

SHORT COMMUNICATION

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Diving behaviour of the critically endangered tope shark *Galeorhinus galeus* in the Natural Reserve of Bahía San Blas, northern Patagonia

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Abstract

Background: Tope sharks (*Galeorhinus galeus*) aggregate in large numbers during spring and summer in closed gulfs and bays in northern Patagonia; these locations are considered the main nursery areas for the species. However, little is known about the spatial ecology or diel behaviour of this critically endangered species. The aim was to evaluate the short-term diving behaviour and habitat preferences of tope sharks using electronic tagging.

Findings: Five female tope sharks, four adult and one sub-adult, were tagged with pop-up satellite archival tags in the Natural Reserve of Bahía San Blas, northern Patagonia, during spring 2011 and 2012. High-resolution archived data were collected for 40 days, including 29 days for two recovered tags. Sharks travelled up to 51.2 km after release. Archived data indicated that female tope sharks preferred to remain within 24.5 m of the surface and that there were no diel changes in preference. Individuals spent most of the time within 10 m of the surface during the day (80%) and at night (83%), and were primarily in water between 17°C and 19°C (day, 75%; night, 70%). Moreover, tope sharks exhibited vertical oscillatory movement ('yo-yo diving'). Maximum vertical speeds and dive depths were recorded at night. Ascents from depth had a greater speed than descents, overall.

Conclusions: Female tope sharks were found in shallow coastal areas during November at Bahía San Blas, near the surface at relatively restricted depths and temperatures. Longer tracking periods will be important for describing the species' migratory movements across the south-west Atlantic.

Keywords: Argentina, Marine protected areas, Pop-up satellite archival transmitter, 'yo-yo diving'

Introduction

The use of shark satellite tagging has increased over the past decade, facilitating the description of migratory patterns, habitat use and diving behaviour for a variety of species [1,2]. Behavioural data provided by these telemetry studies provide valuable information for the management of this vulnerable group of fishes [1].

The tope shark, *Galeorhinus galeus*, is a transient coastal species [3] distributed between Brazil and Argentina in the south-west Atlantic Ocean [4]. It has been hypothesized that tope sharks comprise a single population across Argentina, Uruguay and Brazil, migrating between

southern Brazil and northern Patagonia during spring [5,6]. As a result of the large shark aggregations in closed gulfs and bays of northern Patagonia during spring and summer, these areas are believed to be the primary nursery grounds for the species [5-7].

In the south-west Atlantic Ocean, tope sharks are classified as critically endangered [8], largely as a result of overfishing. This study provides the first observations of short-term diving behaviour and habitat preferences of *G. galeus* in northern Patagonia and the south-west Atlantic Ocean.

Methods

Study site

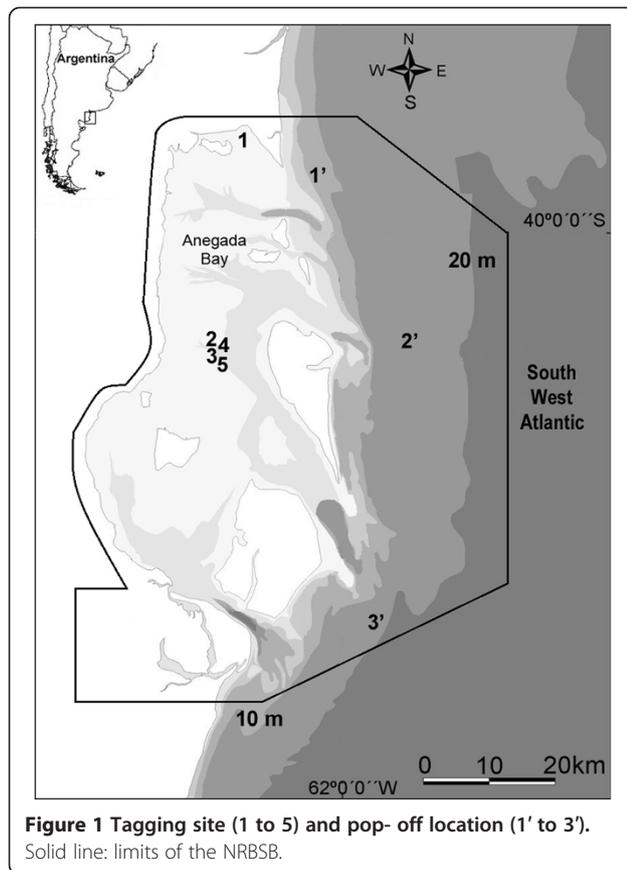
Bahía Anegada and Bahía Unión are shallow (less than 2 m during high tides) areas inside the Natural Reserve of Bahía San Blas (NRBSB), with sandbanks, small inner rivers, natural channels and small islands in the northern

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zone (Figure 1). The northern edge of the NRBSB is highly influenced by discharges of nutrient-rich waters from the Colorado River and the southern edge receives nutrients from the Negro River [9]. The resulting abundance of food coupled with a scarcity of large predators make these bays important spawning and nursery areas for bony [10] and cartilaginous fishes [5,11].

