The foraging distribution of Cape gannets in relation to Addo Elephant National Park Marine Protected Area

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Abstract

Seabirds are considered to be the sentinels of the ocean, as they are able to locate their prey in spite of the great heterogeneity of the marine environment. During the breeding season, these central-place foragers not only need to find prey to maintain themselves but also to feed their young. The changes in the distribution of their prey due to environmental and human activity factors can affect their individual and population health.

In order to protect the local biodiversity, the Addo Elephant National Park Marine Protected Area was proclaimed in 2019 in Algoa Bay, Eastern Cape, South Africa. Bird Island (Algoa Bay) hosts the largest Cape gannet (*Morus capensis*) colony in the world and lies within Addo Elephant Nation Park Marine Protected Area. This Marine Protected Area aims to offer refuge to a vast variety of species and promote fisheries sustainability.

This study is focused on the foraging distribution of Cape gannets in relation to Addo Elephant National Park Marine Protected Area. The deployment of adult Cape gannets with GPS devices during the rearing season of 2021, enabled the analysis of their foraging range, behaviour, and the speculation on possible enhancements in their foraging effort as a result of the implementation of this Marine Protected Area.

These top predators showed a variety of distributions, but the majority of the birds stayed in the vicinity of Algoa Bay. Their behaviour was classified and feeding grounds related to the Marine Protected Area were identified. Comparison to previous data from 2010 until 2020 indicated a fluctuating foraging range, but showed a possible reduction in the gannet distribution since the Marine Protected Area implementation. Last, an area of high activity was identified and paired with results from previous studies. In conclusion, this location could be proposed as an additional Marine Protected Area after further investigation.

This research provides an assessment of the foraging distribution of Cape gannets that can be used for their management, but also for the monitoring of the Addo Elephant National Park Marine Protected Area.

Keywords: Cape gannets, *Morus capensis*, Marine Protected Areas, Addo Elephant National Park Marine Protected Area, foraging distribution

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Abbreviations

MPA	Marine Protected Area
AENP MPA	Addo Elephant National Park Marine Protected Area
BI MPA	Bird Island Marine Protected Area
MSP	Marine Spatial Planning
SANParks	South African National Parks
GPS	Global Positioning System
NA	Non-Applicable
QGIS	Quantum Geographic Information System

1. Introduction

Understanding the foraging distribution of the animal species is a key component of conservation and management (Cherel & Hobson 2007). This becomes particularly challenging in the marine environment, as the oceans are characterized by great heterogeneity (Russell et al. 1992; Adams & Klages 1999). Apart from the complexity of the oceanographic features, what is also important to consider when studying the distribution of marine life is climate change (Crawford et al. 2015) and the influence of human activity (Crawford et al. 1983; Pichegru et al. 2007). Seabirds are thought to be important ecosystem indicators (Cairns 1987; Adams & Klages 1999; Piatt et al. 2007). Their foraging distribution and diet composition can portray the occurrence of their fish prey (Cairns 1987; Russell et al. 1992). Consequently, by combining the species range with the environmental conditions, we can work towards their conservation and management (Piatt et al. 2007).

Such an ecosystem indicator is the marine top predator Cape gannet (*Morus capensis*) (Adams & Navarro 2005; Distiller et al. 2012). Cape gannets are seabirds endemic to southern Africa, which predate mainly on sardines (*Sardinops sagax*) and anchovies (*Engraulis encrasicolus*) (Crawford et al. 1983; Adams & Navarro 2005) by plunge-diving (Berruti et al. 1993; Gremillet et al. 2004). These central-place foragers breed on six islands: Mercury, Ichaboe, and Possession Islands in Namibia and Bird Island (Lambert's bay), Malgas Island, and Bird Island (Algoa Bay) in South Africa (Crawford et al. 1983; Berruti et al. 1993). Their population numbers have fluctuated variably over the decades, due to mortality in fisheries (Grémillet et al. 2019), predation on colonies by Kelp gulls (*Larus dominicanus*) (Green & Pistorius 2013) or around the colonies by Cape fur seals (*Arctocephalus pusillus pusillus*) (Makhado et al. 2006), colony disturbance by visitors, oiling, disease, extreme weather events (Pistorius et al. 2015), guano collection, but principally, scarcity of prey (E Mullers et al. n.d.) and climate change (Crawford et al. 1983; Sherley et al. 2019). While in the middle of the 20th century, their population size counted approximately 250 000 pairs (M Crawford et al. 1956, 2007), in 2018/2019 they were estimated to number around 135 000 pairs (Sherley et al. 2019). In addition to that, as a consequence of the reasons mentioned above, the colonies in the west, located in the Benguela upwelling system, have declined dramatically (Sherley et al. 2019). Cape gannets in Namibia only account for approximately 7% of the total population (M Crawford et al. 2007). On the contrary,

