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Discovery of an important aggregation area for endangered scalloped hammerhead sharks, *Sphyrna lewini*, in the Rewa River estuary, Fiji Islands

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Abstract. The scalloped hammerhead shark, *Sphyrna lewini*, is endangered throughout its global distribution. Management and protection of this species is challenging in many locations because of limited scientific data and the vulnerable life-history traits of the species. Our study investigated anecdotal evidence that the Rewa River estuary in Fiji serves as an important nursery area for this shark. Research findings indicated that the average length of both males (60.6 ± 6.78 cm, $n = 31$) and females (60.4 ± 6.85 cm, $n = 51$) was well within published size limits of juvenile *S. lewini* studied in other locations (range = 38.0–89.5 cm). On the basis of published reference points for umbilical scar status we postulate that the first captured juveniles were born in January of the study year. Stomach content analysis found the following prey items: Decapoda (represented by prawns and shrimps), Stomatopoda, anguilliformes and osteichthyes. Decapods were the most numerous prey item by both count (59.17% of total prey items) and weight (60.25% of total weight). Our study provides strong support that the Rewa River estuary is an important aggregation area for *S. lewini* in Fiji.

Additional keywords: diet, index of relative importance, nursery, umbilical scar.

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Introduction

The scalloped hammerhead shark, *Sphyrna lewini* (Griffith & Smith, 1834), is one of just 15 shark species listed as endangered on the IUCN Redlist and Appendix II of CITES (Chapman *et al.* 2009; Liu *et al.* 2013; Dulvy *et al.* 2014). The primary reasons for this listing are due to fishing pressure in terms of by-catch on both adult and juvenile populations, as well as direct targeting for the highly prized fins (Baum *et al.* 2007; Vincent *et al.* 2014). In addition to these direct threats, in many locations data on basic biology and population characteristics are lacking. These gaps in scientific knowledge represent an additional reason for concern given the suite of vulnerable life-history traits of this species, such as relatively low fecundity, late maturity, unique schooling behaviour (which increases vulnerability to fisheries), as well as reliance (and movement between) critical habitats such as nursery and foraging areas at various life stages (Miller *et al.* 2013).

Shark nurseries are considered to be critical habitats, which should be afforded protection in fishery management plans. They are commonly located in inshore areas such as coastal waters and estuaries. Traditional defining parameters of nurseries, apart from the presence of newly born or hatched and juvenile sharks, are that such locations typically have high productivity, relatively higher prey density, and present a lower risk from predators (McCandless *et al.* 2007). The practical application of these definitions has been considered limiting for the protection and management of this habitat type, as it may encompass very large areas or incorrectly identify an area as a nursery. A standardised definition of characteristics of shark nurseries has therefore enabled greater consistency and comparability (Heupel *et al.* 2007), i.e. the timeframe over which juveniles remain in the area (or if they do leave, that they return to the same area for long periods), the relative density of juveniles in a given area, and the consistency of use of the area over several years (Heupel *et al.* 2007). In addition, active feeding by juveniles for improved growth is considered to be another important function of shark nurseries. Diet for most species is typically determined by prey availability at a certain place and time, as well as the experience level of the predator itself (Cortés *et al.* 2007).

The Fiji Islands fall within the global distribution of *S. lewini*, but population size, key habitats and distribution for this species are relatively unknown in this location. However, anecdotal observations over several years suggest the consistent presence of juvenile *S. lewini* in the Rewa River estuary in south-eastern Viti Levu during at least the first 4–5 months of the year (J. Seeto, unpubl. data). An additional report observed adult *S. lewini* in adjacent waters in December 2011, and the catch of juvenile *S. lewini* in gill-nets soon thereafter in the estuary (S. Nagatalevu, pers. comm.). The primary objective of this study was to assess the Rewa River estuary as a potential nursery area for *S. lewini* within Fijian waters. Specifically, the study aimed to: (1) confirm the consistent presence of young age classes in the study area;

