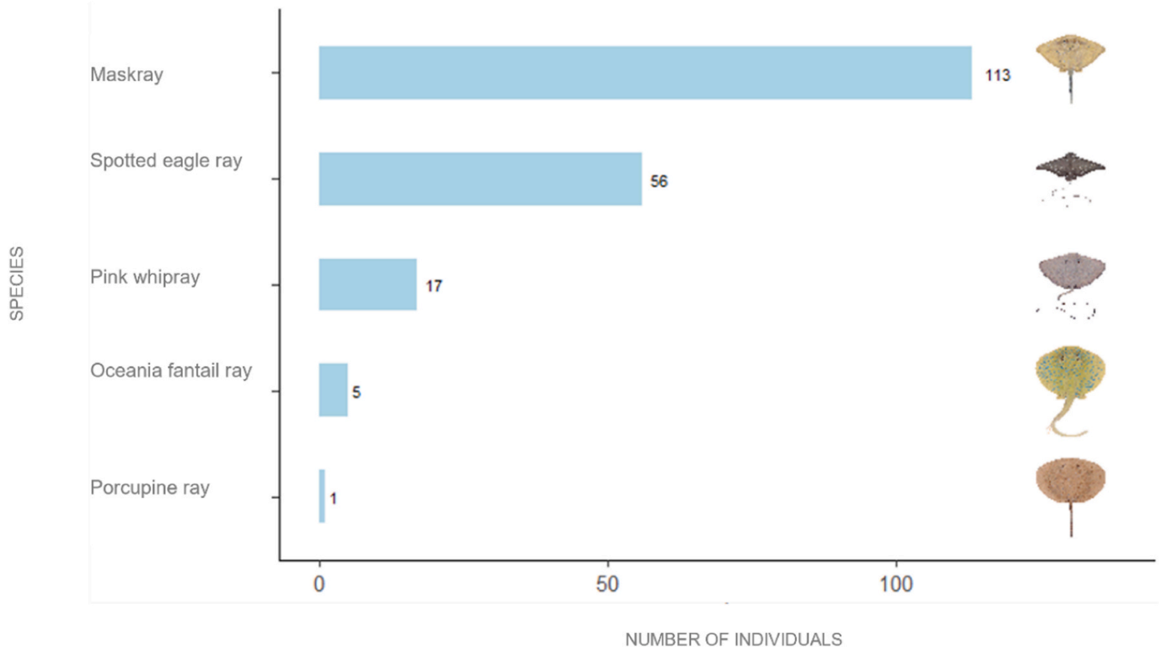

Fig. 2. Total number of rays by species recorded at the Suva fish market from the third week of January 2022 to mid-January 2023.

The Oceania fantail rays has only recently been identified and is limited to Melanesia in the Western Central Pacific [59]. The species lacks the distinctive pair of broad blue stripes on the tail, which are characteristic for the bluespotted lagoon ray [41,60]. Considering the absence of blue stripes on the tail in the specimens photographed in Suva (Supplementary, S2), it is reasonable to conclude that these specimens are indeed Oceania fantail rays. Accordingly, sequences of barcoded specimens were uploaded to GenBank, with the Accession number OR482643. DNA amplification for the visually identified porcupine ray (*U. asperrimus*) did not provide a sufficient quality amount of DNA.

Rays were captured and sold throughout the year. The maskray was the most frequently sold species at the Suva fish market, followed by the spotted eagle ray, the pink whipray, the Oceania fantail ray, and the porcupine ray (Fig. 2). The highest number of maskrays were sold in November 2022. A potential seasonal peak in January was observed for the spotted eagle ray. Conversely, the Oceania fantail ray was encountered only between May and July (Fig. 3).

Suva fish market vendors who sold rays alongside mixed-species reef fishes reported that they catch rays using gillnets. Between 20 and 25 vendors regularly sold fish. Of these, two consistently sold rays throughout the year. One fisher frequently sold maskrays, spotted eagle rays and pink whiprays, all of which were caught between the Rewa estuary and the coastal waters off Nausori (Figs. 1 and 4). The other sold the same three species and a porcupine ray once, all of which caught in

