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Results of a pilot study using acoustic telemetry to assess the movements of coastal elasmobranchs in Namibia's only marine protected area

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Abstract

Many elasmobranch (shark, skate and ray) species inhabit the Namibian Islands Marine Protected Area (NIMPA), but little is known about the home ranges and movements of these species. Such information is essential for understanding whether a marine protected area provides effective protection to species of conservation concern. This study describes the first effort to tag and acoustically track three elasmobranch species in Namibian waters. A total of eleven individuals of three species – *Mustelus palumbes, Acroteriobatus blochii* and *Raja straeleni* – were tagged in February 2023. Three acoustic receivers were deployed at sites in the vicinity of Lüderitz Bay and a fourth was deployed further south, in Grosse Bucht. Data collected over 12 months revealed some of the small-scale movements of nine of the eleven tagged animals, but the limited spatial coverage provided by the four

receivers was not enough to fully describe the movement behaviours of these animals. Nonetheless, this research – the first study to internally tag and track chondrichthyans in Namibian waters – has revealed how tracking studies can contribute valuable data that can inform the management and protection of mobile species like sharks, skates and rays, and the design of future marine protected areas.

Introduction

Biotelemetry – the use of electronic tools to track the movements of animals – is now widely used to study the movements and behaviours of aquatic animals (Hussey et al. 2015). Acoustic telemetry is one of the most widely used methods for tracking the movements of marine animals. 'Coded' tags are used in conjunction with an array of acoustic receivers, positioned to give adequate coverage throughout the study area. The tags, each transmitting a unique code, are surgically implanted into animals; when a tagged animal passes within detection range of a moored receiver, the identity code, time and date of the detection are logged. Receivers are downloaded periodically by researchers to obtain data on animal detections. Acoustic telemetry facilitates the monitoring of the long-term movements of multiple individuals in a continuous and largely automated way, and results in large volumes of data that provide invaluable insight into spatial and temporal patterns of habitat use and large-scale movements of aquatic animals. This information can in turn be used to describe species' critical habitats, to inform fisheries management, to evaluate the level of protection provided by existing marine protected areas (MPAs) and to design new MPAs (Alós et al. 2022; McGowan et al. 2017; Abecasis et al. 2014).

MPAs are established for a variety of reasons and with a diverse array of objectives, including the protection or restoration of specific species or habitats and the maintenance of existing ecosystem services. These are often achieved by designating areas of ocean where human activities, such as fishing, are restricted to varying degrees, thereby theoretically safeguarding marine biodiversity from anthropogenic activities (Gaines et al. 2010; Halpern et al. 2010; Duarte et al. 2020). However, whilst MPAs have been documented to contribute to the protection and recovery of teleost populations (e.g. Ojeda-Martinez et al. 2007; Rojo et al. 2019), their contribution to the protection of elasmobranchs is not as well understood. Some evidence of MPAs benefitting elasmobranchs exist, but the outcomes can be variable, and the extent of the protection may not be sufficient, especially when isolated MPAs are implemented (Dwyer et al. 2020).

Effective conservation of marine vertebrates including chondrichthyans relies on a good understanding of their patterns of habitat use, movements and migrations (e.g. Daly et al. 2023; Kraft et al. 2023a; Doherty et al. 2017). Many MPAs are not designed specifically to protect elasmobranchs and thus were likely designed without knowledge of the movements and home ranges of these species, many of which are highly mobile and undertake long migrations (Kraft et al. 2023a; Dwyer et al. 2020; MacKeracher et al. 2019). Movement data can provide insight into the habitats a species uses, as well as the threats it may encounter as it moves from one region to another, both of which have direct implications for conservation (Lennox et al. 2023). Understanding the movement behaviour of elasmobranch species of conservation interest is thus essential to improve the protection offered by established MPAs and to more effectively design new MPAs.