Tagging task

Five individuals were tagged inside the NRBSB in November 2011 and 2012 (Figure 1). The sharks were captured with sport fishing gear using barbless hooks baited with mackerel (*Scomber scombrus*) or Brazilian

menhaden (*Brevoortia aurea*). The length (total length) and sex of each individual was recorded before external application of an MK10 pop-up satellite archival transmitter (PSAT) tag [12]. The first three individuals were tagged on the right side of the base of the dorsal fin with a stainless steel harpoon with the tag secured intramuscularly by a polymer dart. The next two individuals were tagged using a plastic sheep ear ID tag to anchor the PSAT on the front side of the dorsal fin. The PSAT tags were programmed for a deployment period of either 180 days (Sharks 1 to 3) or 270 days (Sharks 4 and 5). Tags were programmed to record water temperature, depth and light level at 5-s intervals. These data were automatically binned into 6-hour histograms (depth bins: the first bin for depths shallower than 10 m, then bins at 10-m increments, 10 to 20 m and so on, and the last bin for depths greater than 200 m; temperature bins: the first bin for temperatures below 3°C, then bins at 2° increments, 3°C to 5°C and so on, then the last bin for temperatures above 27°C). The automatic release feature was to be triggered if tags recorded depth variations of ± 3 m for 48 hours at a constant depth.

Data analysis

Igor Pro Version 6.2 (WaveMetrics) and the Data Analysis Program 3.0 (Wildlife Computers) were used to analyze the tracking data. Depth and temperature preference distribution histograms during day and night periods were constructed. The vertical speed of ascents and descents as well as maximum dive depths were calculated from depth profiles (Sharks 1 and 2) during the day, at night, and at sunset and sunrise. Local hour intervals were defined as: 9 to 10, 12 to 13, 15 to 16 (day) and 21 to 22, 0 to 1, 3 to 4 (night). The sunset and sunrise period at the study area were obtained from dawn and dusk data for the tracking period using the Navy Hydrographic Service. Vertical speed and dive depths were defined, assuming constant speed for straight ascent and descent movements (0° and 45°) between two consecutive points.

Table 1 Tagging information for *Galeorhinus galeus*

Shark number	Tagging depth (m)	Tagging date	Tagging location	Pop-off date	Pop-off location	Distance moved (km)	Note
1	5	11/11/2011	40° 7' 37.78" S 62° 16' 37.05" W	19/11/2011	39° 59' 34.80" S 62° 1' 51.60" W	19.4	Tag recovered
2	2.5	13/11/2011	39° 56' 49.61" S 62° 14' 31.85" W	04/12/2011	40° 11' 9.60" S 61° 54' 46.80" W	29.91* 48.68#	Tag recovered
3	2.5	13/11/2011	40° 7' 28.16" S 62° 16' 8.56" W	24/11/2011	40° 33' 54.00" S 61° 56' 27.60" W	51.12	Tag not recovered
4	2	18/11/2011	40° 7' 42.97" S 62° 16' 11.88" W	Expected date 18/6/13	-	-	Tag failed
5	2	18/11/2011	40° 7' 38.59" S 62° 15' 49.08" W	Expected date 18/6/13	-	-	Tag failed

*, minimum distance travelled; #, maximum distance travelled.

