Large-scale movements and site fidelity of bull sharks (*Carcharhinus leucas*) at Reunion Island (Indian ocean)

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Short communication

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Abstract

Two bull sharks (*Carcharhinus leucas*) were tagged in coastal waters off Reunion Island in the tropical Indian Ocean and where tracked for 174 and 139 days using both popup satellite archival tags (pSAT) and acoustic tags. Both sharks spent a majority of their time inshore (58.1% and 89.9% in the male and the female respectively). The female performed short excursions. The male alternated residence time along the coast with wide ranging movements and performed one extensive open-ocean excursion near a seamount situated at more than 200 km from the island. The differences in the residency and home range of both sharks probably reflect different patterns of foraging and mating behaviors in the male and the female. These results underline the importance of developing risk-mitigation management taking into account the movements of sharks, and of double tagging in telemetry studies that attempt to measure the degree of fidelity of a species.

Background

Bull sharks occur in warm inter-tropical zones, mostly on continental shelves of Africa, America and Australia [1,2]. They are reported as being mostly philopatric with some seasonal migrations along the coast [3]. It is one of the rare euryhaline species of sharks allowing females to give birth in estuaries and/or mangroves. Juveniles stay in such ecosystems several years before reaching the oceanic coastal zones [4]. According to IUCN, bull shark is a near threatened species. It is a fragile top predator because of slow growth. Like other apical predators, he is essential for the proper functioning of coastal tropical and subtropical ecosystems [5]. Globally, shark populations around the world, including bull sharks, have been under intense fishing pressure throughout their range [6] resulting in a substantial decline in populations. At the same time, bull sharks have been implicated in attacks on humans, particularly in Reunion island. Since 2011, the mean number of shark bites per year increased markedly in Reunion Island, from 1.1 to 3 for the periods 1980–2010 and 2011–2019 respectively [7]. Between 2011 and 2019, 27 attacks (including 11 fatal shark bites) occurred in Reunion Island, representing on average 10% of fatal attacks worldwide during the same period. This is considerable when compared to the population of Reunion Island (863000 habitants in 2016). To this date, little is known about the large scale movement behavior of bull sharks, especially around small oceanic islands with narrow insular shelf habitat [8,9]. There is therefore a critical need to improve our understanding of habitat use and especially site fidelity and movements of this species to mitigate the negative consequences for humans and sharks [10–12]. This study aims to determine extent of the movements of bull sharks when they leave the coastal waters of Reunion's island.

Methods

Two bull sharks were equipped with two different types of electronic tags: pop-up archival transmitting tags (MiniPAT-247A PSAT tags, Wildlife Computers, http://wildlifecomputers.com) and coded acoustic transmitters (V16TP-4x; delay 40–80 s, power output 158 dB, battery life of 845 days, Vemco). The array of acoustic receivers consisted of 44 receivers (Vemco VR2W) located around Reunion Island deployed on average ca. 2 km apart and 700 m from shore at depths of 10–60 m (Fig. 1). Each time an acoustic tag enters within the detection radius (± 400 m) of receiver [13], its ID and time stamp is recorded. This dataset was used to assert the presence of the sharks in the coastal water of the island throughout the study duration. Tags were programmed to detach after 192 days. The Wildlife Computers software WC-DAP Global Position Estimator Data (V 2.00.0027) was used to process the raw light data [14] to generated two location estimates per day: one at 12h00 and one at 24h00 (UTC).

We used the particle filtering modelling approach described in Tremblay et al. 2009 to estimate likely locations every 8 hours. Constraints such as sea surface temperature and maximum diving depth (DD) were not used to refine position estimates. This was due to that lack of horizontal thermal gradient and as DD of the sharks was relatively shallow and did not reflect the ocean sea-floor in the area. The maximum swimming speed used in the model was based on literature on long distance migrations (Daly et al. 2014, Lea et al. 2015) and speeds estimated from the movements between receivers in the acoustic area. A maximum swimming speed of 4.55 km h^{-1} was chosen. Known locations from the detections was used in order to refine the geolocation estimations. Detections at acoustic receiving stations were considered “error-free”; hence the detected shark was necessarily at the stations at that time, with no error possible. The process was set to avoid land masses. Finally, given the low accuracy of the position estimated by this method, we defined an excursion as a trip for at least 2 days and more than 20 km from the coast.