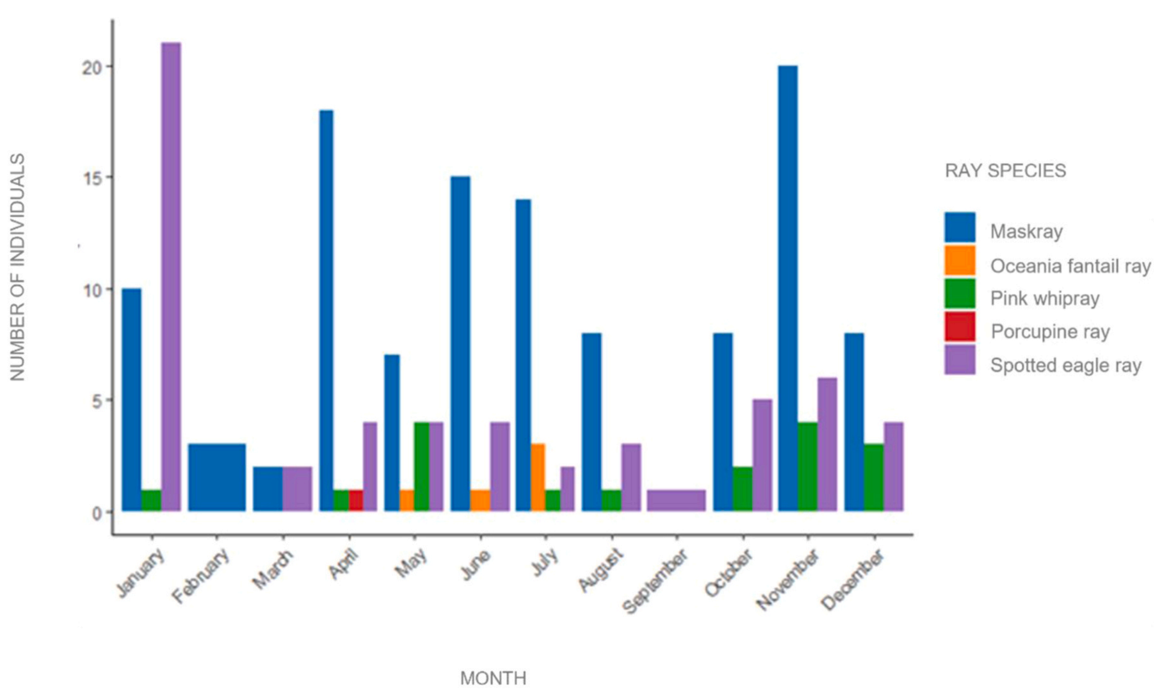

Fig. 3. Seasonal variation of catch compositions and numbers of different species of rays by months as recorded at the Suva fish market.

the province of Tailevu (Figs. 1 and 4). Other fish vendors who only occasionally sold rays reported to obtain them from fishers operating in the vicinity of Nasese and Waqainake, Beqa, Kadavu, and Vanua Levu. For 27 ray specimens, vendors did not know where they were caught (Fig. 4).

3.2. Size, sex ratio, and pricing

For 61 maskrays (54%) and 44 spotted eagle rays (78.6%), DW was measured. Mean of the former DW was 33.6 cm (median = 34 cm, range = 27– 42 cm, standard deviation = 3.47 cm) (Supplementary, S3). DW of the spotted eagle rays ranged between 28 cm to 128 cm, with a mean of ~52.77 cm, standard deviation of 26.61 cm, and a median of 37 cm. Most specimen had a DW of between 28 cm to 40 cm (Supplementary, S3). Sex was determined for 79 of the 113 recorded maskrays. Of these, 37 individuals were males, and 42 individuals were females, with no statistically significant sex bias (binominal tests, $p = 0.653$, 47% males). Of the 21 sexed spotted eagle rays (37.5%), seven were males and 14 were females, again with no statistically significant sex bias ($p = 0.19$, 33.3% males).

Prices of maskrays varied according to size ranging between 2.3 and 7.8 USD per specimen. Prices of spotted eagle rays also varied depending on the size and portion sold. Small specimens were sold for 6.8 USD, a piece of a large spotted eagle ray for 4.5 USD, half of a large one for 13.5 USD, and a whole large animal for 27 USD. Two small spotted eagle rays were sold together for 6.8 USD. Pink whiprays were sold for 6.8 USD for a small specimen, 4.5 USD for half of a small animal, and 9 USD for half of a large one. The only porcupine ray recorded on the Suva fish market was sold for 9 USD for a piece of approximately 25 cm×40 cm, and the price for Oceania fantail rays ranged between 2.3 and 4.5 USD per specimen.

