Lord Howe Island Shark Research Program: testing deterrents to reduce shark bycatch and depredation and continuation of the deepwater acoustic receiver array

Final report for Parks Australia

Australian Government
Parks Australia

Australian Marine Parks

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The University of Western Australia
Sea World Research & Rescue Foundation
SIMS Sydney Institute of Marine Science
IMOS Integrated Marine Observing System
NSW Government Department of Primary Industries and Regional Development
SEA | Consulting
Flinders University

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Important Disclaimer

List of abbreviations

BP	Ball's Pyramid
GLM	Generalised Linear Model
IMOS	Integrated Marine Observation System
LHI	Lord Howe Island
NSW DPIRD	New South Wales Department of Primary Industries and Regional Development
NTZ	No-Take Zones (includes Sanctuary Zones in State waters and National Park Zones in Commonwealth waters)
VMS	Vessel Monitoring System

1. Executive summary

Galapagos sharks (*Carcharhinus galapagensis*) occur in high abundance in the Lord Howe Marine Park (Commonwealth) and Lord Howe Island Marine Park (NSW) marine parks surrounding Lord Howe Island (LHI), and they are an important indicator species for marine park management. These sharks regularly interact with fishing activity, leading to shark bycatch and depredation (where sharks consume hooked fish before they can be retrieved). This is resulting in lost catch and fishing gear leading to conflict with local charter and recreational fishers and negative attitudes towards, and actions against, Galapagos sharks. However, other marine park user groups interact with Galapagos sharks in a positive way, including scuba divers and snorkellers. Supporting these positive interactions and finding approaches to reduce negative interactions between fishers and sharks is therefore critical to promote coexistence between humans and sharks in the marine parks and maintain important environmental, social and economic values.

Research on Galapagos shark movement ecology and interactions with fishing vessels commenced in 2018 and has generated important baseline knowledge on their movement patterns, residency, depth range and overlap with fishing vessel activity (Mitchell et al., 2021; 2024). This research also generated a list of best-practice guidelines to help fishers minimise negative interactions with sharks, which was incorporated into a leaflet and poster for the LHI community and visitors. To further build on this previous work, long term monitoring of the population is valuable to learn more about the movements of the 30 individual sharks tagged in 2018, as they reach maturity, and to identify any changes in movement patterns over time linked to changing fishing dynamics or environmental patterns. The report presents data from the deepwater acoustic receiver array at LHI, from November 2023 to November 2024.

The deepwater acoustic array continued to detect Galapagos sharks originally tagged in 2018, with eight individuals detected 1,508 times across six acoustic receivers between November 2023 and November 2024. Five of the eight sharks were regularly detected throughout this study period, suggesting that part of the LHI Galapagos shark population remains resident, with other animals potentially migrating to other locations. Shark 1280539, which was 139 cm long when tagged in 2018 and is now likely an adult shark of 2.0 – 2.5 m, was detected by five out of the six receivers, suggesting it now has a larger home range than in 2018 – 2021, when it was only detected infrequently on the acoustic array. Detections for all sharks pooled were highest in spring and lowest in late summer/autumn, mirroring trends recorded from 2018 – 2021. Residency index values were low overall, similar to in 2018 – 2021, with all individuals having a residency index <0.2, likely because of the relatively low coverage of the receiver array across the large shelf area of LHI and Ball's Pyramid (BP). As per the 2018 – 2021 detections, the acoustic receiver at the Southeast LHI shelf had the highest number of detections, likely due to the area being a productive shelf edge where upwelling occurs and prey species are concentrated, leading to higher shark presence.

The acoustic receivers also detected 14 tagged animals from other species, including seven yellowtail kingfish tagged at LHI, two tiger sharks originally tagged at Norfolk Island and three white sharks and two tiger sharks tagged in mainland NSW. This highlights the value of the array for monitoring marine megafauna connectivity across the Tasman Sea and between two Australian Marine Parks. Furthermore, the acoustic receivers recorded valuable data on water temperature at depth, providing a high-resolution temperature profile from November 2023 to November 2024, including two previously undocumented occurrences of rapid temperature spikes in these waters, where temperatures increased by 3 – 5 °C over a period of a few days.

The current project also tested two electrical and one magnetic shark deterrent to assess their effectiveness at reducing shark bycatch and depredation, using a two-phase approach. During the first phase, a standardised baited camera rig was used to conduct 50 five-minute trials of each of the three active deterrent devices, plus a control treatment with no active device. This testing recorded the occurrence of sharks either making contact with or biting the bait bag, to simulate shark bycatch and depredation. The two electrical shark deterrent devices tested showed promising results for reducing shark depredation and bycatch, with the frequency of bites on the bait decreasing by up to 55% and the time for sharks to make first contact with the bait being significantly longer compared to the control. However, the magnetic deterrent had a lower effectiveness at reducing bites on the bait. The second phase of testing involved testing the two electrical deterrents and a control treatment under standard fishing practices on local charter fishing vessels. The two electrical devices reduced shark depredation by 83% compared to the control treatment and they also reduced shark bycatch by >50%, although the overall number of datapoints collected (80 fish hooked across all three treatments) was limited due to unfavourable fishing conditions, preventing more detailed statistical analysis of results. Testing of the devices also enabled charter fishing operators to provide important feedback on their practicality and ease of use, which will be passed on to the deterrent device manufacturers to enable continued improvements on the design of their products. Further testing of the two deterrents with charter operators is planned for November 2025, to increase the number of datapoints and thus enable a robust statistical assessment of which device is most effective and suitable for use in reducing shark depredation and bycatch at LHI.

The holistic approach used by this research program since 2018 has provided detailed insights into the biology and ecology of Galapagos sharks at LHI and has designed practical solutions to help reduce conflict between fishers and sharks. This knowledge is valuable for sustainable marine park management to preserve key environmental, social and economic values. Continuing the deployment of the acoustic receiver array at LHI is recommended to further monitor this population and provide new insights into the movement ecology of adult Galapagos sharks, which is limited worldwide. Additionally, maintaining the array will provide vital ongoing benefits for investigating connectivity of marine megafauna across the Tasman Sea region. Further testing of shark deterrent devices to reduce fisher-shark interactions should be conducted to provide a technological solution to this issue and promote improved coexistence. Disseminating the results of the research and conducting further education activities with the LHI community is also highly recommended to raise awareness and foster further interest in Galapagos sharks and the marine parks surrounding LHI.

2. Background

The Lord Howe Island Marine Park managed by New South Wales (NSW) State Government and the Lord Howe Marine Park managed by the Parks Australia in the Australian Government, were established to manage and protect the unique marine biodiversity of the LHI whilst also providing opportunities for ecologically sustainable use (Director of National

Parks, 2018). Galapagos sharks (*Carcharhinus galapagensis*) are a key indicator species for marine park management at LHI (Edgar et al., 2010; Harasti et al., 2022), where they occur in high abundance (Davis et al., 2017). This species has a circumglobal distribution and occurs predominantly at oceanic islands and seamounts throughout temperate and sub-tropical waters (Ebert et al., 2013) where they primarily inhabit epipelagic waters from 0 – 100 m depth (Wetherbee et al., 1996; Kohler et al., 1998; Meyer et al., 2010). LHI, along with Elizabeth and Middleton Reefs and Norfolk Island, are the only known locations where Galapagos sharks occur in Australian waters (Kyne et al., 2019). At LHI, most Galapagos sharks are juvenile (<1.7 m total length) and regular sightings of neonate sharks (Mitchell et al., pers. obs.) suggest that LHI may be an important nursery area for the species.

However, negative interactions between fishers and Galapagos sharks are occurring at LHI, in the form of shark bycatch and depredation (where sharks consume hooked fish) (Robbins et al., 2011; Mitchell et al., 2021; 2024). The frequency of fishing interactions by Galapagos sharks has anecdotally increased in the last 5 – 10 years, possibly due to a change in shark behaviour, because they have learnt to associate boat engine noise with an easy opportunity to feed (Mitchell et al., 2023). Shark depredation causes extra mortality for targeted species, e.g. yellowtail kingfish, injury to sharks from fishing gear and costly loss of fish and gear for fishers. As a result, shark depredation has been identified as one of the top 10 threats to economic values of the LHI State marine park in a recent community survey (EY Sweeney, 2024). The increasing frequency of these impacts are leading to some fishers deliberately injuring and removing sharks, and some community members have been advocating for a cull or the reopening of commercial harvesting for the species. Large numbers of Galapagos sharks are also caught as incidental bycatch in the LHI charter fishery, ranging from 559 – 1,328 animals per year, and whilst >95% of sharks are released, post-release mortality can occur from hook injuries and stress (Figueira and Hunt, 2017). This fisher-shark conflict is therefore threatening a range of environmental, social and economic values in the marine parks surrounding LHI and is a high priority issue for marine park managers.

The first phase of this research ran from 2018 – 2021 and involved tagging and tracking 30 Galapagos sharks using an array of up to 12 acoustic receivers, to generate baseline data about their movement patterns, residency, home ranges and depth use (Mitchell et al., 2021; 2024). These data were analysed in conjunction with information on fishing vessel activity from Vessel Monitoring System (VMS) units on charter fishing vessels, to identify the extent to which shark movements and fishing activity overlap. A survey of LHI fishers was also conducted to provide data on shark interactions rates and potential mitigation methods to reduce them. The research identified that 28 out of the 30 sharks tagged were detected by acoustic receivers, with on average 890 detections per animal (and a range of 8 – 8,636) (Mitchell et al., 2021). Most tagged Galapagos sharks were present year-round, with highest detections in spring and summer months and three sharks had a notably high residency at a site where fish waste has historically been dumped (Mitchell et al., 2021, 2024). The core home range areas of tagged sharks varied widely from 0.3 – 218 km^2, and key hotspots of overlap between shark core home ranges and fishing vessel activity were identified at productive shelf edge areas on the LHI and BP shelves, as well as at the site close to the south of LHI where fish waste has been historically dumped (Mitchell et al., 2021; 2024).

The fishers interviewed as part of the survey for the previous project reported that shark interactions occur frequently, with 50.6 ± 26% of hooked fish lost to shark depredation per trip and the average cost of gear lost per trip being $96 (Mitchell et al., 2021). Fishers also reported that Galapagos sharks are frequently hooked on bait, with 7.7 ± 4.2 sharks caught per trip, most of which were released but with hooks in their jaw due to having to cut the line. The spatial information collected from analysing the overlap between shark movements and fishing vessel activity was subsequently provided to fishers to assist them in making more informed decisions about where to fish, to minimise the occurrence of shark interactions. The spatial maps were complemented by a list of adaptations to fishing techniques aimed at reducing shark bycatch and depredation, which were guided by fisher knowledge and experiences captured in the survey. These techniques included moving location frequently and rotating the areas fished in, preparing all fishing gear before arriving at the fishing spot so fishing can start immediately on arrival, fishing shallower than 30 m or deeper than 100 m to avoid the Galapagos sharks' main depth range, using handlines and electric reels to retrieve fish faster, switching from bait to lures and jigs to reduce chances of attracting sharks and diversifying the fish species targeted (Mitchell et al., 2021). Bringing fish waste back to land to dispose of, rather than at sea, was also recommended, to reduce the provisioning of sharks, and the LHI waste management facility has an industrial composting system that can handle fish waste (Mitchell et al., 2021).

Continuing the deployment of this acoustic receiver array was identified as a priority to further monitor the movement of the tagged sharks, because the battery life of the tags fitted to the sharks in 2018 is 10 years. This would also generate more detailed insights into their movement ecology once they reached maturity, as all the sharks tagged in 2018 were immature (<1.7 m total length (Bass et al., 1973; Wetherbee et al., 1996; Last and Stevens 2009; Ebert et al., 2013) at the time of tagging. This continued research would also allow detection of changes in fisher-shark interactions linked to shifts in fishing dynamics (e.g. fishers moving into deeper water) and environmental changes (e.g. marine heatwaves). Additionally, continued deployment of the acoustic receiver array would provide opportunities to detect other tagged species and gather more information about the connectivity of marine megafauna across the Tasman Sea region.

To build on the practical guidelines developed to mitigate fisher-shark interactions, the next phase of the project sought to identify and test practical tools that fishers can use to reduce depredation. Electromagnetic shark deterrent devices are a tool that has been developed for reducing shark bycatch and depredation in fisheries, because they generate a strong electromagnetic field that overstimulates the highly sensitive electrosensory system of sharks when they come close to the device (Hart and Collin, 2015; Newton et al., 2019). These deterrents have shown promising results for reducing shark bycatch and depredation in some studies around the world (Wang et al., 2008; Brill et al., 2009; O'Connell and He, 2014). However, the effectiveness of deterrents can be context specific and influenced by the number and species of sharks present and their level of motivation to feed (Robbins et al., 2011; Hutchinson et al., 2012; McCutcheon and Kajiura, 2013; Hart and Collin, 2015). So, to assess their effectiveness at deterring the large numbers of Galapagos sharks interacting with fishing gear at LHI, it is important to conduct through scientific testing.

The two objectives of this second phase of research were therefore as follows:

1. To continue the deployment of the deepwater acoustic receiver array at LHI, to expand on the movement ecology data generated in 2018 – 2021 and specifically learn more about the movements of tagged Galapagos sharks as they reach maturity, as well as collecting additional information on the movements of other tagged species detected by the LHI array;
2. To test the effectiveness and practicality of three electromagnetic shark deterrents as a technological solution for reducing shark bycatch and depredation during fishing at LHI

Importantly, the research will promote Galapagos shark conservation in the LHI marine parks, because, if found to be effective, the use of the scientifically-tested deterrent devices is expected to substantially reduce bycatch and removal of sharks. This would mitigate one of the main threats facing this unique isolated population, thus greatly improving their conservation prospects into the future. On a broader scale, the acquired knowledge could have significant applications and benefits for reducing depredation and bycatch for other carcharhinid sharks in other commercial and recreational fisheries around the world. For example, the devices could be deployed in commercial longline fisheries, where high shark bycatch is a critical issue that threatens mutiple species, thus enhancing shark conservation globally.

3. Methods

3.1. Acoustic receiver array

3.1.1. Deployment of acoustic receivers

An array of six Innovasea VR2AR acoustic receivers were deployed on the LHI shelf and BP shelf in November 2023, to detect tagged Galapagos sharks (Table 1; Figure 1). Deployment was covered under Commonwealth Marine Park permit approval (approval number PA2021-00054-1 (variation to PA2021-00054-3)). The deployment locations used for these six receivers were the same as some of those used in 2018 – 2021 (Mitchell et al., 2021), to provide continuity. The original array during 2018 – 2021 had up to 12 acoustic receivers, although some of these were in shallower areas less suitable for Galapagos sharks and thus did not record many detections (Mitchell et al., 2021). The six locations chosen for deployment in 2023 – 2024 were therefore prioritised because they were in mid-shelf depths most likely to be frequented by Galapagos sharks based on anecdotal reports from fishers and because some of these areas were popular fishing grounds, enabling previous study of the overlap between shark presence and fishing vessel activity (Mitchell et al., 2021; 2024). Acoustic receivers were attached to seafloor moorings deployed in depths ranging from 47 – 64 m. The anchors for the acoustic receiver moorings included a 2 – 3 m length of heavy shipping chain to which a large shackle was attached. The acoustic release lug of the VR2AR unit was attached to this shackle, with a 15-litre float attached above the receiver via a 2 m length of rope. Acoustic receivers were retrieved after 12 months in November 2024 by activating the built-in acoustic release system with an Innovasea VR100 deckbox system. Once retrieved the data were downloaded and processed in the Fathom software (Innovasea, Bainbridge Island, WA, USA; https://www.innovasea.com/).

Table 1. List of acoustic receivers deployed around LHI marine parks from November 2023 – November 2024. LHI = Lord Howe Island, BP = Ball's Pyramid, NTZ = no-take zone.

Receiver serial number	Receiver location	Date deployed (UTC)	Time deployed (UTC)	Depth (m)	Latitude (°S)	Longitude (°E)	Date retrieved
553495	Northwest LHI shelf	5/12/2023	2:59:00	64	31.4954	158.9757	19/11/2024
553496	Northeast LHI shelf	5/12/2023	4:10:00	54	31.4487	159.1228	19/11/2024
553497	Southeast LHI shelf	29/11/2023	3:03:00	47	31.6213	159.1739	15/11/2024
553498	Southwest LHI shelf	29/11/2023	3:34:00	55	31.6819	159.0730	14/11/2024
553499	Northeast Balls Pyramid shelf	6/12/2023	2:05:00	51	31.6978	159.2570	22/11/2024
553500	Southern end of BP shelf	6/12/2023	1:27:00	54	31.8580	159.2510	22/11/2024

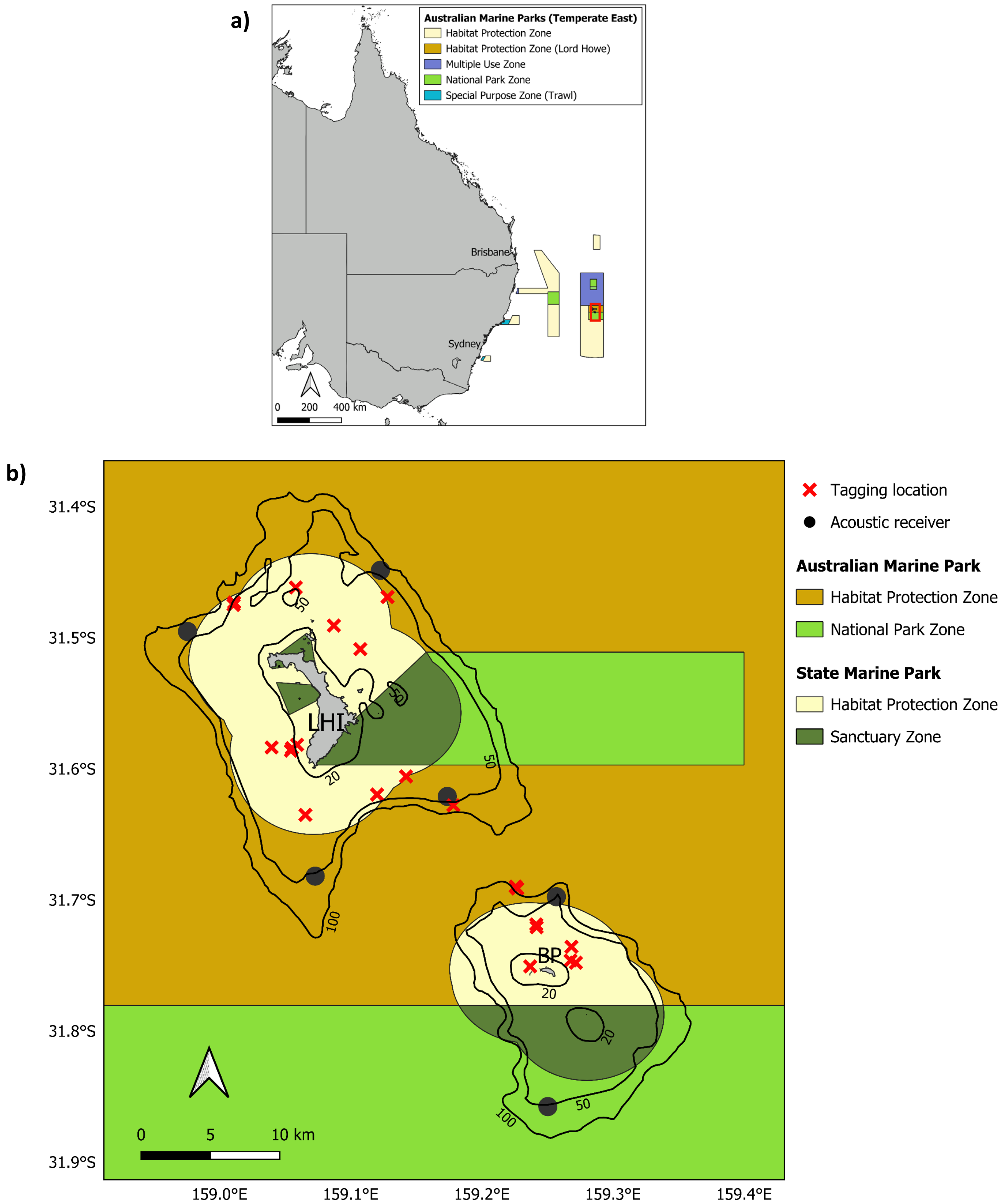


Figure 1. (a) Map of Eastern Australia and the Australian Marine Parks Temperate East Network, including Lord Howe Island (red rectangle); (b) Detailed map showing acoustic receiver locations deployed from November 2023 – November 2024 (black circles) and shark tagging locations from January 2018 (red crosses). Solid black lines indicate the 20, 50 and

100 m depth contours. LHI = Lord Howe Island, BP = Ball's Pyramid. The locations of acoustic receivers previously deployed from 2018 - 2021 are shown in Mitchell et al. (2021).