the colony on Bird Island (Algoa Bay) in the south-east of South Africa has increased five-fold since the 1950s (Sherley et al. 2019). This is likely to be attributed to the over-exploitation of the fish stocks in the west and the subsequent eastward shift in the distribution of sardines and anchovies (Brooke 2004; Fairweather et al. 2006; Van Der Lingen et al. 2006; Coetzee et al. 2008). The abundance of Cape gannets is significantly correlated to the distribution of energy-rich prey (Cairns 1987; Lewis et al. 2006) as a result of their high energetic demands (Green et al. 2015b). The lack of an energy-rich diet can have repercussions on the adult survival, body condition, reproduction, chick quality, and growth (E Mullers et al. n.d.) and cause increased foraging effort (Crawford et al. 1983; Cairns 1987). It can also lead to the exploitation of fishery discards from trawlers and the consumption of low-quality prey (Crawford et al. 1983). These factors have a great influence on the individual's but also the population's health (Mullers & Navarro 2010). The colony on Bird Island (Algoa Bay) currently consists of 70% of the total Cape gannet population worldwide, counting approximately 90 000 breeding pairs (M Crawford et al. 2007; Botha & Pistorius 2018).

Algoa Bay is vastly influenced by the Agulhas Current coming from the Indian Ocean (Schumann 1987; Goschen & Schumann 1988). Warm water is transported from the tropical and subtropical regions along with a variety of species (Schumann 1987; Goschen & Schumann 1988). Together with the narrow shelf edge and the prevailing winds that characterize the coastal oceans of south-east Africa (Schumann 1987; Jacobs et al. 2022), they create an environment that varies substantially (Schumann 1987) both in the short and in the long term (Goschen & Schumann 1988; Distiller et al. 2012). Large meanders, shelf-edge eddies, and upwellings mix the warm with the cold water resulting in an oceanic environment rich in nutrients and biodiversity (Schumann 1987; Jacobs et al. 2022). Concomitantly, they render this marine environment as highly unpredictable (Schumann 1987; Jacobs et al. 2022). Thus, Algoa Bay and the broader area of Agulhas Bank have significant ecological and socio-economic importance, thanks to their species richness (Grantham et al. 2011).

The need for exploiting South Africa's marine economic resources, while protecting the oceans, created "Operation Phakisa" in 2014. Its major component was the Marine Spatial Planning (MSP) that would provide knowledge on how the oceans can be managed sustainably for the benefit of their stakeholders (Dorrington et al. 2018; Mcateer et al. 2022). The "Algoa Bay Project" was established in 2017 to support the MSP for Algoa Bay. Its biophysical, governance, and socio-economic research were expected to result in an update on each ecosystem (Dorrington et al. 2018). In 2019, the newly established Addo Elephant National Park Marine Protected Area (AENP MPA) expanded the former Bird Island Marine Protected Area (BI MPA), covering a large part of Algoa Bay. It is zoned into "Controlled" and "Restricted" areas where its stakeholders can operate with the relevant permits.

Like all the Marine Protected Areas (MPAs) in South Africa, it aims to protect its biodiversity and marine ecosystems, promote a sustainable fishing industry, manage the bycatch, and support research and monitoring to create an integrated governance framework (Sink et al. 2011; Grorud-Colvert et al. 2021). The MPA benefits can also span beyond its boundaries, through the distribution of larvae and juvenile species or the protection of critical life stages of key species (Grorud-Colvert et al. 2021). Overall, MPAs need to go through 4 stages of establishment to facilitate their creation. Many conditions are required for each stage to make an MPA effective and their level of protection evaluates their ecological outcomes (Grorud-Colvert et al. 2021).