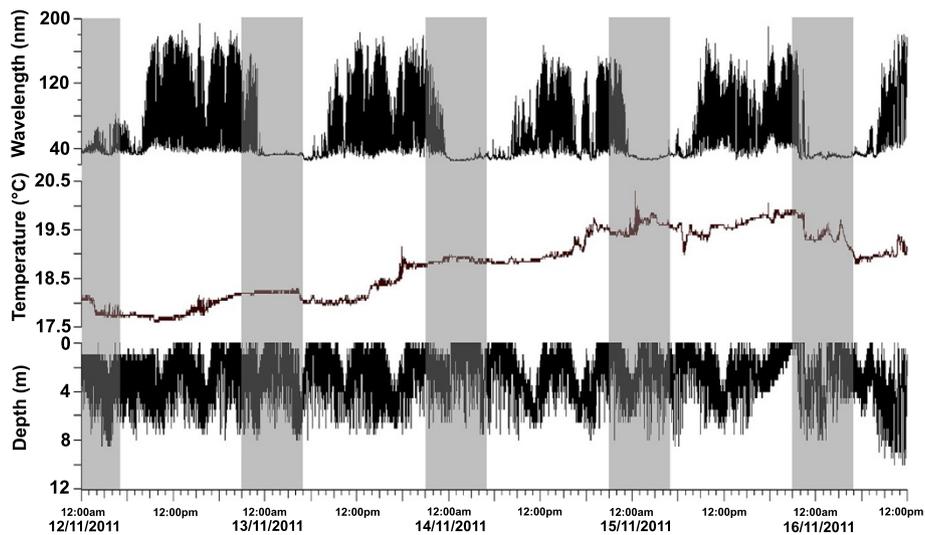


Figure 2 Full archival record of Shark 1 during the tracking period. Shaded bars indicate night time.

Ethical approval

As *Galeorhinus galeus* is fished and commercialized in Argentina, it is regulated by fishery acts. This work was carried out according to the code of good practice for sustainable recreational fisheries suggested by the management plan (not implemented yet) of the Natural Reserve of Bahía San Blas, in compliance with act N° 217/07 for sustainable angling fishing in the Province of Buenos Aires for coastal sharks.

Results

Five female *G. galeus* (122 to 140 cm total length) were tagged in the NRBSB, northern Patagonia (Table 1). The first two tags were recovered and full archival datasets

were downloaded (696 hours). Tag 3 transmitted 1,917 messages but the remaining two tags failed. Movement behaviour was tracked for a total of 40 days. All sharks remained within the limits of the NRBSB until the tags popped off (Figure 1). Complete tagging and pop-off details are reported in Table 1. The tracked sharks had a limited vertical distribution near the surface layer and also swam in waters within a narrow temperature range (Figures 2 and 3). All sharks swam 80% of the day and 83% of the night at depths shallower than 10 m. The remainder of the time was spent between 10 m and 20 m (day, 20%; night, 16.5%) or between 20 m and 30 m (day and night <1%). The tracked sharks swam predominantly in water that was between 17°C and 19°C (day, 75%;

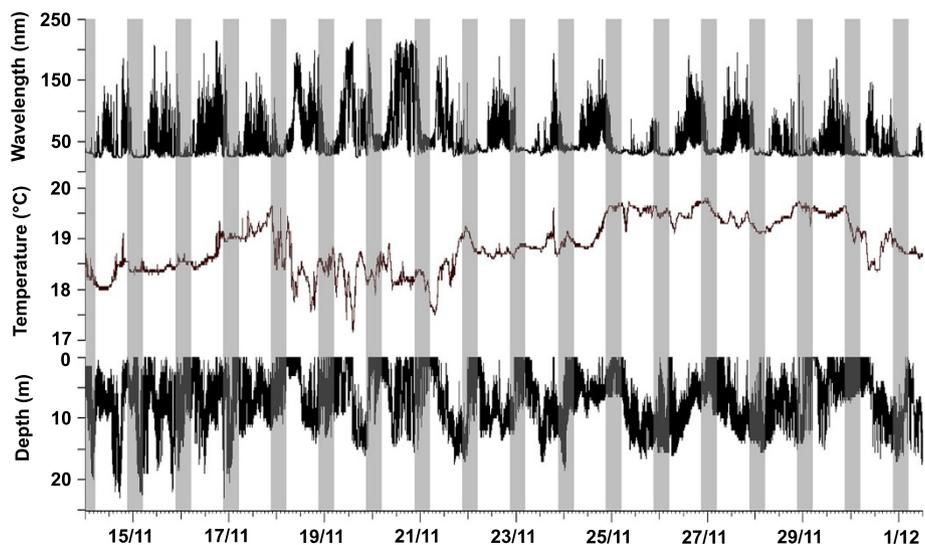
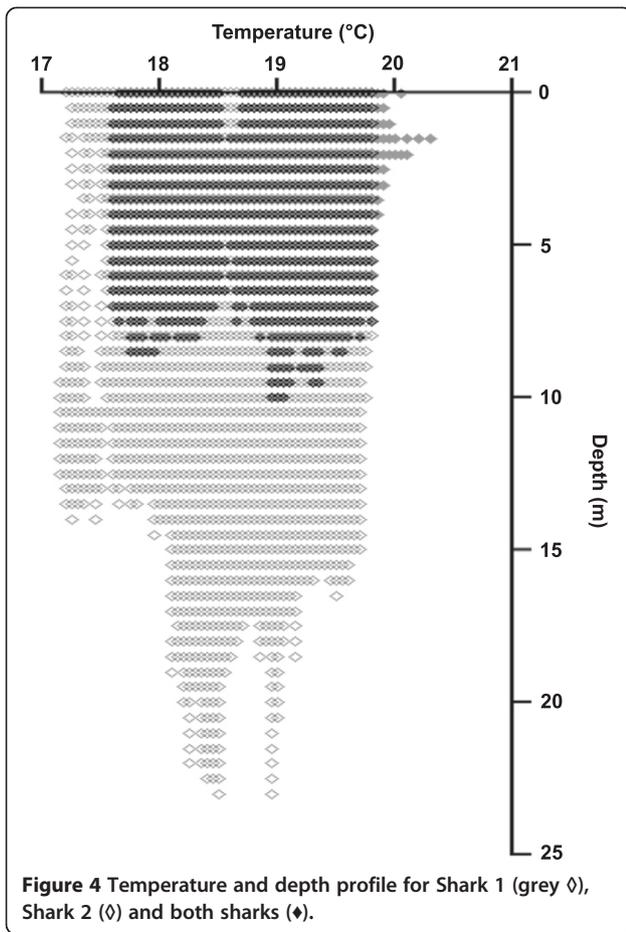


