

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

**CURRENT STATUS:** POSTED



Marc Soria  
Institut de recherche pour le developpement

✉ marc.soria@ird.fr *Corresponding Author*  
ORCID: <https://orcid.org/0000-0001-7409-5872>

Yann Tremblay  
Institut de Recherche pour le Développement

Antonin Blaison  
Institut de recherche pour le developpement

Fabien Forget  
Institut de recherche pour le developpement

Estelle Crochelet  
Agence de Recherche pour la Biodiversité à la Réunion

Laurent Dagorn  
Institut de recherche pour le developpement

**DOI:**

10.21203/rs.2.21006/v1

**SUBJECT AREAS**

*Marine and Freshwater Ecology*

**KEYWORDS**

*acoustic telemetry, bull shark, large-scale movement, site fidelity, pSAT, Reunion island*

## Abstract

Two bull sharks (*Carcharhinus leucas*) were tagged in coastal waters off Reunion Island in the tropical Indian Ocean and were 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 ( $\pm 400$  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  $4.55 \text{ km h}^{-1}$  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 undertaken 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

### **Acknowledgements**

We are grateful to all members of the institutions and associations involved in the CHARC program (Connaissance de l'Habitat des Requins Côtiers de la Réunion), from IRD, CRPMEM, University of Reunion Island, Globice, Kélonia, ARVAM, Squal'Idées, RNMR and Ifremer, as well as the fishermen and all volunteers who assisted with shark tagging and made our work possible.

### **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.

### **Author details**

<sup>1</sup> MARBEC, Univ. Montpellier, CNRS, Ifremer, IRD, Sète, France

<sup>2</sup> ARBRE - Agence de Recherche pour la Biodiversité à la Réunion, Saint-Leu, 18 rue des Seychelles, Lotissement Horizon, 97436 Saint-Leu, La Réunion, France.

### **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.

## **Funding**

This study received financial support from the European Union (convention FEDER ref. 2012-dossier Presage n° 33021), the French government (BOP 113 n°2012/03) and the Regional Council of Reunion Island (POLENV n°20120257). Research grants provided to the second author by the Regional Council of Reunion Island. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

## **References**

1. Daly R, Smale MJ, Cowley PD, Froneman PW. Residency patterns and migration dynamics of adult bull sharks (*Carcharhinus leucas*) on the east coast of Southern Africa. Hyrenbach D, editor. PLoS One. 2014;9:e109357.
2. Heupel MR, Simpfendorfer CA, Espinoza M, Smoothey AF, Tobin A, Peddemors V. Conservation challenges of sharks with continental scale migrations. Front Mar Sci. 2015;2:1-7.
3. Carlson JK, Ribera MM, Conrath CL, Heupel MR, Burgess GH. Habitat use and movement patterns of bull sharks *Carcharhinus leucas* determined using pop-up satellite archival tags. J Fish Biol. 2010;661-75.
4. Simpfendorfer CA, Freitas GG, Wiley TR, Heupel MR. Distribution and habitat partitioning of immature bull sharks (*Carcharhinus leucas*) in a Southwest Florida estuary. Estuaries. 2005;28:78-85.
5. Ferretti F, Worm B, Britten GL, Heithaus MR, Lotze HK. Patterns and ecosystem consequences of shark declines in the ocean. Ecol Lett. 2010;13:1055-71.
6. Queiroz N, Humphries NE, Couto A, Vedor M, da Costa I, Sequeira AMM, et al. Global spatial risk assessment of sharks under the footprint of fisheries. Nature. 2019;572:461-6.