Namibia's only MPA, the Namibian Islands Marine Protected Area (hereafter NIMPA), was designated in 2008. At the time of its declaration, one of its primary objectives was to protect the breeding sites and main foraging areas of the populations of three threatened seabird species – African penguins (*Spheniscus demersus*), Cape gannets (*Morus capensis*) and bank cormorants (*Phalacrocorax neglectus*) – that breed and feed along Namibia's coast and that were, at that time, in rapid decline (Ludynia et al. 2012; Kemper et al. 2007). There has, until recently, been almost no research focusing on elasmobranchs in Namibian waters, including within the NIMPA, and thus the state of knowledge of this group of species is extremely limited (Leeney et al. 2023; Leeney 2024; Leeney and Tshimwandi 2024). As such, there is no understanding of the status of elasmobranch populations within this MPA, or whether its boundaries encompass the home range of any elasmobranch population sufficiently to provide a reasonable level of protection.

This paper describes the first ever acoustic tracking study on chondrichthyans in Namibian waters and the first time that any of the study species have been tracked with acoustic tags. The small receiver array limited the amount of data that was collected, but the results nonetheless demonstrate the contribution this type of research can make to developing appropriate management and conservation plans for elasmobranchs within and outside of MPAs.

Methods

This study was conducted in collaboration with the National Research Foundation - South African Institute for Aquatic Biodiversity (NRF-SAIAB) Acoustic Tracking Array Platform (ATAP). The equipment used for this study was fully compatible with that used by ATAP, allowing for the data collected to be integrated into the ATAP database and ensuring that any large-scale movements into South African waters by animals tagged in Namibia would have the possibility of being detected on the ATAP array.

Study area

This study took place in the NIMPA, which is located in the Benguela Current Large Marine Ecosystem (BCLME), one of the four major upwelling systems on the eastern boundaries of the Atlantic and Pacific Oceans and one of the most productive ocean ecosystems in the world in terms of biomass production and fishery resources (Shannon and O'Toole 2003; Sakko 1998). The NIMPA encompasses 9,500 km² of marine environment in southern Namibia and extends from the shoreline to c. 30 km offshore, reaching depths of over 160 m in some places.

Tagging procedure

Elasmobranchs were caught from shore using conventional rod-and-line tackle. Angling took place from land at both Radford Bay and Griffith Bay (Fig. 1). Barbless circle hooks (sizes 4/0 to 6/0) baited with sardine *Sardinops sagax* were used. No specific species were initially targeted during fishing, but once three different species had been caught and tagged, only additional individuals of those three species were tagged, to ensure that data were collected from multiple individuals of each species.

Once an elasmobranch was hooked, it was reeled in to shore as quickly as possible. The overall health of the fish was assessed and tagging only proceeded for healthy animals that were not overly distressed. The size of each fish was also assessed as soon as it was landed, to ensure that the body cavity was of sufficient size to accommodate the transmitter. The fish was then placed on a tarpaulin. Fish were inverted (i.e. with the ventral surface of the body facing upwards) to induce a state of tonic immobility - a reflex that causes a temporary state of inactivity in elasmobranchs. Tonic immobility is widely used and recognised as an acceptable anaesthetic technique for surgical procedures on elasmobranchs (Kessel and Hussey 2015). On the sandy beach at Radford Bay, a hole was dug in the sand (c. 120 x 50 cm and c. 20 cm deep) near the water's edge, before fishing began. The tarpaulin containing the elasmobranch could then be placed into this hole and filled with seawater, acting as a pool. The animal's gill slits were kept submerged throughout the tagging process, and additional seawater was regularly added using a bucket, to maintain oxygen levels in the water. At Griffith Bay, anglers fished from a rocky outcrop and a small channel in the rocks was used to support the tarpaulin during tagging. The transmitters used for this study have an estimated battery life of 3650 days for the V16-4L transmitters (16 mm in diameter and 68 mm in length) and 1091 days for the V13-1L transmitters (13 mm in diameter and 30.5 mm in length). The minimum size of each species tagged, and the tag size used, is shown in Table 1.

The standard operating procedures for tagging developed by the South African Institute for Aquatic Biodiversity were followed for all tagging work for this study, including aseptic surgery techniques. All surgical equipment and transmitters were stored in ethanol prior to initiation of surgery. All sterilised equipment, including transmitters, was not touched until needed. The individual(s) conducting the surgery sterilised their hands before each new tagging event. Surgery was conducted only by a trained and authorised individual (MCP) and, after sufficient experience, RHL under the supervision of MCP.

