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# Movements of Galapagos Sharks (*Carcharhinus galapagensis*) in Eastern Tropical Pacific Waters off Central and South America

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**Abstract**

Galapagos sharks (*Carcharhinus galapagensis*) are a large species belonging to the family Carcharhinidae, with poorly understood biology, especially along continental coastlines, which limits effective management of their populations. Here, we report preliminary findings of their movements along the Pacific Coast of Panama and Colombia, derived from satellite telemetry. Sharks were tracked for as long as 1.5 years, during which they moved extensively (~400 km along the Panama/Colombia coastline), with areas with high concentrations of detections that spanned the Panama/Colombia border. Sharks appeared to alter their movements during the diel cycle (more detections at night) and in relation to the wet/dry seasons (more detections during the dry season). Locations of shark detections were most commonly within 20 km of shore and in water less than 100 m deep, although detections were recorded hundreds of kilometers from shore in water thousands of meters deep. Galapagos sharks appear to move more extensively along continental coastlines compared to island locations, where most previous information about their movements and biology has been obtained.

**Keywords:** Eastern Tropical Pacific; elasmobranchs; wet/dry seasons; satellite telemetry

**Key Contribution:** This study represents the first information on the movements of Galapagos sharks along continental coasts anywhere in the world. Galapagos sharks moved along continental shelf coastlines in relatively shallow water, similarly to other related species, although detections were also recorded hundreds of kilometers from shore and in water thousands of kilometers deep. If the somewhat limited range of tracked sharks is typical of this species, then their populations may be vulnerable to decline under regional fishing pressure.

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## 1. Introduction

The Galapagos shark (*Carcharhinus galapagensis*) is a large, primarily inshore species, found in the Pacific, Atlantic and Indian oceans. Characterized by a patchy distribution, the Galapagos shark is typically found in waters around islands in tropical and warm-temperate regions [1,2]. Galapagos sharks are reported to prefer rocky substrate with

strong currents, and typically occupy depths of 30–60 m, but have been caught at a depth of nearly 300 m [3–5]. Despite their patchy distribution, these sharks are locally abundant and may occur in groups, especially small individuals, which have been documented to often approach divers, particularly at ecotourism sites [6,7]. The abundance of small sharks in shallow, nearshore areas such as lagoons suggests that these locations may serve as nursery areas [2,8]. Although Galapagos sharks may be one of the most abundant species near some islands, knowledge of many aspects of their biology is fragmentary [2,3,5]. Information about reproduction and diet have been reported for a large number ($n$ = 304) of these sharks examined in Hawaiian waters [5,9], but information on their biology from other parts of their distribution is sparse. Understanding of the biology of Galapagos sharks has been muddled by their confusion over the years with the very similar dusky shark (*Carcharhinus obscurus*). Galapagos sharks are genetically distinguishable from the closely related dusky shark, but these two species are often confused because of their similar morphology and partial overlap of vertebral numbers [10,11]. There has been speculation that the two species are synonymous, with *galapagensis* possibly being an insular form of *obscurus* [2,12,13], although the two species usually differ in vertebral number and teeth and are distinguishable by visual inspection of the shape of their pectoral and dorsal fins [11,14].

Concerns about overfishing and interest in greater understanding of population structure and connectivity for more informed management have prompted assessments regarding the status of and threats to Galapagos shark stocks using genetic methods [6,15–17]. These concerns have also been motivation for studies on the site fidelity and habitat use of Galapagos sharks at islands, with additional interest in their interactions with humans and movements in relation to marine protected areas (MPAs) [3,4,6,18]. Inferences about the movement patterns of these sharks are largely based on tracks acquired using acoustic telemetry methods, although several individuals have been tracked with satellite transmitters [4,6,19,20]. Previous tracking studies of Galapagos sharks have been of relatively short duration and conducted at insular locations and have documented repeated and predictable movements, with a high degree of site attachment to the islands where they were tagged [6,19–23]. The focus of studies on Galapagos sharks at islands is consistent with their infrequent occurrence along coastlines of continents. Although Galapagos sharks have been reported from continental coastlines, early discussions about how to distinguish between Galapagos and dusky sharks were based on the expectation that with few exceptions, a shark present along a continental coastline would be a dusky shark, whereas a shark present at an oceanic island would be a Galapagos shark [11,14].