3.3. Key demographic characteristics of interviewees

In total, 84 people were interviewed, including 71 fishers and 13 vendors. The former included 47 male and 24 female respondents, while the latter consisted of 10 men and three women. The age of interviewed female fishers ranged between 28 and 76 years, and male fishers were between 19 and 66 years old (S4, Supplementary). Overall, the years of fishing experience ranged between three and 45 years. Female and male vendors were between 28 and 41 years old and actively selling seafood for one to 20 years.

3.4. Characteristics of the fishery: practices, gear, catch sites, species, and perceptions towards rays

Of the 71 fishers interviewed, most fished two to five times per week (Table 1). The majority reported catching rays while less than a third stated not to catch any rays (Table 1). Of the 50 fishers who reportedly caught rays, most speared rays. Rays were captured by male and female fishers, with most male fishers ($n = 19$, 51.4%) capturing rays on coral reefs while 11 (84.6%) of the 13 female fishers reported catching rays in coastal sandflats and on coral reefs. Seven male fishers chose not to reveal specific catch sites. According to interviewees, the species they most commonly catch is the maskray ($n = 43$), followed by the spotted eagle ray ($n = 33$). The pink whipray and Oceania fantail ray were each named by 22 fishers. Seven fishers stated that they catch wedgefishes and the porcupine ray. Six fishers reported catching mobula rays and four fishers stated that they caught any type of ray. Fishers exhibited divergent perceptions towards rays, which were regarded as dangerous but beautiful as well (Table 1). Of the respondents, 26 interviewees (30.9%) provided insights into the animals' cultural significance, role as indicators, behavior, and fishing practices. Some interviewees also