3.1.2. Acoustic tagging of sharks

Thirty Galapagos sharks were tagged with Innovasea V16 acoustic tags in January 2018, following the methods detailed in Mitchell et al. (2021; 2024). Metadata for the tagged sharks are provided in Table 2. Positions where sharks were tagged are indicated in Figure 1.

Table 2. Tagging details for Galapagos sharks tagged in the marine parks surrounding Lord Howe Island in 2018. LHI = Lord Howe Island, BP = Ball's Pyramid. V16 = standard acoustic tag, V16TP = acoustic tag combined with temperature and pressure sensors.

Tag ID	Model	TL (cm)	Sex	Date (UTC)	Time (UTC)	Location	Latitude (°S)	Longitude (°E)
1280540	V16	96	F	21/01/2018	03:45	Northwest LHI shelf	31.473267	159.011283
1280541	V16	128	M	21/01/2018	04:15	Northwest LHI shelf	31.473267	159.011283
1280542	V16	137	F	21/01/2018	04:45	Northwest LHI shelf	31.47515	159.010833
1280543	V16	116	F	21/01/2018	05:35	Northwest LHI shelf	31.4618	159.05825
1280544	V16	121	M	23/01/2018	02:36	East LHI shelf	31.490867	159.087333
1280559 *	V16TP	127	M	23/01/2018	05:44	South LHI fish cleaning area	31.5818	159.059283
1280560	V16TP	155	F	23/01/2018	06:05	South LHI fish cleaning area	31.583833	159.039833
1280561	V16TP	146	F	23/01/2018	06:15	South LHI fish cleaning area	31.58435	159.055383
1280562	V16TP	136	F	23/01/2018	06:30	South LHI fish cleaning area	31.5863	159.054533
1280563	V16TP	117	M	23/01/2018	21:52	South LHI shelf	31.6198	159.120267
1280564	V16TP	121	M	23/01/2018	22:19	South LHI shelf	31.6198	159.120267
1280565	V16TP	116	M	23/01/2018	22:45	South LHI shelf	31.6198	159.120267
1280566	V16TP	117	F	23/01/18	23:00	South LHI shelf	31.6198	159.120267
1280567	V16TP	136	F	24/01/2018	00:45	South LHI shelf	31.6353	159.0656
1280568	V16TP	141	M	24/01/2018	04:15	East LHI shelf	31.508833	159.1075
1280545	V16	116	F	24/01/2018	05:45	East LHI shelf	31.469067	159.128217
1280546	V16	115	M	24/01/2018	06:20	East LHI shelf	31.469067	159.128217
1280547	V16	156	F	26/01/2018	05:10	North BP shelf	31.689983	159.2259
1280548	V16	177	F	26/01/2018	05:47	North BP shelf	31.69145	159.227183
1280549	V16	152	M	26/01/2018	06:05	North BP shelf	31.69145	159.227183
1280550	V16	138	F	3/02/2018	01:30	Close to BP	31.750883	159.237

1280551	V16	121	M	3/02/2018	02:21	Close to BP	31.746417	159.267733
1280552	V16	114	M	3/02/2018	03:03	Close to BP	31.74805	159.27185
1280553	V16	133	F	3/02/2018	03:19	Close to BP	31.74805	159.27185
1280554	V16	137	F	3/02/2018	03:42	Close to BP	31.7359	159.268467
1280555	V16	125	F	3/02/2018	05:14	North BP shelf	31.721017	159.241917
1280556	V16	125	F	3/02/2018	05:44	North BP shelf	31.71885	159.241633
1280557	V16	129	M	3/02/2018	22:41	Southeast LHI shelf	31.605917	159.14235
1280558	V16	115	F	4/02/2018	00:47	Southeast LHI shelf	31.628033	159.17845
1280539	V16	138	F	4/02/2018	01:16	Southeast LHI shelf	31.628033	159.17845
1280559 ☨	V16TP	146	F	29/01/2019	02:50	South LHI fish cleaning area	31.584283	159.0595

*Shark caught and killed by fisher in October 2018, ☨ tag re-deployed in January 2019

3.1.3. Data analyses

To investigate the presence of sharks over time from November 2023 – November 2024, the overall number of detections per tagged shark was calculated and mapped using an abacus plot. To assess residency patterns, a residency index value was generated for each tagged shark, by dividing the number of days each shark was detected by the number of days in the study period (360 - from when the first acoustic receiver was deployed to when all receivers were retrieved). The seasonality of shark presence was also analysed by summing the total number of shark detections per month. Additionally, to assess the spatial variation in shark presence, the number of tagged shark detections at each of the six acoustic receivers was calculated and mapped. Temperature and depth data were available for two of the tagged sharks, however due to the limited number of datapoints, these were not analysed further.

3.1.4. Temperature data from acoustic receivers

The six deepwater acoustic receivers have built in temperature loggers which record *in-situ* temperature measurements every 10 minutes. These temperature data were analysed in the Innovasea Fathom Central workspace over the 12-month deployment period to build a temperature profile at each location, as well as the overall profile at all six receivers.

3.2. Deterrent testing

A two-phased approach was used to test the effectiveness of three electromagnetic deterrent devices: Rpelx (electrical), Fishtek SharkGuard (electrical) and Sharkbanz Zeppelin (magnetic), which are currently in prototype phase (Fishtek SharkGuard) or commercially available. These devices are all designed to be mounted on the fishing line close to the hook so that the electromagnetic field they create deters sharks as they approach the bait or hooked fish. Testing was conducted under animal ethics approval from the NSW Animal Care and Ethics

Committee (approval no. FISH ACEC-0540) and under NSW DPIRD Marine Park permit approval (approval number MEAA23/307-1). The testing was conducted as follows:

- Phase 1 – testing the three devices using a standardised baited camera rig under controlled conditions, via four randomised treatments (one treatment for each device, plus a control with no device)

- Phase 2 – testing the most effective device(s) from phase 1 during standard fishing practices from charter fishing vessels

3.2.1. Phase 1: Controlled experimental testing

Phase 1 of testing the effectiveness of the three electromagnetic devices was conducted in November 2023 and used a controlled experimental design, involving four treatments: 1) Rpelx active; 2) Fishtek SharkGuard active; 3) Sharkbanz Zeppelin active; 4) Control (no active deterrent). To record the behaviour of sharks around the devices, a custom-built camera rig was used, which had two downward facing GoPro cameras suspended approximately 2.5 m above a weighted bait bag, with each deterrent device attached to the rope close to the bait (Figures 2 and 3). The cameras on the rig were mounted at a specific angle and were calibrated to enable measurement of the distances of the sharks from the bait in the footage. To ensure that only the electromagnetic field of the device being tested during a given trial was affecting the sharks and not the visual appearance of it, mock (inactive) versions of the other two devices were also attached to the experimental rig (in the same position as the active ones would be for the other treatments) for all trials. For example, during a trial of the active Rpelx, mock versions of the Fishtek SharkGuard and SharkBanz Zeppelin would be present as well (Figure 2). Treatment 4 (control) therefore had three mock (inactive) devices.

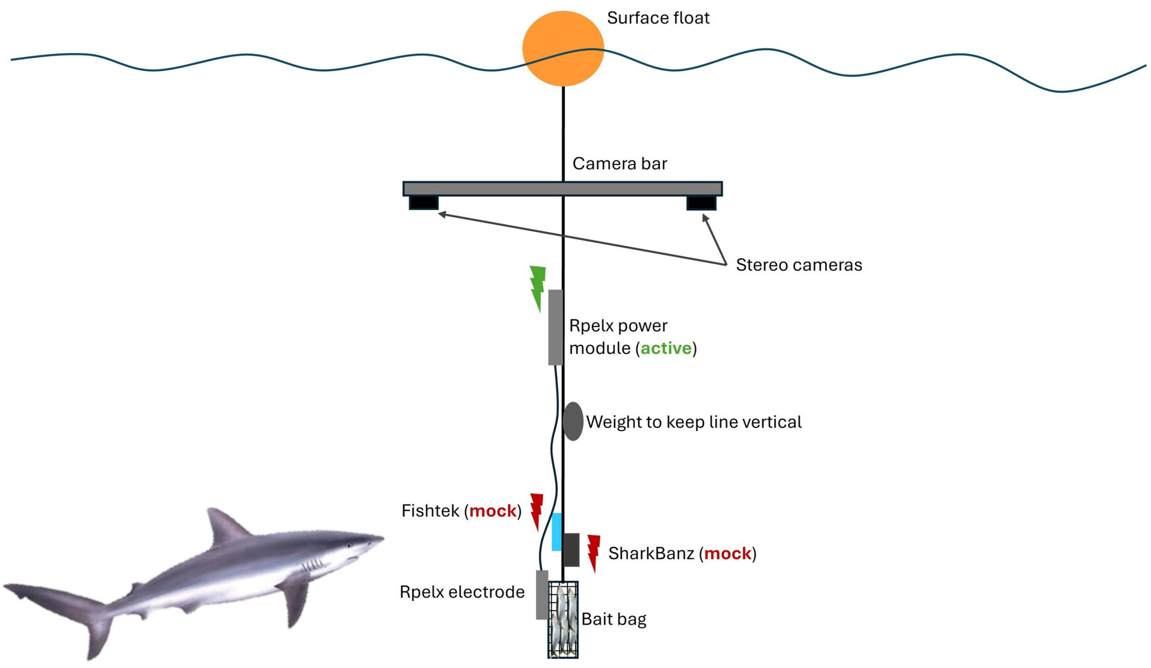


Figure 2. Diagram of the deterrent testing rig, with stereo video cameras, a bait bag, an active Rpelx deterrent and mock (inactive) Fishtek SharkGuard and Sharkbanz Zeppelin deterrents.

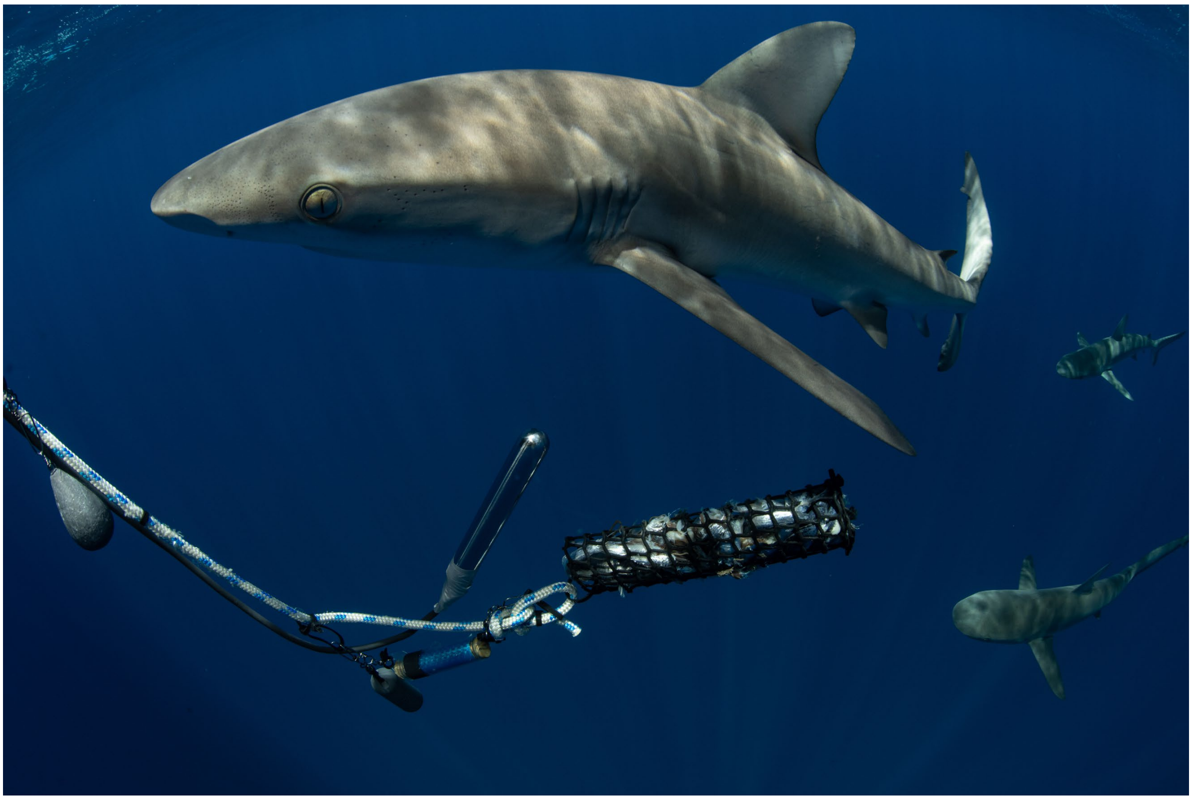


Figure 3. Image of testing rig showing active Sharkbanz Zeppelin (bottom most device), mock (inactive) Rpelx (top) and mock (inactive) Fishtek SharkGuard (middle), mounted close to the bait bag. Photo credit: Justin Gilligan.

Five-minute trials were conducted for each of the four treatments, with 50 replicates completed for all treatments, producing a total of 200 trials. These trials were conducted across a range of locations around LHI (Figure 4), some of which were areas which are regularly fished. Due to time constraints, some sets of trials were conducted in the same area whilst the vessel was drifting, rather than moving to a new location for each trial. This could have influenced the results because the response of sharks to the deterrents can vary over time as individual sharks become habituated to the vessel, the equipment and the electric field produced (Gauthier et al., 2020).

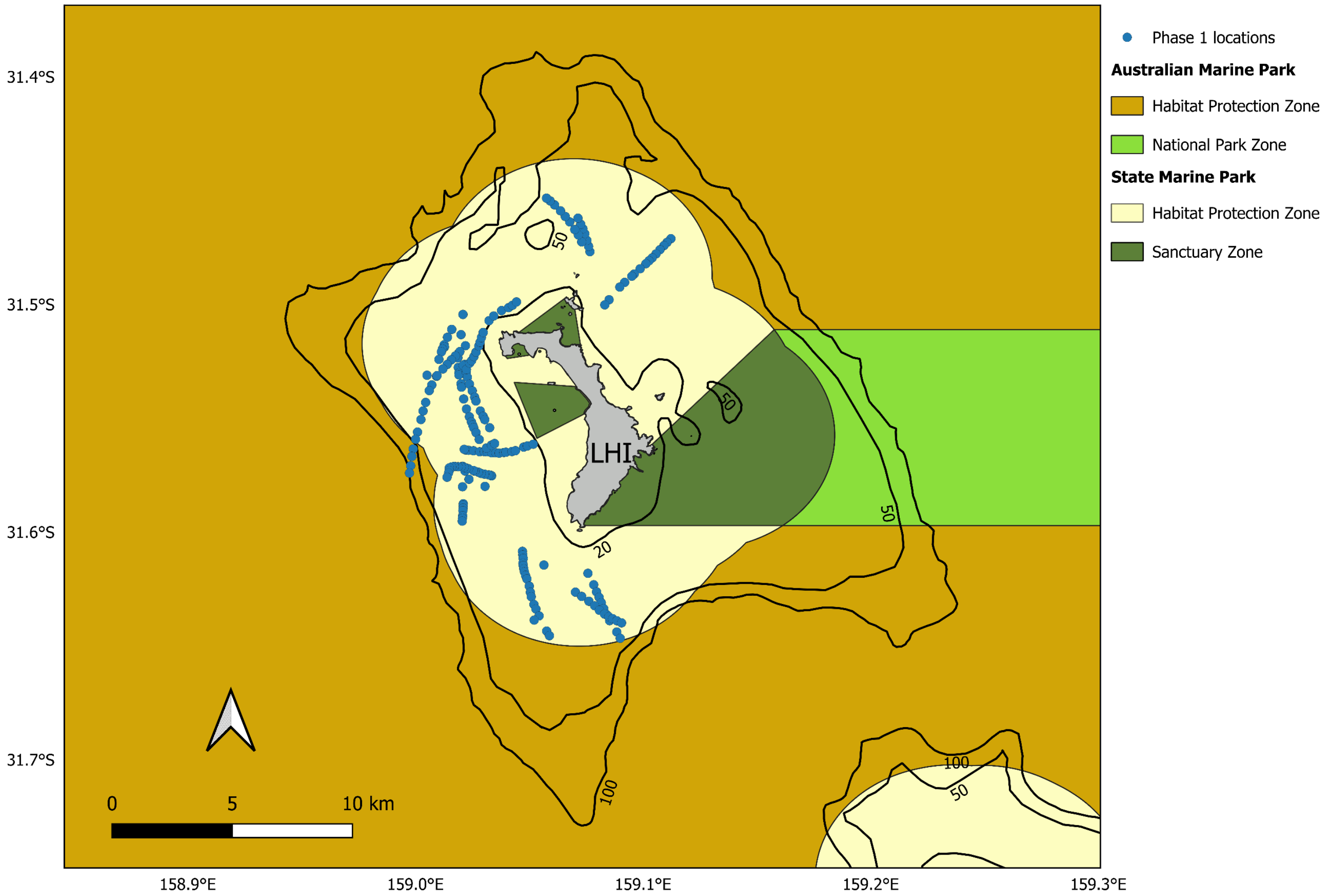


Figure 4. Map of deterrent testing locations during phase 1, as indicated by blue points. Solid black lines indicate the 20, 50 and 100 m depth contours. LHI = Lord Howe Island.

The video files generated from the 200 trials were analysed in the specialist software EventMeasure (SeaGIS; seagis.com.au), which allowed us to record shark behaviours and measure distances, with an associated timestamp for each measurement (Figure 5). An ethogram (list of behaviours) was created to classify the behavioural responses in a consistent and comprehensive way (Table 3, Figure 6). Each time a shark interacted with the bait bag or other parts of the camera rig, a data point was recorded. For each video, the maximum number of sharks present in the field of view, the water temperature, an approximate measurement of current strength, and length measurements of 10 random individual sharks, were also recorded. All 200 videos were reviewed and analysed to produce behavioural data. The effectiveness of the three deterrent devices was compared against the control using four metrics: 1) proportion of trials where sharks contacted the bait; 2) time taken for the first contact with the bait; 3) proportion of trials with bites on the bait; 4) time taken for first bite on the bait.