Intracoelomic implantation (i.e. surgical implantation into the body cavity) was used as it is considered international best practice, despite its relative invasiveness. Transmitter retention using this approach is higher than for other forms of tagging and once the individual recovers from the surgical procedure, the transmitter is thought to have little to no

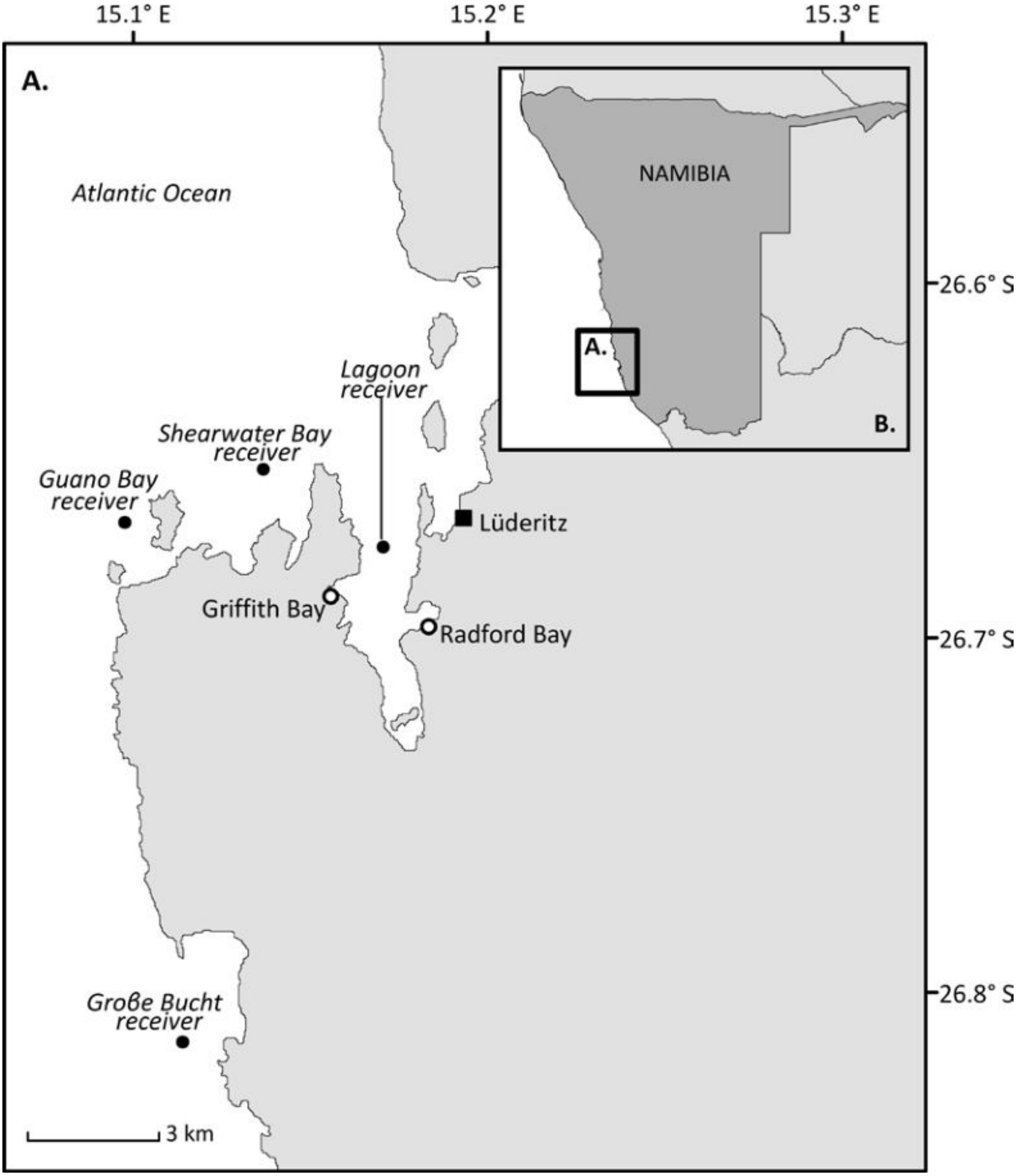

Figure 1: A. Map of the study area showing the sites where shore-based angling took place (white circles) and the receiver stations (black circles). B. Location of the study area relative to Namibia's coastline.

