


TELEMETRY CASE REPORT

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First descriptions of the seasonal habitat use and residency of scalloped hammerhead (*Sphyrna lewini*) and Galapagos sharks (*Carcharhinus galapagensis*) at a coastal seamount off Japan

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Abstract

Background: The Northwestern Pacific is a data-poor region for studies into the movements and habitat use of open ocean and pelagic sharks. However, this region experiences considerable pressure from commercial fishing. Therefore, shark movement data from this region carry significant implications for conservation and management, particularly for threatened species. Here, we provide the first data on seasonal residency and movements of scalloped hammerhead (*Sphyrna lewini*) and Galapagos sharks (*Carcharhinus galapagensis*), using acoustic and satellite telemetry, and dive logbooks, off Japan.

Results: Eight female sharks, four of each species, were tagged around a coastal seamount off southeastern Japan (Mikomoto Island) in August 2015, and monitored for a period of up to 363 days using an array of six receivers around the island. Analyses of the more abundant scalloped hammerhead acoustic data suggest high seasonal residency predominantly from August to November associated with lower chlorophyll-*a* concentrations, before sharks then leave the island and return the following summer. Residency for scalloped hammerhead sharks were highest among those receivers closest to the Kuroshio Current, which produces strong coastal upwelling, however SST was not found to be predictive of occurrence at Mikomoto. Shark presence was corroborated by analysis of dive-log data from a local ecotourism operator. We also produced two unique satellite tracks, whereby a scalloped hammerhead exhibited a 200-km dispersal into a coastal embayment west of the tagging location and a Galapagos shark migrated over 800 km offshore into the high seas.

Conclusion: This study provided some of the first behavioral and movement data for scalloped hammerhead and Galapagos sharks in Japan. Our findings suggest varying spatial and temporal visitation of two shark species to a coastal seamount, underscored by some degree of seasonal residency and site fidelity and linked, for scalloped hammerhead sharks at least, to varying productivity. Furthermore, we provided preliminary evidence for long-distance dispersal of these species, and some site fidelity to seamounts in the region. This study highlights the importance of

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describing shark movements to aid in filling critical data gaps for poorly understood, endemic populations of threatened species.

Keywords: Acoustic telemetry, Hammerhead, Japan, Seamount, Shark

Background

The spatial ecology of threatened, highly migratory marine species is often complex and difficult to capture [36], which can sometimes preclude the establishment of biologically relevant management strategies such as marine reserves [15]. However, identifying and characterizing the areas and times where these species occur regularly and/or may form aggregations, in addition to exploring some of the environmental drivers of these processes, can offer valuable insights to advance conservation efforts. The value in describing and protecting areas of high residency and abundance for threatened marine predators is reinforced by the notion that aggregating species are inherently susceptible to overexploitation [23, 32, 44]. Sharks are among the most threatened marine fishes due to their inherent vulnerability to overfishing, in combination with *k*-selected life-history traits impacting their ability to respond quickly to exploitation [43]. Employing behavioral approaches to identify biological hotspots as such remains both a challenge and an opportunity [38], particularly for species that retain high value for their meat or fins, or in regions where there is limited political will for conservation. Even for species that spend months at a time in pelagic, high-seas habitat, identifying areas and associated environmental correlates, where their movements bring them back to the same place on a semi-regular basis, represents an important first step towards conserving these animals.

Seamounts can serve as hotspots for pelagic diversity, particularly for large pelagic fish and sharks (e.g., [40]). Hammerhead sharks (*Sphyrna* spp.), particularly those from the large species complex, are ecologically specialized and behaviorally complex [17, 19], and are known to form large aggregations in discrete tropical and temperate locations worldwide (e.g., [6, 21, 25]). This group of sharks is also prized in the shark fin industry and typically have high mortality rates when caught as bycatch in longline fisheries [18]. As a result, hammerhead sharks have experienced dramatic population reductions worldwide [9, 16, 19]. In some areas where they were historically abundant, research has demonstrated that hammerhead sharks have been overharvested and even extirpated (e.g., [24]). Despite a circumglobal temperate and tropical distribution, the scalloped hammerhead shark (*Sphyrna lewini*) is currently assessed as Critically Endangered on the

IUCN Red List [39] and may be critically endangered throughout most of their often-extensive range [19]. Consequently, significant research effort has been dedicated to evaluating the residency and habitat use of scalloped hammerhead sharks, in some of their better-known core locations throughout the Atlantic [45], and in particular, the Eastern tropical Pacific. [6, 7, 21, 27]

The Galapagos shark is similarly distributed circum-globally in tropical and warm temperate waters, and is found in open ocean ecosystems and exhibits a preference for isolated oceanic islands [46]. The species is vulnerable to overfishing throughout its range [13, 30] and is currently assessed as Near Threatened on the IUCN Red List [5]. Until recently, knowledge on Galapagos shark habitat use limited to a few discrete locations [31, 35]. Both scalloped hammerhead and Galapagos sharks commonly aggregate at isolated oceanic seamounts, and investigating the habitat use of these species in these locations has assisted with regional conservation efforts such as lobbying for, evaluating—and in some cases establishing—marine protected areas that encompass the core habitat of semi-oceanic shark species [20, 31]. Novel, integrative descriptions of pelagic shark movements, such as those by hammerhead and Galapagos sharks, among and between remote oceanic regions may serve to strengthen or expand existing conservation policies that seek to protect critical habitat [6–8, 21, 34].