7. Taglioni F, Guiltat S, Teurlai M, Delsaut M, Payet D. A spatial and environmental analysis of shark attacks on Reunion Island (1980–2017). *Mar Policy* [Internet]. 2018 [cited 2019 Feb 7]; Available from: <http://www.sciencedirect.com/science/article/pii/S0308597X18302951>
8. Brunnschweiler JM, Barnett A. Opportunistic visitors: long-term behavioural response of bull sharks to food provisioning in Fiji. *PLoS ONE*. 2013;8:e58522.
9. Lea JSE, Humphries NE, Clarke CR, Sims DW. To Madagascar and back: long-distance, return migration across open ocean by a pregnant female bull shark *Carcharhinus leucas*. *J Fish Biol*. 2015;87:1313–21.
10. Ferretti F, Jorgensen S, Chapple TK, De Leo G, Micheli F. Reconciling predator conservation with public safety. *Front Ecol Environ*. 2015;13:412–7.
11. Chapman BK, McPhee D. Global shark attack hotspots: identifying underlying factors behind increased unprovoked shark bite incidence. *Ocean Coast Manag*. 2016;133:72–84.
12. Meyer CG, Anderson JM, Coffey DM, Hutchinson MR, Royer MA, Holland KN. Habitat geography around Hawaii’s oceanic islands influences tiger shark (*Galeocerdo cuvier*) spatial behaviour and shark bite risk at ocean recreation sites. *Sci Rep* [Internet]. 2018 [cited 2018 Jul 11];8. Available from: <http://www.nature.com/articles/s41598-018-23006-0>
13. Soria M, Heithaus M, Blaison A, Crochelet E, Forget F, Chabanet P. Residency and spatial distribution of bull sharks *Carcharhinus leucas* in and around Reunion Island marine protected area. *Mar Ecol Prog Ser*. 2019;630:101–13.
14. Wilson RP, Ducamp JJ, Rees WG, Culik BM, Nickamp K. Estimation of location : global coverage using light intensity. *Wildl Telem Remote Monit Track Anim* [Internet]. Ellis Horwood. New York: Priede IG, Swift SM; 1992 [cited 2018 Feb 8]. p. 131–4. Available

from: <https://ci.nii.ac.jp/naid/10018066932/>

15. Tremblay Y, Robinson PW, Costa DP. A Parsimonious Approach to Modeling Animal Movement Data. PLOS ONE. 2009;4:e4711.
16. Werry JM, Clua E. Sex-based spatial segregation of adult bull sharks, *Carcharhinus leucas*, in the New Caledonian great lagoon. Aquat Living Resour. 2013;26:281-8.
17. Pirog A, Magalon H, Poirout T, Jaquemet S. Reproductive biology, multiple paternity and polyandry of the bull shark *Carcharhinus leucas*. J Fish Biol [Internet]. 2019 [cited 2019 Aug 26];0. Available from: <https://onlinelibrary.wiley.com/doi/abs/10.1111/jfb.14118>
18. Espinoza M, Heupel MR, Tobin AJ, Simpfendorfer CA. Evidence of partial migration in a large coastal predator: opportunistic foraging and reproduction as key drivers? PLoS One. 2016;11:e0147608.
19. Boustany AM, Davis SF, Pyle P, Anderson SD, Boeuf BJL, Block BA. Satellite tagging: Expanded niche for white sharks. Nature. 2002;415:35.
20. Chapman DD, Feldheim KA, Papastamatiou YP, Hueter RE. There and back again: a review of residency and return migrations in sharks, with implications for population structure and management. Annu Rev Mar Sci. 2015;7:547-70.
21. Jorgensen SJ, Reeb CA, Chapple TK, Anderson S, Perle C, Sommeran SRV, et al. Philopatry and migration of Pacific white sharks. Proc R Soc Lond B Biol Sci. 2009;rspb20091155.
22. Morato T, Hoyle SD, Allain V, Nicol SJ. Seamounts are hotspots of pelagic biodiversity in the open ocean. Proc Natl Acad Sci. 2010;107:9707-11.
23. Sibert J, Fournier D. Possible models for combining tracking data with conventional tagging data. Electron Tagging Track Mar Fish. Kluwer Academic Publishers. The Netherlands: Sibert, J. & Nielsen, J.; 2001. p. 443-456.