impact on the fish's behaviour, physiology or survival (Brown et al. 2011). A single incision was made in the ventral surface of each fish, into the coelomic cavity, using a sharp, sterile scalpel blade, and care was taken not to injure or inflict damage on internal organs. The size of the incision was kept to the minimum required to accommodate the specific transmitter to be implanted. After air drying following removal from alcohol sterilant, the transmitter was inserted into the intracoelomic cavity. The incision was closed using multiple independent pseudo-monofilament sutures (2/0 thickness) and topical antibiotic powder was applied to prevent secondary infection. The surgery was completed as efficiently as possible to minimise the amount of time that the fish was handled. Once the surgery was complete, the animal's total length or disc width and sex were recorded, and the fish was then carried in the tarpaulin into the shallows, where its body was righted. One or two individuals then walked into deeper water carrying the tarpaulin, allowing the animal to swim away when it had recovered sufficiently to do so.

A registered veterinarian oversaw the tagging training provided to RHL and the tagging process for the first two days, to ensure it was in line with the requirements of the Namibian Veterinary Council.

Monitoring array

An array composed of four acoustic receivers equipped with acoustic releases (Innovasea VR2AR 69kHz) was used to detect the presence of tagged animals (Figure 1). The acoustic release mechanism – whereby the receiver is released from its mooring once a signal from a vessel-based hydrophone has been issued, and floats to the surface for retrieval – allowed receivers to be retrieved using remote interrogation from a vessel. The mooring for each receiver comprised a 50-kg concrete anchor attached to a rope that attached to the release lug of the receiver. The receiver was attached to a separate length of rope with a sub-surface float at one end, which kept the mooring upright underwater.

Receivers were deployed on 12 February 2023 in Lüderitz's second lagoon (in water 6.6 m deep), Shearwater Bay (15 m), Guano Bay (18 m) and Grosse Bucht (26 m) and retrieved on 11 February 2024. The receiver deployment locations are shown in Figure 1.

Data Analysis

The data processing and analysis for this study were conducted using the statistical software R (R Development Core Team, 2011). To evaluate fish residency patterns, two indices were calculated: the residency index (*IR*) following the method proposed by Afonso et al. (2008), and the weighted residence index (*IWR*) based on the approach by Lino (2012). The IR was estimated by dividing the total days a fish was detected (D_d) by the number of monitoring days (D_t) (Equation 1). The IWR accounts for the number of days a fish was detected (D_d) as a proportion of total monitoring days (D_t), weighted by the interval between the first and last detection (D_i) relative to the total monitoring days (D_t)

(Equation 2). Both indices vary from 0 (no residency) to 1 (full residency) (Kraft et al. 2023b).

$$(1)\ IR = \frac{D_d}{D_t}$$

$$(2)\ IWR = \frac{D_d}{D_t} \times \frac{D_i}{D_t}$$

Indices for each individual fish were calculated for the whole array and for each receiver station.

To assess potential differences in diel detection patterns, each detection was classified into day/night using the R package suncalc (Thieurmel & Elmarhraoui 2019). The number of detections during day and night periods was compared using a Mann-Whitney U-test. In situations where two values tied for the same rank, the Monte Carlo approximation method was used to compute *p*-values and the Bonferroni correction was applied to control for multiple testing.

Results

In total, 11 elasmobranchs (ten females and one male) of three species (*Mustelus palumbes*, *Acroteriobatus blochii* and *Raja straeleni*) were tagged between 10 and 12 February 2023 at either Griffith Bay or Radford Bay south (Table 1). The mean surgery time was 9 minutes 34 seconds.