Results

Details on tagging and tracking data are summarized in Table 1.

Table 1
Characteristics of tagging and tracking data of the male and the female bull shark

Parameter	Male	Female
Size (cm)	290	310
Maturity	Adult mature	Adult mature
Deployment date range	15 Mar 2013–6 Sept 2013	24 Mar 2013–9 Aug 2013
Release position	21°20’S, 55°26’E	21°04’S, 55°12’E
Track duration (day)	174	139
Numbers of light based	320	261
Numbers of inshore detections	400	2429

In the male, the tag detached prematurely. The pop-up location was estimated in the southeast of the island at about 10 km offshore (21°30’S, 55°45’E), using a backward drift model. For the tag of the female, the pressure sensor indicated a fixed depth of 100 meters from August 9 until the tag surfaced.

Consequently, we only used the data collect prior to this date for the analysis. The pop-up location was at 36 km south of the tagging place and 2 km offshore (21°19’S, 55°23’E).

The proportions of time spent in the coastal waters were 58.1% and 89.9% in the male and the female, respectively. Figure 2 indicates the tracks as a succession of location probability fields. It appears that female had limited large-scale movements and remained in the coastal waters southwest of Reunion Island while performing short offshore excursions.

Figure 2 Horizontal movements of the male (A) tracked from March to September 2013 and female (B) bull sharks from March to August 2013. The intensity of the yellow pixels indicates the level of the probability of presence. The pink circle indicates 20km from the coast. The scale gives depth of the ocean floor.

The male exhibited a broader spatial pattern all around the island, and performed one long excursion about 300 km south the island close to 140 km long sub-marine ridge culminating at the seamount situated at 210 km from Reunion Island (23°.17’S, 55°.30’E) and referenced as KW-24316 (http://www.soest.hawaii.edu/PT/SMTS/main.html). This excursion was performed in April during 20 days and covered approximately 1260 km (Table 2), following by 6 other short excursions between forty and ninety kilometers to the coast. The female performed only three excursions during few days near the shore (Fig. 3 and Table 2).

Table 2
Summary of offshore excursions undertook by the tagged bull sharks

Individual	Orientation	Departure date	Return date	Excursion duration (days)	Distance travel (km)	Max distance (km)
Male	South	29-Mar	19-Apr	20	1259 ± 98	290 ± 39
Male	South	3-May	11-May	9	428 ± 44	54 ± 9
Male	West	11-Jun	14-Jun	4	160 ± 16	65 ± 10
Male	North	19-Jun	12-Jul	22	974 ± 82	62 ± 11
Male	South	23-Jul	29-Jul	6	341 ± 34	69 ± 10
Male	West	17-Aug	21-Aug	4	283 ± 37	76 ± 11
Male	North	22-Aug	30-Aug	8	327 ± 41	88 ± 12
Female	South-East	3-Apr	9-Apr	7	179 ± 31	59 ± 14
Female	South-East	17-May	19-May	3	90 ± 20	35 ± 9
Female	North-West	29-Jul	2-Aug	4	192 ± 33	50 ± 11

Discussion

Results showed that both bull sharks were regularly found inshore, suggesting possible fidelity to Reunion Island. This insular fidelity is similar to that described in previous studies on bull sharks [8,16]. The coastal fidelity of the female was also observed in New-Caledonia [16] and could be related to mating activities of bull sharks during cooling season. Mating, likely occurs during this period as it was suggested by Pirog et al. 2019 on bull sharks at Reunion island or in Tiger sharks in Hawaii as suggested by [12].

The offshore excursions of the male did not resemble large scale migrations as previously recorded for this species [18] or in other shark species [19,20], however, it demonstrate the ability of bull sharks to leave the coastal waters and occasionally foray into the open ocean. Intensive coastal movements punctuated by repeated offshore excursions over several hundreds of kilometers is common in sharks. For example, this behavior was observed in great white sharks [21], where several individuals simultaneously occurred in an offshore area and it was hypothesized that these potential meeting points, or "cafés", were motivated by feeding or mating. The offshore excursion of the male bull shark was oriented toward a ridge situated > 200 km from the island. Such features are known to have increased productivity via water enrichment associated with localized upwelling [22] and could potentially offshore feeding area.