Here, we offer new descriptions of a semi-pelagic shark community, dominated by schools of scalloped hammerhead and Galapagos sharks, from a little-known area in the Western Pacific, off the coast of Japan. In this typically data-poor region, we gathered telemetry data deployed on a small number of acoustic and satellite tags from sharks which co-occur seasonally at a seamount off coastal Japan (Mikomoto Island). This location also supports seasonal shark diving tourism activities, and we thus combine our telemetry data with diver ecotourism logbook data, and remotely sensed environmental data, to present novel insights into shark movement and space use from Southeastern Japan. While the small sample size precludes a quantitative analysis of subpopulation trends at this location, we hope these results underscore the potential for expanded work on these species at seamounts in the region.

Materials and methods

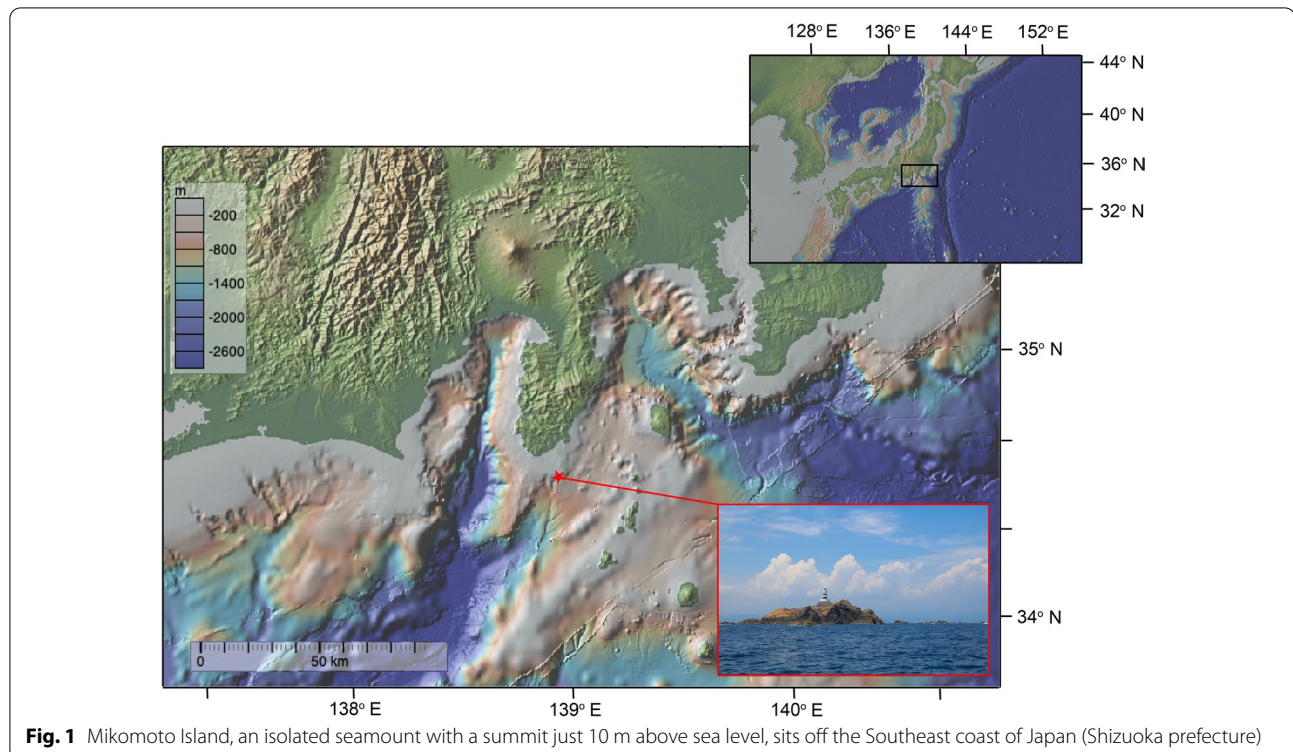
Study area

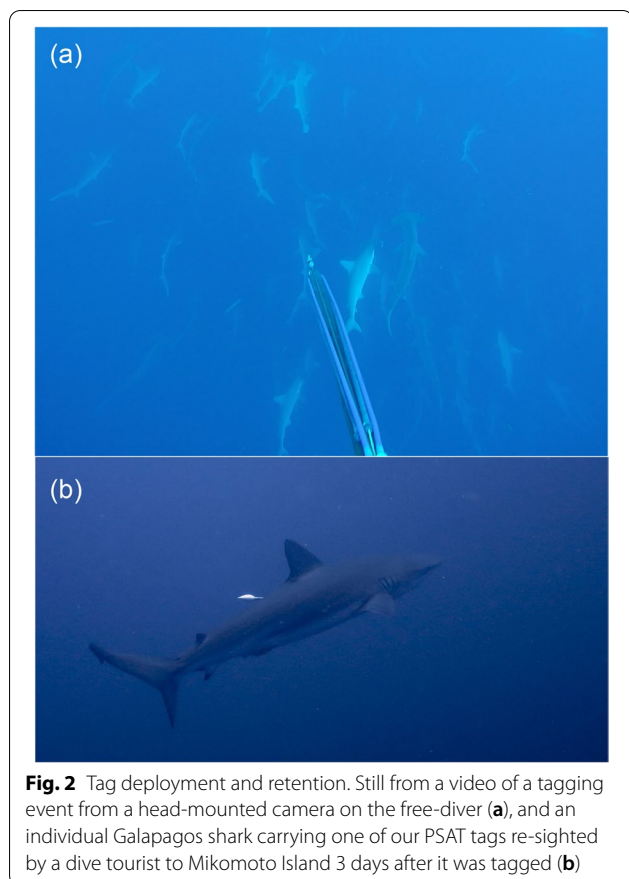
Mikomoto Island is an isolated seamount situated north of the Philippine Sea in the North Pacific Ocean (34.57°N, 138.94°E), approximately 10 km southeast of the Izu Peninsula, Mikomoto, Shizuoka, Japan, and approximately 250 km west from the Japan Trench (Fig. 1). Mikomoto Island rises vertically from 2500 to 10 m above sea level, whereby the ~0.7 km² rock island is situated in the middle of an elevated depth contour of 30–40 m in all directions (Fig. 1). The subsurface topography is composed of hard rock and boulders, there is limited subaquatic vegetation or algal cover due to the strong Kuroshio Current which passes over the seamount. Locally, the area is subject to a few small-scale net fisheries targeting small pelagic fishes as well as sea cucumbers. There is currently no commercial fishery targeting sharks in this region, although sharks are infrequently caught locally as bycatch in regional set-nets. A small fleet of local dive operators (four companies) specialize in local shark diving, as scalloped hammerhead sharks are reliably observed aggregating in large numbers throughout the summer and fall year after year; other species of semi-oceanic sharks such as Galapagos sharks are commonly observed. All shark diving is achieved through natural, non-baited viewings around the seamount. We used passive acoustic telemetry in addition to two satellite tags (detailed below) to

describe preliminary patterns of habitat use and movement by these two species at the seamount.

Animal tagging