Two of the tagged animals (Mp1 and Rs4) were not detected on any of the receivers. The number of detections of the remaining animals varied considerably (Fig. 2). The only *M. palumbes* individual (Mp2) detected was the most frequently and consistently detected of all the tagged animals, being first detected on 13 February 2023 and last detected on 26 December 2023, and with detections on 90 days. The residency indices for Mp2 were thus the highest of all the tracked animals (*IR*=0.243; IWR=0.243; Table 2), with highest site-specific residency values at the Lagoon (*IR*=0.116) and Grosse Bucht (*IR*=0.073) receiver stations (Appendix 1). In contrast, the remainder of the tagged fishes were detected on between 1 and 25 days over the study period (Table 2; Fig. 2), and these fishes had lower residency indices (Table 2).

All animals presented a higher number of detections at the Lagoon station (Appendix 1) and 56% of the tagged animals for which there were detections (5 out of 9) were exclusively detected at this station. Only Mp2 was detected at all four stations (Appendix 1).

Visual inspection of the number of detections per diel phase suggested that some individuals were more frequently detected at night than during the day (Figure 3), but there were no significant differences in the number of detections between day and night periods for any of the individuals (Mann-Whitney U-test; $p>0.05$).

Table 1: Details of the tagged elasmobranchs, including the code given to each fish in the manuscript and each fish's total length (TL) or disc width (DW).

Species	Code	Sex	TL/ DW (cm)	Tag type	Tagging location	Tagging date	First detection	Last detection
M. palumbes	Mp1	F	120	V16-4L	Radford Bay	11/02/2023	no detections	n/a
M. palumbes	Mp2	F	95	V16-4L	Radford Bay	12/02/2023	13/02/2023	26/12/2023
A. blochii	Ab2	F	98	V13-1L	Radford Bay	11/02/2023	14/03/2023	24/10/2023
A. blochii	Ab3	F	103.5	V13-1L	Radford Bay	11/02/2023	05/03/2023	19/03/2023
A. blochii	Ab4	F	98	V13-1L	Radford Bay	11/02/2023	24/03/2023	25/03/2023
A. blochii	Ab5	F	102	V13-1L	Radford Bay	11/02/2023	22/02/2023	02/11/2023
A. blochii	Ab5	F	87	V13-1L	Radford Bay	12/02/2023	06/05/2023	07/05/2023
R. straeleni	Rs1	F	53 (DW)	V13-1L	Griffith Bay	10/02/2023	13/02/2023	23/03/2023
R. straeleni	Rs2	F	53.5 (DW)	V13-1L	Griffith Bay	10/02/2023	13/03/2023	13/03/2023
R. straeleni	Rs3	F	57.5 (DW)	V13-1L	Griffith Bay	10/02/2023	28/04/2023	13/01/2024
R. straeleni	Rs4	M	47 (DW)	V13-1L	Radford Bay	12/02/2023	no detections	n/a