Using a double-tagging approach, we were able to improve considerably the track quality by adding highly precise locations [23]. We have recorded data over several months both in a male and a female, with sizes representative of individuals typically found in Reunion waters. The consistency of the data with others works on the inshore-offshore patterns of horizontal movements suggests that our results are relevant to infer the coastal fidelity pattern of bull sharks around Reunion island. However, the causality of the repetitive offshore excursions of remain unknown for bull sharks and should be further examined in future studies.

Declarations

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Author's contributions

MS, YT, FF and LD have conceptualized and written the manuscript. YT and FF provided expertise on data management processes. MS, YT, AB and EC analyzed the data and drafted the manuscript, with input from all co-authors. AB and EC coordinated the work in field. MS managed and supervised the CHARC project. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

Data used for the analyses described in the manuscript are available upon request from the authors.

Consent for publication

Not applicable.

Ethics approval and consent to participate

All protocols of capture and tagging were approved by the CYROI (Cyclotron Réunion Océan Indien) Ethic Comity (#114) of Reunion Island.

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Figures

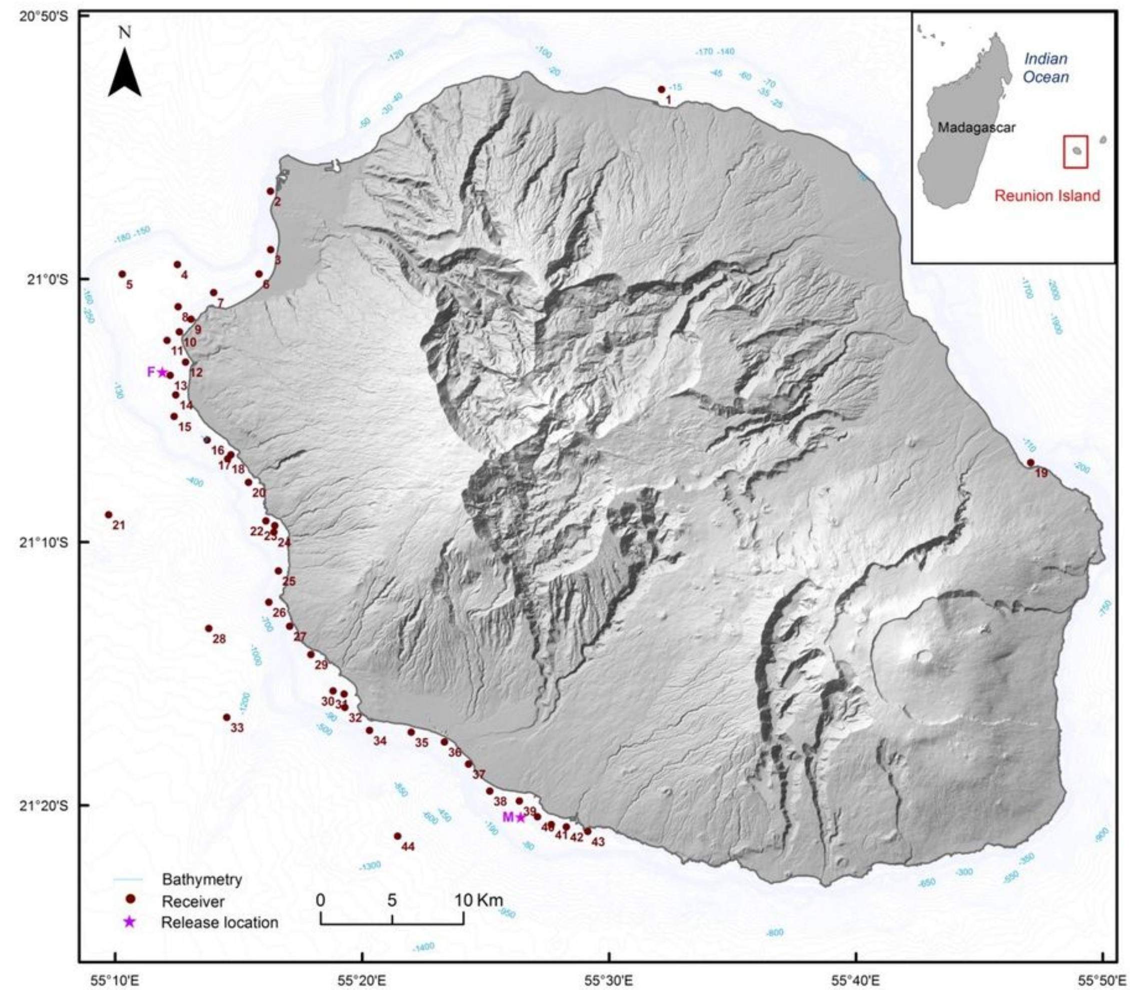

Figure 1

Positions of the 44 acoustic receivers around Reunion Island (red dots) and tagging location (pink stars) of both the male (M) and the female (F) bull sharks.