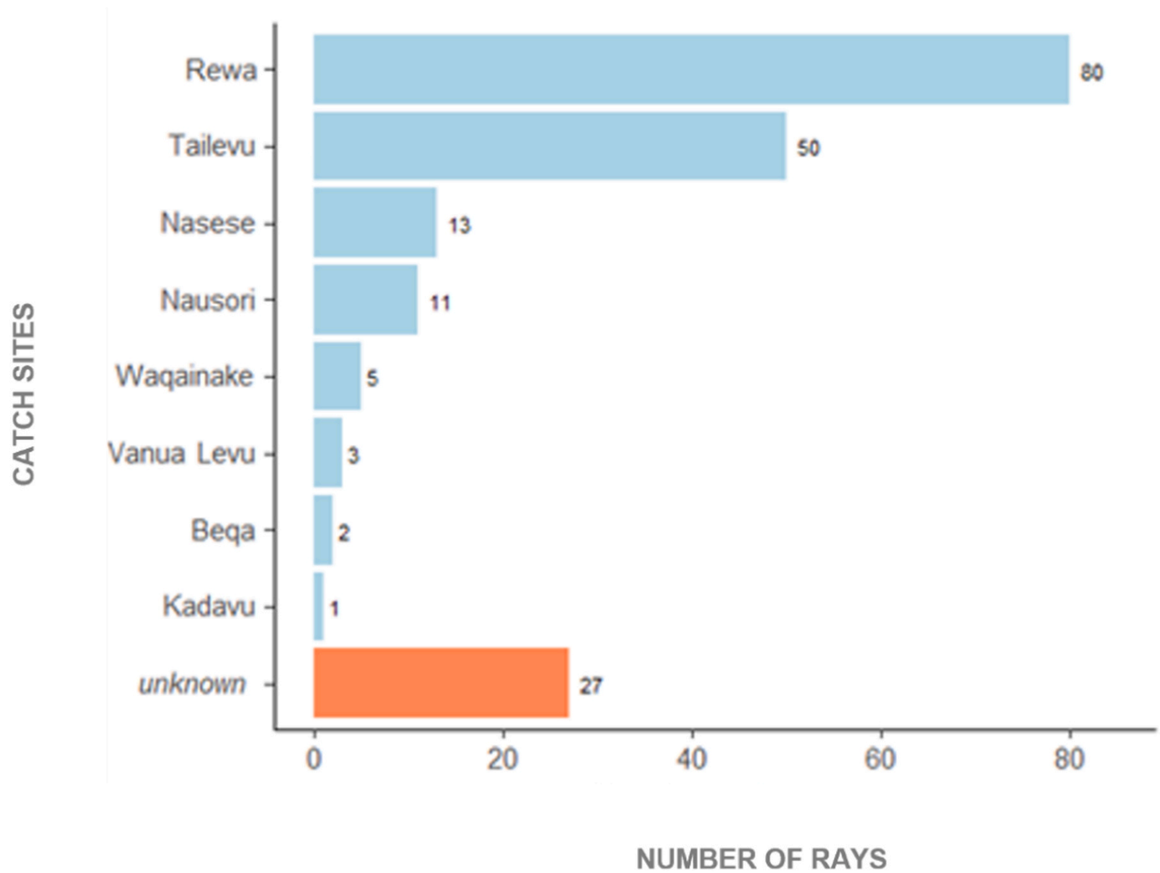

Fig. 4. Number of ray specimens caught at locations provided by fishers and vendors at the Suva fish market.

Table 1
Number (n) of respondents and response rates (%) by response and for each major interview topic.

Topic	Response	Response rate (#, %)	Response rate by topic (%)
Fishing frequency	2–5 times per week	n=34, 47.9%	91.5%
	Daily	n =22, 31%	
	Once per week	n =8, 11.3%	
	Once per month	n =1, 1.4%	
Capturing rays	Yes	n =50, 70.4%	100%
	No	n =21, 29.6%	
Fishing gear used	Spear, speargun	n =30, 60%	
	Gillnet	n =11, 22%	100%
	Lines	n =4, 8%	
	Gillnets, speargun	n =3, 6%	
	Lines and speargun	n =2, 4%	
Change in abundance	Increased	n =22, 31%	87.7%
	Decreased	n =19, 26.8%	
	Unchanged	n =17, 29.9%	
Threats to rays in Fiji	Unaware of threats	n =30, 42.3%	87.3%
	Overfishing	n =13, 18.3%	
	No threats	n =11, 15.5%	
	Habitat conditions	n =5, 7%	
	Boat strikes	n =2, 2.8%	
	Climate change	n =1, 1.4%	
Perceptions towards rays	Dangerous	n =25, 35.2%	88.7%
	Beautiful but dangerous	n =11, 15.5%	
	Beautiful	n =9, 12.7%	
	Just another fish	n =8, 11.3%	
	Dangerous but tasty	n =4, 5.6%	
	Indicators	n =3, 4.2%	
	Cultural relevance	n =2, 2.8%	
	Tasty and friendly	n =1, 1.4%	

expressed concerns about the potential loss of traditional ecological knowledge related to rays. Selected quotes were included as S5 in the Supplementary. Furthermore, respondents reported that they had never been asked about rays and had limited knowledge about their ecological role in the marine environment, the threats they face, their biological characteristics, and would generally like to learn more about 'the fish we eat'. Accordingly, most of the interviewees (n = 56, 78.9%) expressed interest in educational and awareness programs about basic ecological information on rays.

3.5. *Distribution and variability of reported ray catch numbers*

The bootstrap analysis incorporated data obtained from 45 (63.4%) interview respondents who provided ray catch numbers. The resulting bootstrap mean exhibited a slightly right-skewed distribution, with some deviation at upper and lower tails (Fig. 5). The 95% CI yielded a range of 4.6–14.2, indicating that with 95% confidence, the true mean catch across the data set lies within this range at 8.55. The 95% normal percentile for CI indicated that the true mean lies within the 3.6–13.5 interval, when assuming the central limit theorem applied. Overall, the analysis demonstrated good accuracy, with the bias being minimal (within +0.1).

3.6. *Relevance of rays to food security*

Of the 71 fishers interviewed, 60 (84.5%) revealed their perception on how relevant rays were to food security. Most considered rays as moderately important to food security (Fig. 6) and specified that the significance of rays as a food source varied depending on factors such as bony fish availability and weather conditions.

3.7. *Ray trading*

Of the 50 respondents who captured rays, 17 (34%) stated that they sell rays, fresh, frozen, or smoked pieces to community members, other villagers or to local vendors. The sale prices of rays were influenced by the size of the specimen, whether they were sold as whole animals or in pieces and ranged between two and 10 USD. Vendors were actively engaged in buying, processing, and trading fish. Four market vendors reported that they catch rays themselves, while the remaining vendors were only involved in the trade of rays. According to vendors, the maskray, spotted eagle ray and the pink whipray were commonly sold. One vendor indicted that he sold the blotched fantail ray (*Taeniurops meyeni*).

