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Tracking free-ranging sharks with hand-fed intra-gastric acoustic transmitters

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To estimate tag retention time, 39 acoustic transmitters were hand-fed to bull sharks *Carcharhinus leucas*, lemon sharks *Negaprion acutidens* and tiger sharks *Galeocerdo cuvier*, in the Shark Reef Marine Reserve, Fiji. Minimum tag retention times ranged from less than 24 h to 34 days, and bull sharks could be tracked for a minimum mean duration of 6.8 days. Feeding acoustic transmitters wrapped in bait to free-ranging sharks is an alternative and viable method to obtain presence–absence data from free-ranging sharks.

Keywords: regurgitation; Fiji; Shark Reef Marine Reserve; acoustic tracking; movement; tagging; *Carcharhinus leucas*; *Negaprion acutidens*; *Galeocerdo cuvier*

Introduction

Acoustic telemetry and instrumentation of sharks has improved basic knowledge of many ecological, behavioural and physiological aspects of elasmobranch biology, and also provides a useful tool for marine protected area design and evaluation (Nelson et al. 1997; Voegeli et al. 2001; Lowe 2002; Heupel et al. 2004; Chapman et al. 2005; Sims et al. 2006; Papastamatiou et al. 2007a; Skomal 2007; Meyer et al. 2009). Transmitter and data logger attachment methods include surgical implantation, external attachment or ingestion of sensors that monitor stomach temperature or gastric pH (Nakano et al. 2003; Papastamatiou and Lowe 2004; Sims et al. 2006). The latter method has proven useful with captive sharks that could be restrained and anesthetised (Papastamatiou et al. 2007b), but feeding acoustic transmitters wrapped in bait can also be an alternative and less traumatic method to track free-ranging sharks (McKibben and Nelson 1986; Economakis and Lobel 1998). However, the indigestible tag will eventually be regurgitated. Therefore, information about retention time before regurgitation is critical for making informed decisions on study design. To date, the methodological viability of feeding acoustic transmitters to free-ranging sharks in order to obtain presence–absence data has not been investigated. To test the feasibility of gastric tag attachment and to estimate tag retention time, acoustic transmitters were fed to free-ranging sharks at a shark diving site in the South Pacific.

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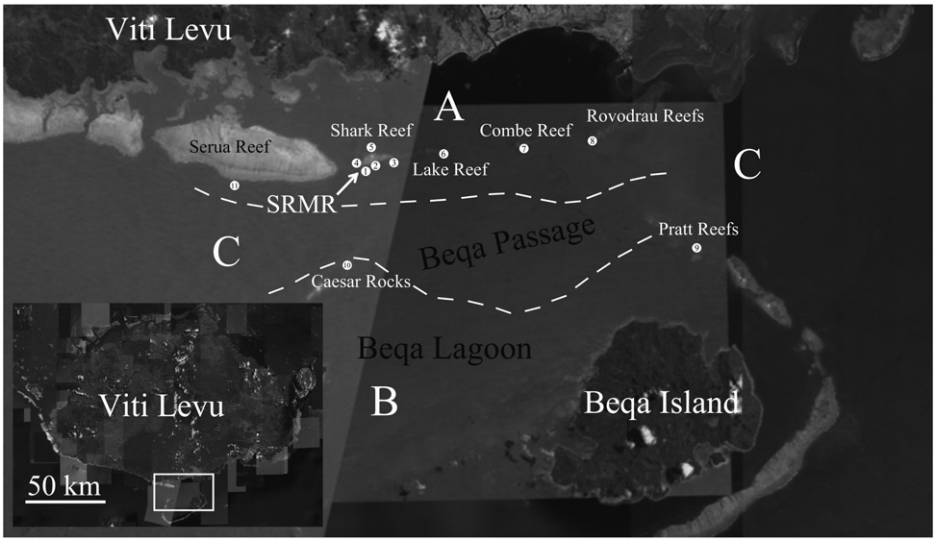

Figure 1. The study site on the southern coast of Viti Levu (inset) showing receivers 1–11 placed on reefs on both sides of the Beqa Passage. All acoustic transmitters were fed on Shark Reef in the SRMR at a permanent diving site close to receiver 1. The Beqa Passage (~250 m deep) separates mainland Viti Levu from the shallow waters of Beqa Lagoon. Areas A and B are ~30 m deep; areas C are >300 m deep. Dashed lines show the 200 m isobath.