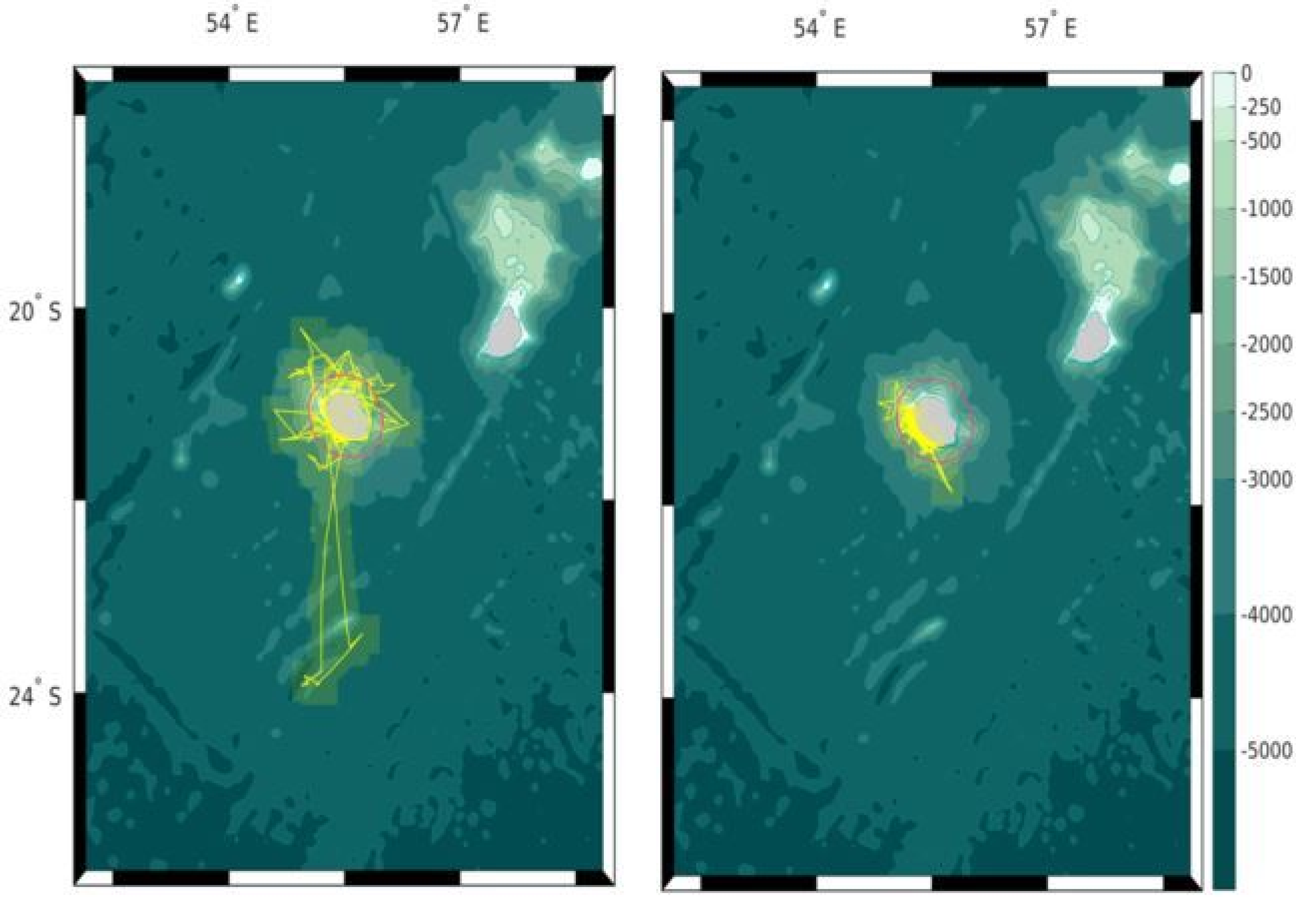

Figure 2

Horizontal movements of the male (A) tracked from March to September 2013 and female (B) bull sharks from March to August 2013. The intensity of the yellow pixels indicates the level of the probability of presence. The pink circle indicates 20km from the coast. The scale gives depth of the ocean floor.