One location where Galapagos sharks have been recorded in waters of a continental coastline is in the Eastern Tropical Pacific (ETP) along the coast of Central America and Colombia [1]. Shark fisheries have been extensive in this region, and Galapagos sharks are captured in both inshore and pelagic small-scale fisheries in the Pacific waters of Panama [24–26]. Coastal development in Panama has intensified, which adds to concern about the effects of habitat modification on shark populations in the region and highlights the need for information on the life history and habitat use of exploited species for informed management [25]. Since knowledge about Galapagos sharks along continental coastlines, including the ETP, is severely limited, we used satellite telemetry to conduct a preliminary investigation of the movements of tagged Galapagos sharks along the continental Pacific coast of Panama.

## 2. Materials and Methods

Sharks were captured on rod and reel and processed in the water while secured alongside the boat with a leader and a tail rope. For each individual, the sex, total length (TL) measurements and capture location were recorded. A Smart Position and Temperature

transmitter (SPOT tag; Wildlife Computers, Redmond, WA, USA) was then attached to the shark's dorsal fin. These transmitters communicated directly with the ARGOS satellite tracking system (argos-system.org) each time the dorsal fin broke the sea surface long enough to trigger a wet/dry sensor on the transmitter, yielding an estimated location and location class (LC) ranging from LC 3 (best quality; error < 250 m) to LC B (error not estimated; [27]). All fishing, measurement and tagging were performed in such a way as to minimize unnecessary stress and injury to the animals, and were carried out according to protocols established and followed by the Guy Harvey Foundation.

All analyses were completed using RStudio (version 2024.12.1) [28]. Data was pre-processed to remove aberrant locations (i.e., on land), and locations that would have resulted from what we considered to be unreasonable rates of movement (>8 km/h). To examine shark distribution, the locations for each shark were plotted, and since environmental conditions and productivity differ seasonally in the Eastern Tropical Pacific [29], we also examined locations during the wet (May–November) and dry (December–April) seasons. Bathymetry/depth and distance to the coast were accessed via ERDDAP servers and extracted using the packages *rerddap* [30] and *rerddapXtracto* [31]). To examine the relationships between depth and location (latitude and longitude), a three-dimensional plot of the depth and geoposition of raw detections was constructed. To examine diel patterns of reporting of tracked sharks, the proportion of diel detections for each hour interval was calculated by converting detection times to radians (0 to $2\pi$). A Rao's spacing test was then used to assess whether detections were uniformly distributed across the 24 h cycle.

## 3. Results

Four Galapagos sharks (3 F, 1 M), ranging in size from 183 to 213 TL, were tagged with SPOT tags in September 2023 and tracked for 244–580 d (Table 1). One shark provided more locations (368) than the other three combined (218); therefore, data was standardized among individuals when possible. Sharks were detected at a modest frequency, on average every 4.2 d (range 1.6–6.5 d), and detected much more often during the dry season (range 49–304) compared to the wet season (range 2–64). Detection locations ranged from waters near the Pearl Islands in the Gulf of Panama in the north, to approximately 200 km south of the Panama/Colombia border, with the majority of detections within 25 km of the coastline, but ranging as far as 200 km from the nearest point on land (Figure 1). Galapagos shark locations were concentrated along the coast spanning the Panama/Colombia border and extended approximately equal distances to the north and south of the tagging location along a ~100 km stretch of the coastline of Panama and a ~60 km stretch of the Colombian coast. The locations of individuals overlapped to a large degree, with the exception of the one male shark (#4) which ranged farther offshore and to the south and northwest. Many more detections were acquired in the dry season (December–April) than the wet season (May–November), and locations were more expansive during the dry season (Figure 2). Dry season locations included a larger portion of the Gulf of Panama and two areas several hundred kilometers offshore and to the south, whereas wet season locations were more contiguous with the coastline and shelf areas.