All field work was conducted from 15 to 22 August 2015 around Mikomoto Island, using a 20-m Japanese fishing vessel from which in-water operations were launched. All animal tagging was non-invasive and performed in water with a trained free-diver as research fishing for sharks is prohibited by the local managers, as well as due to concerns related to hammerhead capture stress and post-release mortality [19]. A free-diver (M. Healey) tagged both scalloped hammerhead and Galapagos sharks with external acoustic-coded V16 4H transmitters potted in a PVC casing with attachment holes at either end (74 mm length × 16 mm diameter, weight in water: 8.1 g, transmission off times: random between 40 and 80 s; battery life estimated at 5 years [although tag retention was certainly less than this]; Vemco, Innovasea, Halifax, Canada). A 10-cm tether of parachute cord was threaded through the external case hole and crimped, which terminated at a 2.5-cm stainless steel anchor to be embedded into the shark's body. Acoustic tags were loaded into a band-powered speargun on the surface and the tagger would locate and free-dive into a group of schooling sharks (Fig. 2a). All tags were shot into the dorsal flank musculature. Each acoustic tag then broadcasted unique identification





‘pings’ at semi-random intervals all at 69 kHz. Since all tagging were done in the water, shark total length was visually estimated by the sole free-diver using the tagging gun (120 cm in length) as a reference. A total of four scalloped hammerhead sharks and four Galapagos sharks were tagged with external acoustic transmitters. A further single individual of each species was equipped with a satellite tag (Desert Star-GEO, 132 mm length, 13 mm diameter, weight in air 29 g), attached externally and in situ using the same methods as the acoustic tags, bringing the total tags deployed to 10. Briefly, the satellite tags’ internal memory allowed for recordings of temperature (− 40 to +85 °C, 0.2 °C accuracy) and geomagnetic field values (3 axes) three to four times per day across a 90-day deployment. Onboard light sensors recorded 12-h position estimates using light-based geolocation, and each tag was programmed to transmit raw data and daily average data for the 3-month deployment. The satellite tags have a solar battery and the potential to transmit their data continuously when the tagged animal neared the surface such that the PSAT float antenna could be picked up by an ARGOS low Earth orbiting satellite (<http://www.argos-system.org/>) [4]. Once detached or shed, all archived data were transmitted from the tag via