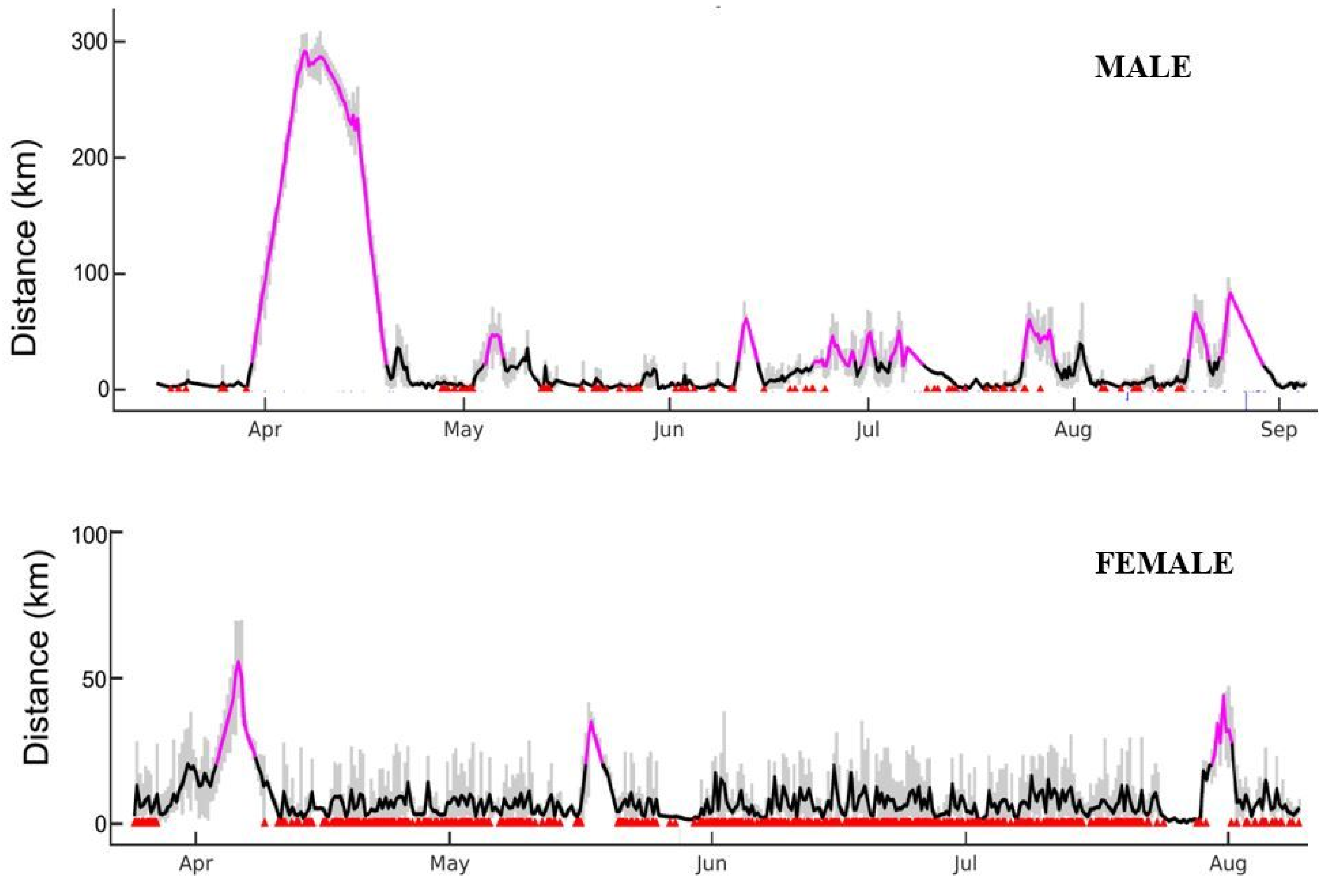

Figure 3

Timeline displaying distance from the coast estimations (solid line) and acoustic detections of the individuals (red triangles) of bull sharks in the coastal water. Pink line indicates excursions over 20 km and minimum 2 days duration.