**Table 1.** Metadata for tagged Galapagos sharks and details of transmitter reporting. Dates are formatted as mm/dd/yyyy.

| Shark Number | Argos ID | TL (cm) | Sex | Date Tagged | Tagging Latitude | Tagging Longitude | Last Detection | Track Duration (days) | Total Detections | Detections in Wet Season (May–November) | Detections in Dry Season (December–April) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 220464 | 213 | F | 09/13/2023 | 7.5717 | −78.3316 | 03/05/2025 | 580 | 368 | 64 | 304 |
| 2 | 220465 | 183 | F | 09/14/2023 | 7.5717 | −78.3316 | 02/13/2025 | 518 | 97 | 16 | 81 |
| 3 | 220468 | 198 | F | 09/13/2023 | 7.5717 | −78.3316 | 08/09/2024 | 331 | 51 | 2 | 49 |
| 4 | 220469 | 183 | M | 09/13/2023 | 7.5717 | −78.3316 | 05/14/2024 | 244 | 70 | 8 | 62 |

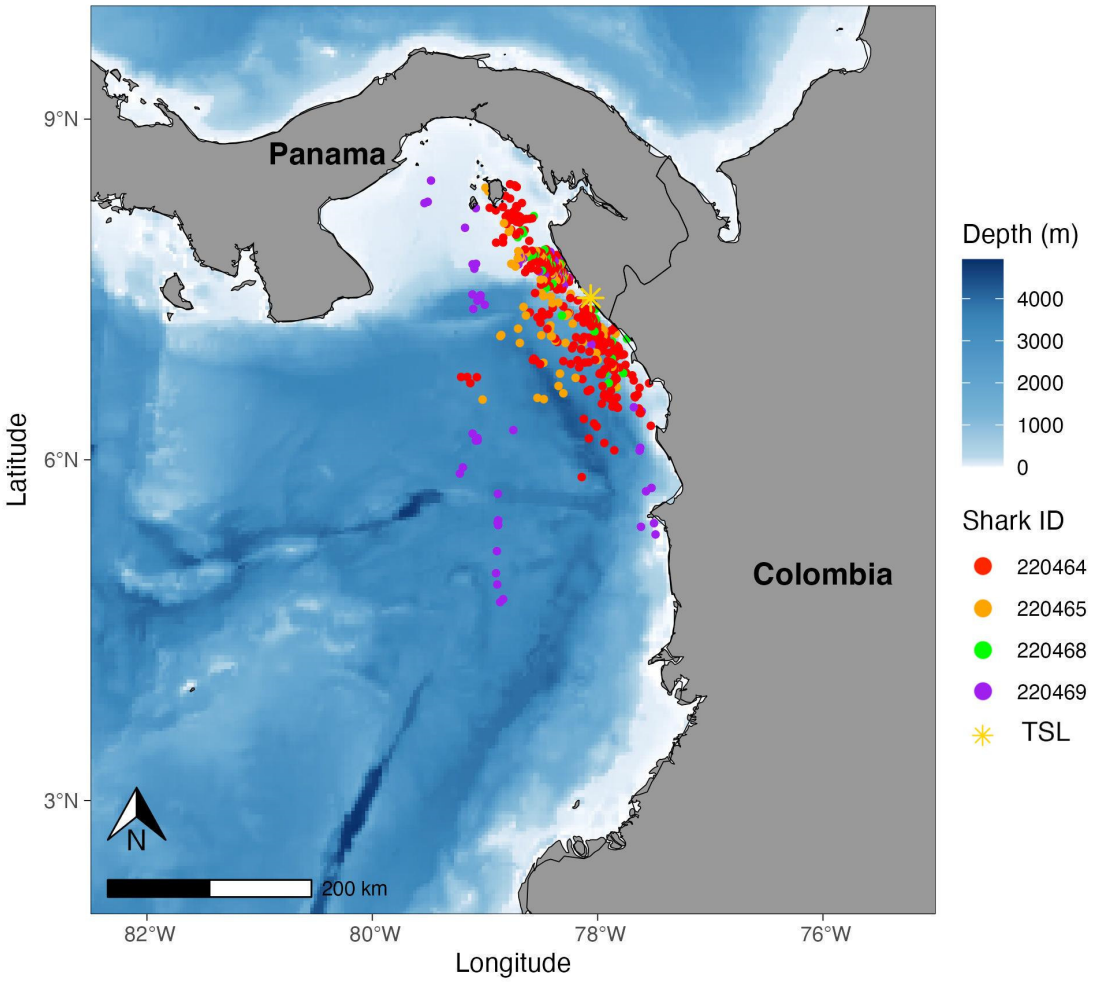



**Figure 1.** Locations of 586 detections of Galapagos sharks tracked between September 2023 and March 2025. Asterisk is Tropic Star Lodge (TSL). All sharks were females except 220469.

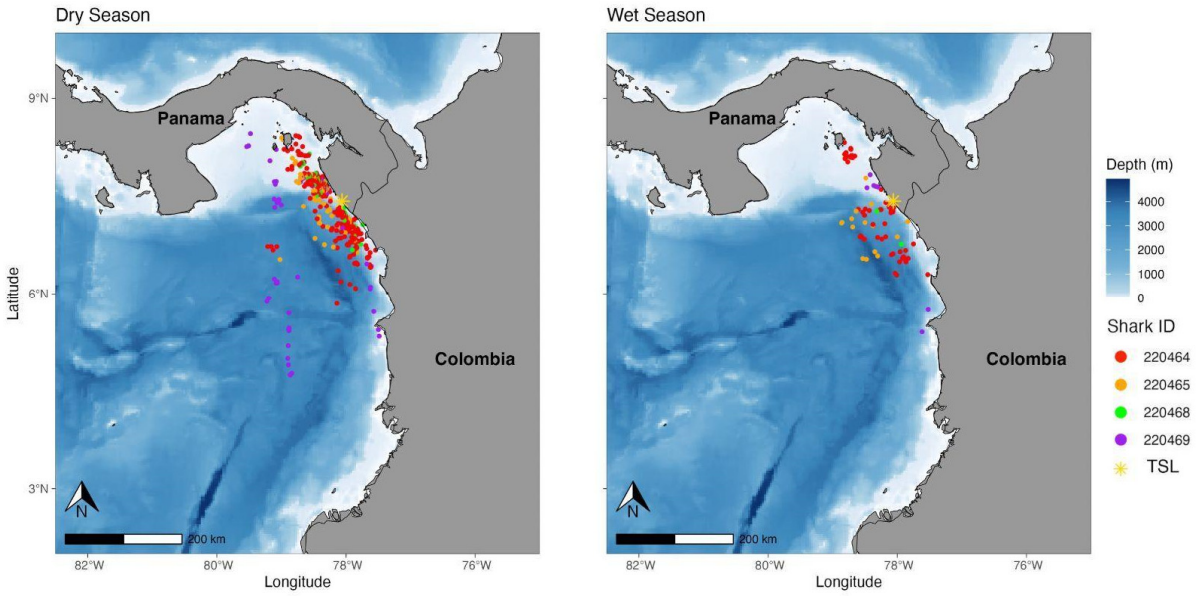



**Figure 2.** Locations of four Galapagos sharks tracked from September 2023 to March 2025 during wet (May–November) and dry (December–April) seasons. Asterisk is Tropic Star Lodge (TSL). All sharks were females except 220469.