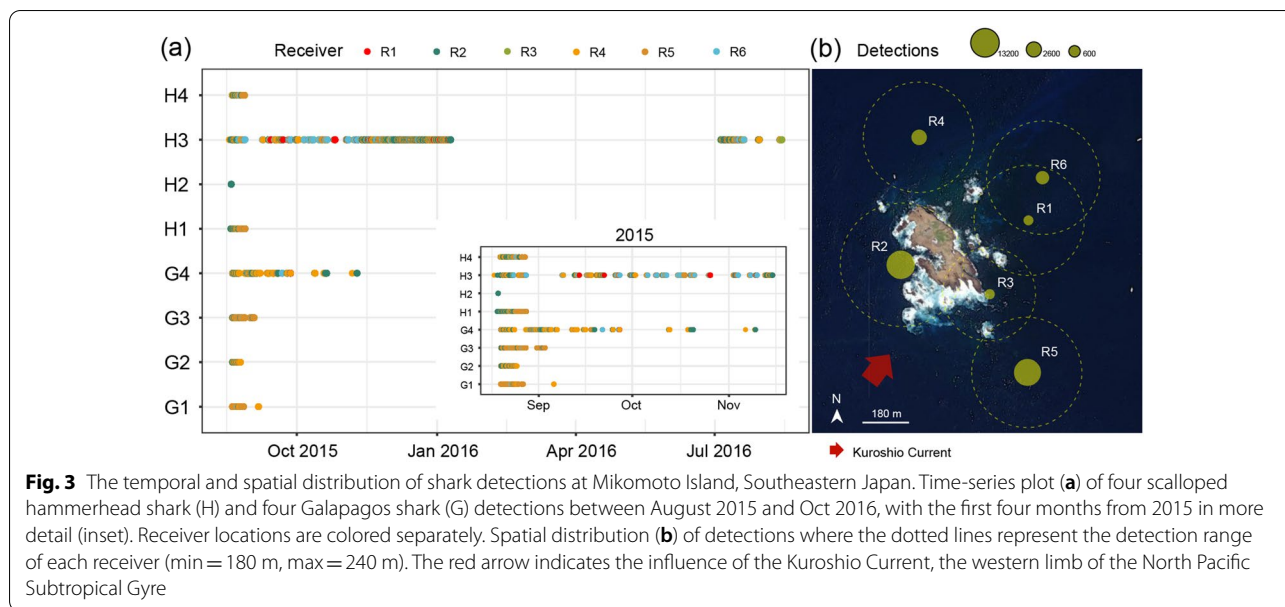
ARGOS satellite. Similar to other studies utilizing spear-guns to externally affix tags on scalloped hammerhead sharks (e.g., [6, 7]), tag retention was assumed to be relatively low (e.g., <1 year). Empirical, initial tag retention was validated by in situ re-observation of tagged sharks by tourists a week following tagging (Fig. 2b) and in the longer-term by the longevity of the tracking data (maximum known retention = 363 days).

Telemetry array

To record the occurrence and residency of acoustically tagged sharks around Mikomoto Island, an array of six hydrophones (Vemco, Innovasea VR2W) were deployed in the study area (Fig. 3). The receivers were placed around the island, spaced at 500–800 m intervals at depths between 15 and 25 m to enable maintenance by divers. Due to the lack of soft substrate, all receivers were attached to rocky benthos and tied around large boulders using 2 cm polypropylene line, floating 1 m off the sea-floor. Range testing on all receivers was performed using a test tag and multiple passes, with results suggesting an average detection radius of 0.215 km, implying the array maintained coverage of the perimeter of the island. All receivers were retrieved with batteries still operational on 21st October 2016, and data from the 14-month deployment were subsequently downloaded.

Diver logbook data

A collaborative local dive operation maintains a robust, publicly available dive-log containing digital photos on hammerhead shark observations throughout the year, from 2003 to present (Additional file 1: Mikomoto Hammers, <http://www.mikomoto.com/english/>). To gather comparative information on shark presence at the study site, these dive-logs were accessed and analyzed by a native Japanese speaker (co-author YYW) for a period of 16 months inclusive of our study period, from 4 July 2015 to 29 November 2016. Available digital photos for every dive-log record during this period (resolution ~640 × 480 pixels) were scored in one of three categories, according to the presence of scalloped hammerhead sharks: “0” where no sharks were seen on that day; “1” where one shark was seen that day; and “2” where multiple scalloped hammerhead sharks were observed on that day. The dive operator visits Mikomoto Island regularly during the diving season (July–November), but did not dive every day during the study period due to weather conditions; furthermore, we were not able to control for the number of photos posted for a given day, nor the variation in photographer or ability to find sharks on a dive. Thus, these records served as a coarse proxy for shark presence over a representative time-frame for which to compare with our acoustic data.



Movement, space use and environmental analyses

The acoustic time-series data were plotted both linearly and in an aggregated form to explore differential patterns in both seasonal and diel occupancy at Mikomoto Island, between individuals and species. Residency at each of our receiver locations was calculated as a proportion of the number of days each individual was recorded at each location relative to their total time at liberty [15]. Sea Surface Temperature (SST) and chlorophyll-*a* (CHL) concentrations, as a proxy for ocean productivity, are the two most widely used remotely sensed environmental variables for explaining patterns of movement in elasmobranchs [47]. There is also evidence to suggest some association in scalloped hammerhead shark movement and occurrence in relation to seasonal changes in SST [14] and reductions in CHL concentrations [45]. For these reasons, we included these environmental variables in our models. Satellite data were obtained from the AVHRR sensor aboard Polar Operational Environmental Satellites (POES) for daily optimum interpolation SST and from the VIIRS sensor aboard the Suomi National Polar-orbiting Partnership (SNPP) satellites for daily chlorophyll-*a* concentrations via the National Oceanic and Atmospheric Administration (NOAA) environmental data portal ERDDAP. Data were extracted at a resolution of 0.25° and 0.04°, respectively, for the duration of the tracking period using the R package *rerddap* [10].

Generalized Additive Modeling (GAM) was used to investigate the temporal occurrence of scalloped hammerhead sharks to Mikomoto island from the acoustic data. Data on Galapagos sharks were limited temporally, so the decision was made to only model

scalloped hammerhead sharks given the high numbers of this species regularly observed at this location. The occurrence of tagged scalloped hammerhead sharks ($n=4$) on a given day of the year was quantified as “1” if >1 detection per day was recorded and “0” if ≤ 1 detection was recorded as per Andrzejczek et al. [3]. The GAM was constructed using a binomial error structure with a log link function using maximum likelihood estimation in the R package *mgcv* [48]. Binary presence was used as the response, with day of the year, daily SST and CHL concentrations as the continuous, smoothed predictor variables. Combinations of these predictor variables were ranked using Akaike’s information criterion (AIC) to determine the best model.