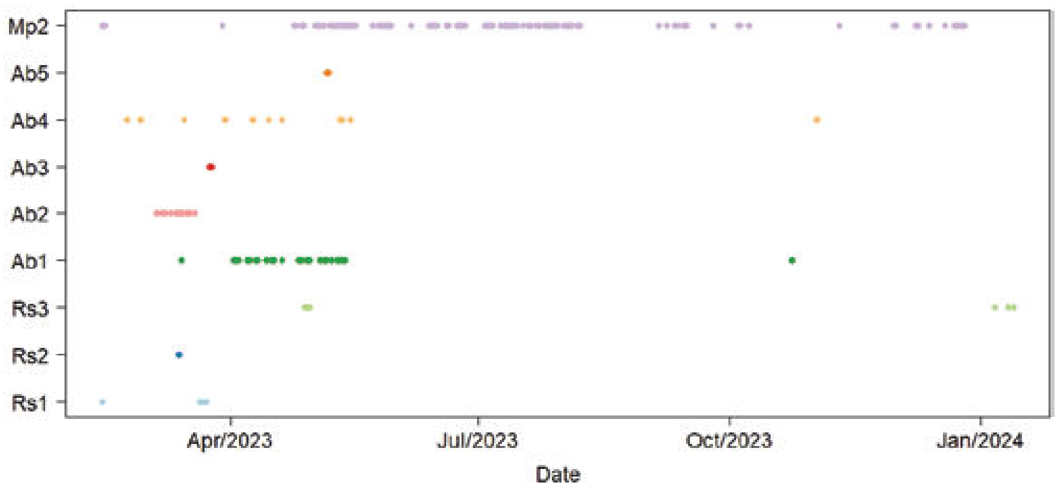

Figure 2: Abacus plot showing detections of each tagged animal on all receivers combined, between the receiver deployment (12/02/2023) and retrieval dates (11/02/2024 for three receivers and 17/02/2024 for one receiver). Mp – Mustelus palumbes*; Ab -* Acroteriobatus blochii*; Rs -* Raja straeleni.

Table 2: Residency indices of each tagged individual, for the whole array. D_d – total number of days detected, D_i – detection interval (number of days between first and last detections), D_t – monitoring interval, IR – residency index, IWR – weighted residency index.

Tagged animal	D_d	D_i	D_t	IR	IWR
Rs1	4	369	372	0.011	0.011
Rs2	1	341	372	0.003	0.002
Rs3	6	295	372	0.016	0.013
Ab1	25	340	371	0.067	0.062
Ab2	10	349	371	0.027	0.025
Ab3	2	330	371	0.005	0.005
Ab4	11	360	371	0.030	0.029
Ab5	2	287	370	0.005	0.004
Mp2	90	369	370	0.243	0.243

Discussion

This study presents, for the first time, acoustic telemetry data on three species of elasmobranchs and demonstrates the usefulness of this method in an area such as the NIMPA. Of the three species tracked in this study, one (*R. straeleni*) is listed as Near Threatened on the IUCN Red List of Threatened Species, whilst *M. palumbes* and *A. blochii* are listed as Least Concern (Jabado et al. 2021; Pollom et al. 2020; Pollom et al. 2019). *Acroteriobatus blochii* is a regional endemic, occurring only between Western Cape Province (South Africa) and Namibia. All three species are often caught by shore-based recreational anglers and both batoids have, in the past (and in the case of *R. straeleni*, as recently as 2023; R.H. Leeney pers. obs.) been used by anglers as bait for catching larger sharks. *R. straeleni* has also been recorded as a bycatch of the deepwater bottom trawl fishery for hake (R.H. Leeney unpubl. data) and *M. palumbes* may also be an occasional bycatch in Namibian fisheries, as in South Africa it is caught in bottom trawl, line and gillnet fisheries (da Silva et al. 2015). The limited spatial coverage provided by the small receiver array and the short duration of this study precluded the collection of a large dataset, and thus do not allow for any significant conclusions to be made regarding the movements of the tagged animals. Nonetheless, this project has provided useful preliminary data that can be used in the development of future management and monitoring work in the NIMPA.

The consistency of detections for one *M. palumbes* individual throughout the study period suggests a high degree of residency in the area covered by the receivers. Acoustic