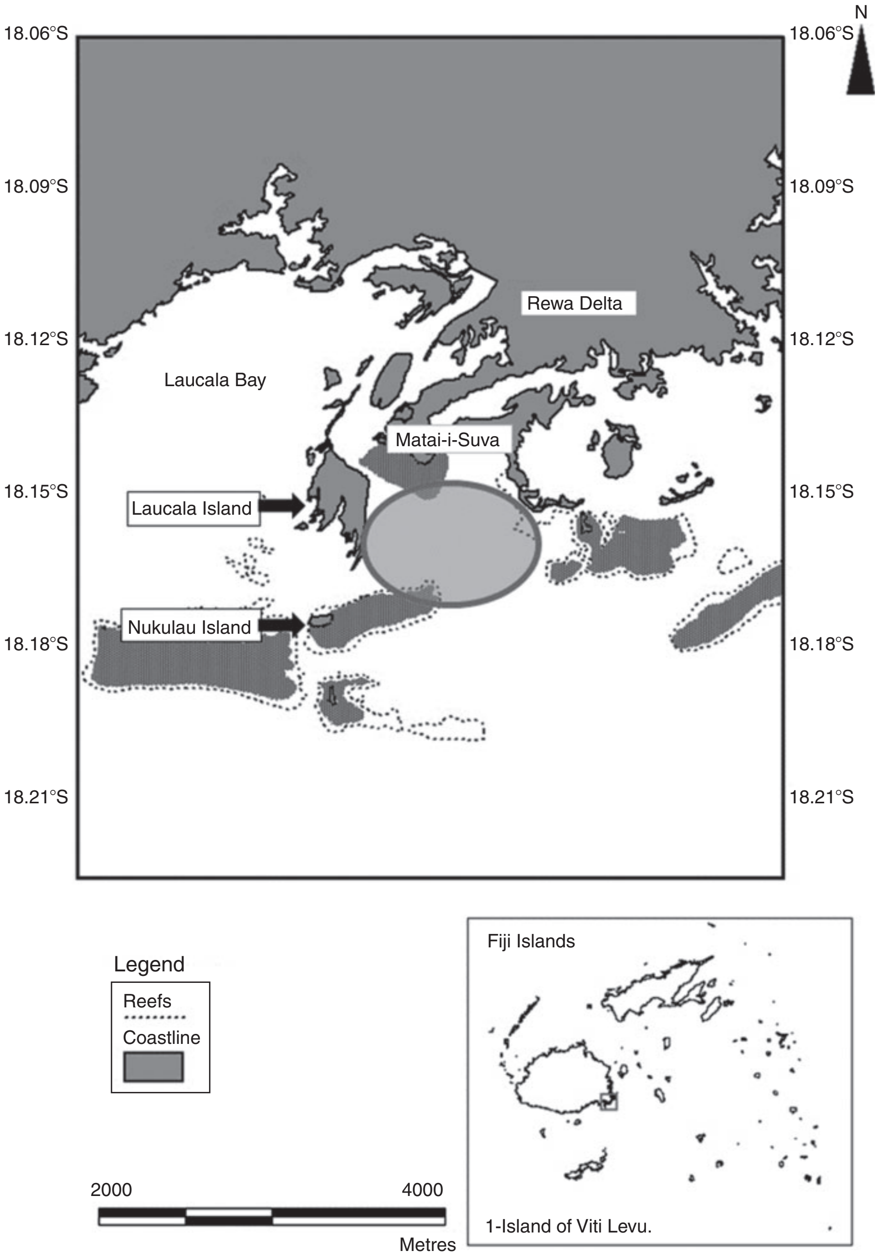

Fig. 1. Location of the Rewa River estuary on the island of Viti Levu, Fiji Islands. The study site is encircled.

(2) summarise biological measurements of sampled juveniles (length, weight and sex); and (3) describe and assess the relative importance of prey items consumed by juvenile *S. lewini*.

Materials and methods

Our research activities took place between February and June 2012 in the Rewa River estuary (Fig. 1) in the south-eastern corner of the island of Viti Levu in Fiji. Fiji's largest river system, the Rewa River, discharges into the estuary and it is a common location for local fishing activities using gear that includes handlines, gill-nets and longlines.

Within the Rewa River estuary a 100-m gill-net made up of 3-, 3.5- and 4-inch nylon monofilament mesh sizes was used to capture juvenile sharks. Net construction and deployment methodology were adopted from Carlson and Brusher (1999) and Bethea *et al.* (2008). Fifteen night deployments beginning at 1700 hours were performed with soak times of either 1 or 2 h depending on the prevailing weather and sea conditions. At least one deployment was carried out each week from late February 2012 to mid-March 2012. Additional weekly deployments were completed during May 2012.