Geolocations for the two PSAT-tagged sharks were estimated using archival data that were transmitted from each tag. Raw light-level data from the tag were run through a state-space model (unscented Kalman filter with sea surface temperature, UKFSST, [28]). A continuous-time correlated random walk (CTCRW) state-space model was then applied to produce a regular (daily) time-series of interpolated positions, following Queiroz et al. [38]. Tracks were then constructed between the daily estimated geolocations in chronological order using the known deployment and pop-off locations.

Frequency histograms were constructed for the diver log book data for each categorical shark presence level, for each sampling month present. To examine whether there were differences in qualitative observations of shark presence and relative abundance across months, we ran a Kruskal–Wallis ANOVA with pairwise Wilcoxon rank sums test on the raw dive-log data.

Results

The eight sharks fitted with external acoustic tags were monitored for between 1 and 363 days, by the six receivers deployed around Mikomoto Island (tag metadata are included in Table 1). Based on visual estimation via the in situ diver, hammerhead shark size was estimated between 210 and 280 cm (total length, ±40 cm error), whereby Galapagos shark size was estimated between 170 and 230 cm (total length, ±40 cm error). All sharks tagged across species were identified as female. During this monitoring period, a total of 25,779 detections were recorded for scalloped hammerhead sharks (mean ± SD = 6445 ± 11,270) and 4611 detections for Galapagos sharks (1153 ± 815) across the array with most individuals being detected on all receivers (Fig. 3).

Diel and seasonal patterns of residency to Mikomoto Island

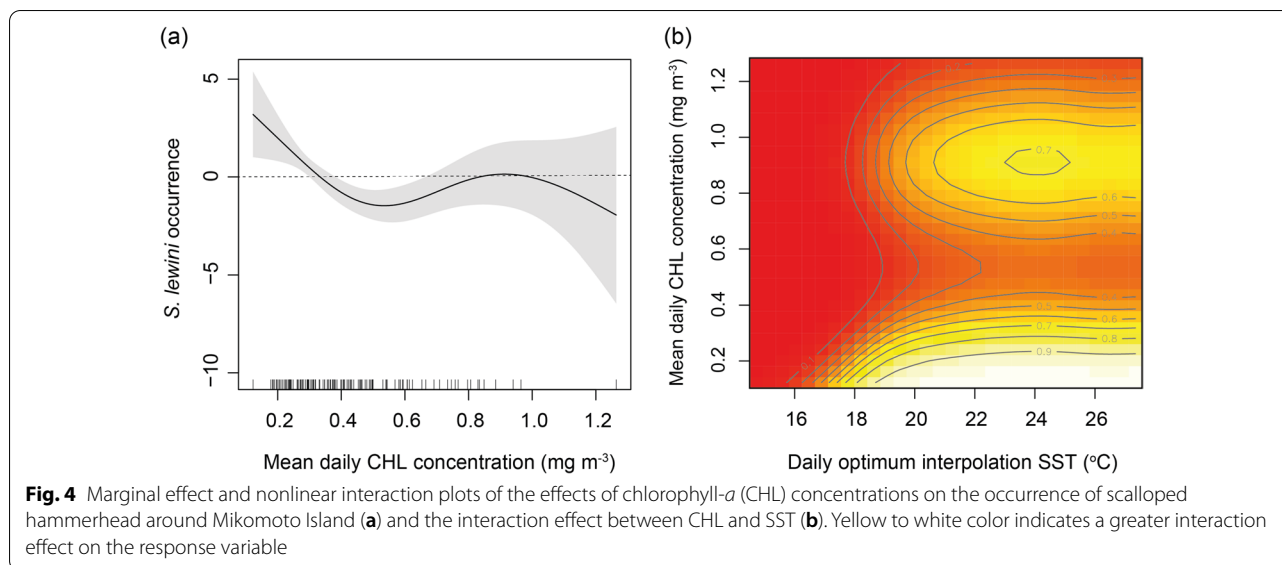
Small sample sizes for both shark species, in addition to short times at liberty for some individuals preclude our ability to measure long-term visitation and residency of these species to Mikomoto Island. The one individual scalloped hammerhead shark that we do have long-term data for however (i.e., ~12 months), suggests high residency to this small area between Aug–Feb followed by a long period of absence before a return to this location at the same time the following year (Aug 2016) (H3, Fig. 3). Further research on many more individuals would be required to confirm whether this was a population trend. However, dive center sightings data suggest that aggregations are most likely during the months of August and September, suggestive that numerous individuals might indeed return to this location around the same time to aggregate. The

best fitting GAM, identified by the lowest AIC score, retained all three explanatory variables within the model and explained 45.4% of the variation in these data. The model indicated that only CHL concentration had a significant effect on the probability of tagged scalloped hammerhead sharks occurring at Mikomoto Island ($df=3.7$, $p(\chi^2)=0.004$), with probability reducing during periods of higher concentrations (Fig. 4a). While still important in the model, SST was marginally non-significant ($df=3.8$, $p(\chi^2)=0.065$) but appears to influence the nonlinear effects of CHL through an interaction (Fig. 4b). Day of the year did not influence occurrence.