The purpose of this research is to study the foraging distribution of Cape gannets breeding on Bird Island (Algoa Bay) in relation to AENP MPA and to demonstrate if and how they utilize the MPA during the guard phase of the rearing season of 2021. This is achieved by depicting the foraging range of 27 adult gannets, calculating the foraging trip parameters, and comparing their activity to the MPA boundaries. In particular, their behaviour is classified into "foraging", "resting" and "traveling" and the time spent for each behaviour inside and outside the MPAs is estimated. Emphasis is given on the foraging grounds of the birds in relation to the MPA. Furthermore, the foraging distribution of these results is compared to previous data obtained during the guard phase of the rearing seasons 2010-2020. Even though there is a distribution fluctuation over the years, it can be supported that there might be a significant range reduction since the enlargement of the MPA. Last, an area of high activity is identified as of importance and combined with previous research. Various studies highlight the rich biodiversity of this area and the variety of species utilizing it as a feeding ground. Therefore, further monitoring and its consideration in the MSP as an MPA are suggested.

The relevance of this study lies within the conservation management of Cape gannets and the monitoring and evaluation of the AENP MPA. Its purpose is to provide input regarding the gannet distribution and, hence, the distribution of resources in Algoa Bay. Hopefully, it can contribute to the "Algoa Bay Project" and the AENP MPA assessment.

2. Materials & Methods

2.1 Ethics statement

The collection of data for this study took place in accordance with the guidelines and the approval of both SANParks and the Nelson Mandela University Ethics Committee (references A10-SCI-ZOO-008 and A18-SCI-ZOO-009). Our team, which consisted of 2 people, tried not to cause any distress to the birds while being on the island. A fair distance was always kept from the colony in avoidance of causing stress. Only birds with nests on the perimeter of the colony were targeted for deployment for the same reason. The weight of the GPS devices was less than 1% of the adult total body mass, thus they did not cause any inconvenience (Gremillet et al. 2004; Adams & Navarro 2005). Handling was kept to a minimum and never exceeded a 10-minute period to limit stress as proposed (Botha & Pistorius 2018). During the GPS retrievals, as the chick would stay alone on the nest, it would get covered with vegetation in avoidance of predation by Kelp gulls or sunburn. While the parent was being handled, the chick would be observed at all times. If the adult bird did not return to the nest immediately after the GPS retrieval, it would be observed until its successful arrival at the nest. The livestock spray used for marking the tagged adults on the chest was almost entirely removed after the foraging trip and was expected to fade completely shortly thereafter.

2.2 Study site

The study site of this project is Bird Island (33◦ 50′ 26″S 26◦ 17′ 10″E), Algoa Bay, Eastern Cape, South Africa. Algoa Bay is a gulf facing the southwest Indian Ocean on the southeast side of the African continent (Goschen & Schumann 1988; Stewardson et al. 2012). It spans from Cape Recife in the west to Cape Padrone in the east (Stewardson et al. 2012). The effect of the Agulhas ocean current in the area determines several oceanographic and climate features (Schumann 1987; Stewardson et al. 2012). Bird Island, Seal Island, Stag Island, and Black Rocks form the Addo Elephant Islands and are located inside the Addo Elephant National Park Marine Protected Area (AENP MPA) in Algoa Bay, approximately 8-9 km from

the mainland. The Islets of St Croix are also within the boundaries of Algoa Bay (Stewardson et al. 2012). Bird Island is the largest breeding site for Cape Gannets in South Africa, and the largest gannetry in the world, hosting approximately 90 000 breeding pairs (M Crawford et al. 2007; Botha & Pistorius 2018).

The fieldwork took place during the guard phase of the breeding season in 2021. The arrival on the island was on December 4th, 2021, and the fieldtrip lasted 8 days including the arrival and departure.

Figure 1 Cape gannet colony on Bird Island, Algoa Bay. Photo taken by Pelagia Maria Tsousi.

2.3 Deployments

The deployment of GPS devices on 30 adult Cape gannets, started on the 6th of December 2021, and ended on the 8th of December 2021. The last GPS was retrieved on the 10th of December 2021. This period falls within the guard phase of the rearing season of Cape gannets. This means that the parents take turns on the foraging trips. One parent remains on the nest to guard the chick and the other is traveling in search of prey. Adult birds that were sitting on a nest in the perimeter of the colony and had a chick of the desired size were eligible for deployment. The chick should preferably be small and black without feathers or medium-sized with a few white feathers. This development stage requires the adults to make shorter trips to fulfill the chick's feeding needs (Botha & Pistorius 2018). At the same time, this limited the waiting period for the adult to return. When the bird's partner would return from its foraging trip, and after preening, the bird that was waiting on the nest would be captured and tagged before its departure for the foraging trip. By doing so, the bird would be tagged immediately before the foraging trip, while the other parent would stay on the nest, to feed and protect the chick from threats.