4. Discussion

This study presents the first focused exploration of the species composition, sex-, size- and age structure of ray landings in Fiji's small-scale fishery operations. Although rays are a regular component of Fiji's small-scale fishery, they were not considered a highly valued commodity and were sold at relatively low prices per individual when compared to lobsters, mud crabs or groupers [61–63].

4.1. *Market surveys: traded rays*

With 88% of all recorded individuals, the maskray and spotted eagle ray were the most prevalent ray species sold at the Suva fish market. Species of the genus *Neotrygon*, commonly known as 'maskrays,' are native to the Indo-West Pacific region [34]. The blue-spotted maskray was considered a single species, *N. kuhlii*, across its distribution range. However, molecular analyses have revealed discrete genetic diversity within this group and indicated the occurrence of several cryptic species [64,65]. Due to morphological ambiguity, it is often difficult to distinguish between congeneric maskrays. Maskrays are demersal, inhabiting intertidal sand flats, coral reefs, lagoons and slopes and as many other stingrays, they are likely susceptible to habitat degradation [66]. In this study, molecular barcoding did not unequivocally identify the maskray species. The closest similarity was found with the Kuhl's maskray and the Coral Sea maskray. The International Union for the Conservation of Nature, IUCN, assessed the former as Data Deficient [67] and the latter as Least Concern based on its Red List criteria [68]. Kuhl's maskray occurs in the Solomon Islands, while the Coral Sea maskray is present in eastern Australia and new Caledonia [41]. Given the low reproductive output of congeneric species [39], the finding that the maskray is the most traded ray in Suva and reportedly also the most captured ray by local fishers, caution is warranted concerning the fishery's sustainability, particularly in the absence of clear species knowledge. Additional genetic and morphological analyses are currently underway to characterize Fiji's maskray species (KG, personal communication).

The spotted eagle ray is semi-pelagic and found in tropical and subtropical waters of the Indo-Pacific region, typically along coastal regions and the continental shelf [69]. It is commonly linked to coral reefs, lagoons, and estuaries, but also found in open offshore waters [41]. This low fecundity species [70,71] is assessed as Vulnerable on a global scale and as Near Threatened in Australian and Oceania waters, if conservation measures are in place [72].

The pink whipray, Oceania fantail ray and porcupine ray were rarely documented. The pink whipray and porcupine ray are assessed as Vulnerable and typically found in shallow-water habitats where fishing pressure is usually high. No life-history data is available for the porcupine ray but related species such as the brown stingray (*Dasyatis lata*) have a long generation length of more than 20 years [73]. Interviewed