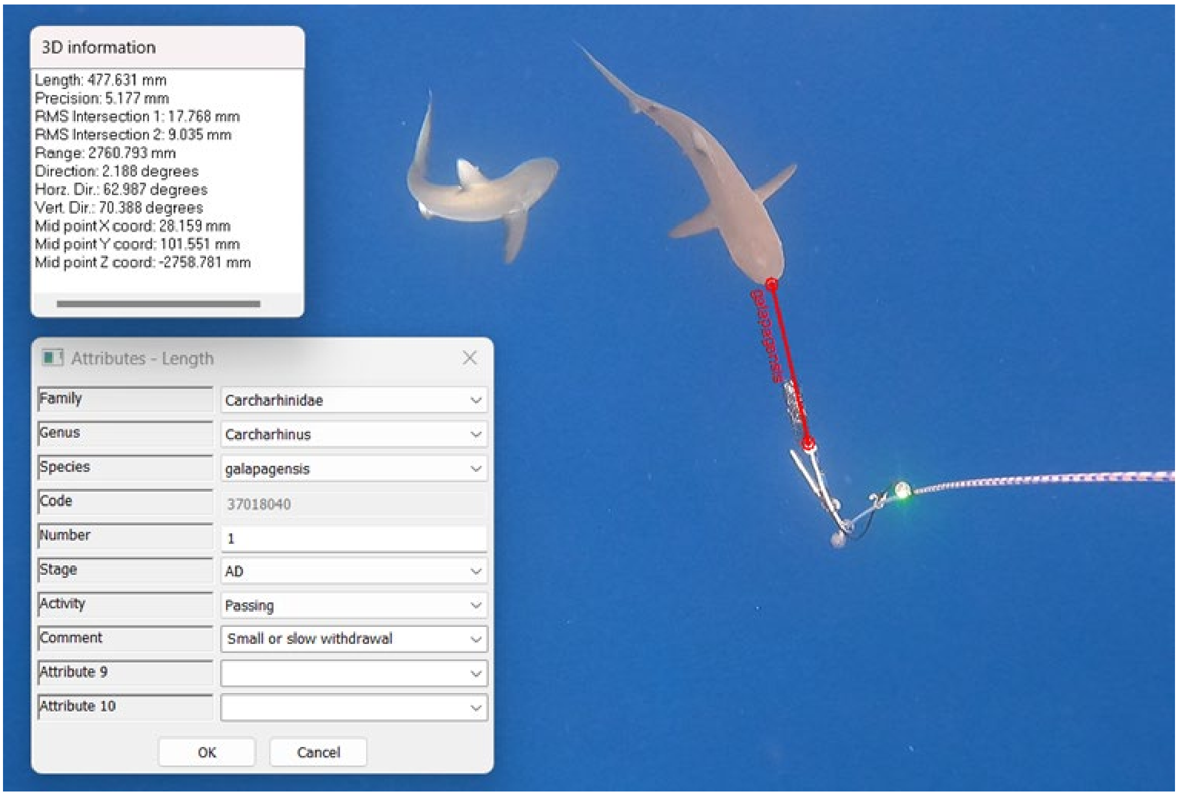


Figure 5. Example image of a distance measurement and behaviour classification in the EventMeasure software.

Table 3. Behavioural ethogram listing all shark behavioural responses observed during the video analysis, with a description of each behaviour.

Behaviour type	**Description**
Attempted bite	A shark opens its mouth and attempts to bite the bait (or other parts of the rig) but misses
Bite on bait	A shark makes a clear bite on the bait bag
Bite on deterrent	A shark bites part of the deterrent device or mock deterrent
Bite on rope	A shark bites the rope of the camera rig
Bite on sinker	A shark bites one of the two sinkers on the camera rig
Close approach	A shark approaches close to the testing rig (<2 m away)
Eye twitch	The eye(s) of a shark open and close involuntarily
Gill spasm	The gills of a shark visibly spasm (contract involuntarily)
Head shake	A shark moves its head side to side or rolls it
Jaw gape	A shark opens its mouth widely (but not in the context of making a bite)
Large or fast withdrawal	A shark makes a turn >90° away from the camera rig and/or swims away at speed with >2 strong tail beats
Small or slow withdrawal	A shark makes a small turn <90° away from the camera rig and swims away with 1 slow tailbeat
Medium withdrawal	A shark makes a rapid head turn, but not necessarily >90° away from the camera rig, and/or swims away at 1 - 2 average tail beats
Mouth opening	A shark opens its mouth slightly (but not in the context of making a bite)
Muscle twitch	Muscles on the shark’s body twitches involuntarily
Nudge on bait	A shark nudges the bait bag with its snout or body without opening its mouth to bite
Nudge on deterrent	A shark nudges part of the deterrent device or mock deterrent with its snout or body without opening its mouth to bite
Nudge on rope	A shark nudges the rope with its snout or body without opening its mouth to bite
Nudge on sinker	A shark nudges one of the sinkers with its snout or body without opening its mouth to bite
Tail flick	A shark flicks its tail rapidly

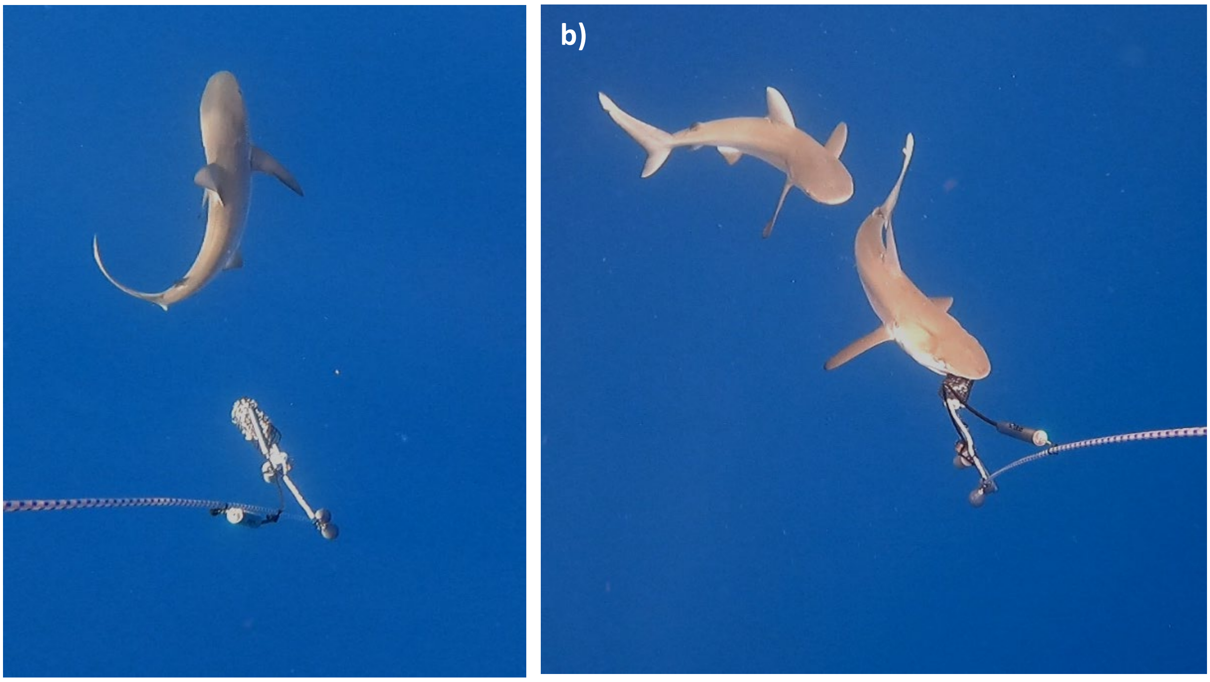


Figure 6. Examples of shark behaviours observed during video analysis: a) shark making a large withdrawal away from the camera rig; b) shark biting the bait bag.

To determine whether there was a significant difference in the mean time of first contact or the mean time of first bites on the bait bag, a Kruskal-Wallis test was conducted, due to the time data for both metrics not meeting a normal distribution and therefore being unsuitable for parametric Analysis of Variance (ANOVA) tests. If results for the Kruskal-Wallis test were significant then post-hoc pairwise comparisons between treatments were tested with Wilcoxon tests. To further investigate how environmental and operational factors, i.e. treatment, number of sharks present, location, number of previous trials at that location, depth and water temperature, affected the probability of a bite on the bait occurring, a Generalised Linear Model was run in the R language for statistical computing (R Core Team 2023). The probability of a shark biting the bait bag was considered to be the most important metric because it closely resembled a shark taking a bait or hooked fish during fishing, hence this was the only metric used for GLM analysis. Combinations of predictor variables were checked for correlation using Pearson's correlation coefficients, with combinations having coefficient values >0.4 excluded from the same model. The response variable for the GLM was binomial, with 0 = no bite on the bait occurred, or 1 = bite on the bait occurred, with each trial being a datapoint. The GLM was run using the 'lme4' package in R (Bates et al., 2015), with the 'dredge' function from the 'MuMIn' package (Barton, 2024) used to identify the best model based on AIC (Akaike, 1974) and the significance of predictor variables. Variables in the best model were plotted with 95% confidence intervals using the 'visreg' function (Breheny and Burchett, 2017), to identify the nature of their relationship to the response variable. Model diagnostics were performed to check the fit of the model, including visualising residual plots.

3.2.2. Phase 2: Testing during fishing with charter operators

In November 2024, the second phase of deterrent testing was conducted, working with two charter fishing operators to test the Rpelx and Fishtek SharkGuard during real fishing conditions. These two devices were deemed to be the most effective based on phase 1 results, whereas the Sharkbanz Zeppelin was substantially less effective. To test the Rpelx and Fishtek SharkGuard, three treatments were conducted in a randomised order: 1) Rpelx deployed; 2) Fishtek SharkGuard deployed, and 3) control (with no devices deployed). For each treatment, fishing was conducted until three catch events had occurred, with a catch event being classed as where a fish was hooked and either landed undamaged or depredated by sharks. If a shark was hooked directly on the bait then this was also classed as a catch event, because bycatch is another component of the fisher-shark interactions occurring at LHI, which the deterrent devices may be able to reduce. After three catch events had occurred, the treatment was changed. The testing involved using standard rod and reel fishing gear representative of what the charter fishers commonly use, with the deterrents attached to the line, 55 cm away from the hook for the Rpelx and 15 cm for the Fishtek, based on manufacturers guidelines (Figure 7). Waterwolf underwater video cameras were mounted on fishing lines during some fishing sessions, to opportunistically observe shark behavioural interactions with the fishing gear and record when depredation events occurred. The cameras also provided another opportunity to assess shark behaviour in the presence of the deterrent devices. Cameras were only deployed during a limited number of fishing sessions, due to only three cameras being available, and because each camera had only four hours of battery life. Information on the practical useability of deterrent devices was also collected in the form of verbal feedback from the charter fishing operators, such as how easily it was to attach to the line, how easy it was to handle and whether it caused any tangles in the fishing lines.

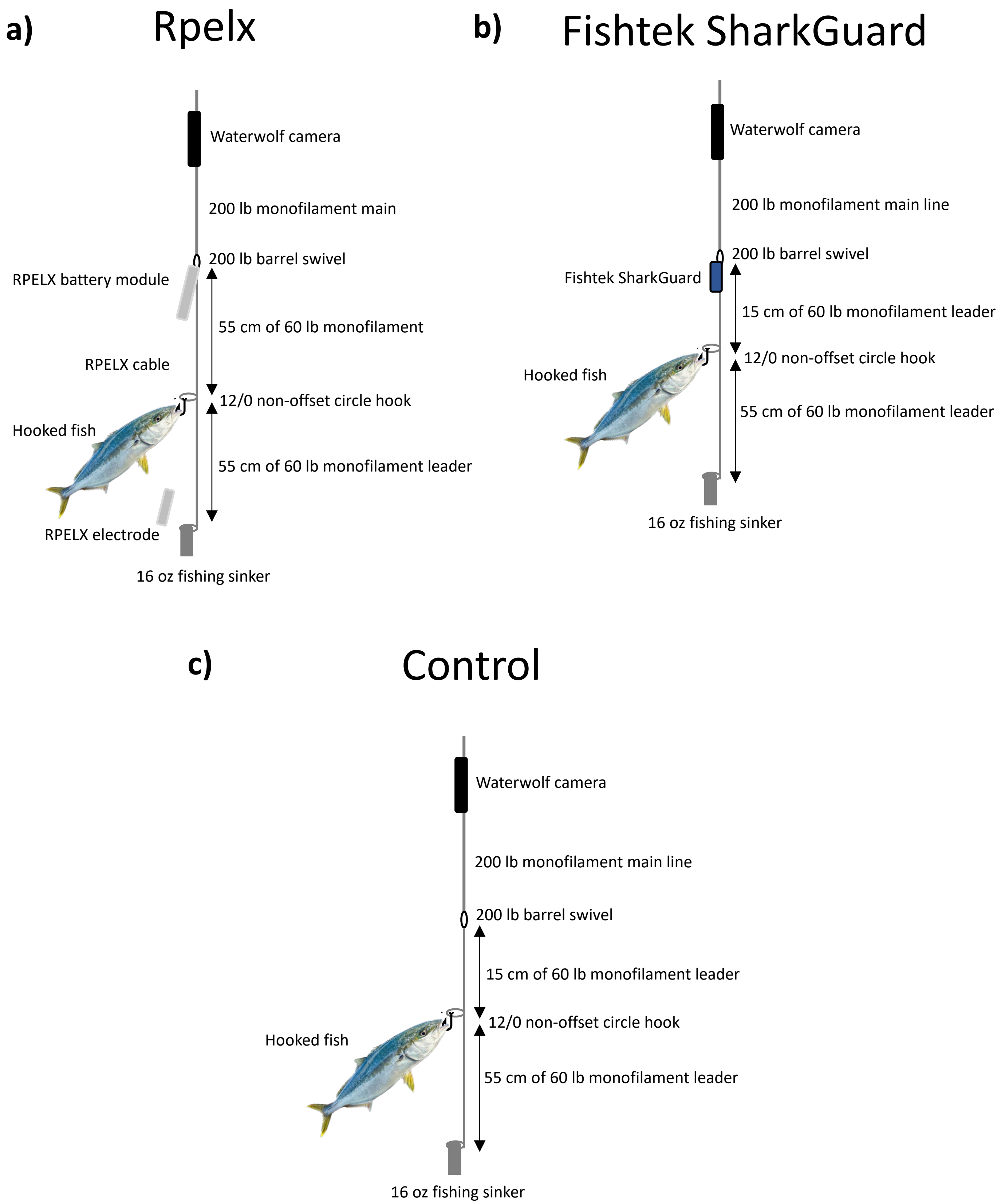


Figure 7. Fishing gear setup for testing the Rpelx and Fishtek SharkGuard under real fishing conditions. Diagrams not to scale.

The testing took place at key fishing locations around LHI and BP (Figure 8), which are known hotspots of depredation (Mitchell et al., 2021; 2024). Because the number of productive fishing spots was limited and due to time constraints, fishing across multiple treatments sometimes took place in the same general location whilst drifting, similar to Phase 1, so it was possible that individual sharks interacted with the fishing gear across multiple trials.

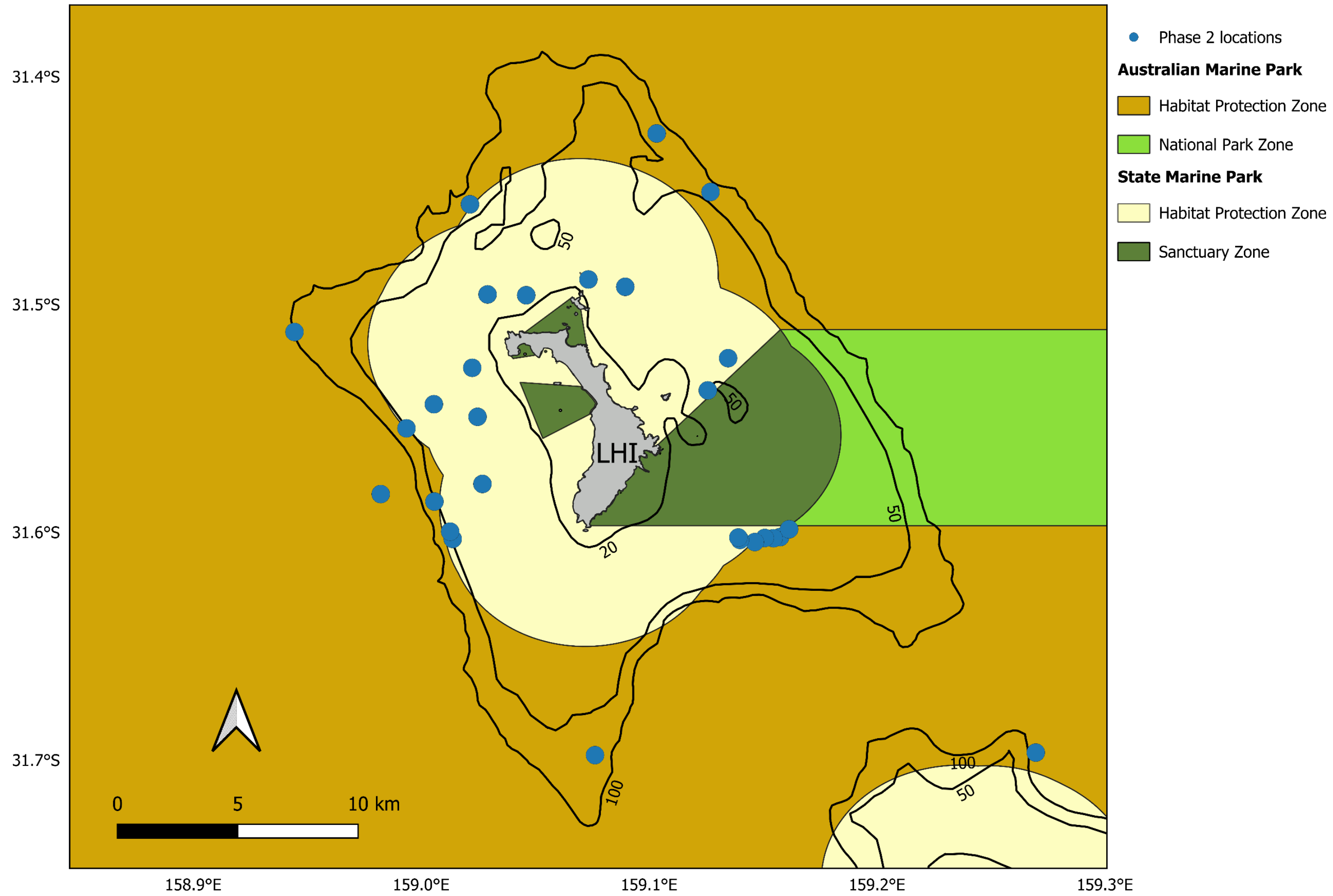


Figure 8. Map of deterrent testing locations during phase 2, as indicated by blue points. Solid black lines indicate the 20, 50 and 100 m depth contours. LHI = Lord Howe Island.

The number of fish landed successfully and the number depredated by sharks were quantified across each treatment, as well as the number of sharks bycaught. Data for other variables were collected during the testing, such as depth, water temperature and amount of fishing gear lost, however the lower-than-expected number of overall datapoints prevented more detailed statistical analysis such as a GLM from being conducted at this stage. To complete this phase 2, the same experiment will be replicated in November 2025 to increase the number of datapoints and allow for in-depth statistical analysis.

3.3. Community engagement activities

Community engagement activities have been a key part of the shark research program at LHI, to educate the local community and visitors about Galapagos sharks and how to interact with them in a safe and sustainable way.

3.3.1. Communication materials: leaflet and poster on shark interactions

To build on the results from the first phase of this research from 2018 – 2021, a leaflet and poster were designed for the local community and visitors, to communicate information about the biology of Galapagos sharks and how to mitigate negative interactions with them whilst fishing. The leaflet and poster included a map of shark interaction hotspots generated from the spatial overlap mapping of Galapagos shark home ranges and fishing vessel activity, as well as best-practice guidelines for how to reduce negative interactions through improved selection of fishing sites, gear and target species. These materials were designed to help fishers make more informed choices about where and how to fish to mitigate the ongoing fisher-shark conflict and reduce impacts on marine park values.