The majority of detections were located relatively close to shore, although a small number of detections were from nearly 200 km offshore (Figure 3). The highest proportion of detections was recorded for the interval of 10–20 km from shore, and 52.3% of detections were within 20 km of the coast and 84.1% within 40 km of shore. The highest proportion of detections was recorded within the depth range of 50–100 m (Figure 4). Detections were also reported from locations within a wide range of water depths, with over 45% recorded from locations with water depths greater than 1000 m. A three-dimensional plot of depth versus location indicated depths skewed towards shallow and deep water, but few detections at intermediate depths at western longitudes (Figure 5). Based on the finding that diel detections were skewed to 1 and 2 am local time (Rao's spacing test of uniformity, $p < 0.05$, test statistic = 349.2359), the Galapagos sharks tracked in our study may have been more surface-oriented at night than during the rest of the 24 diel period (Figure 6).

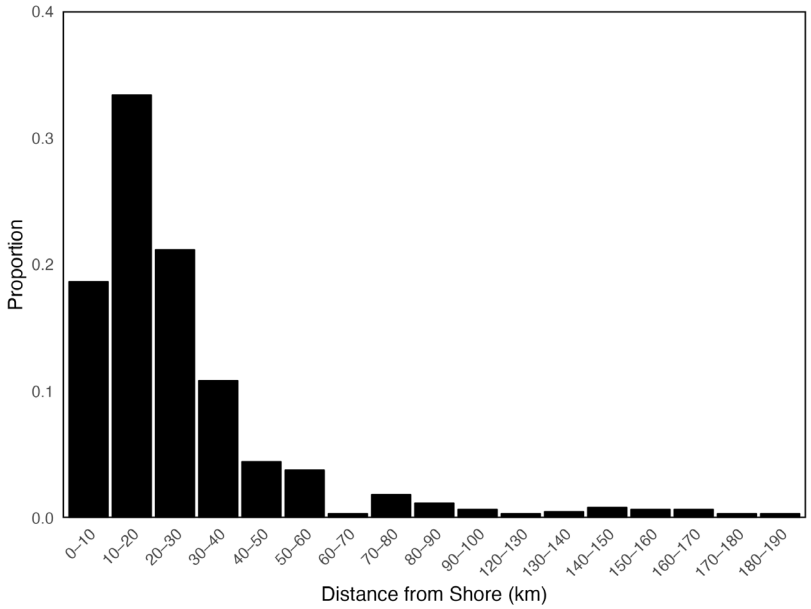



**Figure 3.** Proportion of locations recorded at 10 km intervals distant from shore.

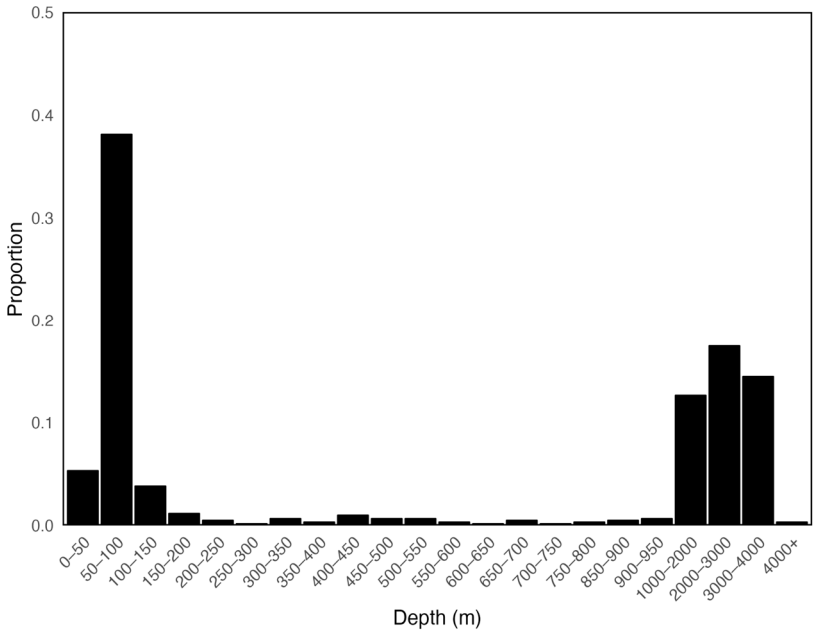



**Figure 4.** Proportion of locations recorded at 50 m depth intervals (depths greater than 1000 m, grouped by 1000 m depth intervals).

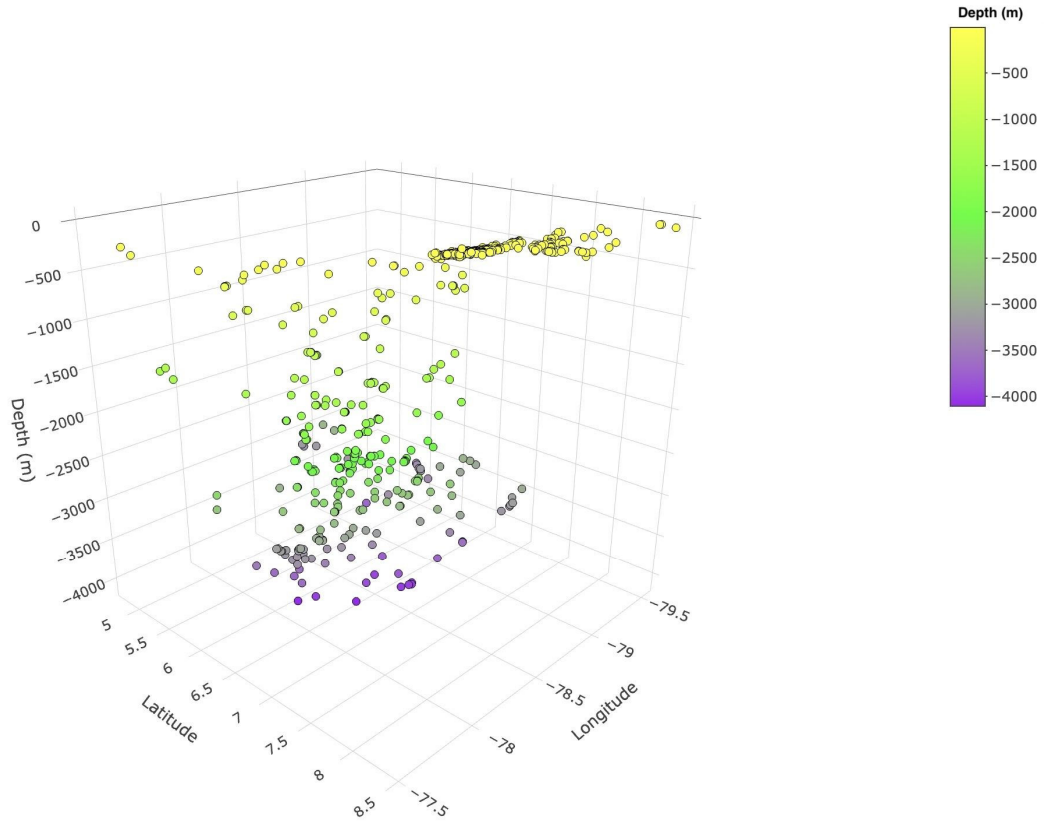



**Figure 5.** Three-dimensional occurrence of location (latitude and longitude) and depth of water (m) where locations were recorded.