Materials and methods

Between 2005 and 2008 a total of 39 acoustic transmitters (Vemco Ltd, Nova Scotia, Canada) were fed to bull sharks *Carcharhinus leucas* ($n = 36$), lemon sharks *Negaprion acutidens* ($n = 1$) and tiger sharks *Galeocerdo cuvier* ($n = 2$) in the Shark Reef Marine Reserve (SRMR) in Fiji. This small protected area encompasses the south-western part of Shark Reef, a small reef patch on a fringing reef that forms the northern edge of the Beqa Passage located off the southern coast of Viti Levu (Figure 1). Shark Reef and neighbouring reefs rise to sea level and are separated by water >30 m deep. Transmitters were hand-fed by a diver during morning hours (1000–1200 h) at a shark diving site in SRMR, where a local dive operator has been feeding different species of fish (Figure 2; Brunnschweiler and Earle 2006). The feeder was always positioned at the same spot at 16 m depth from where the reef slopes down into Beqa Passage to depths of ~250 m.

Using natural distinguishing markings (Castro and Rosa 2004), a number of individual sharks have been identified and can be recognised reliably at the site. Twenty-nine acoustic transmitters were fed to 14 of these previously identified (known) bull sharks and seven tags to unknown bull sharks, one transmitter to a known lemon shark and two transmitters to the same known tiger shark (Table 1; see also supplementary material for the feeding of tag #27 to a female bull shark that has been identified by its missing apex of the second dorsal fin. This can be found at http://www.informaworld.com/mpp/uploads/second_tagfeeding_290308.zip). Transmitters were placed in fish bait using three different methods: the acoustic tag was either treble hooked into the gill chamber of a fish head (Figure 3a), treble hooked to the tissue and wrapped into fish loins (Figure 3b, c) or simply inserted into a fish head without using hooks (Figure 3d). Two known bull sharks were double tagged with V16 acoustic transmitters both fed and externally attached (Table 1).

Figure 2. Diver hand-feeding a silvertip shark, *C. albimarginatus*, in SRMR. Photograph copyright Seapics/Doug Perrine.

Tagged sharks were registered by coded acoustic receivers (Table 2) placed on Shark Reef and neighbouring reefs at depths between 10 and 38 m at both sides of the Beqa Passage (Figure 1). The receiver array has been designed to collect presence–absence data at specific sites as part of a larger study that will eventually, together with the visual census data, provide a basis for making inferences about site occupancy and movement patterns of individual sharks in the area. Preliminary depth data collected with pop-up satellite archival tags in the area indicate that bull sharks along the Viti Levu coast spend most of their time below 30 m (e.g. in the Beqa Passage). Receivers have therefore been placed on the Beqa Passage-facing sides of individual reefs or at diving sites from where shark sightings are reported (receivers 9 and 10; Figure 1). Additionally, two receivers were situated at the bottom of the channel that separates Shark Reef from Serua reef to the west and on the inside of Shark Reef (receivers 5 and 6, respectively) in order to estimate shark presence in and around the SRMR. Minimum tag retention time (days) was defined as the time from tag ingestion to the final detection of the tagged shark by any one of the receivers. For known individuals (Table 1), the maximum tag retention time was estimated to be the time from tag ingestion to the first visual observation of the shark at the tagging site after the last detection. All times reported here are local times and mean tag retention values ±SD are reported.

Results

Overall, minimum tag retention times ranged from less than 24 h (bull shark) to 34 days (tiger shark; Table 1), and bull sharks could be tracked for a minimum mean

Table 1. Summary statistics for 39 acoustic tags ingested by 21 bull sharks *C. leucas*, one lemon shark *N. acutidens* and one tiger shark *G. cuvier*.

Tag#	Acoustic tag type	Name	Sex	Date of ingestion	Baiting method	Date of last detection	Date of first visual observation after last detection	Date of regurgitation	Minimum tag retention time (days)	Maximum tag retention time (days)
C. leucas										
1	V16	Grandma	F	23.09.2005	1	27.09.2005	15.10.2005	NA	5	22
2	V16	Whitenose	M	17.03.2006	1	26.03.2006	05.04.2006	NA	10	19
3	V16	Whitenose		01.02.2008	3	03.02.2008	04.02.2008	03.02.2008	3	3
4	V16	Monica	F	17.03.2006	1	26.03.2006	05.04.2006	NA	10	19
5	V16	Monica		04.01.2007	2	15.01.2007	16.01.2007	15.01.2007	12	12
6	V16	Monica		05.02.2008	3	12.02.2008	05.03.2008	NA	8	29
7	V16	Monica		05.03.2008	3	07.03.2008	26.04.2008	NA	3	52
8	V16	Monica		25.07.2008	3	07.08.2008	16.08.2008	NA	14	22
9	V16	Stumpy	F	20.03.2006	1	31.03.2006	14.02.2007	NA	12	331[b]
10	V16	Hook	F	23.06.2006	1	27.06.2006	28.06.2006	27.06.2006	5	5
11	V16	Hook		13.02.2008	3	16.02.2008	18.02.2008	NA	4	5
12	V16	Crook	F	19.05.2006	1	21.05.2006	26.05.2006	NA	3	7
13	V16	Crook		06.01.2007	2	22.01.2007	24.01.2007	22.01.2007	17	17
14	V16	Crook		28.01.2008	3	28.01.2008	27.02.2008	NA	1	30
15	V9	Crook		28.06.2008	3	04.07.2008	07.07.2008	NA	7	9
16	V16	Flop	F	06.01.2007	2	08.01.2007	13.01.2007	NA	3	7
17	V16	Flop		21.03.2008	3	22.03.2008	26.03.2008	NA	2	5
18	V16	Bum	F	09.01.2007	2	17.01.2007	19.01.2007	NA	9	10
19	V16	Bum		05.02.2008	3	10.02.2008	14.02.2008	NA	6	9
20	V16	Bum		21.03.2008	3	22.03.2008	29.03.2008	NA	2	8
21	V16	Hotlips	F	08.02.2008	3	12.02.2008	16.02.2008	NA	5	8