3.3.2. Citizen Science project (photoID with Dive Lord Howe)

The ecotourism operator Dive Lord Howe has been running Galapagos shark experience tours since 2021, where customers have the chance to snorkel with Galapagos sharks up close, which is a unique experience only possible in a small number of locations worldwide. This experience involves only using sounds such as the vessel engine noise and plastic bottles to attract sharks, instead of bait. These regular tours offer the opportunity to collect further important data on Galapagos shark ecology, population dynamics and behaviour, due to the ability to take close-up photos of sharks. These photos can also offer the possibility of identifying individual sharks, due to unique patterns of pigmentation and scarring on their body. Because of this, the research team established a collaboration with Dive Lord Howe in 2021, to share images taken during the Galapagos shark experience tours and build a database of images. This initiative also enables customers to learn more about Galapagos sharks and become involved in the research as citizen scientists. Images have been collected between October 2021 and December 2024, from a wide range of locations around LHI and BP. To ensure standardisation of the images used for research and enable identification and possible resighting of the same individuals, only images of the left flank of Galapagos sharks are used in the database. Key metadata are recorded for every Galapagos shark experience tour, including the date, time, latitude and longitude of the tour, the number of sharks interacted with, the number of guests in the water and the attractants used. Key environmental factors such as water temperature, current strength, wind strength and direction, sea state and weather are also recorded for every tour. Images are analysed by the research team to visually identify each shark and assess whether it has any clearly identifiable pigment markings and/or scars. If so, the shark is added to the image database with key information including the date, time and location of the sighting. For any sharks that are resighted, the metadata are cross-checked to identify whether the shark was resighted at the same site as the initial sighting, or a different site.

3.4. Preliminary research on deepwater shark taxonomy

Anecdotal reports from fishers at LHI during the first phase of research in 2018 – 2021 indicated that deepwater sharks from the *Squalus* genus are caught seasonally when fishing deeper than 200 m off the edges of the LHI and BP shelves. There are also small seamounts (300 m deep) in the channel between LHI and BP shelves where these sharks are caught. Very little is known about the biology or ecology of this genus worldwide, and especially at LHI, with the potential for hybrids, subspecies or endemic *Squalus* species unique to LHI. To investigate this further, a *Squalus* specimen was donated to the research team during the first phase of the project (collected under Australian Marine Park permit PA2018-00060-3), which was subsequently donated to the Australian Museum for taxonomic analysis and identification. Since 2021, there have been more reports of deepwater sharks caught by charter fishing operators, therefore the research team sought to opportunistically secure more specimens for donation to the museum and collection of samples. The goal of this research is to contribute to the taxonomic revision of the *Squalus* genus globally and also produce further knowledge on the deepwater fish biodiversity at LHI, which is an understudied yet important connecting area in the Tasman Sea.

4. Results

4.1. Acoustic tracking results

The deployment of six new deepwater acoustic receivers in November 2023 enabled resumption of data collection for movements of the Galapagos sharks tagged in January 2018. Between 29/11/2023 when the first receiver was deployed and 23/11/2024 when the last of the receivers were retrieved for data download, there were 1,508 detections of the tagged Galapagos sharks. Eight different sharks were detected throughout this 12-month period, with some individuals being regularly detected throughout the year (sharks 1280539, 1280545, 1280558 and 1280566), with others being detected more sporadically (Figure 9). Some sharks were only detected at one or two receivers, including shark 1280558, which was regularly detected at the receiver located at the Southeast corner of the LHI shelf. Sharks 1280552 and 1280554 were only detected at the receiver at the Southern end of the BP shelf. Conversely, other sharks were detected across >3 receivers, including shark 1280566, which was detected at the Southeast LHI, Southwest LHI, Northwest LHI and Northeast LHI receivers and shark 1280539, which was detected at all receivers except the Northwest LHI receiver (Figure 9).

Figure 9. Abacus plot showing the temporal pattern of acoustic receiver detections between November 2023 and November 2024. Tag numbers represent individual sharks and colour points indicate acoustic receiver locations.

Residency index values were generated using the number of days on which tagged sharks were detected by acoustic receivers out of the entire 12-month data set. Three of the tagged sharks (1280552, 1280554 and 1280564) had very low residency indexes <0.01, due to only being detected on 2, 1 and 3 days, respectively (Figure 10). The remaining five sharks had notably higher residency index values of 0.04, 0.1, 0.13, 0.13 and 0.17. Of these, Shark 1280539 had the highest residency index value of 0.17, as a result of being detected on 62 different days across the 12-month period (Figure 10).

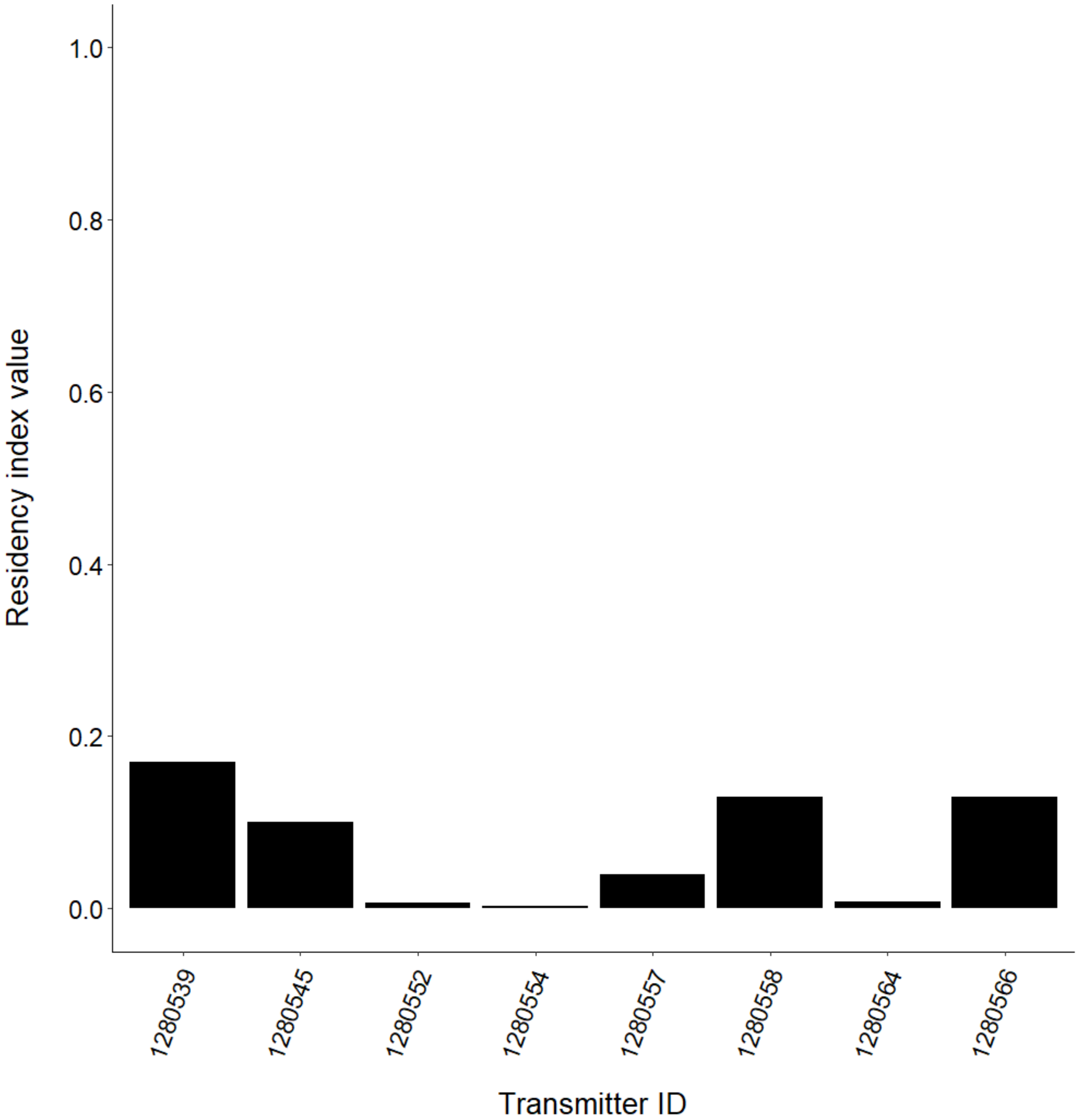


Figure 10. Residency index values generated for the eight sharks detected by acoustic receivers from November 2023 to November 2024. Residency index values are calculated by dividing the number of days detected by the total number of days in the study period (360).

Substantial temporal variation in shark detections was evident throughout the year. Acoustic receivers recorded around 100 detections per month for most of the months between November 2023 and November 2024, however low numbers (<50 detections) were recorded in February and March 2024 and much higher numbers (>300 detections) occurred in October 2024 (Figure 11).

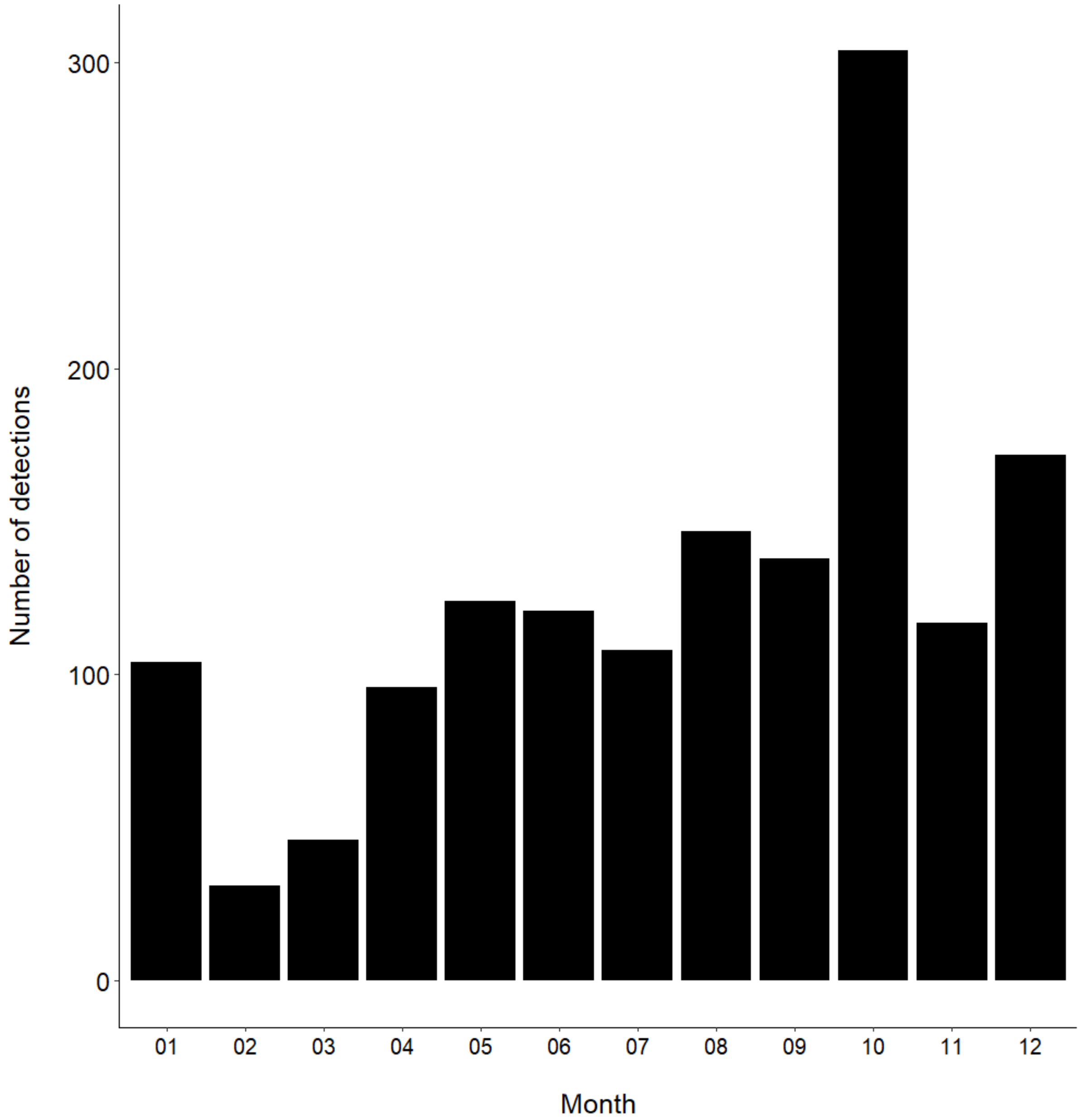


Figure 11. Number of shark detections per month between November 2023 and November 2024, with all receiver locations pooled together.

All six of the acoustic receiver locations recorded detections of tagged sharks, with the highest number of detections (636) occurring at the receiver located in the Southeast corner of the LHI shelf (Figure 12). Three other locations (Northeast LHI shelf, Southwest LHI shelf and Northeast BP shelf) also recorded >100 detections, whereas the receivers at the Southern end of the BP shelf and at the Northwest LHI shelf only recorded 45 and 3 detections, respectively (Figure 12).

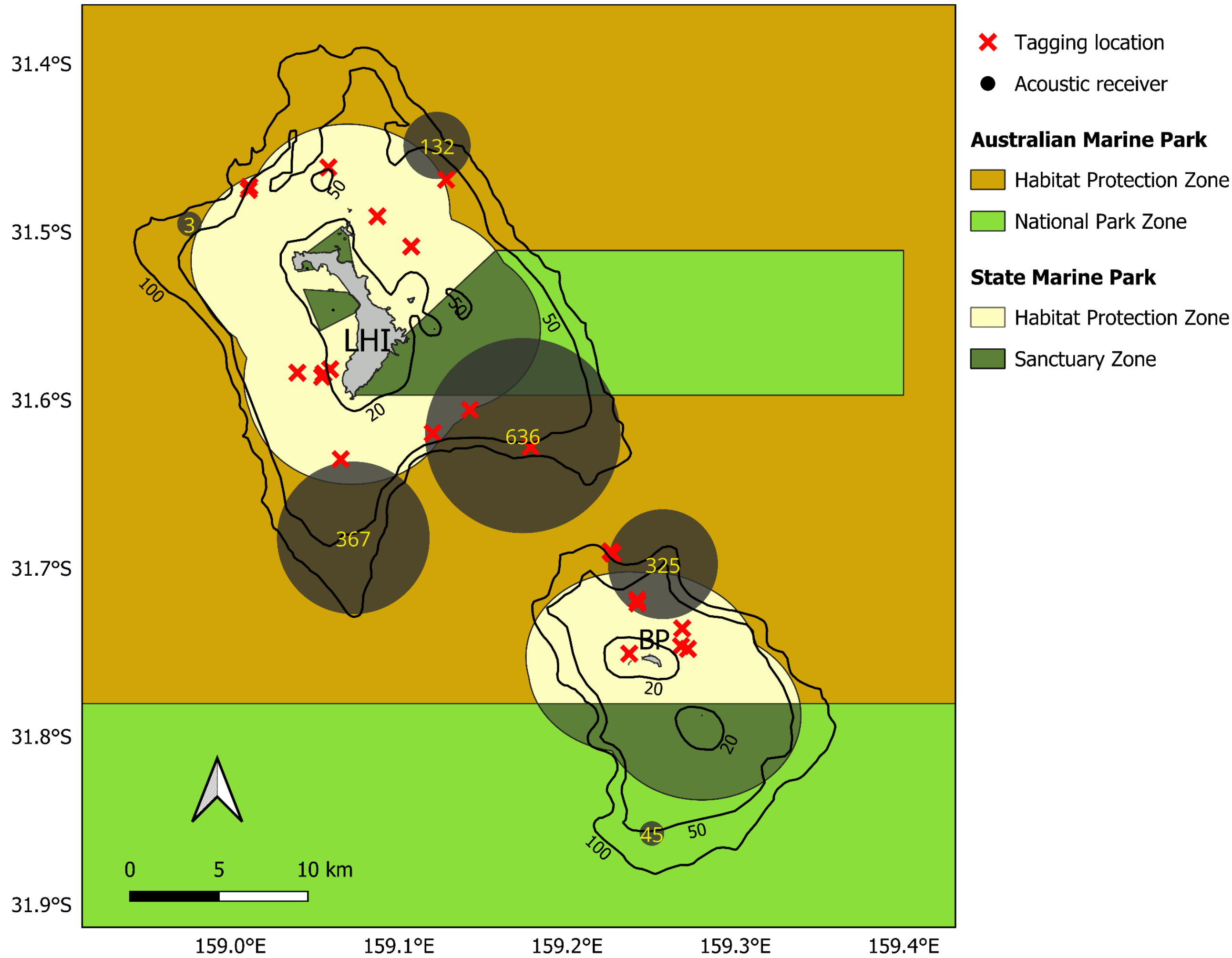


Figure 12. Number of tag detections at each of the six deepwater acoustic receiver locations, as indicated by the size of the black circles. Numbers inside circles show the total number of detections. Depth contours are marked with black lines and corresponding numbers for the 20 m, 50 m and 100 m depth contours. Red crosses show original tagging locations of sharks in January 2018. LHI = Lord Howe Island, BP = Ball's Pyramid.

The six deepwater acoustic receivers also detected 14 other tagged animals from other research projects and locations. The most common additional species detected was yellowtail kingfish (*Seriola lalandi*). In total, there were seven individual yellowtail kingfish detected, with 1,127 detections recorded for these tagged animals across the six acoustic receivers. These kingfish were originally tagged in November 2023 by researchers from Project Kingfish. Additionally, there were 38 detections from two tiger sharks (*Galeocerdo cuvier*) originally tagged at Norfolk Island, as well as 340 detections from three white sharks (*Carcharodon carcharias*) and two tiger sharks originally tagged in mainland NSW.

4.2. Acoustic receiver temperature loggers

In addition to recording detections of tagged animals, the acoustic receivers have a built-in temperature logger that continually collected temperature data. This allowed creation of temperature plots for all six deepwater receivers across the 12-month study period. Temperature ranged from a maximum of 26.6 °C on 20/02/2024 to a minimum of 16.7 °C on 27/04/2024 and followed a relatively similar pattern across all acoustic receivers (Figure 13).