Individual sharks captured in the gill-net were measured for total, fork and precaudal lengths (cm) and weight (g), sexed and checked for the status of their umbilical scars. Lengths were measured in a straight line (see Francis (2006)) and weight was measured using a hanging balance. Scar categorisations were determined to be open, semihealed, healed (scar still present) or absent as per published definitions (see Adams and Paperno (2007); Merson and Pratt (2001)).

Fifty dead individuals captured in the estuary were retained for the diet study. Following dissection and removal of the stomach of each shark, the stomach contents were collected, weighed and then sorted according to prey type and taxonomic classification. Identification to species level of all prey items was not possible due to level of digestion and so for consistency Order-level classification was conducted. Calculation of the index of relative importance (IRI) of the sampled prey items was carried out using the formula described by Torres-Rojas *et al.* (2010):

$$\mathrm{IRI} = (\%\mathrm{N} + \%\mathrm{W})\%\mathrm{F}$$

where %N is the count of a given prey type from all samples (expressed as a percentage), %W is the weight of a given prey type from all samples (expressed as a percentage), and %F is the percentage of individuals caught in which a given prey item was found to be present in their stomach.

Results

Umbilical scar status and biological measurements

Eighty-two *S. lewini* juveniles were captured during the study period. All individuals were determined to have either semi-healed, healed or an absent umbilical scar. None of the individuals captured had open umbilical scars (Fig. 2). Juveniles with semihealed umbilical scars were caught only during the earlier portion of the study period (23 February to 17 March). After this time, 43% of the individuals caught had no umbilical scars (i.e. scars were absent). Individuals possessing healed umbilical scars were captured throughout the entire study period.

Females were the smallest and largest, as well as the lightest and heaviest of the two sexes (Figs 3, 4, Table 1). However, Welchs' two-sample *t*-tests performed on the total lengths and weights of male and female *S. lewini* revealed there were no significant differences ($P = 0.909$ and $P = 0.957$ respectively)

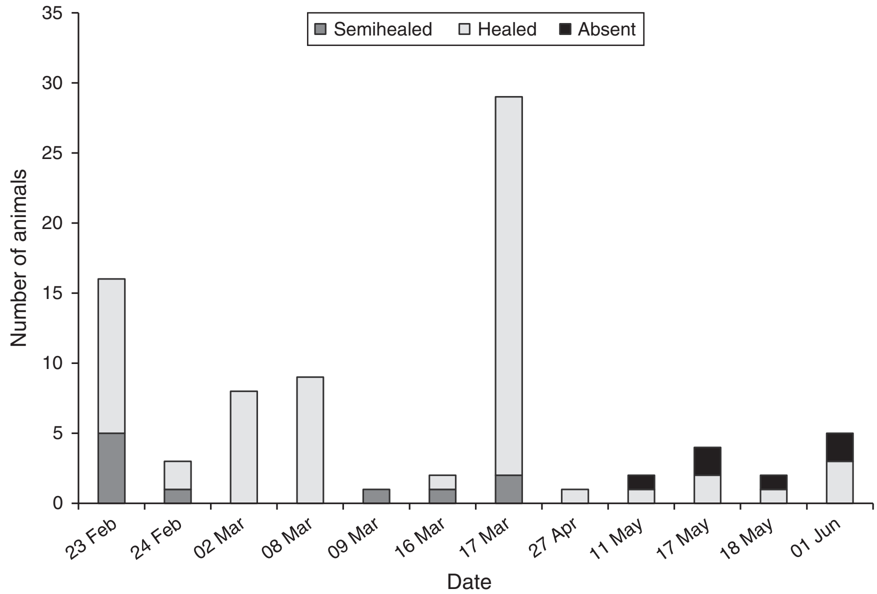

Fig. 2. Number of juvenile *S. lewini* with different umbilical scar status types. Scar categorisations were determined to be open, semihealed, healed (scar still present) or absent as per published definitions (see Adams and Paperno 2007; Merson and Pratt 2001). Summaries of numbers of types of scars are given per deployment.