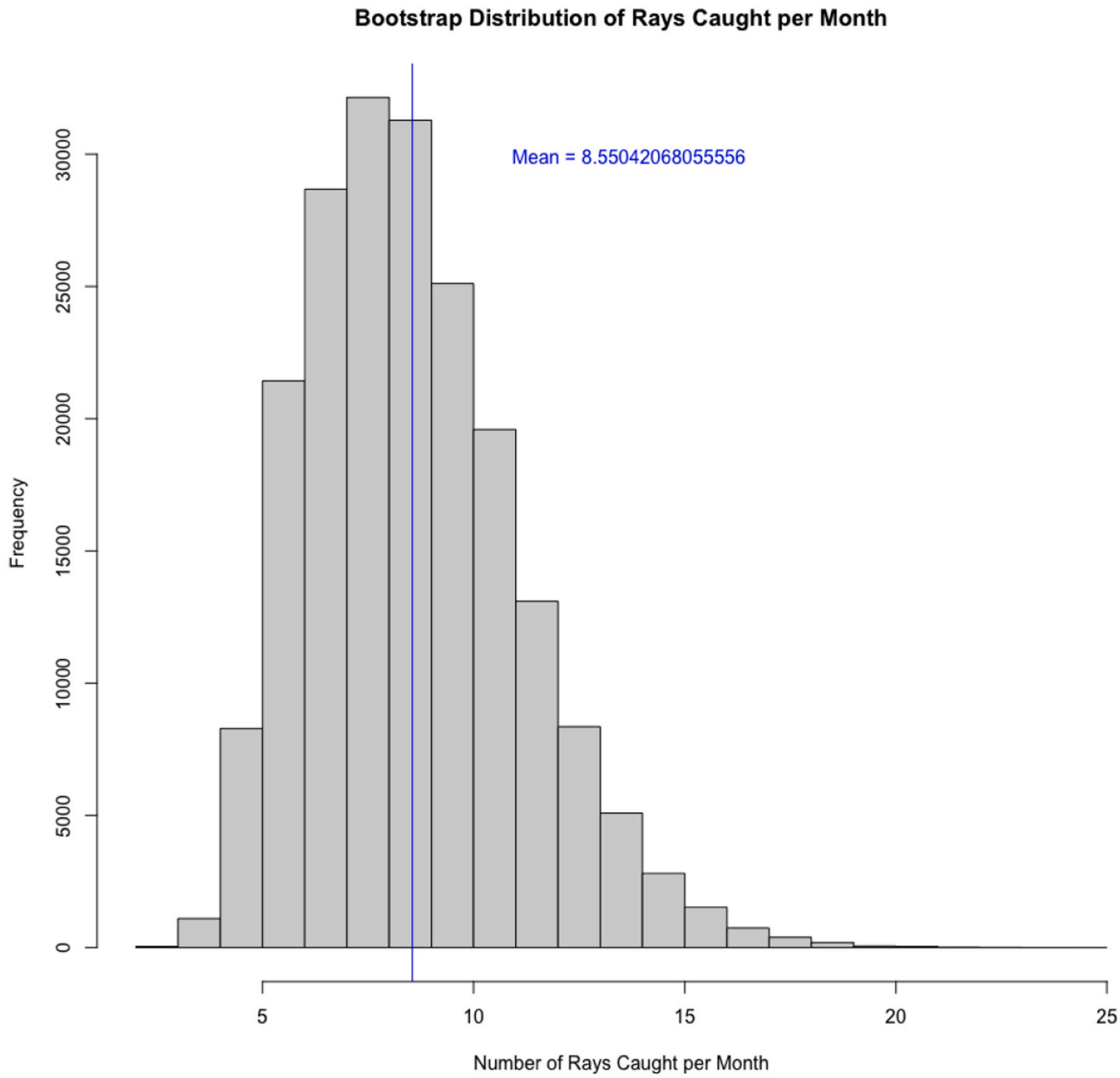

Fig. 5. Histogram depicting the results of a non-parametric bootstrap sampling strategy with 100,000 samples.

fishers stated that this species is difficult to spear and catch due to its thorns and spines covering its dorsal surface [74], which may be one reason why this species was encountered at the market only once and thus, just one tissue sample of this species was collected. However, this sample was likely compromised by contamination due to the co-presence of various fish species in the market environment and lower quality extracted DNA post sample processing hindered species identification.

4.2. *Age classes and sex in the maskray and spotted eagle ray*

The average size of traded mask rays (~34 cm DW) corresponds to mature individuals [39,75]. Conversely, male spotted eagle rays mature at 100–130 cm DW and females at 150–160 cm DW. Immature rays tend to frequent shallow-water nursery habitats [76], with spotted eagle rays showing ontogenetic habitat shifts [77]. Predominantly small individuals of the spotted eagle ray were recorded in Suva, suggesting that young age-classed are exposed to fishing pressure. Although catching juveniles of a low fecundity species does not necessarily make it vulnerable [78], sensitivity analyses of age- and stage-structured models emphasize the significance of juvenile survival in determining population growth, particularly for species with a low maximum population growth rate [79,80]. This suggests that fishing activities in the Suva-Rewa-Tailevu area may increase juvenile mortality in potential nursery grounds. Finally, the absent sex bias in the sex ratios of landed rays suggests no sex segregation, which is consistent with the limited evidence for sex-differentiated movements in batoids [81].

4.3. *Social dimension and characteristics of the fishery*

Ray meat consumption was widespread among the communities interviewed. The capture and consumption of rays was largely driven by subsistence needs and according to respondents associated with declines in targeted bony fish. Mirroring the market survey results, the maskray and spotted eagle ray emerged as the most frequently captured species. The reports of capturing mobulid rays contradict earlier findings that had indicated these rays were not caught in Fiji's SSF [33]. However, more data are needed to fully understand the nature and extent of mobuilds caught in Fiji's SSF. Seven fishers reportedly captured wedgefishes, a group of highly endangered rays [82], which occur along several coastlines in Fiji [83].