Figure 3 Full archival record of Shark 2 during the tracking period. Shaded bars indicate night time.



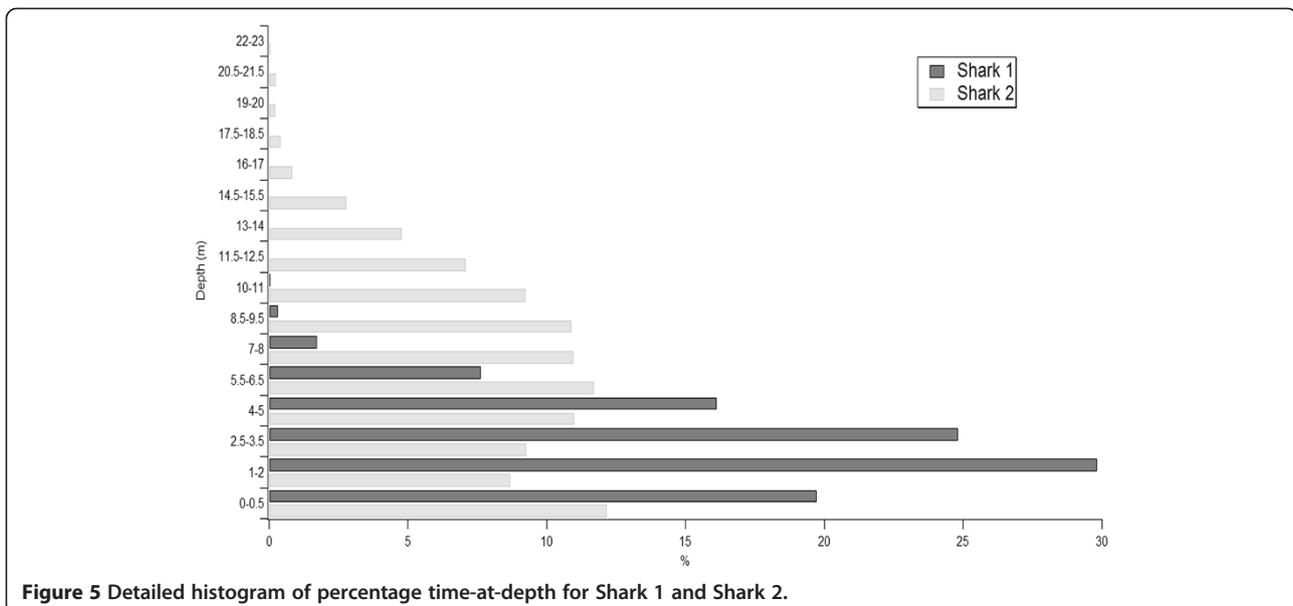
night, 70%). Other temperatures logged were 19°C to 21°C (day, 24%; night, 28%) and 15°C to 17°C (day, 0.5%; night, 2%). Shark 2 (mean, 6.48 ± 4.40 m) exhibited a wider range of depth use than did shark 1 (mean, 2.57 m, ± 1.84), and a wider thermal range (Figure 4). Sharks swam near the surface (0.5 to 0.0 m) for the most part, with maximums of 9 (Shark 1) and 41 min (Shark 2) and a vertical oscillatory movement changing depth over a short period of time (<1 min), termed 'yo-yo diving', was recorded (Sharks 1 and 2). Shark 1 swam exclusively in depths <10 m, mostly at 1 to 2 m during both day and night (Figure 5). Sharks 1 and 2 used areas with similar water temperatures ($18.79 \pm 0.67^\circ\text{C}$, and $18.89 \pm 0.50^\circ\text{C}$, respectively). The maximum vertical speeds and dive depths were recorded at night (Additional file 1: Table S1) and overall ascending movements (3.36 ± 0.17 m and 3.40 ± 0.08 m for Sharks 1 and 2, respectively) were larger than descending movements (2.34 ± 0.24 m and 2.50 ± 0.26 m, for Sharks 1 and 2, respectively, Additional file 2: Figure S1 and Additional file 3: Figure S2).