Exploration of the diel distribution of the detection data suggests that *S. lewini* are more likely to be present around the island from midday into the evenings (Fig. 5a). Residency to the array around Mikomoto Island was higher for scalloped hammerhead sharks (mean = 0.42, range 0.17–0.67) than for Galapagos sharks (mean = 0.33, range 0.14–0.59). This varied considerably across the six receiver locations (Fig. 5b) with the highest residency, in scalloped hammerhead sharks particularly, at the receivers southwest of the island, those that are most influenced by the southwest to northeasterly Kuroshio Current (Figs. 3b and 5b). Despite the small sample size, the acoustic telemetry data were relatively congruent with the dive-log data (Fig. 5c). Shark presence and abundance, inferred from opportunistic dive-logs from the main operator at the site, appeared to significantly differ according to month ($n=167$, Kruskal–Wallis; $H=42.19$, $p<0.0001$). Peak abundance, which appeared to occur in August, was statistically similar in September and November, but significantly different from June, July, May, and October (Fig. 5c).

Table 1 Summary of sharks externally tagged with acoustic and satellite tags while freediving around Mikomoto Island, Japan

Shark	Species	Tag ID	Tag type	Tag date	Time_local	Attachment	Number of detections	Time at liberty (days)
<i>Acoustic transmitters</i>								
1	<i>Sphyrna lewini</i>	1216471	V16 high power	19-08-2015	10:30:00	External	1321	10
2	<i>Sphyrna lewini</i>	1216472	V16 high power	19-08-2015	12:50:00	External	26	1
3	<i>Sphyrna lewini</i>	1216473	V16 high power	20-08-2015	10:40:00	External	23329	363
4	<i>Sphyrna lewini</i>	1216474	V16 high power	20-08-2015	12:35:00	External	1103	8
5	<i>Carcharhinus galapagensis</i>	1216475	V16 high power	20-08-2015	13:10:00	External	617	17
6	<i>Carcharhinus galapagensis</i>	1216476	V16 high power	20-08-2015	13:45:00	External	645	5
7	<i>Carcharhinus galapagensis</i>	1216479	V16 high power	20-08-2015	14:00:00	External	1002	15
8	<i>Carcharhinus galapagensis</i>	1216481	V16 high power	21-08-2015	09:30:00	External	2347	82
<i>Satellite archival tags</i>								
9	<i>Sphyrna lewini</i>	979	SeaTag-GEO PSAT	20-08-2015	10:15:00	External	NA	12
10	<i>Carcharhinus galapagensis</i>	990	SeaTag-GEO PSAT	21-08-2015	09:02:00	External	NA	217



Preliminary broad-scale movements away from Mikomoto Island

Both PSAT tag deployments, one on each species, yielded interesting tracks with tag retention substantially different between animals (Fig. 6). The scalloped hammerhead traveled an estimated total distance of 295.62 km over 12 days, exhibiting a two-phased movement pattern, whereby the shark first traveled offshore to what appears to be another set of coastal seamounts, then returning inshore and traversing a nearby coastal embayment (Fig. 6a). The scalloped hammerhead tag then prematurely released. The Galapagos shark carried its tag for a total of 217 days over an estimated 897.47 km, exhibiting a large distance oceanic movement into the open ocean away from the tagging site (Fig. 6b).

Discussion

This study presents preliminary evidence of seasonal residency and site fidelity by scalloped hammerhead sharks, and to a lesser extent, Galapagos sharks, at what appears to be an important aggregation site for the former, Mikomoto Island, off the southeast coast of Japan. Using a combination of acoustic and satellite telemetry, remotely sensed environmental variables, as well as opportunistic citizen science photo log data provided by a collaborating dive operator, we show spatial (e.g., fine-scale differences) and temporal variation (several months after tagging) in visitation to this isolated seamount and associated with chlorophyll-*a* concentrations in scalloped hammerhead sharks at least.

Over the course of a year-long study, we recorded many more detections for scalloped hammerhead sharks than

Galapagos sharks, with detections occurring from around midday into the evening. Of the small number of individuals that were tagged, residency was highest to receivers positioned to the west of the island (Fig. 3), potentially indicating a preference for areas most influenced by the Kuroshio Current, although further research would be required to fully confirm this. Peak abundance of scalloped hammerhead sharks, inferred from the dive-log data, indicated this species was most likely to occur in high numbers (>10 sharks, as seen in photos during this period) between August and November, a period consistent with the four highest monthly detection values logged on our acoustic receivers (Fig. 5). Although largely descriptive, this study provides some of the first, long-term tracking data on a Critically Endangered elasmobranch from southeastern Japan, an area of significant conservation relevance.