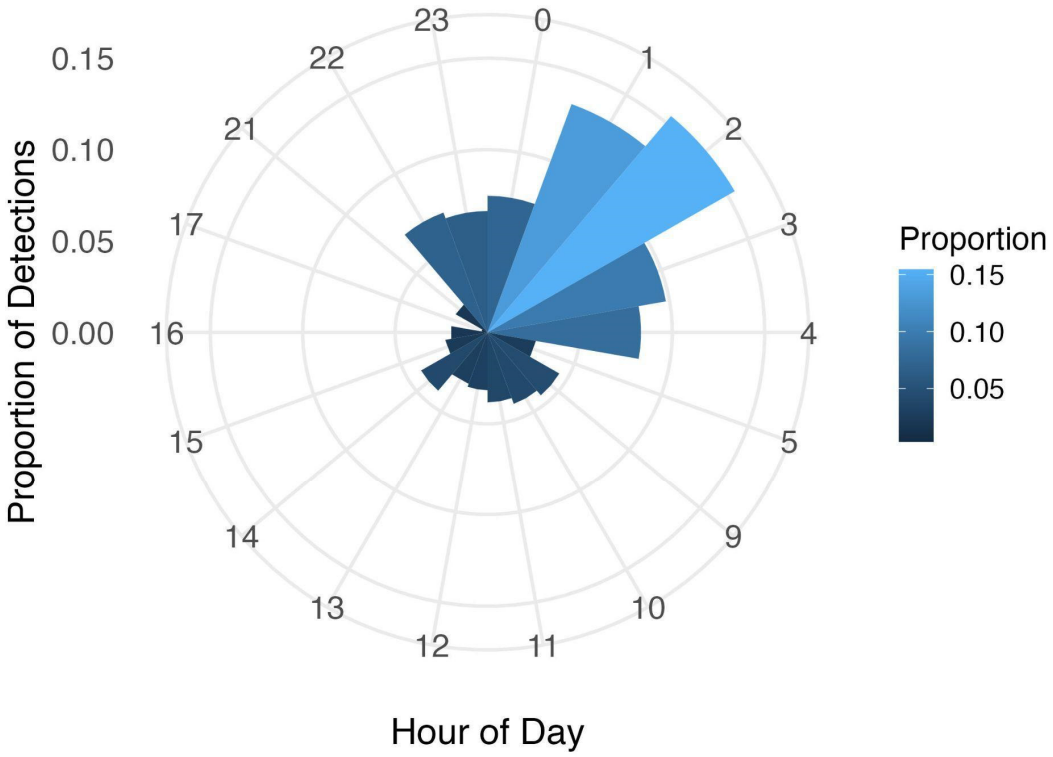



**Figure 6.** Proportion of detections recorded within 1 h intervals over 24 h diel period.

## 4. Discussion

The fin-fixed satellite transmitters used in this study were successful in attaining detections of Galapagos sharks over a long time period (18 months) and over a large geographic area that spanned hundreds of kilometers, and documenting the movements and habitat use of this shark in continental waters in the Eastern Tropical Pacific. Given that a number of studies on the movements of Galapagos sharks have been motivated by concerns about the vulnerability of their populations to fishing pressure and interactions with fisheries [32–34], expanded knowledge about their movements is useful for better understanding their populations. Previous Galapagos shark movement studies have relied on conventional [14,35,36] and acoustic tracking [6,18,19,21,22,35], with short-duration tracks, almost exclusively in insular waters. These studies have found that Galapagos sharks demonstrated a high degree of site attachment to waters surrounding the islands where they were tagged, and have contributed to the perception that Galapagos shark populations might be rapidly and dramatically affected by fishing [3,20,23,32,37]. Although satellite telemetry typically reveals greater distance movements than acoustic telemetry methods [38,39], the small number of satellite telemetry studies on Galapagos sharks have resulted in short-duration tracks and revealed a high degree of site attachment at insular locations, consistent with findings using acoustic telemetry [4,18,19,23].