Discussion

The deployment time for PSATs attached to Sharks 1, 2 and 3 was less than the programmed deployment period because the tag pin burnt out prematurely when the sharks had remained at 6 ± 3 m deep for 48 hours. As the sharks mostly frequented shallow and turbid coastal waters, it was not possible to estimate geolocation based on light-level data.

Vertical movements

During the tracking period, tagged *G. galeus* exhibited regular oscillatory movements in which they rapidly changed depth (<1 min.). Explanations for this so called 'yo-yo'



diving [13] could include searching for cues [14] or for prey, such as striped weakfish (*Cynoscion guatucupa*), which are abundant in the NRBSB during November [11]. Although, tracked *G. galeus* swam in shallow depths in the NRBSB, they showed higher ascending and descending speeds than similar-sized females in Australia [15].

Depth distribution

In Golfo Nuevo, Patagonia, Elías *et al.* [7] caught male (40 m) and female tope sharks (>110 m) at greater depths than those in which tope sharks frequented in the NRBSB. However, *G. galeus* is fished at similar depths to those used in our study (6 to 15 m and 20 to 30 m) in Uruguay [6]. In southern Brazil, *G. galeus* are abundant at depths between 40 and 350 m and have been recorded at depths up to 375 m [16]. In southern Australia, West and Stevens [15] found that *G. galeus* spent 91% of their time on the continental shelf (<200 m), with a peak at 50 to 75 m for females and 75 to 100 m for males. The relatively shallow depths that tope sharks utilized during this study might be an artefact of the short period of time tracked, as sharks remained close to the coast and inside the NRBSB for most of the tracking period. Surface swimming behaviour for prolonged periods (hours to days or weeks) has been observed in *G. galeus* in southern Australia [15]; however, we only recorded surface swimming for periods shorter than 1 hour.

Temperature preferences

In Golfo Nuevo, females were caught in deeper (>110 m) and cooler (11°C to 12°C) waters than those used by female tope sharks in the NRBSB [7]. Female tope sharks experience similar temperatures in southern Brazilian waters from April to June (18°C to 20°C) [17]. In Uruguay, De Buen [18] found lower temperature preferences (15.9°C to 14°C) than our study. West and Stevens [15] showed that tope sharks from southern Australia spent 63% of their time in cooler waters (13°C to 16°C), and 30% in a similar temperature range (16°C to 20°C) to tope sharks in the NRBSB.

Conclusions

Within the NRBSB, female *Galeorhinus galeus* exhibited oscillating diving behaviour in a narrow depth and temperature range and resided primarily near the surface. Surface swimming behaviour and 'yo-yo diving' were also observed. Longer tracking periods will be necessary to confirm regional migratory movements across the species' entire distribution for the successful development of an effective coordinated Regional Species Conservation Plan for the south-west Atlantic population.

Additional files

Additional file 1: Table S1. Summary of dive information for *Galeorhinus galeus* in the NRBSB.

Additional file 2: Figure S1. Ascent and descent vertical speed (m s^{-1}) movements of *Galeorhinus galeus* in the NRBSB.

Additional file 3: Figure S2. Figure S2 Maximum vertical dive height (m) of *Galeorhinus galeus* in the NRBSB.

Abbreviations

NRBSB: Natural Reserve of Bahía San Blas; PSAT: Pop-up satellite archival transmitter.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

JMC made substantial contributions to the design, acquisition, analysis and interpretation of data. MG drafted the manuscript and revised it critically for important intellectual content. EDG participated in the manuscript coordination and helped to draft it. All authors read and approved the final manuscript.

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