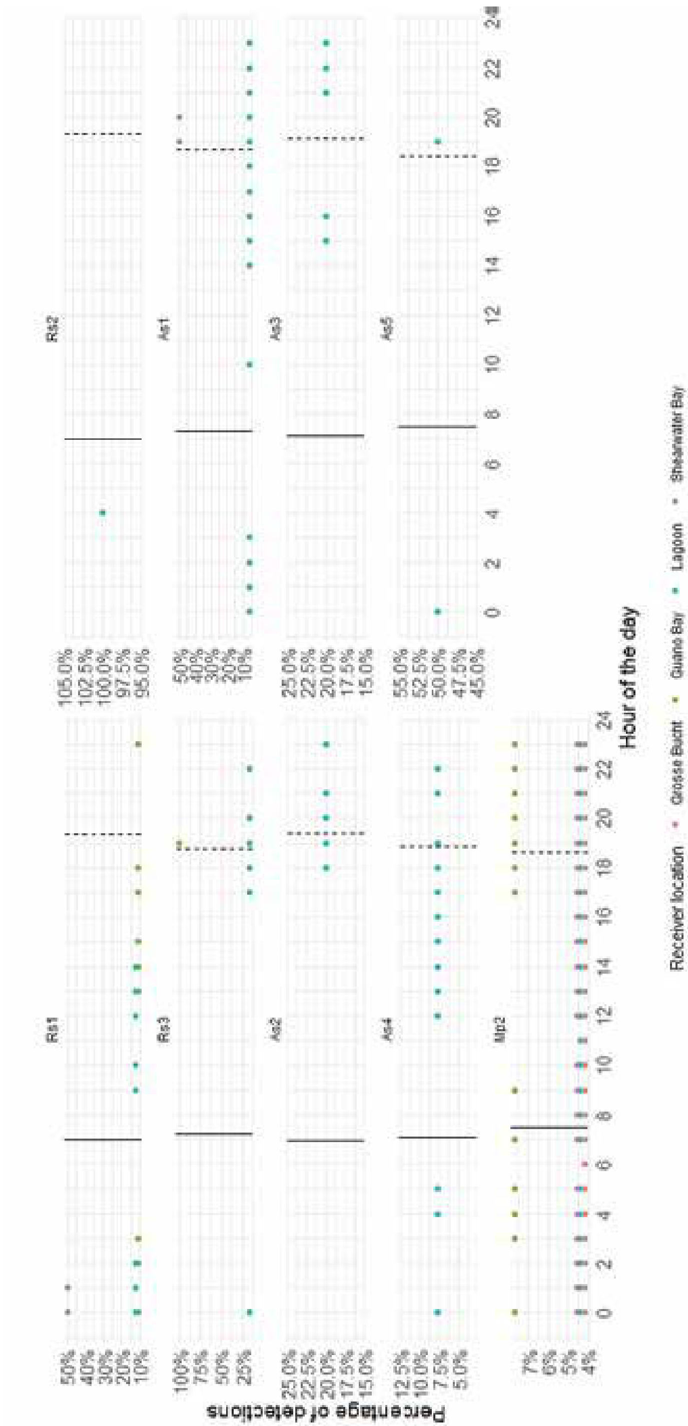

Figure 3: Proportions of all detections for each tagged fish, in each hour of the day. The colour of each point represents the different stations. The solid line indicates the mean sunrise and the dotted line the mean sunset time (estimated using the R package suncalc).

telemetry may thus be an ideal method for tracking the movements of this species. The highest residency index values for this individual were in the lagoon, and the majority of detections for all the other tagged animals also came from the lagoon receiver. This highlights that this habitat may be regularly used by several elasmobranch species, despite its proximity to Lüderitz port and the likely impacts of numerous human activities in the area, including vessel traffic and various aquaculture projects. The presence of large numbers of eggcases from *R. straeleni* and *Rostroraja alba* (spearnose/white skate) on the beach at Griffith Bay (R.H. Leeney, pers. obs. February 2024) suggests that these two species may use an area inside the lagoon as a 'nursery' area for eggcase deposition. This further emphasises the importance of mitigating the impacts of human activities on the lagoons, and ensuring that they are considered as important habitats within the NIMPA.

There are several possible reasons why two of the tagged animals were not detected on the receivers. The most likely reason, given the very limited extent of the receiver array, is that they may have moved beyond the range of any of the receivers, immediately after they were tagged, and during the course of the study simply not returned to an area in which they would have been detected. Their tags may have been faulty and unable to transmit, although this is unlikely as each tag was checked to ensure it was functioning before it was used. The tagged animals may have been caught by fishers and not released alive. Finally, the animals may have been predated after the tagging process or may have died as a result of the surgery. Research has shown that there is high variability amongst shark species in responses to capture and release (Binstock et al. 2023), and likely this is also the case for responses to the tagging process. Since this is, as far as we are aware, the first time that these three species have been tagged using acoustic transmitters inserted surgically, there are no available data on how each species responds to the tagging process.

Light can be a cue for diel or seasonal patterns of activity in elasmobranchs (Carroll and Harvey-Carroll 2023). However, there were no discernible diel patterns to detections of any of the tagged animals. This may have been because the full extent of each animal's daily movements was not captured by the limited spatial coverage provided by our receiver array.