For the captivation, a 3-meter-long crooked pole was utilized, in order to keep distance from the colony while capturing the birds from their long necks. During the deployments, one person would hold the bird and the other would make notes and attach the GPS device on the 3 central feathers of the bird's tail using black, waterproof Tesa ® tape (Tesa, Hamburg, Germany). The devices used (CatLog-S, Catnip Technologies, Hong Kong or Axy-trek GiPSy-5, TechnoSmart, Italy) were weighing less than 25 g (~0.9% of adult body mass) (Botha & Pistorius 2018). Cape gannets were weighing from 2.4 to 3.1 kilograms (own measurements), and thus the devices did not cause any inconvenience. After the deployment, the bird was marked on the chest with a Spraymate ® Fast Drying (Spraymate P Ltd, Randvaal, South Africa) and released towards the departure runway. A big rock covered in green Tesa ® tape (Tesa, Hamburg, Germany) would be placed next to the nest of the recently tagged bird. The purpose of this method was to know where to be expecting a tagged parent to return.

The GPS device retrievals were taking place following a similar procedure. In all of the cases, the tagged bird had already returned from the foraging trip and was sitting on the nest, while the other parent had already left. Provided the absence of the second parent, the chick would be exposed while we were handling the tagged bird. In avoidance of predation from Kelp gulls or sunburn, the chick would be covered with vegetation. After the GPS retrieval, the vegetation and the rock covered in green tape were removed from the nest. The adult bird was being released towards the nest and observed if it had returned successfully.

2.4 Data Analysis

Out of the 30 GPS devices, one failed the extrapolation of data, and two foraging trips were significantly incomplete due to battery failure. Thus, the analysis was performed on 27 single foraging trips that lasted one or two days.

2.4.1 Initial data manipulation

The data collected from the foraging trips were manipulated and analysed using R statistical environment (R Core Team 2020). First, the data were retrieved from the GPS devices. After converting them into .csv files, the two types of data were brought in the same format. All the non-applicable (NA) values were removed and only the information that was of essence for the analysis was kept. All files were combined in one dataset and put in the correct date and time format. The packages installed for this step were "lubridate" (Grolemund & Wickham 2011), "data.table" (Dowle & Srinisavan 2022), and "tidyverse" (Wickham et al. 2019).

Next, the time duplicates and the points that were recorded after the devices had been removed from the birds were deleted from each track and the trajectories were

plotted. The packages downloaded were “trip” (Sumner et al. 2009), “sf” (Pebesma 2018), and “adehabitatLT” (Calenge 2006). To check for the validity of the results the “amt” package (Singer et al. 2019) was applied.

2.4.2 Movement metrics

The movement metrics of the bird trajectories, such as turning angles, bursts, step length, and relocations were calculated using the “bcpa” package (Gurarie 2013). For the calculation of total, maximum, and mean distances travelled, the Net-Squared Displacement (NSD) model was used from the “amt” package (Singer et al. 2019). The duration of each trip was also calculated at this step.

2.4.3 Trips and behaviour classification

Each trip got segmented into 3 behaviours, namely “foraging”, “resting” and “traveling”. Concerning their classification, a Behavioural Change Point Analysis was operated via the “bcpa” package (Gurarie 2013). Points with similar autocorrelation and velocity values were clustered together by the model. By examining the speed and the autocorrelation of each group of points, a behaviour was assigned to each entry. The results of the behaviour classification were illustrated by time spent and in relation to the MPA using the “ggplot2” (Wickham 2016) and the “viridis” (Garnier et al. 2021) packages.

2.4.4 Foraging distribution in comparison to previous years

In the interest of getting an image of the foraging distribution of Cape gannets over the years, the data collected during the guard phases of the rearing seasons 2010-2020 were plotted. The comparison of the results of 2021 to the foraging trips of the previous years took place using the “ggplot2” (Wickham 2016), “ggspatial” (Dunnington 2022), and “ggsn” (Baquero 2019) packages.

2.4.5 Area of high activity

After visual inspection of the foraging trips in QGIS 3.2, an area of high gannet activity was observed. A density evaluation was performed through the “ggplot2” package (Wickham 2016) to validate these speculations. Moreover, a density evaluation of the behaviours was enacted. In pursuance of observing if this was a repetitive behaviour, the density evaluation was performed for the data collected during 2010-2020 as well.