# Figures

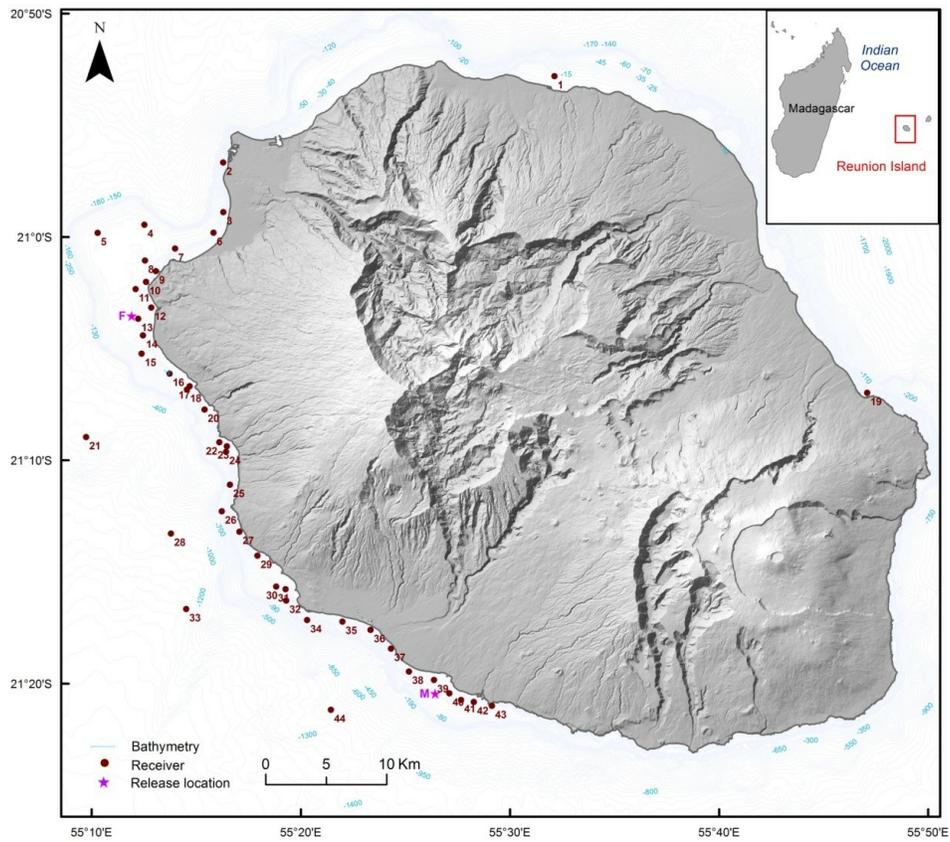


Figure 1

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.