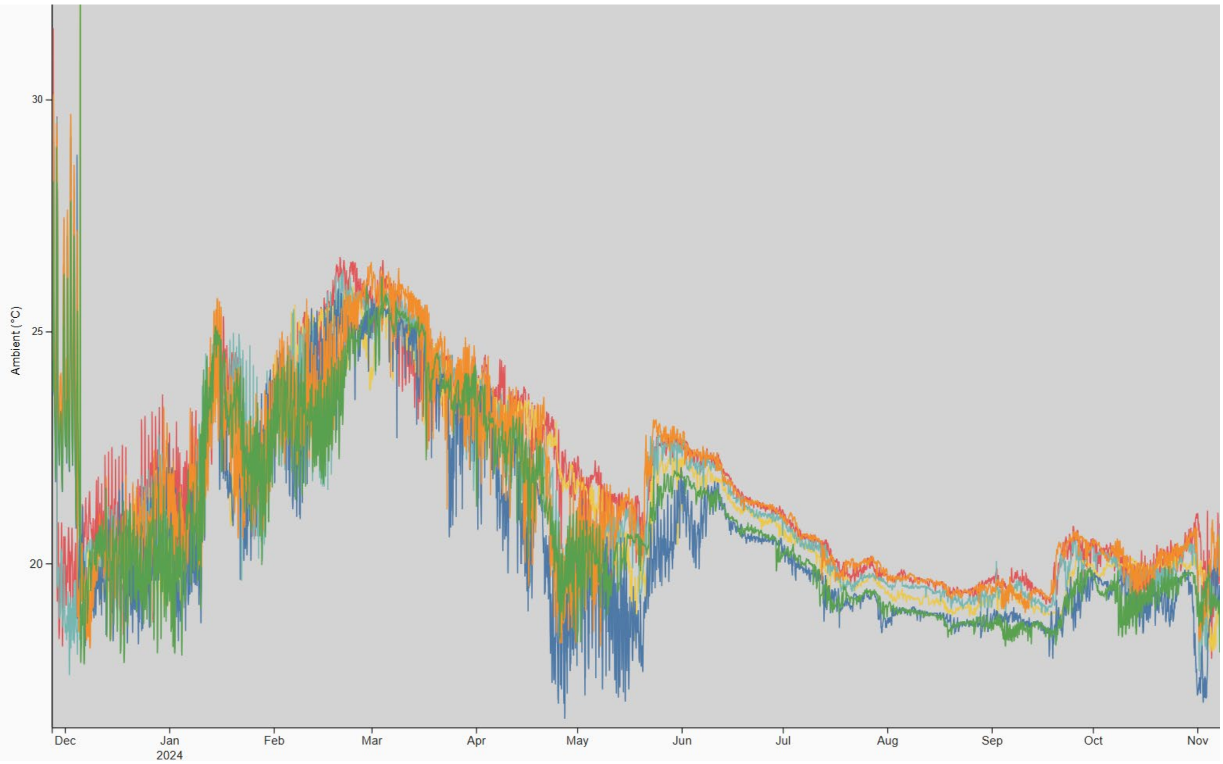
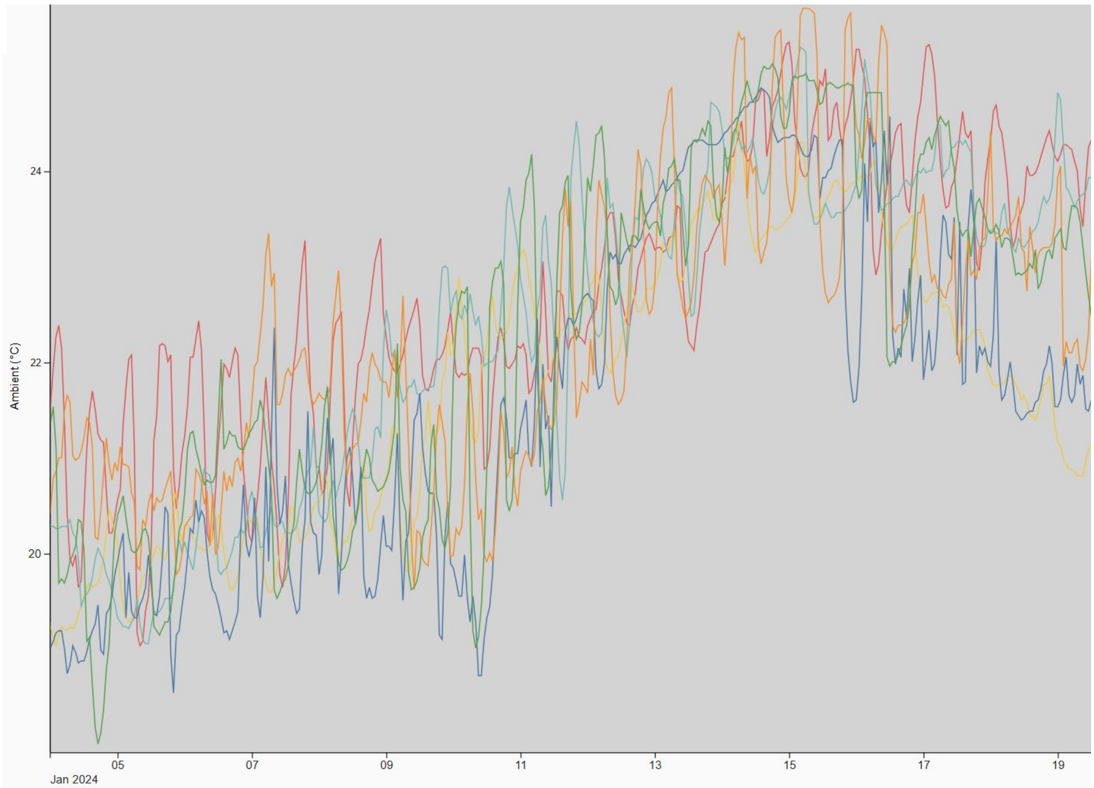


Figure 13. Temperature profiles recorded by six deepwater acoustic receivers deployed off Lord Howe Island between November 2023 and November 2024. Coloured lines indicated each of the six locations: blue = Northwest LHI shelf, orange = Northeast LHI shelf, red = Southeast LHI shelf, turquoise = Southwest LHI shelf, green = Northeast BP shelf, yellow = Southern end of BP shelf. Note that the high and rapidly fluctuating temperature values at the end of November 2023 and early December 2024 were from during the deployment process, so they represent air temperatures rather than water temperatures.

Interestingly, there were two notable short term temperature spikes recorded by all acoustic receivers between 10/01/2024 and 15/01/2024 and between 19/05/2024 and 24/05/2024, where temperatures increased by approximately 5 °C and 3 °C, respectively (Figure 13, 14a,b). These rapid increases in temperature were accompanied by large increases in the tilt angle values recorded by two of the acoustic receivers (Figure 15a,b), which suggest a strong warmer current pushing through the area.

a)



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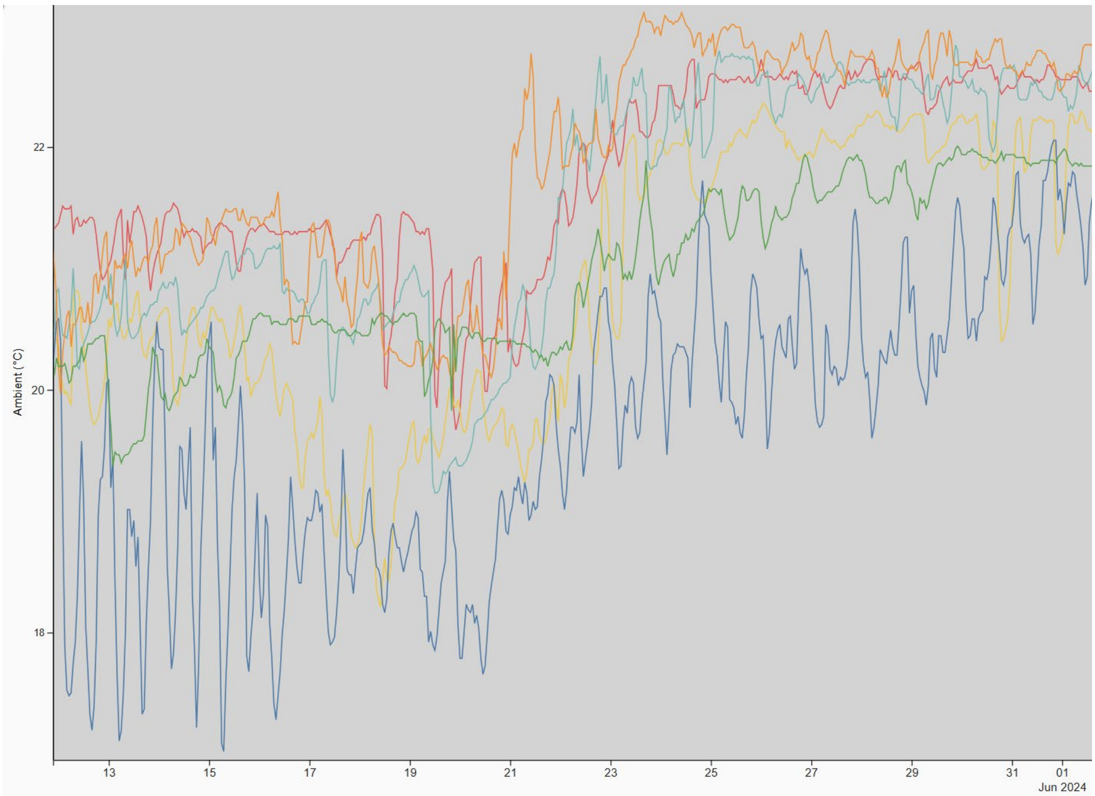

Figure 14. Temperature spikes recorded across all receiver locations off Lord Howe Island from a) 10/01/2024 to 15/01/2024 and b) 19/05/2024 to 24/05/2024. Coloured lines indicated individual acoustic receivers: blue = Northwest LHI shelf, orange = Northeast LHI shelf, red = Southeast LHI shelf, turquoise = Southwest LHI shelf, green = Northeast BP shelf, yellow = Southern end of BP shelf.

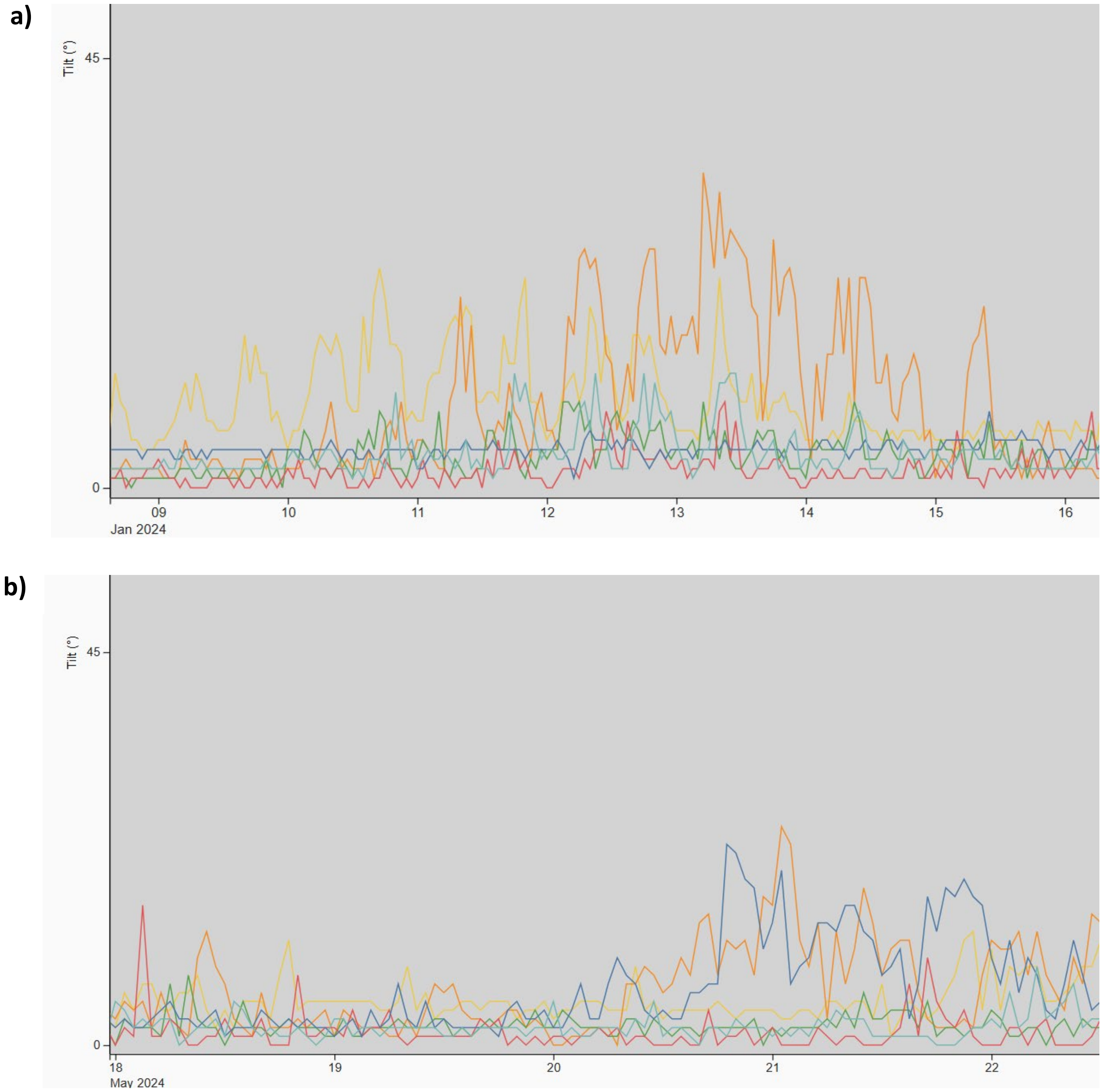

Figure 15. Acoustic receiver tilt angle values during two temperature spikes from a) 10/01/2024 to 15/01/2024 and b) 19/05/2024 to 24/05/2024. Coloured lines indicated individual acoustic receivers: blue = Northwest LHI shelf, orange = Northeast LHI shelf, red = Southeast LHI shelf, turquoise = Southwest LHI shelf, green = Northeast BP shelf, yellow Southern end of BP shelf.

4.3. Deterrent testing

4.3.1. Phase 1: Controlled experimental testing

The results from phase 1 indicated that sharks made contact with the bait (i.e. either a nudge, bite or attempted bite on the bait bag) on 98% of trials for the control treatment, 96% of trials with Sharkbanz Zeppelin, 74% of trials with the Fishtek SharkGuard and 72% of trials with the Rpelx (Figure 16).

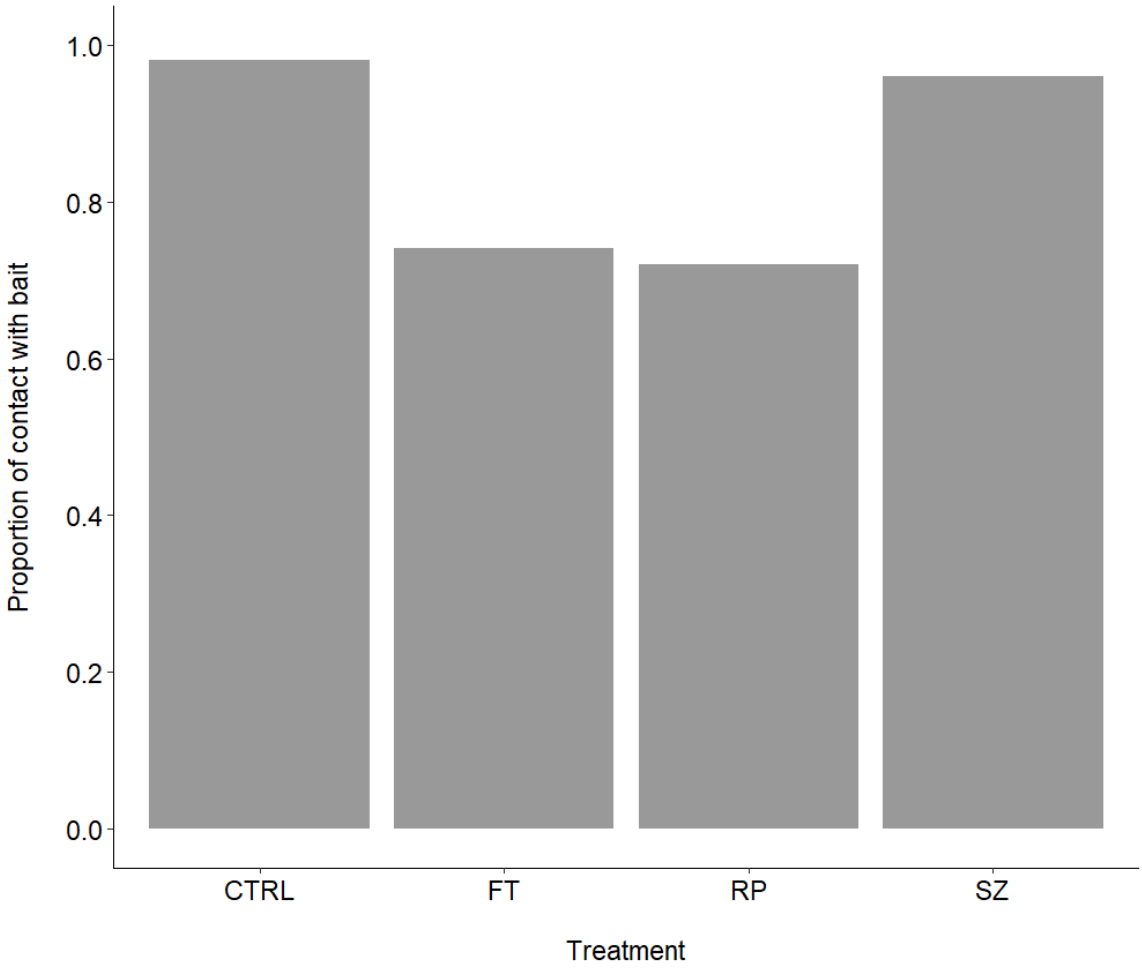

Figure 16. Proportion of times that sharks made contact with the bait bag during each treatment, across the 200 videos analysed. CTRL = control treatment; FT = Fishtek SharkGuard; RP = Rpelx; SZ = Sharkbanz Zeppelin.

The time it took sharks to first make contact with the bait bag (either a nudge, bite or attempted bite) was variable across trials within the same treatment, as shown by the large standard deviation (Figure 17). There was a significant difference in the mean time of first contact between treatments (Kruskal-Wallis chi-squared = 17.844, Degrees of Freedom (DF) = 3, p-value = 0.00047). Post-hoc pairwise Wilcoxon tests showed that there were significant differences between CTRL and RP (p-value = 0.008), RP and SZ (p-value = 0.003) and SZ and FT (p-value = 0.027). The shortest mean time to first contact was for the Sharkbanz Zeppelin treatment at 46 ± 53 seconds (standard deviation), followed by the control treatment (52 ± 59 seconds), Fishtek SharkGuard (92 ± 85 seconds) and Rpelx (102 ± 76 seconds) (Figure 17).

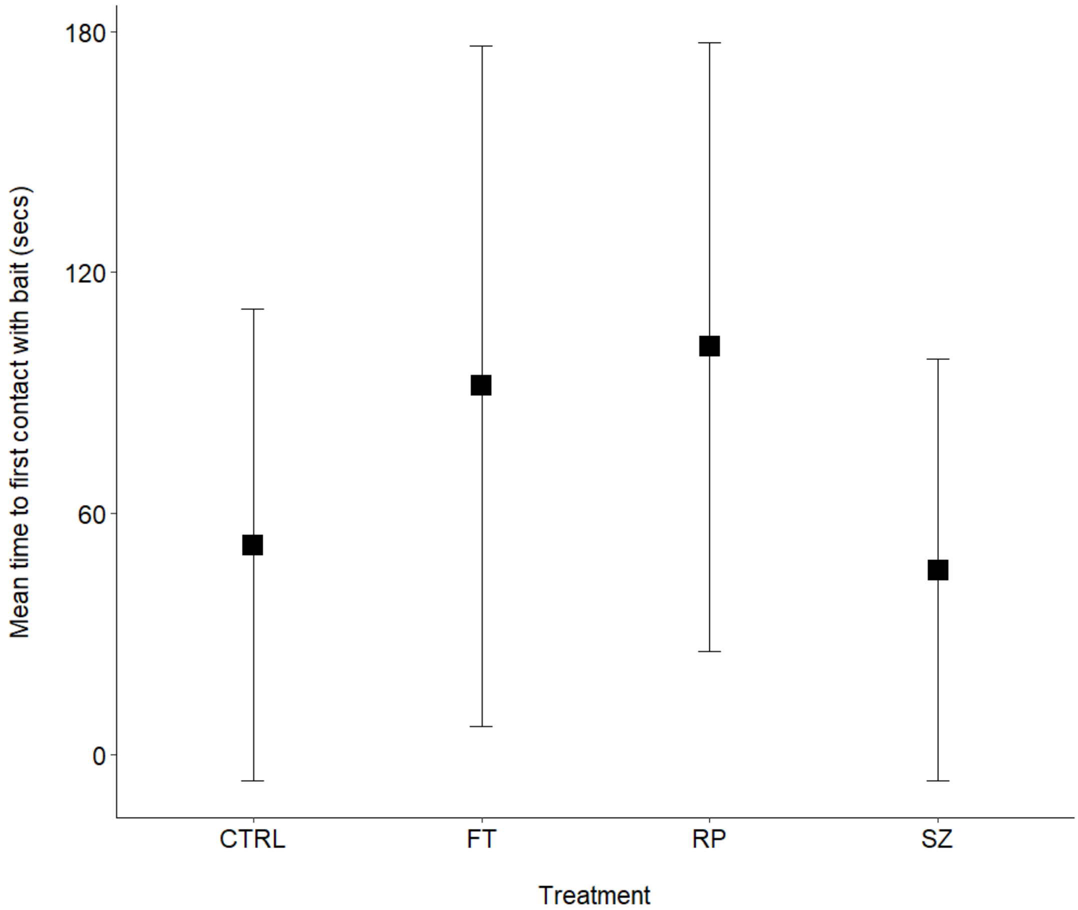

Figure 17. Mean time for sharks to first make contact with the bait bag in seconds, which included nudges, bites or attempted bites. CTRL = control treatment; FT = Fishtek SharkGuard; RP = Rpelx; SZ = Sharkbanz Zeppelin.