Large assemblages of scalloped hammerhead sharks elsewhere are often associated with seamounts and offshore islands, suggesting a preference for high-energy locations influenced by major ocean currents [1, 11, 21]. In the Eastern Pacific, the Galapagos Marine Reserve (GMR), an area well documented for scalloped hammerhead aggregations, is influenced by the Cromwell, the Humboldt and Panama Currents [21] generating highly dynamic oceanographic conditions in which scalloped hammerhead sharks typically favor up-current habitats [26]. While we had to consider all four tagged scalloped hammerheads together due to the low detection rates in all but one individual, satellite derived CHL concentrations were predictive of occurrence around Mikomoto Island. Concentrations overall were low, but probabilities of occurrence were highest between 0.2 and 0.4 mg m⁻³,

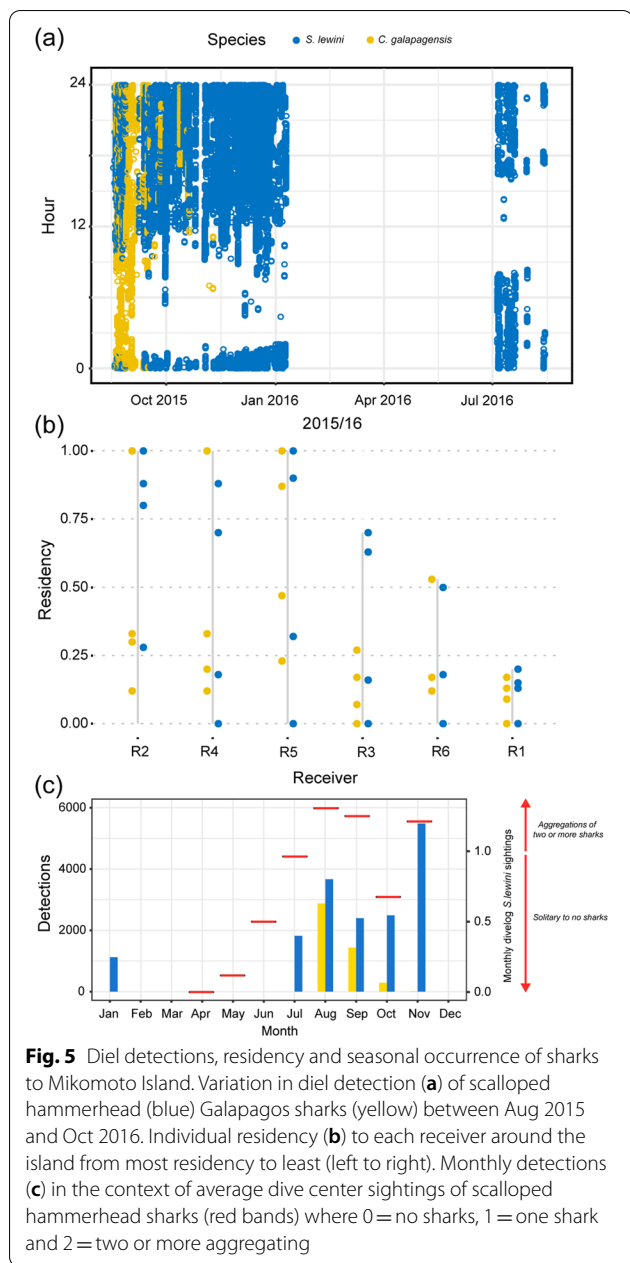


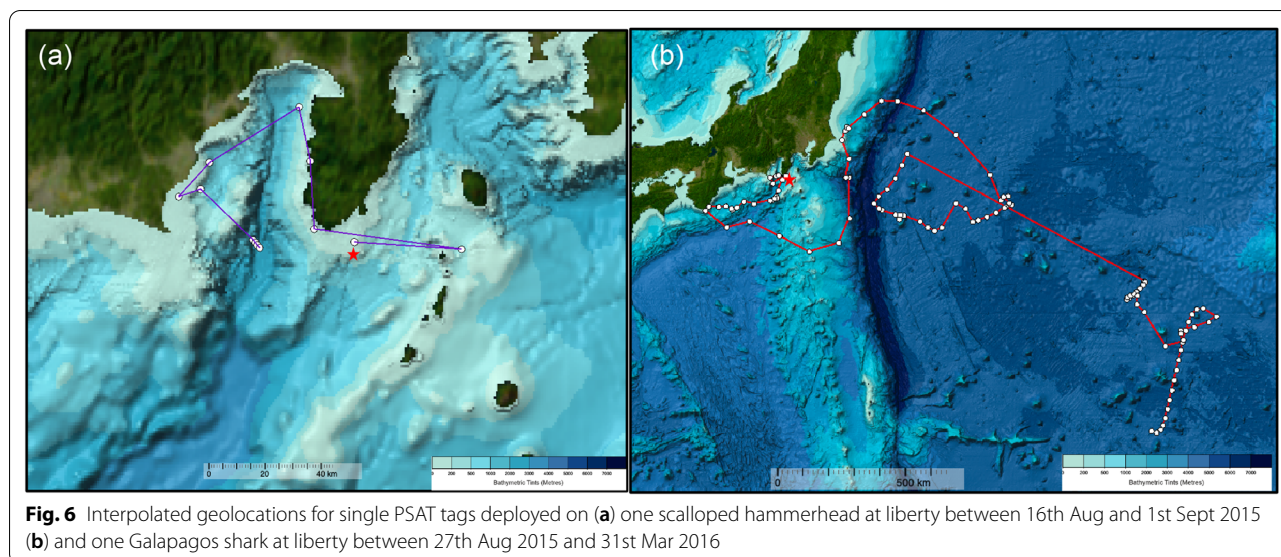
Fig. 5 Diel detections, residency and seasonal occurrence of sharks to Mikomoto Island. Variation in diel detection (a) of scalloped hammerhead (blue) Galapagos sharks (yellow) between Aug 2015 and Oct 2016. Individual residency (b) to each receiver around the island from most residency to least (left to right). Monthly detections (c) in the context of average dive center sightings of scalloped hammerhead sharks (red bands) where 0 = no sharks, 1 = one shark and 2 = two or more aggregating

supporting Wells et al. [45], who predicted scalloped hammerheads were most likely to use continental shelf waters in the Gulf of Mexico when chlorophyll-*a* concentrations fell within $\sim 0\text{--}4 \text{ mg m}^{-3}$.