3. Results

The tracking data concern 27 adult Cape gannets with young chicks during the guard phase of the rearing season of 2021. Each track corresponds to one foraging trip of one adult gannet.

3.1 Foraging distribution

The distribution of Cape gannets varied depending on the individual, with some birds traveling relatively close to the colony and others traveling a few hundred kilometres in search of feeding ground. Notably, there was a bird that travelled more than 350 km away from the colony, until Sedgefield in Western Cape, and spent 2 nights at sea. Six birds travelled as far as Tsitsikamma MPA (~200-270 km from Bird Island), six birds travelled until Cape St. Francis (~140-160 km from the colony), while 13 gannets remained in the vicinity of Algoa Bay, not exceeding a maximum distance of ~100 km or less from the colony. The easternmost foraging trip was until the estuarine of Mtati River, 113 km from the colony, and inside the Amathole Offshore Marine Protected Area (Figure 2).

Some of the devices failed to record the full foraging trip. In three cases, the missing points are of minor importance, as it is clear that the birds were on their return flight and in proximity to the colony. In 9 cases, the foraging trips were incomplete to a greater degree. Provided that, there is not a clear image of their total foraging trip. However, those foraging trips were kept in the dataset and analysed, as the sample size of the project was relatively small. More importantly, some of them contained essential activity within or close to the AENP MPA.

Table 1 Maximum and mean distances travelled by each individual. The trips marked as incomplete prohibit us from drawing a clear conclusion about the maximum and mean distances travelled. The trips marked as incomplete with an asterisk (*) were not importantly affected.

Cape gannet ID	Maximum distance (km)	Mean distance (km)	Incomplete trips
CAGA01_06122021	232.7579083	14.147313	No
CAGA02_06122021	56.70534348	4.326674656	No
CAGA03_06122021	22.21359112	1.649184826	No
CAGA04_06122021	84.71582027	5.313350426	No
CAGA05_06122021	270.0723604	15.85636772	No
CAGA06_06122021	146.8006998	10.24736621	No
CAGA07_06122021	143.4558378	10.24192441	No
CAGA08_06122021	161.7551857	11.46833481	No
CAGA09_06122021	270.7331567	15.14714917	No
CAGA10_06122021	127.9637482	9.074682707	No
CAGA11_06122021	83.70857072	4.425263314	Yes
CAGA12_06122021	96.65431923	7.669345623	Yes
CAGA13_06122021	38.14260736	3.186055538	Yes
CAGA14_07122021	113.5283981	2.407991081	Yes
CAGA15_07122021	47.01983749	3.3470649	Yes
CAGA16_07122021	82.4626939	4.019649874	Yes
CAGA18_07122021	206.2328452	15.73706644	Yes
CAGA19_07122021	219.2111123	12.83572564	Yes
CAGA20_07122021	85.3747643	5.906373774	Yes
CAGA21_07122021	81.28235992	5.14405175	No
CAGA22_07122021	80.46423751	5.531473455	No
CAGA23_07122021	79.7949141	5.225747147	Yes*
CAGA24_07122021	46.06544256	2.849511481	Yes*
CAGA26_08122021	211.1004191	14.29657797	No
CAGA27_08122021	363.6052188	24.88457362	Yes*
CAGA28_08122021	121.7724158	24.88457362	No
CAGA29_08122021	138.422149	10.72887476	No