Villagers' accounts revealed that rays were predominantly speared on coastal sandflats and coral reefs, while at the Suva market, fishers and vendors indicated gillnets as the primary catch method for sale. The

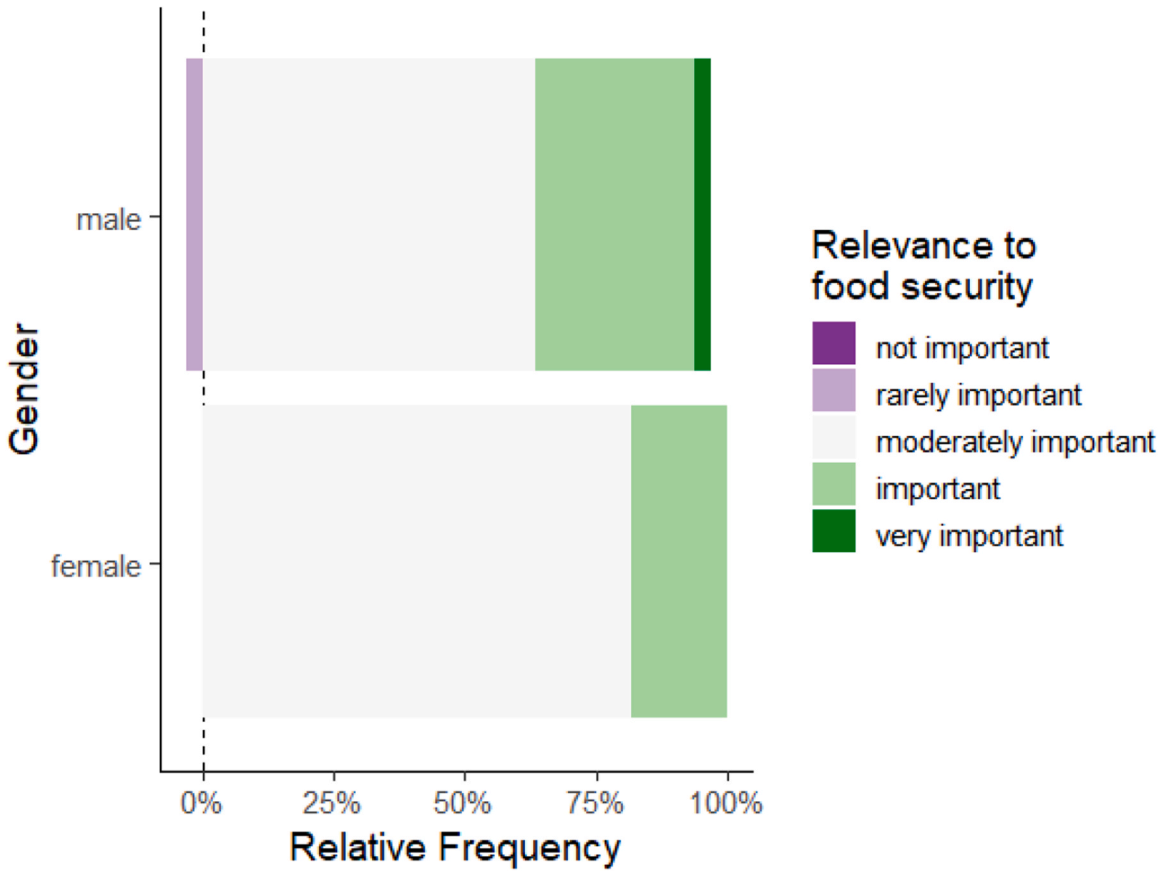

Fig. 6. Perception of rays' relevance to food security by gender.

markets' lack of speared rays might stem from spearfishing affecting catch quality, making it less marketable, and instead destined for local consumption [63]. Alternatively, varied methods could reflect site-specific factors or intergenerational fishing knowledge. An equal number of interviewees noted ray abundance either increasing or decreasing. Observed rises in ray populations might also be linked to mesopredator releases resulting from declines in top predator populations [84], site-specific differences or shifting baselines [85]. This study encompassed varied fishing communities (urban, remote, near reefs/mangroves/estuaries/seagrass beds), necessitating gender, experience, and site grouping for shifting baseline estimates, which was hindered by limited interview numbers per gender, experience, and site. Many interviewed fishers perceived rays as dangerous. Also, traditional ecological knowledge associated with rays is diminishing. Reviving this knowledge could help preserving Fiji's cultural heritage and potentially provide alternative perspectives to the modern perceptions of stingrays as dangerous animals.