The Kuroshio Current—the western limb of the North Pacific Subtropical Gyre—strengthens significantly when it rejoins the Pacific Ocean, reaching approximately 65 million cubic meters per second to the southeast of Japan [2]. A recent study showed that a highly aperiodic event known as the Kuroshio Large Meander is associated with positive anomalies of

chlorophyll-*a* concentrations that may have influenced presence/absence, with the meander impacting a large area that includes Mikomoto Island [29]. Productivity aside however, it was on the western and southwestern situated receivers (i.e., those with the greatest exposure to the Kuroshio Current) that we obtained the most detections for this species. In a recent study on grey reef sharks occupying a channel influenced by strong currents and updraft zones in French Polynesia, Papatamatiou et al. [37] found that sharks aggregate and coordinate their behavior (accounting for tidal change) in order to best maintain their position within predictable updraft zones, thus reducing their energy expenditure during periods of refuging. We suspect that similar mechanisms may also underpin scalloped hammerhead schooling behavior, and further meta-analyses of oceanographic conditions around isolated islands/seamounts would be interesting to determine the potential for updrafts to explain hammerhead hotspot locations.

Residency for scalloped hammerhead sharks was higher than that of Galapagos sharks, suggestive of a greater reliance of this species on the conditions around Mikomoto Island. An average residency of 0.42 for scalloped hammerhead sharks was comparable to residency at locations in the Eastern Tropical Pacific where tagged sharks of this species spent on average around half of their time (RI=0.52) within an acoustic array situated around Cocos Island (Costa Rica), in particular at a shallow seamount to the southeast of the island [34]. For the short period of time that the four Galapagos sharks individuals were present, they were also most resident at same three acoustic receivers (R2, R4 and R5). Our two PSAT deployments provided limited data, but the data allowed us to confirm that both species appeared to exhibit seasonal dispersal away from the seamount, although the types of behavior differed between species. The scalloped hammerhead female exhibited behavior consistent with that seen in other regions (e.g., [22], with a contrast between habitat use at offshore islands or seamounts, and the use of insular bays which function as inshore nursery habitats (e.g., [12, 42]. While it remains unknown why the tagged hammerhead in the present study moved into an insular bay, use of these areas may be biologically important, as local fishers commonly report bycatch of both adult and juvenile scalloped hammerhead sharks in beach set-nets targeting finfish throughout bays along the southeastern Japanese coastline (Pers. Comm, YYW). The offshore movements of the Galapagos shark highlighted expansive dispersal into the high seas of the Western Pacific—movements greater than seen for the species in other localities [31, 35], yet the function of these movements remains unknown. Nevertheless, both species demonstrated a combination



of movements that suggest overlap with coastal and high seas fisheries pressure.

For a preliminary study such as this, it is important to acknowledge the limitations of our data. Logistical challenges precluded further subsequent deployment of tags in the area, meaning that we were limited in the generalizability of our tagging data to just the eight acoustic and two satellite tags. That said, the importance of publishing data on endangered species from under-represented areas cannot be understated [41]. The citizen science data, although opportunistic and lacking information about effort, provided clear, and complimentary evidence of when sharks were likely to be present and when in large numbers (Fig. 5c), with 10 s to 100 s of individuals seen regularly by staff and tourists throughout the season and year-on-year (Mikomoto Hammers, Pers. Comm).

Conclusions

Whereas the majority of research into the movements of pelagic sharks exhibiting residency to coastal and oceanic seamounts, particularly that of the scalloped hammerhead, have been conducted in the Eastern Tropical Pacific, our data suggest the occurrence of regional populations of these species which exhibit seasonal residency at coastal seamounts in the northwest Pacific, a data-poor region for shark conservation. Given that the northwestern region of the Pacific Ocean was recently highlighted within the global distribution map of longline fishing effort as one of a few large-scale areas of heavy longline use [38], we argue that it should receive rapid research and conservation attention for its potential in safeguarding the biodiversity of seasonally resident, Critically Endangered shark species.

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s40317-022-00293-z>.

Additional file 1: Material S1. Screen-shot of publicly available dive-log from collaborative partner and dive operator, Mikomoto Hammers, which was used and analyzed in the present study (<https://www.mikomoto.com/logs/2015/08/009890.php>).

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Author contributions

AJG and TP conceived the study; AJG, TP, and DMPJ secured funding. All authors performed field work. DMPJ performed formal analyses and data interpretation; DMPJ and AJG performed mapping; DMPJ and AJG conceptualized the manuscript and performed writing; All authors reviewed and edited the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed for this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

All research activities, including animal tagging, were communicated to and approved by fisheries officers within Japanese government (a formal research permit was not required).

Consent for publication

Not applicable.

Competing interests

The authors declare they have no competing interests.

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