The sharks tracked in our study primarily moved along the coastline of Panama and Colombia within a relatively short distance (40 km) from shore. The sharks exhibited much more extensive movements (over a span of at least 400 km) than have been observed for Galapagos sharks in tracking studies around islands [4,6,14,18,19,21–23,35,36,40]. Long-distance movements (over 3000 km) have been recorded for a few individual Galapagos sharks in telemetry studies, and there is speculation that islands serve as stopover points that enable more extensive movements [6,20,36,41]. Contrary to early reports that a Galapagos/dusky-type shark found at an island was *C. galapagensis,* whereas one found along a continental coastline was *C. obscurus* [11,14], the Galapagos sharks tracked in our study moved considerable distances along the continental coastline. Previous studies [20] have speculated that Galapagos sharks may exhibit different patterns of horizontal movements between wet and dry seasons. In our study, we obtained many more total detections in general, and offshore detections in particular, during the dry season (December–April) than during the wet season (May–November), but because the tracked sharks were tagged in September, the elevated number of detections recorded in the dry season may be an artifact of the tagging date, rather than actual differences in the movements of sharks between seasons.

Previous depth records for free-swimming Galapagos sharks or those captured in fisheries have ranged from very shallow water to water at least 286 m deep, with most captured in waters less than 80 m [3,5], but aggregations of small sharks in lagoons or close to the shores of islands have also been reported [7,8,35]. The tags used in our study did not report depth in the water column, but reported a large number of locations over deep water. The abundance of offshore locations obtained in our study, in combination with reports of occasional long-distance movements [6,20,36,41], indicate that Galapagos sharks do not restrict their movements to coastal waters and may occasionally undergo long-distance movements. Although the sample size in our study is limited, preliminary results suggest that Galapagos sharks along the Pacific coast of Central and South America may display longitudinal differences in depth and may occur in shallower water at night.

Our study has advanced understanding of the movements and habitat use of Galapagos sharks along the continental coastline of Central and South America, and suggests that sharks in this region may concentrate their activity within an area that spans the Panama/Colombia border. Additionally, Galapagos sharks that move along continental

coastlines appear to spend the majority of their time in waters slightly offshore, and are most commonly found in water 50–100 m in depth. These characteristics are consistent with carcharhinid sharks, which are subject to overfishing due to their relatively limited range and their distribution that overlaps small- and large-scale fisheries.

## 5. Conclusions

The Galapagos sharks tracked in our study remained primarily in continental shelf waters and moved from the tagging location to both the north and south along the Pacific coast of Panama and Colombia. Tracked individuals were most often recorded within 20 km of shore and in waters less than 100 m deep, although detections far from shore and in deep water suggest that they occasionally range far from continental shelf waters. Galapagos sharks are locally abundant at locations throughout the Eastern Tropical Pacific, primarily around islands, but also inhabit continental shelf waters, where they may interact with humans and influence community structure.

**Author Contributions:** B.M.W. wrote the manuscript and performed analyses. G.M.C.H. conceived the study, coordinated funding, performed fieldwork and commented on versions of the manuscript. C.D.K. wrote portions of the manuscript, performed data analyses and commented on versions of the manuscript. M.K.B., O.W.F. and N.A.K. performed data analyses and commented on versions of the manuscript. J.J.V. commented on versions of the manuscript. M.S.S. coordinated funding and commented on versions of the manuscript. All authors have read and agreed to the published version of the manuscript.

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**Institutional Review Board Statement:** All fishing, measurement and tagging were performed in such a way as to minimize unnecessary stress and injury to the animals, and were carried out according to methods established and practiced by the Guy Harvey Foundation. This study was approved by the Institutional Animal Care and Use Committee and the Institutional Review Board (Code: #AN1617-020 Date: 1 July 2025).

**Data Availability Statement:** The data that support the findings of this study are available from the corresponding author upon reasonable request.

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**Conflicts of Interest:** The authors have no conflicts of interest.

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