22	V16	Hotlips		26.03.2008	3	28.03.2008	15.04.2008	NA	3	20
23	V9	Hotlips		02.07.2008	3	05.07.2008	15.07.2008	NA	4	13
24	V16	Chopper	M	15.02.2008	3	22.02.2008	05.03.2008	NA	8	19
25[a]	V16	Chopper		05.03.2008	3	05.03.2008	26.03.2008	05.03.2008	<1	<1
26[a]	V16	Bumphead	F	01.03.2008	3	10.03.2008	14.03.2008	10.03.2008	10	11
27	V16	Second	F	29.03.2008	3	30.03.2008	04.04.2008	NA	2	6
28	V16	Blunt	F	28.01.2008	3	30.01.2008	07.02.2008	NA	3	10
29	V16	Grin	F	28.01.2008	3	06.02.2008	07.02.2008	06.02.2008	10	10
30	V16	UKN1	F	18.03.2006	1	25.03.2006	NA	NA	8	NA
31	V16	UKN2	F	18.03.2006	1	21.03.2006	NA	NA	4	NA
32	V16	UKN3	F	02.01.2007	2	07.01.2007	NA	NA	6	NA
33	V16	UKN4	M	03.01.2007	2	22.01.2007	NA	NA	20	NA
34	V16	UKN5	F	03.01.2007	2	09.01.2007	NA	NA	7	NA
35	V16	UKN6	M	08.01.2007	2	21.01.2007	NA	NA	14	NA
36	V16	UKN7	F	10.01.2007	2	11.01.2007	NA	NA	2	NA
N. acutidens										
1	V16	Whitetail	F	02.02.2008	3	08.02.2008	03.05.2008	NA	7	90
G. cuvier										
1	V16	Scarface	F	15.03.2006	1	21.03.2006	21.04.2006	NA	7	38
2	V9	Scarface		25.07.2008	3	27.08.2008	16.09.2008	NA	34	53

Notes: NA = not available; UKN = unknown.
[a]Double tagged.
[b]Excluded from maximum tag retention time analysis.

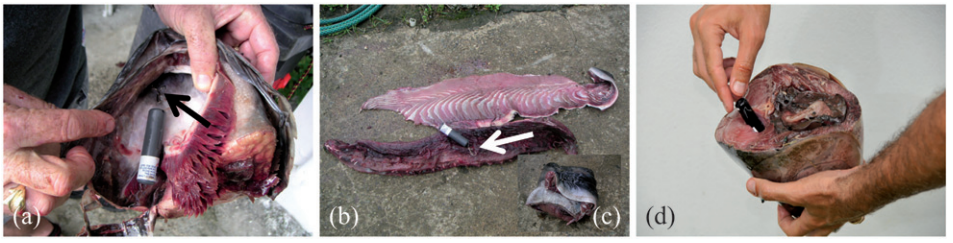

Figure 3. Tag baiting methods: the acoustic tag was either (a) treble hooked (black arrow) into the gill chamber of a fish head; (b) treble hooked (white arrow) to the tissue and wrapped into fish loins (c); or (d) simply inserted into a fish head without using hooks.

Table 2. Time periods covered by the 11 VR2 receivers (Vemco Ltd, Nova Scotia, Canada).