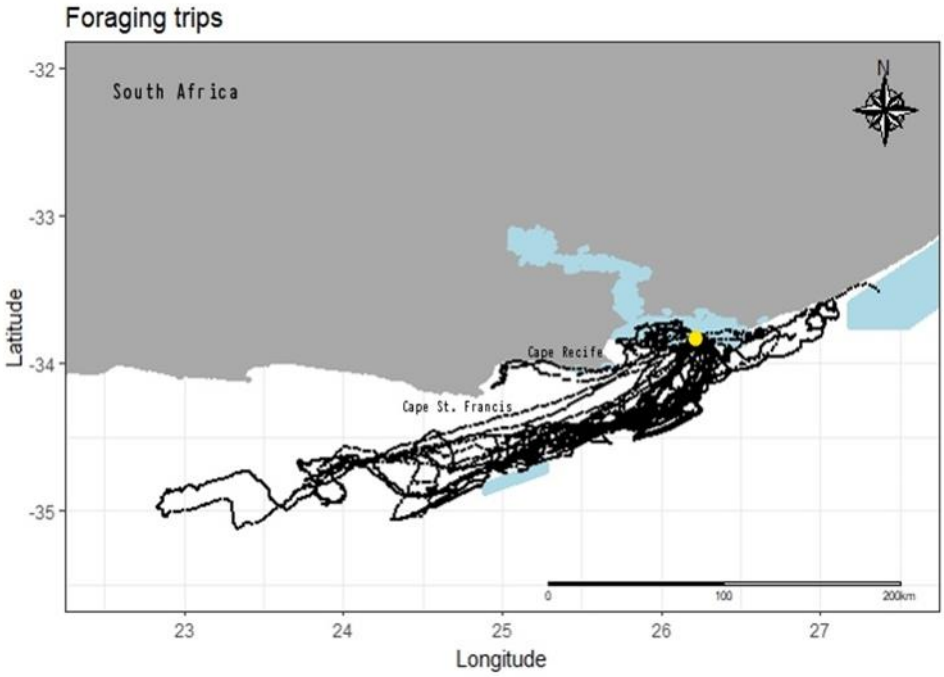

Figure 2 Foraging trips of 27 adult Cape gannets during the guard phase of the rearing season 2021. The grey part represents part of South Africa, the light blue areas are MPAs in the area, and the black points illustrate the individual foraging trips. The yellow point depicts the location of the colony on Bird Island. Made with R (R core team 2020).

3.2 Foraging trip parameters

For an overview of the foraging trips, the following parameters were accounted for: total distance travelled, maximum distance travelled, mean distance travelled, trip duration, and nights spent at sea. As mentioned above, 9 tracks were incomplete. In some of the cases, it can be speculated that these birds did not make a foraging trip further than the vicinity of Algoa Bay, but this is unsure. As a consequence, the total, maximum, and mean distances travelled that can be seen in Tables 1 & 2, only contain the available information. Half of the incomplete trips were depicting the second half of the trip, i.e., they are missing the departure but contain the returning trip to the colony. As the deployment and retrieval times were noted during the fieldwork, the start and end times of the foraging trips were corrected. Therefore, the duration of the trips was calculated accurately. The same applies to the results on the nights spent at sea. 85.18% of the gannets spent 1 night at sea, while 7.41% spent 0 nights and the rest 7.41% spent 2 nights at sea.

Table 2 Foraging trip parameters. The table demonstrates the total, maximum, and mean distances travelled in kilometres, the duration of the trips in hours, and the nights spent at sea by 27 Cape gannets.

Total distance (km)	Maximum distance (km)	Mean distance (km)	Duration (hours)	Nights spent at sea
619.78 (24.24 – 3765)	138.73 (22.2 – 363.6)	8.61 (1.64 – 24.8)	24.56 (5.09 – 52.99)	1 (0 – 2)

3.3 Foraging trip behaviours

The classification of the behaviours during the foraging trips played a significant role in understanding the important feeding grounds of Cape gannets during the guard phase of the rearing season of 2021. More specifically, 3 behaviours were determined (foraging, resting, and traveling) during the foraging trips. The interest was focused on the amount of time spent overall on each behaviour (Figure 3), as well as the time spent on each behaviour inside and outside the MPA (Figure 4). The main focus was turned on the foraging behaviour. It is evident that, overall, the birds spent most of their time resting on the sea surface. It has been documented before, that Cape gannets rest on the surface of the water during the night (Adams & Klages 1999) and this was the case, too, in this study. From approximately sunset until dawn, the velocity was extremely low, indicating lack of movement and therefore, resting behaviour. Previous studies have documented the foraging behaviour of gannets in more detail, accounting for isolated dives, feeding bouts, and foraging only by submerging their head in the water while resting on the sea surface (Ropert-Coudert et al. 2004). Nevertheless, in this project, foraging is considered only the behaviour where the individuals actively search for prey by making circles above an area and performing foraging bouts, i.e., consecutive plunges in the water (more than 3 dives). This is because the main foraging grounds are attempted to be determined in this study. The bout size and the distance between the dives within a feeding event have been positively correlated to the size and density of the prey patch (Sommerfeld et al. 2015), and so the attention is turned to these events. The gannets spent approximately 30% of the time foraging during the trips. Resting accounted for a little more than 35% of the time and traveling for a bit less than 35% of the time spent during the foraging trip (Figure 3). Out of the total foraging points 8.81% fall within the MPA, whereas 91.1% fall outside of the MPA boundaries.