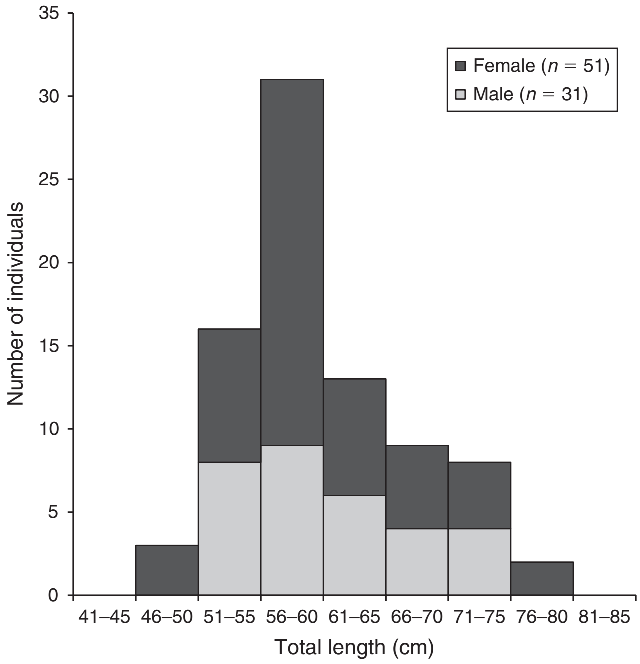

Fig. 3. Total lengths of captured *S. lewini*.

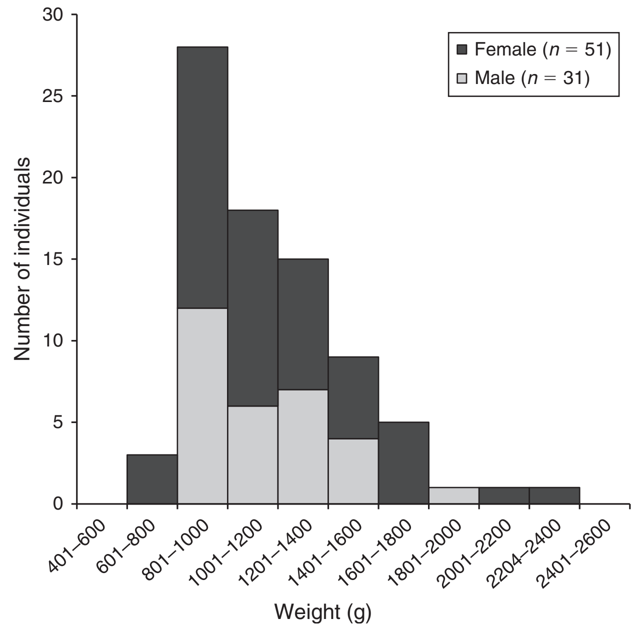

Fig. 4. Weights of captured *S. lewini*.

between the two sexes. A strong positive linear correlation was found ($R^2 = 0.838$) when the weights and lengths of all individuals were regressed against each other.

Diet characterisation

All individuals examined had prey in their stomach at various levels of digestion. Four key prey groups were identified in *S. lewini* stomachs: decapoda (primarily estuarine and marine prawns), stomatopoda (mantis shrimps), anguilliformes (estuarine eels) and osteichthyes (various bony fish). Decapods were found in 50% of the stomachs sampled (Table 2). Furthermore, decapods were the most numerous prey item by both count (59.17% of total prey items) and weight (60.25% of total weight). The average percentage body weight of the recovered stomach contents was $0.70 \pm 0.96\%$ with a median of 0.28% (Fig. 5).

Discussion

S. lewini juveniles were found in the estuary throughout the sampling period from February to June in 2012, along with evidence that all juveniles collected had been actively feeding. These two observations provide strong support that the Rewa River estuary is an aggregation site and possibly shares habitat connectivity with a nursery area for *S. lewini* in Fiji, and represents the first identification of critical habitat and habitat-use for this species in Fijian waters.

No neonates were observed during the course of the study. This finding could suggest several different scenarios regarding potential neonate use of the study area, including: (1) birthing did not occur in the area, (2) birthing occurred earlier than would allow open scars to be observed during the sampling period, or (3) birthing did occur in the area during the study period, yet neonates were not caught during our samples. For the latter point, the water depth at which our net was set (depth range = 7.5–14.8 m) may have a bearing given that in other studies nets have sometimes been set at shallower depths (e.g. 1.9–9.0 m) (Bethea *et al.* 2007; Bethea *et al.* 2008).