The proportion of bites on the bait was substantially lower for all three treatments with an active shark deterrent, compared to the control (Figure 18). The Fishtek SharkGuard had the lowest proportion of bites at 28%, followed by Rpelx (32%) and Sharkbanz Zeppelin (32%), whereas shark bites on the bait occurred on 62% of trials for the control (Figure 18). The percentage reduction in the proportion of bites on the bait was 55% for the Fishtek SharkGuard, compared to 48% for Rpelx and 42% for Sharkbanz Zeppelin.

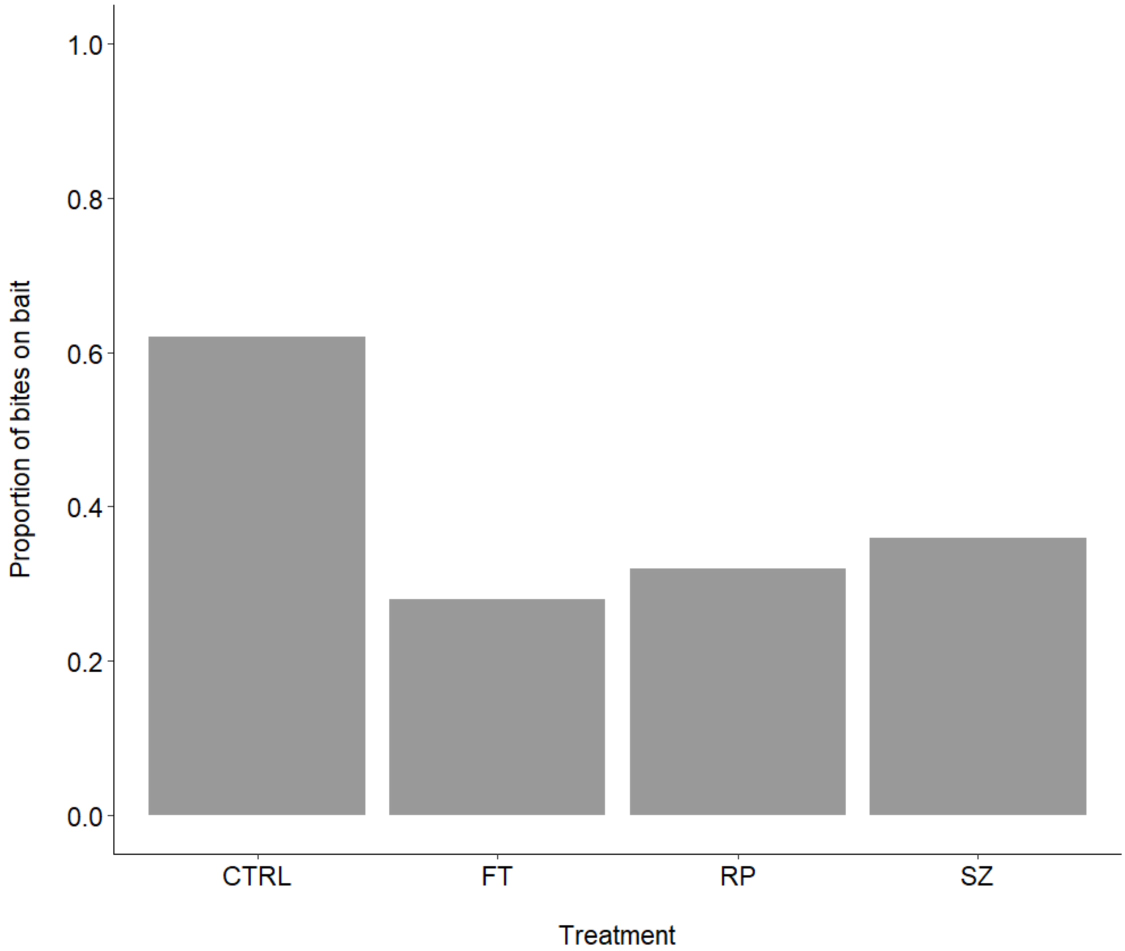

Figure 18. Proportion of times that sharks made a bite on the bait bag during each treatment, across the 200 videos analysed. CTRL = control treatment; FT = Fishtek SharkGuard; RP = Rpelx; SZ = Sharkbanz Zeppelin.

Time to first bite was also highly variable within each treatment, with large standard deviations (Figure 19). The fastest time to first bite was during the control treatment, with a mean of 105 ± 80 seconds, followed by the Sharkbanz Zeppelin (112 ± 81 seconds), Fishtek SharkGuard (153 ± 96 seconds) and Rpelx (162 ± 81 seconds) (Figure 19). Yet, there was no significant difference between treatments (Kruskal-Wallis chi-squared = 6.3572, DF = 3, p-value = 0.09547).

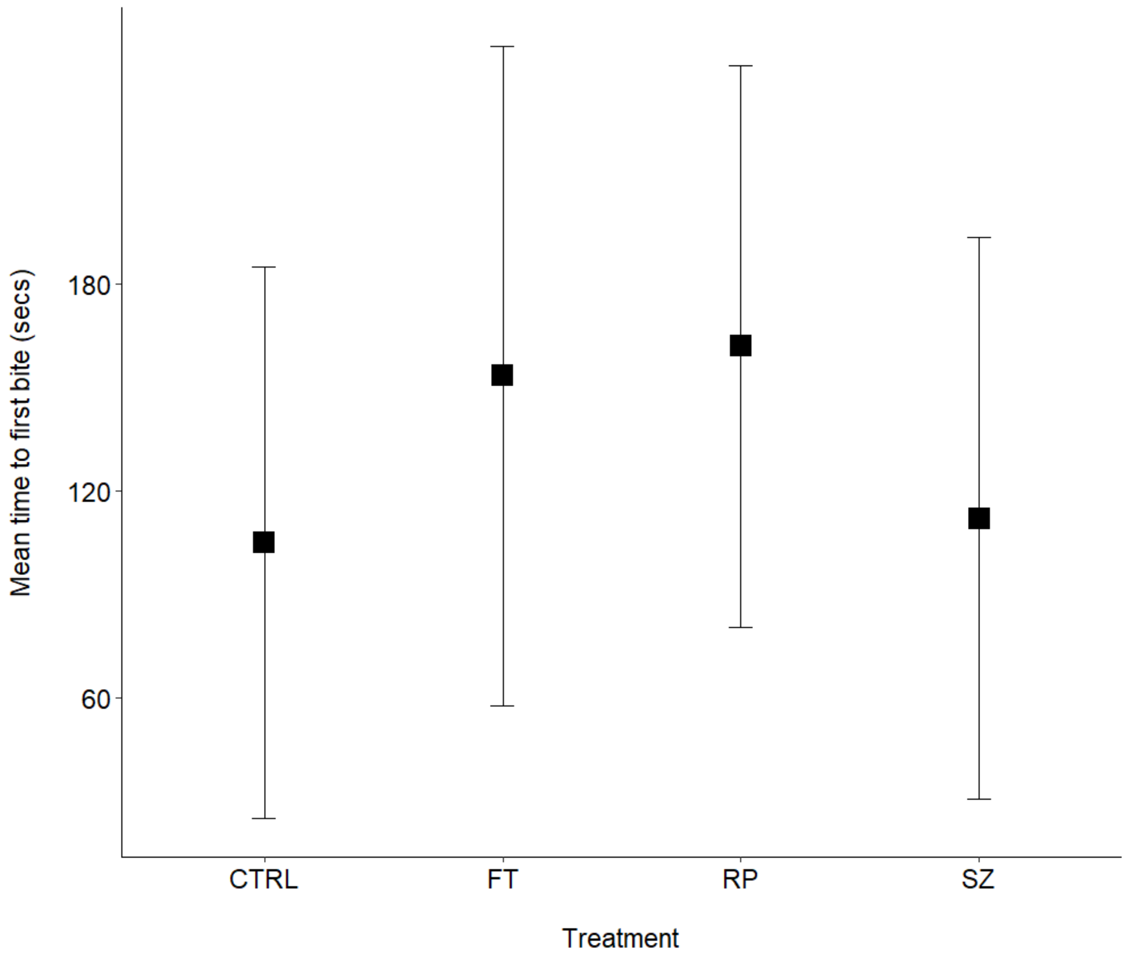

Figure 19. Mean time for sharks to first bite the bait bag in seconds. CTRL = control treatment; FT = Fishtek SharkGuard; RP = Rpelx; SZ = Sharkbanz Zeppelin.

The GLM indicated that treatment and the number of prior trials conducted at that location had a significant effect on the probability of a shark biting the bait (Table 4). However, this model only explained 10% of the deviance in the response variable, suggesting that other operational and environmental variables not accounted for in the model were having a large effect. Corroborating the results presented previously, the highest probability of a bite occurring was for the control treatment, followed by the Sharkbanz Zeppelin, Rpelx, then Fishtek SharkGuard, (Figure 20).

Table 4. Generalised Linear Model outputs for the effect of predictor variables on the probability of a bite on the bait bag occurring. Significant p-values are indicated with a * symbol.

Predictor variable	Chi-squared value	Degrees of Freedom	P - value
Location	3.6373	6	0.725623
Depth	2.1543	1	0.142176
Treatment	16.1970	3	0.001033*
No. prior trials	5.2623	1	0.021792*
No. sharks	1.7785	1	0.182336
Water temperature	0.0223	1	0.881251

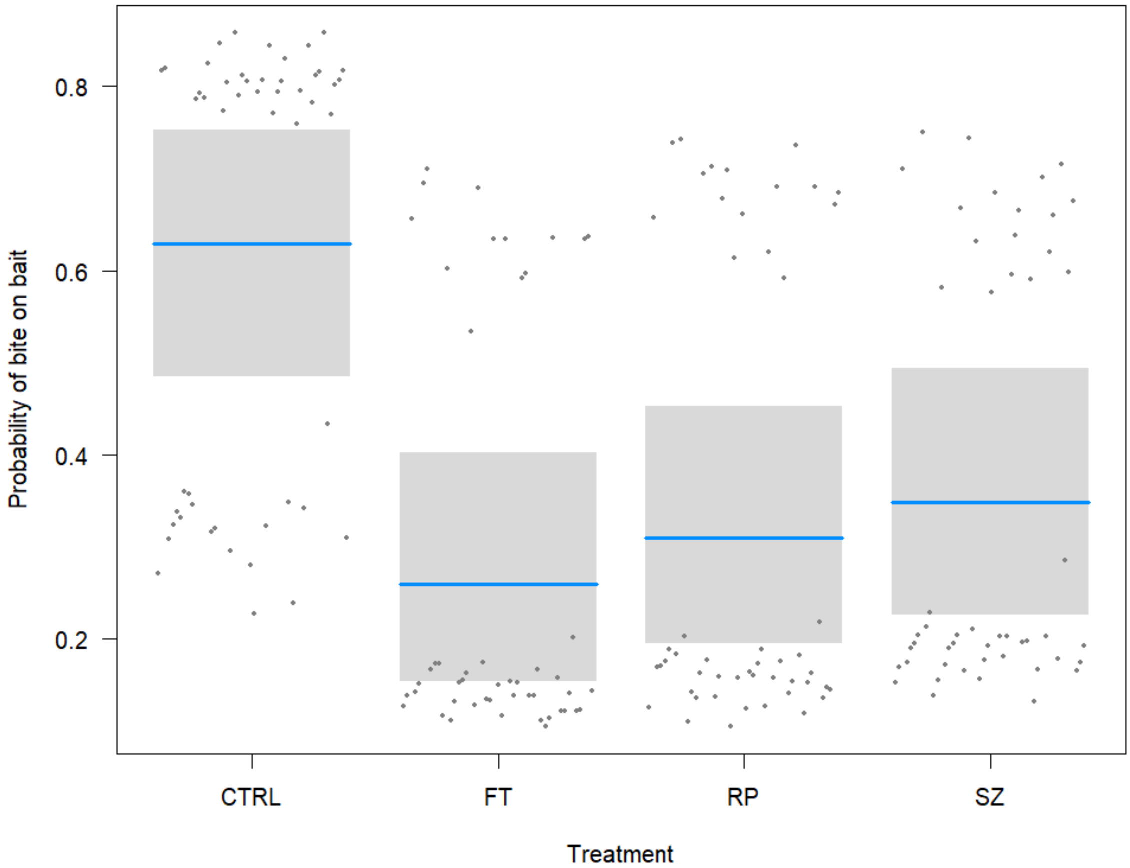

Figure 20. Generalised Linear Model plot showing the effect of treatment on the probability of a bite on the bait bag occurring. Blue lines indicate model fitted values. Grey shaded areas represent 95% confidence intervals. CTRL = control treatment; FT = Fishtek SharkGuard; RP = Rpelx; SZ = Sharkbanz Zeppelin.

The number of prior trials conducted also had an important influence on the probability of a bite occurring. This variable showed a linear effect, with the probability of a bite occurring steadily decreasing with number of trials (Figure 21).

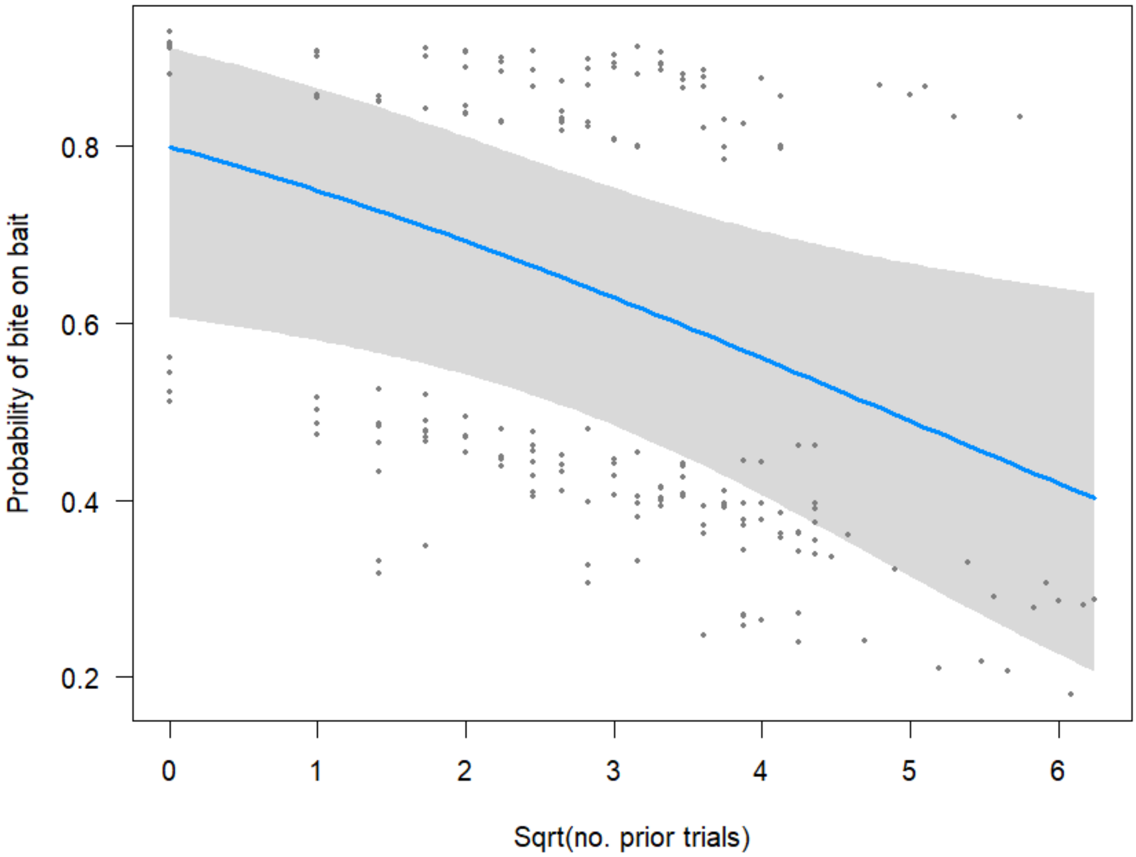

Figure 21. Generalised Linear Model plot showing the effect of number of prior trials that had occurred at the same location on the probability of a bite occurring on the bait bag. The number of trials has been square root transformed to create a more even distribution of data for more robust modelling. Blue line indicates model fitted values. Grey shaded area represents 95% confidence intervals.

4.3.2. Phase 2: Testing during fishing with charter operators

The Fishtek SharkGuard and Rpelx were tested across nine days of fishing in November – December 2024. Both devices substantially reduced the depredation rate compared to the control, with the Fishtek SharkGuard having a depredation rate of 4%, the Rpelx 5% and the control 19% (Table 5). This represented an 83% reduction in depredation for both devices, relative to the control. The two devices also reduced shark bycatch by 94% (Rpelx) and 53% (Fishtek SharkGuard), compared to the control (Table 5). However, when interpreting these results, the low sample size must be considered (Table 5). The low number of datapoints collected across all three treatments was due to unfavourable fishing conditions caused by strong currents and the associated difficulty in catching the main target species, yellowtail kingfish. The dataset was too limited for conducting more detailed statistical analysis, therefore a further trip is planned for November 2025, where more data will be collected with charter fishing operators.

Table 5. Summary data for deterrent testing conducted with charter fishing operators.

Treatment	No. fish hooked	No. fish landed undamaged	No. fish depredated	No. sharks hooked
Control	31	25	6	17
Fishtek SharkGuard	27	26	1	8
Rpelx	22	21	1	1

The behaviour of Galapagos sharks interacting with the fishing gear was observed opportunistically using Waterwolf cameras mounted on the fishing lines during some fishing sessions. Although no depredation events were directly observed due to the limited number of camera deployments, one instance of Galapagos sharks following a hooked yellowtail kingfish up and unsuccessfully trying to depredate it when the Fishtek deterrent device was on the line, was observed (Figure 22). A large black cod (*Epinephelus daemelii*) was also observed on the cameras trying to depredate hooked fish, although unsuccessfully (Figure 23).

Figure 22. Galapagos sharks unsuccessfully attempting to depredate a hooked yellowtail kingfish when the Fishtek SharkGuard (centre of image) was deployed on the fishing line, as observed from a WaterWolf underwater video camera mounted on the line.

Figure 23. A large black cod unsuccessfully attempting to depredate a hooked scorpionfish (*Scorpaena cardinalis*).