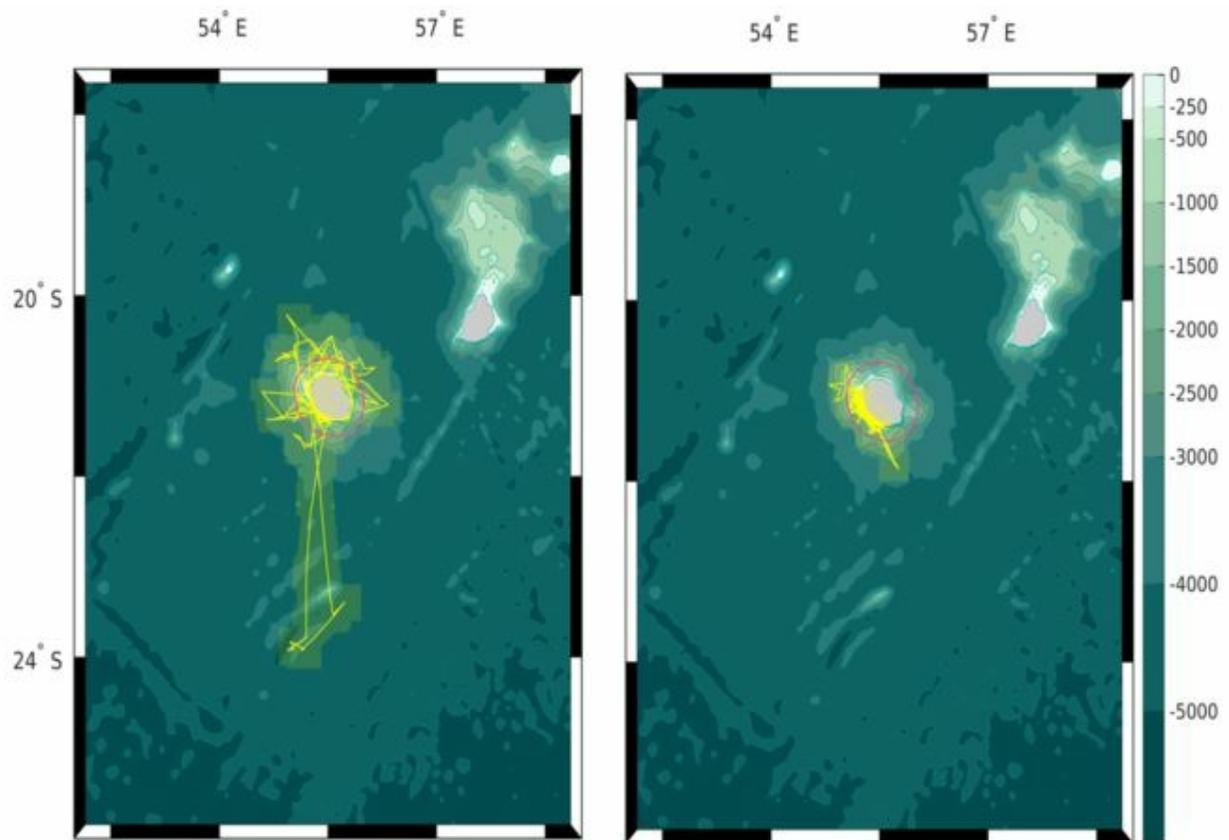


Figure 2

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.

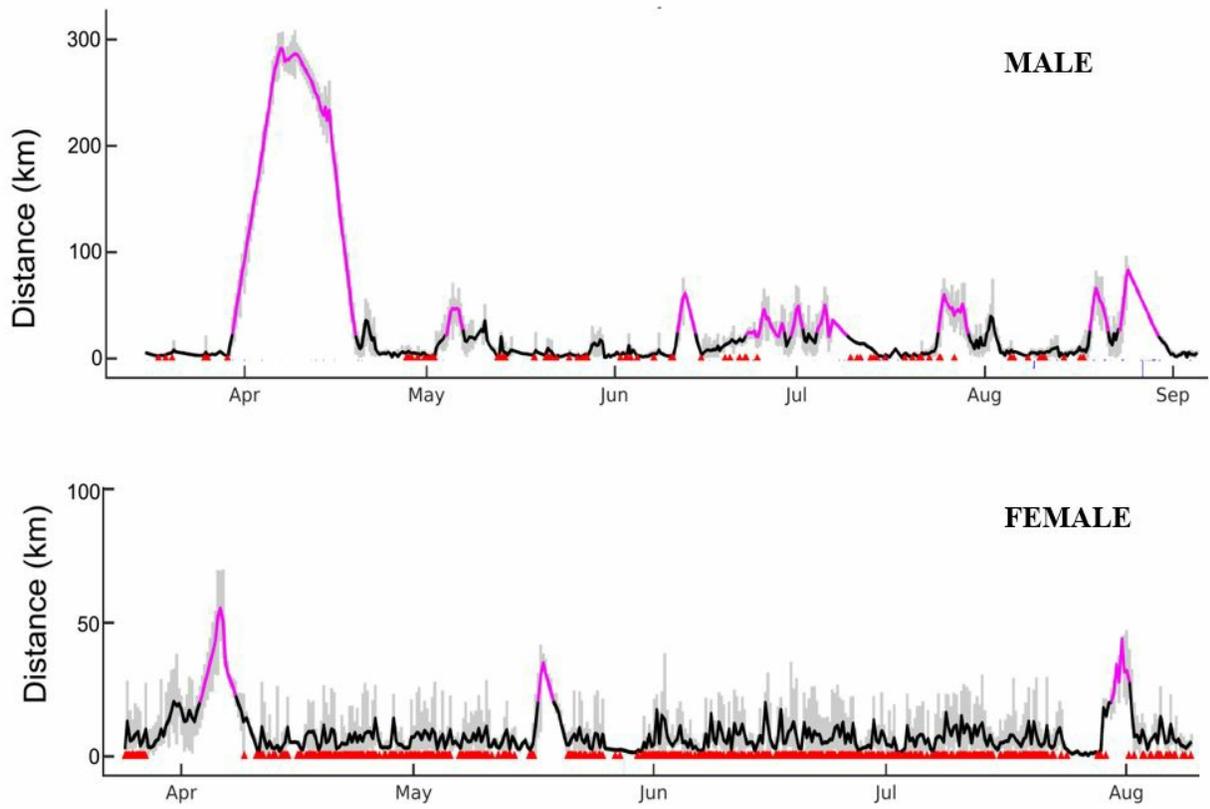


Figure 3

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.