All but one of the elasmobranchs caught and tagged in the NIMPA were female, suggesting that there may be some sexual segregation for one or more of the study species. Sexual segregation has been documented for many shark species (e.g. Braccini and Taylor 2016; Kock et al. 2013; Mucientes et al. 2009) and also for batoids (Simpson et al. 2021). Further research is required to investigate whether there is any spatial segregation of males and females of any of the species tagged in this study.

Data on the movements of aquatic animals can contribute to both fisheries management and marine spatial planning, for example when making evidence-based cases for spatial or temporal protections from activities such as fishing, shipping and marine renewable energy installations (Lennox et al. 2023). The gaps in data on the movement ecology of elasmobranchs in Namibian waters may hinder the effective management of these animals. Previous studies have documented that bronze whalers (*Carcharhinus brachyurus*) regularly travel between South African and Namibian waters (Rogers et al. 2022) and this may also be true for other species. In contrast, broadnose sevengill sharks (*Notorynchus cepedianus*), one of the largest shark species present in the NIMPA, show a high level of site fidelity and do not appear to move regularly between Namibian and South African waters (Engelbrecht et al. 2020). Understanding these patterns in movement and habitat use, for the different focal species in the NIMPA, is essential for the management of elasmobranch species and for understanding the role that MPAs play in protecting species with varying levels of connectivity with other regions. If there is to be any zoning of the NIMPA in the future, to ensure that critical habitats are protected from potentially harmful activities, then having movement data for species of conservation interest will be essential.

This work, although spatially and temporally limited, demonstrates the value of acoustic telemetry data for understanding the movements and patterns in habitat use of species inhabiting an MPA. Establishing an expanded array of receivers to cover the entire NIMPA, and ideally extending into unprotected waters to the north and south, would provide insight into whether the species tracked during this study are adequately protected by the protected area. Future acoustic telemetry studies should perhaps rather focus on threatened chondrichthyan species inhabiting the NIMPA such as tope *Galeorhinus galeus* (listed as Critically Endangered; Walker et al. 2020), bronze whaler shark *Carcharhinus brachyurus* (Vulnerable; Huveneers et al. 2020) and *Rostroraja alba* (Endangered; Dulvy et al. 2006). Tracking the movements of those species would provide insight into the level of protection afforded them by the NIMPA, and whether they are exposed to threats present outside the NIMPA, in particular bycatch in industrial fisheries. Other species of interest, including teleost species that use the waters of the NIMPA and that have value for commercial fisheries and recreational anglers, could also be tagged. Investing in a receiver array and establishing a tracking programme to track multiple species would maximise the value of the required investment in equipment, and result in a wealth of useful data for managers and scientists.

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Appendix 1

Residency indices of each tagged individual at each station. D_d – total number of days detected, D_i – detection interval (number of days between first and last detections), D_t – monitoring interval, IR – residency index, IWR – weighted residency index.

Code	Station	D_d	D_i	D_t	*IR*	*IWR*
Rs1	Guano Bay	2	331	372	0.005	0.005
Rs1	Lagoon	2	333	372	0.005	0.005
Rs1	Shearwater Bay	1	332	372	0.003	0.002
Rs2	Lagoon	1	341	372	0.003	0.002
Rs3	Guano Bay	1	42	372	0.003	0.000
Rs3	Lagoon	5	35	372	0.013	0.001
Ab1	Lagoon	24	280	371	0.065	0.049
Ab1	Shearwater Bay	1	116	371	0.003	0.001
Ab2	Lagoon	10	335	371	0.027	0.024
Ab3	Lagoon	2	329	371	0.005	0.005
Ab4	Lagoon	11	107	371	0.030	0.009
Ab5	Lagoon	2	286	370	0.005	0.004
Mp2	Groβe Bucht	27	165	370	0.073	0.033
Mp2	Guano Bay	7	78	370	0.019	0.004
Mp2	Lagoon	43	53	370	0.116	0.017
Mp2	Shearwater Bay	16	54	370	0.043	0.006

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