Testing of the two deterrent devices during fishing also provided an important opportunity to assess their practicality and ease of use for fishers. The Fishtek SharkGuard was viewed by the charter operators as being more user-friendly due to its smaller size and weight, and it was quick and easy for fishers to attach to their lines. Also, the small profile and low weight of the device meant that it did not interfere with being able to feel target fish biting the bait near the seabed, which is an important consideration. However, one unit was lost when the housing was damaged by a large fish taking the bait and fighting strongly. The Rpelx was generally viewed to be less user-friendly, due to its larger size and the fact that it often got wrapped around the fishing line, causing tangles. This was exacerbated when water currents were stronger than 1 knot, which is common at LHI. The catch rate of target species was also lower when using the Rpelx (Table 5), possibly due to its larger size and because the visual presence of the device on the line may make target fish more wary of taking the bait. Fishers also received electrical shocks from the device on a few occasions, especially when it was raining, due to the saltwater immersion switch of the Rpelx not turning off. This practical feedback was therefore important for evaluating the suitability of these two devices for fishing at LHI, in addition to their effectiveness at reducing depredation and bycatch.

4.4. Community engagement activities

4.4.1. Communication materials: leaflet and poster on shark interactions

The leaflet and poster providing information about Galapagos sharks at LHI and best-practice guidelines on how to mitigate negative interactions with sharks when fishing, were completed in 2024, with support from NSW DPIRD (Figure 24a,b). These leaflets were distributed to both local residents and visitors and have been made available at the NSW DPIRD marine parks office and the LHI museum. An online version is also available at:
https://australianmarineparks.gov.au/parks/temperate-east-marine-parks-network/lord-howe-marine-park/#publications-section

a) b)

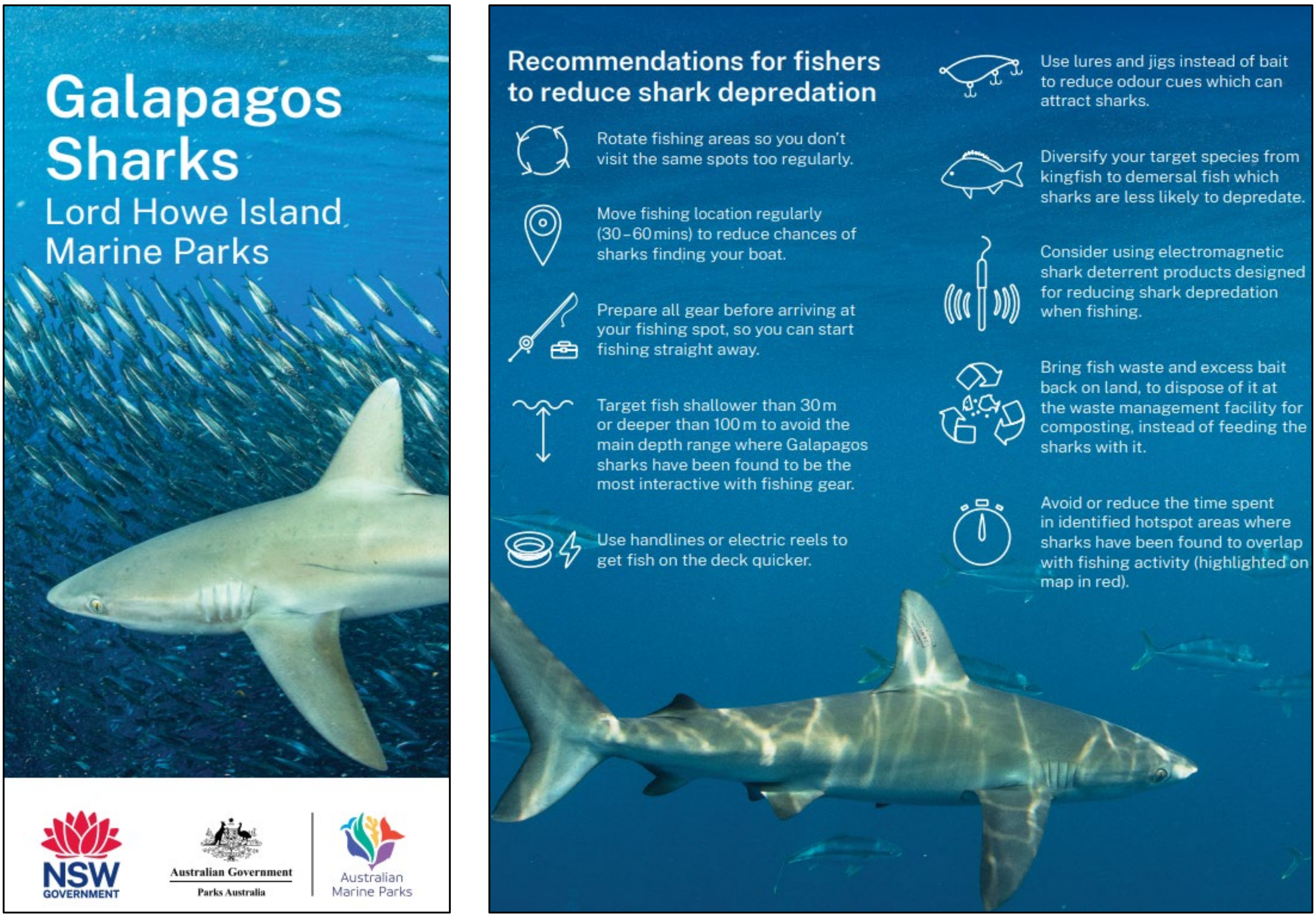

Figure 24. a) front page of the Galapagos shark educational leaflet for Lord Howe Island, b) best-practice guidelines for reducing shark interactions when fishing, as featured in the leaflet and poster.

4.4.2. Citizen Science project (photoID with Dive Lord Howe)

The collaboration between the research team and Dive Lord Howe has led to the collection of data from 103 Galapagos shark experience tours between December 2021 and December 2024. Over 2,000 images of Galapagos sharks have been submitted for these tours, from both Dive Lord Howe staff and customers participating as citizen scientists. A database of photoID images has been built using images of the left flanks of Galapagos sharks showing key identifying pigment patterns and scars on some individuals recorded (Figure 25). The database currently contains images of 98 individual sharks identified, with 20 of these resighted, some up to five times over periods of one day to nine months.

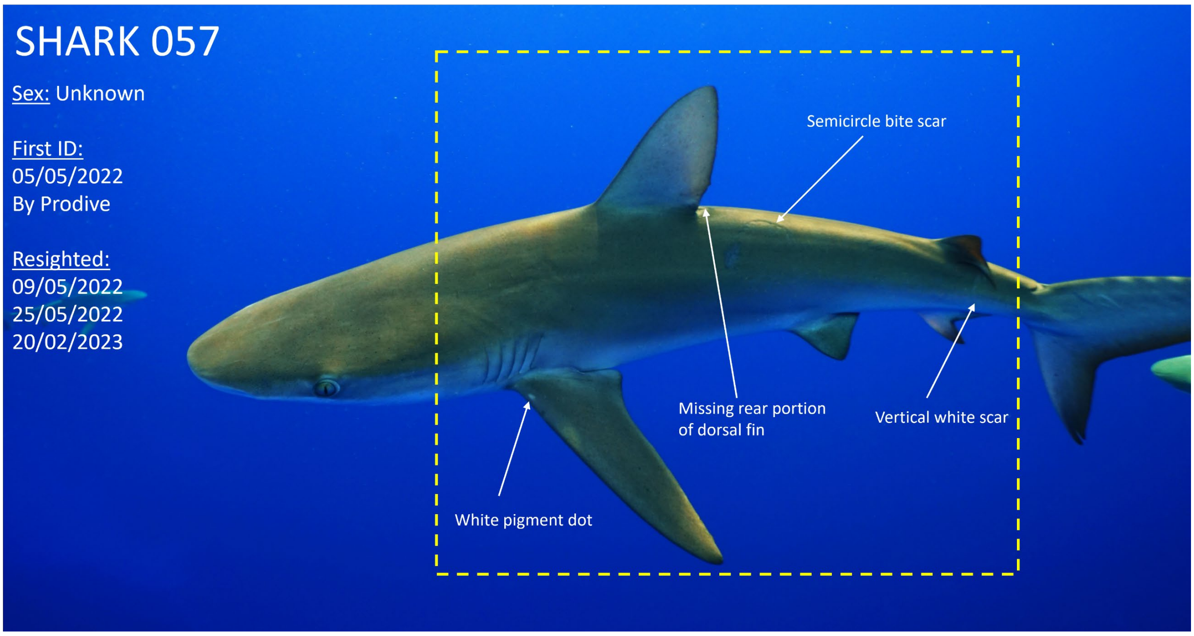

Figure 25. Example photoID of a Galapagos shark left flank, showing key identifying pigment marks and scarring patterns. Image credit: Dive Lord Howe.

4.4.3. Guest lectures and meetings

To further disseminate information about the research, educational talks were given at the LHI museum to local residents and visitors, to provide them with an overview of the research project since 2018. These talks were well attended by 20 – 30 people and gave the attendees further opportunity to engage with the project team and ask additional questions about Galapagos shark biology and ecology and interactions with fishing. Further one-on-one meetings were held with prominent local fishers and charter operators to update them on the progress of the research, demonstrate how the shark deterrent devices work and gather their feedback on the devices' practicality. Likewise, informal meetings with members of the LHI Board were conducted, to provide information about the research.

4.5. Preliminary research on deepwater shark taxonomy

In addition to the deepwater *Squalus* specimen donated to the research team in 2020 (Figure 26), two more individuals were donated by fishers in 2022 (under NSW DPIRD marine park permit LHIMP/R/20004/04012021) (Figure 27). These individuals were also from the *Squalus* genus, with one male of 79 cm total length and one female 87 cm total length, which were both caught at 400 m depth. A range of morphometric measurements and photographs were taken from both sharks using the NSW DPIRD shark necropsy form, to aid in future taxonomic research on these specimens. Tissue samples were also taken for genetic analysis, as well as vertebrae for ageing and liver and muscle for stable isotope analysis. Cartilage samples were taken to share with researchers at the Queensland University of Technology (V. Camilieri-Asch and colleagues), who are investigating the mechanical properties of cartilage tissues from deepwater shark species. The female shark was heavily gravid (pregnant), bearing four pups with yolk sacs attached, so these were also retained and sent to the Australian Museum to aid in taxonomic identification and analyses.

Figure 26. Deepwater *Squalus sp*. donated to the Australian Museum in 2020.

Figure 27. Two deepwater Squalus sp. (male top, female bottom) donated for research.

4.6. Research outputs

In addition to the communication leaflet and poster described above, there have been a range of outputs from this research since the previous report in 2021, including:

1. A peer-reviewed scientific publication in the journal *Marine Biology*, presenting the results of the first phase of the research from 2018 – 2021 (Mitchell et al., 2024);
2. Multiple articles (at least two per year on average) published in the LHI newsletter *The Signal* and the NSW DPIRD Lord Howe Island Marine Park newsletter, to keep the LHI community updated on the progress of the research ;
3. A presentation delivered to the Oceania Chondrichthyan Society conference in 2022 on the results from the first phase of the research;
4. A poster and presentation delivered at the 2022 Sharks International conference in Spain, summarising the multi-disciplinary approach of the research and key results to date;
5. A presentation was delivered to the Parks Australia Temperate East Marine Park Advisory Committee in March 2024, to provide an update on the research findings from previous years and the preliminary results of the deterrent testing;
6. A research talk was delivered at the symposium 'A Lost Volcanic World: LHI Rise and South Tasman Sea' at the Sydney Maritime Museum in May 2025;
7. A peer-reviewed scientific publication is in preparation, which will present the results of the deterrent testing. This will be completed in 2026, after collection of the final results during the next fieldtrip planned for November 2025;
8. An additional peer-reviewed scientific publication is in preparation, which aims to clarify the global and local population status of the Galapagos shark using genetic analyses, in collaboration with Macquarie University (Adam Stow's Lab: PhD and MSc student projects co-supervised externally by JDM and VCA).

5. Discussion

5.1. LHI acoustic array: a remote gateway connecting the dots

The data collected by acoustic receivers from November 2023 to November 2024 showed that eight of the 30 Galapagos sharks originally tagged in January 2018 were still present and five of those individuals were regularly detected at LHI throughout 2024. This long-term residency of these individuals over the last seven years indicates that this population of Galapagos sharks is at least partially resident around LHI, which corroborates long-term residency in other Galapagos shark populations in locations such as Hawaii, Bermuda and the Eastern Tropical Pacific (Kohler et al., 1998; Meyer et al., 2010; Lara-Lizardi et al., 2020). However, 20 individuals that were tagged in 2018 and detected between 2018 and 2021 were not detected in 2023 – 2024, implying either they died due to natural mortality or from fishing interactions, or they may have left the waters of LHI and BP and moved to other parts of the Tasman Sea. The latter scenario suggests that the phenomenon of partial migration may occur in this population, which is where some animals remain resident and others travel much longer distances and is common in a range of shark species (Papastamatiou et al., 2013; Lea et al., 2015; Espinoza et al., 2016). In support of this, two Galapagos sharks previously tagged with external dart tags as part of the NSW Gamefishing Tagging Program have been recorded travelling to/from LHI and Elizabeth Reef in the past (Mitchell et al., 2021). Moreover, previous movements ~3,000 km have been recorded for tagged Galapagos sharks in the Eastern Pacific Ocean (Lara-Lizardi et al., 2020), so it is feasible that some individuals would leave LHI waters during their life cycle. Although, no tagged Galapagos sharks were detected on three acoustic receivers that were deployed at Elizabeth and Middleton Reefs between

June 2021 and June 2022; however, the chances of these individuals being detected with so few receivers in a vast habitat such as found at these two reefs is remote. Similarly, the relatively few receivers deployed within the 765 km^2 of suitable shelf habitat at LHI and BP during 2023 – 2024 may have affected detection rates of tagged sharks, potentially explaining why only eight out of the 30 sharks originally tagged in 2018 were detected in 2023 – 2024. It is therefore possible that some of the other sharks may have still been present, but in deeper waters off the edge of the shelves, for instance, and thus were not detected by the current acoustic receiver array.

The eight sharks (five female and three male) detected in 2023 – 2024 had total lengths ranging from 114 – 138 cm when they were initially tagged in January 2018, so although the growth rate for this species is not well defined, it is likely that after almost seven years of growth, some of these sharks will be over 2 m in total length. Galapagos sharks are known to reach maturity from 1.7 – 2.5 m in total length (for males and females, respectively), corresponding to 6 – 9 years old (Bass et al., 1973; Wetherbee et al., 1996; Last and Stevens 2009; Ebert et al., 2013). Therefore, results from the current study could also indicate that some Galapagos sharks continue to be resident at LHI into adulthood, although the length and age at maturity values may differ for the LHI subpopulation compared to those studied in other locations. Interestingly, shark 1280539, which was 138 cm when tagged in 2018 and likely now >2 m and thus potentially mature, had a relatively low number of detections (195) and was present sporadically between 2018 and 2021 (Mitchell et al., 2021 – see Figure A1 in appendix for abacus plot of 2018 – 2021 detections), leading to a low residency index value (0.01) during the three-year post-tagging period, whereas it had a much higher number of detections (442) and higher residency index value (0.17) in 2023 – 2024, despite the shorter deployment period and lower number of receivers. Additionally, this shark was only detected at two acoustic receiver locations during 2018 – 2021 (Mitchell et al., 2021), whereas it was detected at five locations during November 2023 – November 2024. This result suggests that this female shark had a larger home range area with age, which has been recorded in other shark species (Speed et al., 2010; Knip et al., 2011). Shark 1280566 (117 cm female) was detected only 35 times during the 2018 – 2021 study, almost all of which were at the Southeast LHI acoustic receiver (Mitchell et al., 2021), whereas it was detected 432 times at four receivers in the current study, suggesting this animal's home range also increased with age. Shark 1280545 (116 cm female) also showed a similar pattern with 34 detections at two receivers during 2018 – 2021 (Mitchell et al., 2021), compared to 191 detections across four receivers in 2023 – 2024. Conversely, shark 1280564 (121 cm male) was detected 144 times at five receivers in 2018 – 2021 versus only 15 detections at two receivers in 2023 – 2024. Likewise, shark 1280557 (129 cm male) had notably higher detections (274) at more acoustic receivers (six) in 2018 – 2021 (Mitchell et al., 2021), compared to 2023 – 2024 (96 detections at three receivers). Other tagged sharks showed more consistency between the 2018 – 2021 and 2023 – 2024 study periods, with shark 1280558 (115 cm female), being detected regularly throughout November 2023 – November 2024 at the receiver in the Southeast corner of the LHI shelf and also detected frequently at only this location between 2018 and 2021, suggesting little change in its home range. Likewise, sharks 1280552 (114 cm male) and 1280554 (137 cm female), which were tagged on the BP shelf in 2018, were almost exclusively detected at the two receivers on the BP shelf, during both the 2018 – 2021 and 2023 – 2024 study periods, suggesting residency to this shelf system.

The residency index values of the eight sharks detected from November 2023 – November 2024 were low overall, with 0.17 being the highest value for shark 1280539. This followed a relatively similar patterns to those detected from 2018 – 2021, where 25 out of 28 were also <0.2 (Mitchell et al., 2021; 2024). Two of the three individuals that had residency indexes >0.2 in 2018 – 2021 were both detected almost exclusively at a single acoustic receiver location close to the south of LHI where fish waste has historically been dumped, which has likely attracted sharks to this location over a long period and now remains a learnt behaviour (Mitchell et al., 2021; 2024). However, no detection data was available for this site between November 2023 and November 2024, because the mooring was damaged and its acoustic receiver lost in early 2023. The overall low level of residency was likely due to the fact that the array had relatively low coverage of the large area of shelf waters at LHI, with receiver spaced at least 5 – 15 km apart.

When assessing temporal variation in the number of detections, the results from November 2023 – November 2024 showed that highest detections occurred in spring, most notably October 2024, with lowest detections in autumn (Feb and March 2024). This pattern was also evident between 2018 and 2021, where April had the lowest number of detections and November the highest (Mitchell et al., 2021). The seasonal fluctuations in Galapagos shark presence corroborate reports of higher catch of this species during the summer months off Hawaii (Wetherbee et al., 1996). The changing seasonal pattern in number of detections at LHI may be caused by seasonal shifts in current patterns and related changes in prey availability and distribution, rather than being driven by temperature per sé, because numbers of detections were still consistent during winter, ruling out the possibility that sharks leave LHI waters during the winter months.

The acoustic receiver located at the Southeast LHI location had the highest number of detections (636) in the current study. This location also had a high number of detections in the previous study between 2018 – 2021, being the second highest with 5,497 detections (Mitchell et al., 2021). This site was identified to be a key hotspot area where shark presence and fishing vessel activity overlapped during the first three years of this project, likely due to this being a productive shelf edge area, where currents and upwelling create favourable habitat for prey and predator species (Mitchell et al., 2021; 2024). The acoustic receivers at the Northeast corner of the BP shelf and the Southwest corner of the LHI shelf had similar numbers of detections in November 2023 – November 2024, whereas from 2018 – 2021 the former location had substantially more detections of tagged sharks and was a notable hotspot area of overlap between sharks and fishing vessel activity (Mitchell et al., 2021; 2024). Conversely, the acoustic receiver location at the Southern end of the BP shelf had low numbers of detections in both periods, perhaps because it was a less productive feeding ground for Galapagos sharks and due to the fact it is within a large NTZ so no fishing activity is occurring. The acoustic receiver at the Northeast LHI shelf also received low numbers of detections, whereas this site was previously an important area in 2018 – 2021, with relatively high numbers of detections and overlap with fishing vessel activity (Mitchell et al., 2021; 2024). Lastly, the acoustic receiver in the Northwest LHI shelf only recorded three detections and no data were available for this location between 2018 – 2021 (Mitchell et al., 2021) due to receivers being lost in this location, implying that the bathymetry of this area may be unsuitable for future deployments of acoustic receivers.