According to scar status the relative age of individuals increased throughout the period of the study. This finding suggests that at least part of the peak development period of the younger age class was captured. An umbilical scar study on captive *S. lewini* carried out in Hawai'i reported that it took five days for scar development from open to semihealed (i.e. partly healed) scars, and 14 days from semihealed to healed scar status (Duncan and Holland 2006). Although this study was undertaken in captive conditions, it provides a useful timeframe for estimating ages of individuals based on scar status. Application of these findings to the current study of Fijian *S. lewini* in the wild would suggest that those sharks captured with semihealed scars on 23 February may have been born at least five days before capture. Accordingly, those sharks with healed scars on this date were possibly born at least two weeks before capture (i.e. early February). Studies of *S. lewini* in Australia report births in spring and summer (September to February) (Miller *et al.* 2013) while another study reports births all year round yet with a peak occurring during this same period (Harry *et al.* 2011). Longer-term research is needed to determine whether parturition occurs all year round or whether there are peak parturition times for this species in the Rewa River estuary, as well as transition times for juvenile cohorts through the area.

The fact that all the stomachs examined contained prey at various levels of digestion indicates that all individuals had been feeding before capture. The calculated relative stomach fullness levels (0.28%) were similar to those reported by Bush (2003) on *S. lewini* juveniles in Hawai'i (0.22%). These studies also found

Table 1. Mean lengths and weights (±1 standard deviation) of juvenile *S. lewini* captured in the Rewa River estuary, Fiji

Ranges are given in parentheses. Note: fork length (FL) to total length (TL) conversion analysis through linear regression ($R^2 = 0.9831$) provided the following relationship: $FL = 0.7386 \times TL + 1.0368$

	Male ($n = 31$)	Female ($n = 51$)
Total length (cm)	60.6 ± 6.8 (52.0–75.0)	60.4 ± 6.9 (49.0–77.0)
Fork length (cm)	45.9 ± 5.0 (39.5–56.5)	45.6 ± 5.2 (37.5–58.0)
Precaudal length (cm)	41.3 ± 5.1 (30.0–52.0)	41.4 ± 4.6 (33.0–52.5)
Weight (g)	1245.2 ± 302.0 (900.0–2000.0)	1241.2 ± 352.8 (700.0–2400.0)

Table 2. Calculations of the Index of Relative Importance (IRI) of prey items found in the stomachs of 50 juvenile *S. lewini* in the Rewa River estuary, Fiji

Calculation of the IRI of the sampled prey items was carried out as per the formula described by Torres-Rojas *et al.* (2010)

Prey item	%N	%W	%F	%IRI
Anguilliformes	10.65	3.45	13.10	2.51
Decapoda	59.17	60.25	50.00	81.04
Stomatopoda	14.20	6.84	19.05	5.44
Osteichthyes	15.98	29.46	17.85	11.01

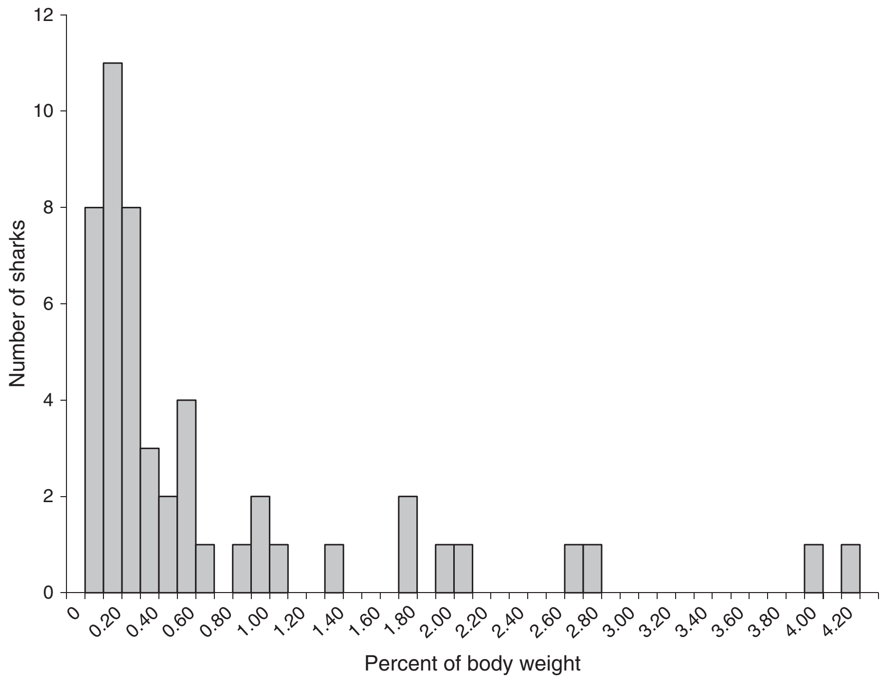

Fig. 5. Frequency of stomach content weight as a percentage of *S. lewini* body weight.