4.4. Management implications

Given the unknown population status and trends, lack of species knowledge (e.g., maskray), and Data Deficient status (e.g., Oceania fantail ray), it is imperative to establish science-based baseline data for each ray species in Fiji. Similar to other large ocean states in the Pacific [86], Fiji's inshore fisheries management is primarily carried out at the community level through a marine tenure system, which is based on local authority and self-reliance control [87,88]. Also, the Fiji Fisheries Act (Laws of Fiji, Chapter 158), is applicable to inshore fisheries and grants authority to the Ministry of Fisheries and the Department of Environment for crafting regulations. These regulations can encompass actions like species-specific harvesting bans, demarcation of restricted fishing zones, and oversight of fish stock conservation and protection. The Fisheries Act explicitly prohibits the use of nets, excluding hand nets, wading nets, and cast nets, in estuaries or within 100 m of river/stream mouths. However, many rays are captured in gillnets within estuaries, particularly in the Suva-Rewa-Tailevu area, which is thus a violation under the Fisheries Act CAP 158 A. Consequently, enhancing both compliance and enforcement activities is a vital approach that fishers comply with the existing rules [89] and to safeguard some of Fiji's coastal rays until the fishery's sustainability, catch data and trends are better understood. Effective species conservation can be enhanced through well-enforced and large marine protected areas (MPAs) [90,91]. Although MPAs are key tools to benefit shark and ray populations [10,92], they often fall short in safeguarding species across all life stages and critical habitats [93], while assessing their effectiveness is hindered by inconsistent terminology and the absence of standardized evaluation methods [94]. Hence, MPAs should focus on the most important life stages for each species, be based on spatial data analysis on where these species and different life stages occur and be well-connected to account for species life history and spatial ecology. Community initiatives should be strengthened, particularly as socio-economic interests of fishing communities and ecological goals need to be balanced [93,95]. The importance of rays as a fishery resource is moderate, yet particularly relevant to food security as a substitute for bony fish. Therefore, a decline in bony fish availability can lead to increased ray catches. Thus, regulations governing all fish resources can exert reciprocal influences and any conservation strategy for rays should actively engage fishing community members.

5. Conclusions

Overall, this study establishes a baseline for Fiji's domestic ray fishery and trade and indicates its relevance to food security. We caution that the estimate of the total number of rays traded at the Suva market is a snapshot and likely too conservative. Key knowledge gaps identified include (1) documentation of the fishery's sustainability through risk assessments and time-series of species-specific catch data (per unit effort) including surveying additional major fish markets; (2) resolving the unclear taxonomy with regard to Fiji's maskray (in progress), including determining species age and growth parameters; (3) verification of catch estimates through on-site monitoring in fishing communities; (4) continued analysis of species' length-frequency distribution, including size-at-maturity estimates; and (5) to determine the population genetic structure of Fiji's ray species and effective population size estimates. Finally, rays should be explicitly considered in future management arrangements and processes for inshore fisheries. As a precautionary approach, enhancing compliance and enforcement of existing regulatory instruments, such as the gillnet ban in nearshore areas is vital to safeguard potentially at-risk ray species.

Ethics

This research was approved by The University of the South Pacific (USP), by the Provincial Councils, and by the Pacific-European Union Marine Partnership (PEUMP) Programme Project Management. Also, in accordance with protocols of the USP, Provincial Councils were consulted, to explain the research, objectives, methodologies and expected outcomes. For sample shipment, an export permit by Fiji's Ministry of Fisheries was obtained. The permission to conduct interviews at the various fishing communities was granted by chiefs, the fishers, and their elders.

CRediT authorship contribution statement

Rusila Savou: Writing – review & editing, Methodology, Investigation, Conceptualization. **Juerg M. Brunnschweiler:** Writing – review & editing, Writing – original draft, Validation, Conceptualization. **Kerstin Glaus:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Conflict of interest

The authors declare no conflict of interest

Data availability

Non-sensitive data were submitted to datadryad.org with DOI https://doi.org/10.5061/dryad.4j0zpc8k8.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2024.106082.

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