In addition to the Galapagos sharks detected by the acoustic receiver array in November 2023 – November 2024, there were also several other acoustically-tagged species detected, comprising seven yellowtail kingfish and seven sharks (three white sharks and four tiger sharks). Continuing the deployment of the acoustic array will therefore provide valuable ongoing data on the yellowtail kingfish (which were tagged at LHI in 2023), enabling investigation of how their movements overlap with Galapagos sharks and fishing activity in space and time. This will be of value to marine park managers, as these two species are the most frequently caught by charter and recreational fishers at LHI and because Galapagos sharks regularly depredate hooked kingfish, leading to conflict with fishers (Mitchell et al., 2021). The detection of tiger sharks originally tagged at Norfolk Island and white and tiger sharks originally tagged off mainland NSW, builds on previous detections of five other white and tiger sharks from NSW and South Australia between 2018 – 2023 (Mitchell et al., 2021) and highlights the value of this acoustic receiver array for identifying migratory connectivity across the Tasman Sea, facilitating future collaborations with other researchers.

The deepwater acoustic receivers also collected data on water temperature at LHI and BP, using built-in temperature loggers. These data are particularly valuable because they are collected at depths of 47 – 64 m where the receivers are deployed, whereas previously there was very little data available for these depths due to remote sensing platforms only being able to measure sea surface temperature. The deepwater temperature data is therefore invaluable for monitoring longer term temperature profiles at LHI and detecting marine heatwaves at depths previously unstudied at LHI. This is significant because there was a marine heatwave event at LHI in early 2024, so the temperature data collected from the acoustic receivers will be made available to other researchers investigating this phenomenon. The temperature data collected during the current study showed two clear spike events in January 2024 and May 2024, where the temperature rapidly increased by 3 – 5 °C over a period of a few days, likely linked to strong warm currents pushing through, as denoted by the increased tilt angle of receivers over these periods. Interestingly, one of the two tiger sharks originally tagged at Norfolk Island was detected at the same time as the temperature spike recorded in late May, suggesting it may have followed this warm water mass. This is contrary to the usual pattern of presence for tiger sharks previously detected at LHI, which was between November and February (Mitchell et al., 2021).

5.2. Deterrent testing: an important first step towards a future solution

5.2.1. Phase 1: Controlled experimental testing

The results of phase 1 of the deterrent testing provided important insights about the effectiveness of the three electromagnetic devices. None of the devices were 100% effective at deterring sharks from touching or biting the bait bag. This is likely related to the large numbers of sharks present during the trials leading to competition for the bait, which can reduce the effectiveness of deterrents (Jordan et al., 2011; Robbins et al., 2011; O'Connell et al., 2014). There may also be individual variations in the response of sharks to electromagnetic fields that might arise from a combination of different levels of satiation, motivation, experiences, dominance hierarchies, or personalities (i.e., behavioural syndromes or consistency of responses across situations) (Mandelman, 2008; Hutchinson et al., 2012; McCutcheon and Kajiura, 2013; Hart and Collin, 2015). While variations among individuals could not be tested here because sharks could not be identified, intra-specific variability is often detected in previous studies on shark deterrents in the context of shark bites on humans, with shark ID having a large influence on the effect of electric deterrents when included in the models (Huveneers et al., 2013; 2018; Gauthier et al., 2020; Clarke et al., 2024). This emphasises the need to ensure that shark deterrents are tested on a sufficient number of individuals to identify and account for such individual variability.

The two electrical deterrent devices Rpelx and Fishtek SharkGuard produced substantial reductions in the proportion of trials which ended with a bite on the bait, with a maximum 55% reduction for the Fishtek device. This is, however, lower than a similar study using the Rpelx device at Cocos (Keeling) Islands, where depredation by grey reef sharks (*Carcharhinus amblyrhynchos*) was reduced by 76% with the Rpelx device on the line, versus a control treatment (Mitchell et al., in review). This difference may be due to inter-specific variation in sensitivity to electromagnetic fields (Hart and Collin, 2015), and/or due to larger numbers of Galapagos sharks being present and competing to access the bait compared to the smaller numbers of grey reef sharks depredating catch at Cocos (Keeling) Islands. Another study in North Queensland found up to a 66% reduction in shark depredation when an alternative electrical deterrent device, the OceanGuardian FISH01, was deployed (Vardon et al. unpubl. data). It should be noted that the FISH01 is a much larger deterrent which is designed to be hung under the vessel, rather than attached to the fishing line close to the hook. As such, the results are not directly comparable with line-deployed mitigation devices such as those tested in the current study. Also, due to the depth at which LHI fishing and associated shark depredation occurs, this device was considered not viable for this community and was therefore not tested in this study. In the current study, the time it took sharks to make contact with or bite the bait when electric deterrents were active was markedly longer, compared to the control treatment, suggesting that these deterrents may provide fishers extra time to retrieve hooked fish before sharks can depredate it.

The effect of the magnetic device Sharkbanz Zeppelin was smaller, with no change in the proportion of times that sharks contacted the bait or in the time to first contact or first bite on the bait, relative to the control. However, the proportion of times that sharks made a bite on the bait was slightly reduced (albeit by a smaller amount than with Rpelx or Fishtek), relative to the control. Previous research at LHI in 2009 tested eight configurations of magnets and electropositive metals on Galapagos sharks, with one magnet configuration reducing bites on the bait by up to 50%, although the other seven configurations had negligible effect (Robbins et al., 2011). Most notably, the number of sharks present had a strong effect on the time it took to strike the bait, with significantly faster strikes and low effectiveness of the deterrents when >3 sharks were present (Robbins et al., 2011). Yet, Wang et al. (2008) tested the effectiveness of electropositive metals on Galapagos sharks, finding a significant reduction in number of bites on the bait compared to a lead control treatment. This variability in results is reflected across a number of other studies, when testing magnets and electropositive metals as a deterrent, with some showing successful reduction in catch rates (Brill et al., 2009; O'Connell and He, 2014), but others no effect, likely due to species-specific variation in sensitivity to electromagnetic fields, conspecific density and hunger levels (Hutchinson et al., 2012; McCutcheon and Kajiura, 2013).

The difference between the electrical and magnetic deterrent devices in the current study was likely due to the strength of the electromagnetic field that they generate, with the Rpelx producing 200 V and the Fishtek 35 V, with clear behavioural responses to the devices visible in video footage, from up to 2 m away. Conversely for the Sharkbanz, the effective range appeared to be much smaller corroborating previous research on this device which measured the electrical field to be ~30 cm (S. Kajiura, unpubl. data). Furthermore, there were certain occasions where the sharks seemed to bite the magnetic Sharkbanz device rather than the bait or other parts of the experimental equipment, suggesting that it could, in some cases, be attractive to them or at a minimum confuse their predatory senses. Other studies recently testing a similar magnetic device (Sharkbanz Sentry, also designed to be attached to the fishing line as a sinker, similar to the Zeppelin) has also recorded variable effects of the device on sharks, including reductions in depredation of up to 31% in Western Australia (Coulson et al., unpubl. data), but sharks clearly attracted to and biting it on other occasions (G. Jackson, J. Vardon, pers. comm.). The results in the current study are also similar to other research testing the efficacy of shark deterrents to reduce shark bites on humans, which showed that while electric deterrents could reduce the risk of shark bites by ~60%, magnets had minimal to nil effects on the probability of shark bites because of their small range (Gauthier et al., 2020; Huveneers et al., 2018). As a result of the low effectiveness of the Sharkbanz device on Galapagos sharks during the current study, only the two electrical devices (Rpelx and Fishtek) were chosen for further testing in phase 2 of the project.

Interestingly, the probability of a bite on the bait decreased with increasing number of trials at the same location, which is the opposite effect to that observed in other deterrent testing studies, where sharks have become habituated to a deterrent such that its effectiveness declined over time (O'Connell et al., 2011; Kempster et al., 2016; Gauthier et al., 2020). This divergence of results may be due to the sharks initially responding to the novel stimulus and potential source of food by investigating and biting the bait bag in the current study, but then over time and increasing number of trials, the sharks became accustomed to the presence of the bait bag and learnt that they were unable to access the bait inside, therefore being less likely to bite it. This reduction in response to a stimulus due to lack of a reward has been observed in other studies on shark behaviour, including for white sharks during cage diving operations (Niella et al., 2024), as well as in captive juvenile lemon sharks (Heinrich et al., 2022). However, in a real fishing setting where a shark can access and depredate a hooked fish, this effect of declining responsiveness over time would be unlikely to occur, highlighting the need for the testing in a real fishing scenario that was conducted in phase 2.

5.2.2. Phase 2: Testing during fishing with charter operators

The second phase of testing for the Rpelx and Fishtek devices took place with local charter fishing operators and found a substantial reduction in rates of shark bycatch and depredation when the two electrical deterrent devices were deployed, compared to the control treatment. Although, the limited number of depredation events that occurred during this testing (only eight across three treatments), must be considered when interpreting the results. Nonetheless, the reduction in shark depredation recorded in the current study was comparable to testing of the Rpelx at Cocos (Keeling) Islands during deepwater line fishing, where a 76% reduction in depredation was recorded (Mitchell et al., in review). Interestingly, whilst the depredation rate was the same for the Fishtek SharkGuard and Rpelx, the latter device had a notably lower level of shark bycatch. This may be due to the stronger power output of the Rpelx (200 V) compared to the Fishtek (35 V), or it may have been because of the larger size of the Rpelx and its movement near the bait created a visual disturbance that made sharks more wary of taking the bait. The opportunistic deployment of Waterwolf underwater cameras on fishing lines during some fishing sessions provided an opportunity to observe the shark behavioural interactions with the fishing gear, as well as the effect of the deterrent devices. Although no shark depredation events were directly observed on the cameras due to the limited number of camera deployments (because the number of cameras available and their battery life was limited), one instance of sharks unsuccessfully trying to depredate a hooked fish when the Fishtek SharkGuard was on the line was observed, suggesting that the deterrent was effective in this instance. The fact that the cameras also observed a large black cod attempting to depredate a hooked fish suggests that teleosts may also be responsible for a small proportion of the depredation at LHI. These interactions that were recorded highlight the added value of deploying cameras on the fishing lines to ground truth depredation events and other behavioural interactions of sharks and fish with the fishing gear. To build on the data collected so far in phase 2 and enable more detailed analysis to be conducted for assessing the effectiveness of the deterrent devices during standard fishing practices, a further field trip is planned for November 2025, to conduct more testing during fishing with charter operators. This will enable clear recommendations to be made to the LHI fishing community about which deterrent device is most effective for reducing shark depredation and bycatch at LHI.

The practical feedback provided by charter fishing operators clearly showed that the Fishtek SharkGuard was more user friendly and suitable for the style of fishing that occurs at LHI, compared to the Rpelx. Additionally, catch rates were higher when using the Fishtek device and it was safer to use due to lower risk of electrical shocks. This feedback from fishers was therefore vital for making a more comprehensive assessment of the suitability and potential future uptake of shark deterrent devices for reducing shark depredation and bycatch at LHI. The information was provided to the manufacturers of these two devices, to assist them in developing changes that would improve their useability. Further testing in November 2025 will also include more evaluation of these practical considerations and will inform final recommendations made to marine park managers and local fishers about which device will be most suitable for fishing at LHI.

5.3. Community engagement activities

Engagement activities have been a key part of the LHI shark research program since its inception in 2018 and community outreach activities were continued during fieldwork in November 2023 and November 2024. The leaflet recently created for local fishers and visitors provides important information on how to mitigate negative interactions with sharks when fishing, which ultimately will help fishers to reduce loss of tackle and catch to sharks, as well as limit bycatch of sharks and related injuries to the caught sharks. The ongoing photoID project run in collaboration with Dive Lord Howe is also collecting important information on shark movements and behaviour and is engaging with a different demographic of visitors who come to LHI for nature-based activities and ecotourism. Presentations to visitors and local residents at the museum, one-on-one meetings with tourism operators and 10 days of charter fishing with two operators, SeatoSummit and SeaLordHowe, provided extensive opportunities for two-way knowledge exchange to learn more about the biology and ecology of Galapagos sharks and their interactions with fishing and other activities at LHI. Overall, the scope of the engagement conducted for this project was vital to gain local knowledge and disseminate research findings to community members and visitors and foster more engagement with and support for the marine parks.

5.4. Preliminary research on deepwater shark taxonomy

Preliminary morphometric and genomic analysis is underway in collaboration with researchers from the Australian Museum and CSIRO, to conduct integrated taxonomic research on the *Squalus* specimens collected from LHI to date, as well as many others in the Australian Museum collection which were previously collected at seamounts in the Tasman Sea and in New Zealand. This research will have important benefits by further clarifying the taxonomic status of the *Squalus* genus, which is understudied worldwide, and by contributing to baseline knowledge of fish biodiversity at LHI. For example, it is possible that these specimens are species that have only previously been found in mainland Australian waters, in which case they will constitute a range extension, or they may be new subspecies or species not previously described. Such knowledge is therefore valuable for assisting marine park managers to better understand which species are present at LHI and assess potential impacts from activities such as deepwater fishing (>200 m depth), which is anecdotally increasing at LHI.

5.5. Future research and recommendations

To further build on the successful outcomes of this research project since 2018, a range of future research recommendations are detailed below:

1. Continuing with the deployment of the deepwater acoustic receiver array at LHI is highly recommended, because this array is providing important long-term data on the ecology of Galapagos sharks at LHI (since 2018), with many of the tagged sharks now reaching adulthood. This study therefore represents one of the longest tracking studies of this species worldwide and it will continue to generate important insights into its ecology and habitat use within this important Australian Marine Park;
2. Investigate how movements of tagged Galapagos sharks overlap with those of yellowtail kingfish and fishing vessel activity, to further increase understanding of fisher-shark conflict and the ecology of these pelagic species at LHI;
3. Continue with the collection and sharing of data from other tagged megafauna species such as white sharks and tiger sharks, to enable research on connectivity between Australian Marine Parks and across the Tasman Sea. New collaborations with other research groups will be established to investigate these data;
4. Temperature data from the acoustic receivers will be shared with other research groups to provide new insights into the oceanography of the LHI marine park, including assessment of temperature profiles, current patterns and marine heatwaves;
5. The two electrical shark deterrent devices Fishtek and Rpelx should continue to be tested with local charter fishing operators, to generate further data for conducting robust assessments of their effectiveness at reducing shark bycatch and depredation. Practical feedback from the fishers should be incorporated to improve their design and uptake of these devices by charter fishers should be monitored;
6. Community engagement and outreach activities should continue to be conducted in line with research on sharks at LHI, to spread awareness of their biology, ecology and

interaction with fisheries. This will also help to improve co-existence between humans and sharks and support both sustainable fishing and marine ecotourism activities which interact with Galapagos sharks;

7. Opportunistic research on the biology of other shark species at LHI should be pursued, particularly deepwater sharks, for which there is almost no current information on their biology or ecology. This is important because local fishers are increasingly moving into deeper water to fish and are catching more deepwater shark species, which are likely to be highly vulnerable to fishing pressure due to their conservative life history (i.e. slow growth, late maturity and low reproductive output). Preliminary research in collaboration with the Australian Museum and CSIRO suggests there may be undescribed species of deepwater sharks from the *Squalus* genus at LHI, so this should be investigated further using an integrated taxonomic approach combining morphology and genomics, to improve baseline knowledge of biodiversity in the Lord Howe Marine Park and its ongoing management.

6. Permits

Parks Australia (Australian Marine Parks):

- Permit to conduct scientific research in the Lord Howe Marine Park (permit no. PA2021-00054-1 (variation to PA2021-00054-3)
- Permit for access to biological resources from Commonwealth areas (permit no. AU-AU-COM2021-514)

New South Wales Department of Primary Industries and Regional Development, Marine Parks:

- Application for a Marine Parks permit for Lord Howe Island Marine Park (permit no. MEAA23/307-1)

NSW DPIRD Animal Care and Ethics Committee:

- Animal research authority (permit no. FISH ACEC-0540)

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8. Appendices

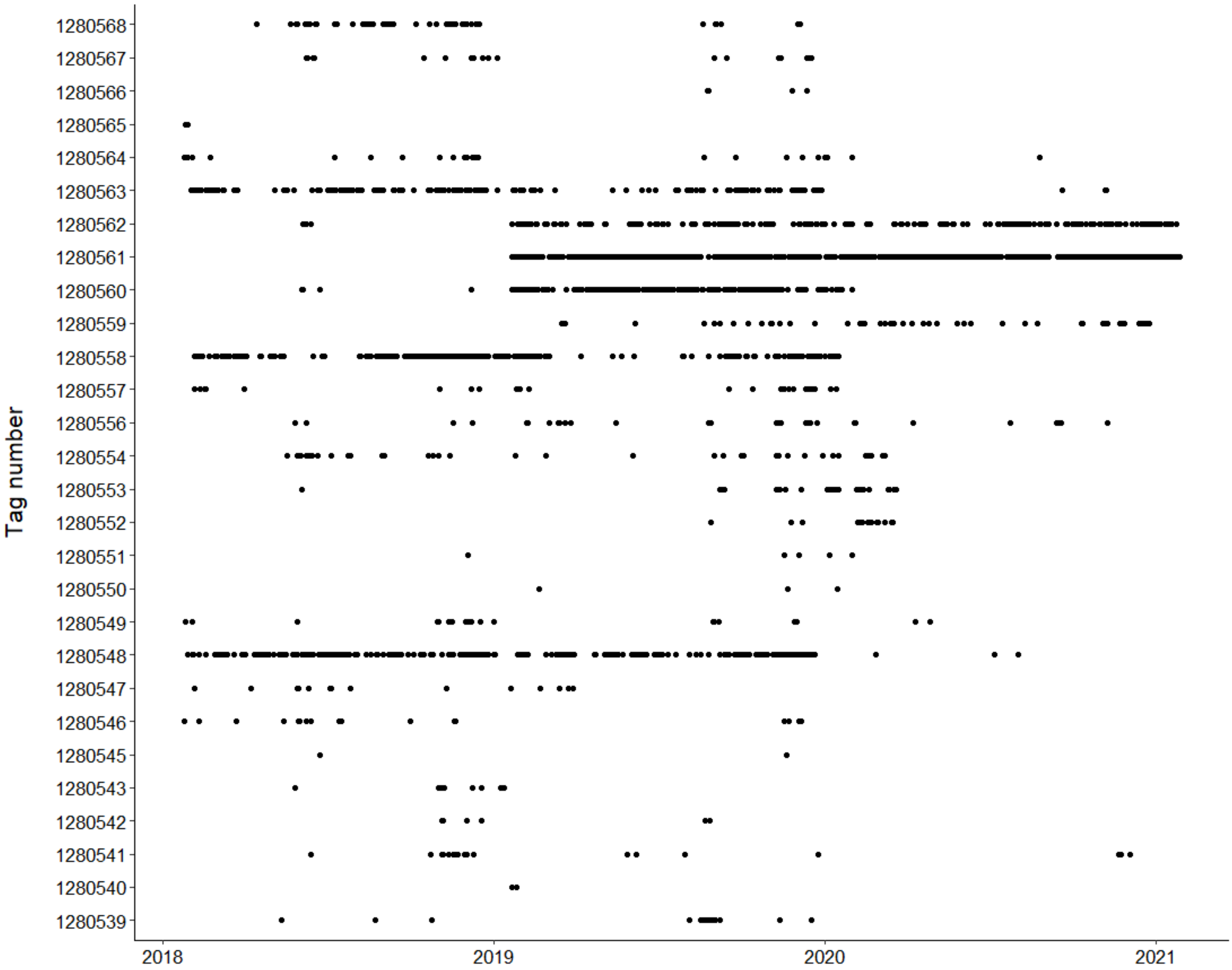

Figure A1. Detection patterns of 28 tagged Galapagos sharks from January 2018 – 2021 (Mitchell et al., 2021).