that prawns and shrimps (decapods) made up the most common (81.0%) and therefore most important component of the diet, followed by bony fish (teleosts). Teleosts made up the highest IRI percentage in studies of juvenile *S. lewini* reported from Mexico (74.8%) and Australia (93.8%) (Simpfendorfer and Milward 1993; Torres-Rojas *et al.* 2010) while decapods made up the highest IRI percentage in a Hawai'ian study at 62.0% (Bush 2003). The differences in IRI may be attributed to varying prey availability in the different geographic locations. It is interesting to note that decapods and bony fish appear to dominate the composition of the diet of juvenile *S. lewini* even across such a broad expanse of the species' distribution. Future

Table 3. Summary of neonate and juvenile length data from published studies on *S. lewini*

Total length (cm)	Location	Reference
Neonate		
37.0–52.0	Brazil (northern)	Capapé *et al.* (1998)
>38.0	Brazil (north-east)	Hazin *et al.* (2001)
40.0–50.0	Brazil (northern)	Lessa *et al.* (1998)
45.0–50.0	Australia (northern)	Stevens and Lyle (1989)
45.0–76.0	USA (Gulf of Mexico)	Hueter and Tyminski (2007)
>47.0	Taiwan (northern)	Chen *et al.* (1998)
49.0	Gulf of Mexico	Branstetter (1987)
50.0	Mozambique (southern)	Bass *et al.* (1975)
Juvenile		
38.0–45.0	USA (South Carolina)	Castro (1993)
39.0–57.0	Indonesia	White *et al.* (2008)
39.5–89.5	Hawaii	Clarke (1971)
45.0–50.0	Australia (northern)	Stevens and Lyle (1989)
49.0–77.0	Fiji (south-east Viti Levu)	Present study

diet research should aim to collect stomach contents from a larger sample size. A complementary prey survey study of the estuary would also be useful in comparing prey preference with prey availability.

When compared with values reported by other studies, the total lengths (49.0–77.0 cm) of the juveniles captured in this study fall within the upper limits of the ranges reported for both neonates and juveniles (Table 3). For example, lengths of 40.0–76.0 cm for neonates were reported by Hueter and Tyminski (2007) in the Gulf of Mexico, and Hazin *et al.* (2001) in Brazil, and lengths of 38.0–89.5 cm were recorded for juveniles as collectively reported by White *et al.* (2008) in Indonesia, Castro (1993) in South Carolina (USA) and Clarke (1971) in Hawai'i (USA). The lengths and weights of males and females in this study were not significantly different, and indicate that there is likely to be no difference (at this life-history stage and over the study time frame) in growth rate between males and females. It may also suggest that the individuals captured were part of the same, rather than separate, cohorts.

This study has identified the Rewa River estuary as an aggregation site, and potentially a nursery area for *S. lewini* in the Fiji Islands. Our study provides the first records of juvenile life history, length and weight data for this species in Fiji, as well as a preliminary investigation of the species' diet at the juvenile stage. These findings can be used to form the basis for future work on *S. lewini* nursery investigations in the Fiji Islands. Pertinent future studies should include site surveys at other locations adjacent to major estuary systems, interviewing fisherfolk to assess other potential nursery and aggregation sites, as well as similar surveys on other elasmobranch taxa. The government of Fiji is in the process of formulating national regulations for the fishery management of sharks in its National Plan of Action (NPOA) for sharks, and we recommend the incorporation of our findings in the development of that policy. More specifically, we suggest that consideration should be given to the restriction of fishing gear such as gill-nets within the Rewa River estuary – particularly during possible peak parturition times for this species to ensure uninterrupted recruitment rates into subadult and adult populations. These objectives would need to be underpinned by further scientific investigations of candidate nursery and aggregation areas (similar to the present study), as well as the implementation and monitoring of effective fishing restrictions within positively identified critical habitats. Such management measures would act to enhance protection of sharks in Fiji waters by mitigating exploitation and supporting self-sustaining populations.

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