Receiver#	Date of placement	Out of the water
1	September 2005	–
2	January 2008	–
3	January 2008	–
4	September 2005	March 2006
	January 2007	–
5	January 2008	–
6	March 2006	March 2006
	January 2007	January 2008
7	March 2006	March 2007
	January 2008	March 2008
	May 2008	–
8	February 2008	–
9	February 2008	–
10	September 2006	February 2007
	January 2008	–
11	January 2008	–

Note: – denotes the receiver being in the water beyond the end of the study.

duration of 6.8 (±4.7) days. Mean maximum tag retention time from 28 tags fed to known bull sharks (Table 1) was 13.8 (±10.6) days. The percentage of bull sharks detected was below 50% after 6 days for transmitters placed in bait (baited) with methods 1 ($n=8$) and 3 ($n=19$) and 10 days for tags baited with method 2 ($n=9$), respectively. The three tag baiting methods did not statistically differ with regard to tag retention time (two-sample t-tests; $p>0.05$). Bull sharks that were fed transmitters using baiting method 2 could be detected for a minimum of 10 (±6.2) days on average while tags fed using baiting methods 1 and 3 were regurgitated after 7.1 (±3.3) and 5.1 (±3.6) days, respectively. Although no statistical difference was detected between the three different baiting methods for bull sharks, mean minimum tag retention time was higher for transmitters anchored and wrapped in fish loins compared to the other two methods.

The minimum tag retention time can be accurately estimated for seven of the transmitters (19.4%) fed to bull sharks. Four tagged bull sharks (transmitters 3, 5, 10 and 29) were sighted at the tagging site 1 day after they were last picked up by one

of the receivers (Table 1). Transmitter 13 was fed to a female bull shark on 6 January 2006. After 17 days, the transmitter was constantly recorded by receiver 1 for several months, indicating that the shark regurgitated the transmitter within detection range of the receiver. Transmitter 26 as well as the external tag that was attached to the same individual were both detected on 10 March 2008 at 1243 h by receiver 4. Only the externally attached transmitter was picked up again on 12 March 2008 (with no detections during the intervening period) at 1605 h by receiver 4. For the other double-tagged bull shark, tag retention time could be estimated precisely. Transmitter 25 was regurgitated only hours after it was fed to the male bull shark on 5 March 2008 at around 1100 h (Table 1). The gastric as well as the externally attached transmitter were both detected on that day before 1300 h by receiver 1. Four hours later, only the externally attached transmitter was detected by receiver 4.

Discussion

Tag retention time found in this study more than doubles mean detection time that was reported from a limited number of acoustically tagged free-ranging grey reef sharks, *C. amblyrhynchos*, using a similar tag attachment method (McKibben and Nelson 1986; Economakis and Lobel 1998). Of the three different baiting methods described here, mean minimum tag retention time was higher for transmitters anchored and wrapped in fish loins compared to the other two methods. This might be because tags anchored in the gill cavity of tuna heads or simply inserted into them without using hooks are more easily regurgitated by the shark when getting rid of indigestible food particles compared to transmitters that are well anchored in easily digestible fish loins. It is important to note that tag retention times reported here are minima. It is possible that sharks kept the transmitters for longer time periods before regurgitation, but simply moved out of the detection range covered by the receivers.

The mechanism by which sharks regurgitate intragastric tags is proposed to be via stomach evacuation. To date, voluntary stomach eversion in free-living sharks has been observed and described in the scientific literature only once (Brunnschweiler et al. 2005), but it remains largely unknown how often sharks evacuate their stomachs. The rate of stomach evacuation most likely depends on the frequency, amount and quality of food intake by the fish, which is not possible to control in free-ranging sharks. Studies that force-fed pH/temperature probes to captive free-swimming leopard sharks, *Triakis semifasciata*, nurse sharks, *Ginglymostoma cirratum* and blacktip reef sharks, *C. melanopterus*, under controlled conditions report six animals that regurgitated the probes after between 3 and 12 days (Papastamatiou and Lowe 2004, 2005; Papastamatiou et al. 2007b), retention times that were found to be in the same order of magnitude in this study (Table 1).

Advances in bio-logging technology have allowed scientists to acquire large, quantitative data sets of behaviour from animals moving freely in their natural environment (Ropert-Coudert and Wilson 2005). Although stomach evacuation seems to occur quite frequently in bull sharks, and consequently limits tracking time, the present study, as well as results from experiments with captive sharks (Papastamatiou et al. 2007a), provides preliminary data that show fed acoustic transmitters or sensors are viable tools to collect presence–absence data or physiological parameters of free-ranging elasmobranchs. The proposed method is promising for circumstances when sharks can be readily attracted close to a feeder

and it is undesirable to catch them for surgical tag implantation or external tag attachment, such as working in a marine protected area, at known shark aggregations sites used by recreational shark diving operations or when continuously tracking the target species over a period of only hours or days. In such situations the method of feeding acoustic transmitters to free-ranging sharks offers an alternative method that does not require handling and restraining the animal for transmitter or sensor application, and largely circumvents ethical and welfare issues that can arise from the application of permanent or temporary tags (Wilson and McMahon 2006).

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