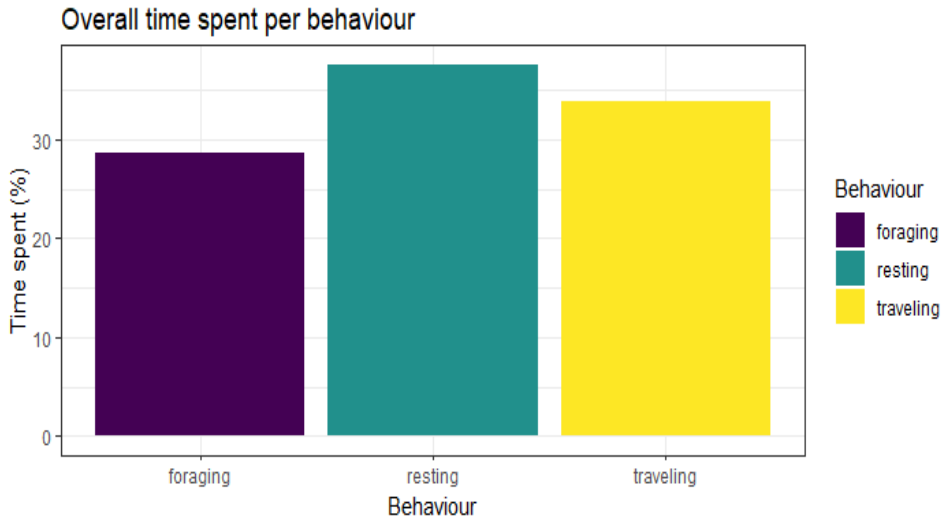

Figure 3 Overall time spent per behaviour. This plot depicts the overall proportion of time spent on foraging (purple), resting (green), and traveling (yellow) during the single foraging trips of 27 individuals. Made with R (R Core Team 2020).

3.3.1 Overlap with the MPA

When comparing the time spent on each behaviour inside and outside the MPA, the following is observed: Inside the MPA foraging occupies more than 50% of the time spent, resting accounts for less than 10% and traveling is approximately 40%. When outside of the MPA, foraging accounts for less than 30% of the total time. Resting accounts for more than 35% and, last, traveling is less than 35% (Figure 4).

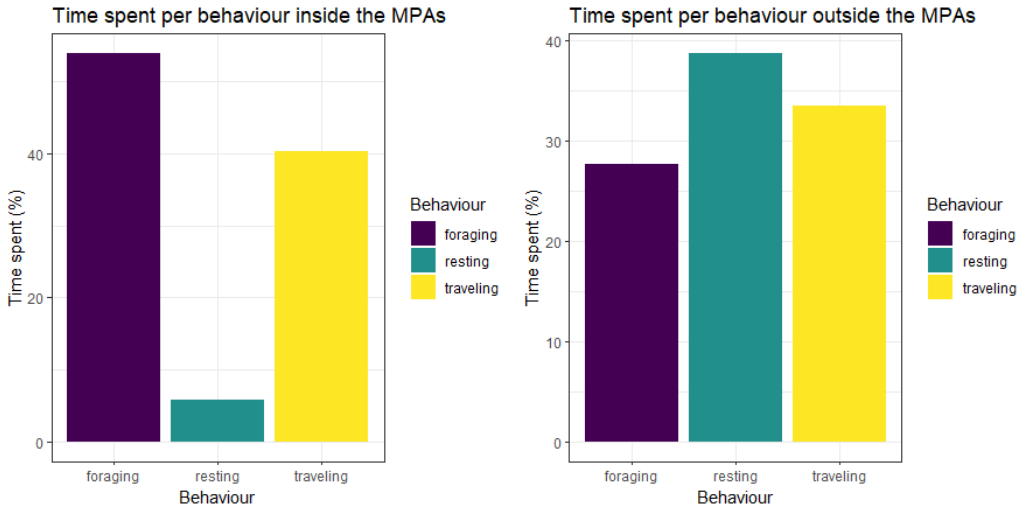

Figure 4 Time spent (%) on each behaviour inside and out outside the MPA. This plot depicts the proportion of time spent on foraging (purple), resting (green), and traveling (yellow) during the single foraging trips of 27 individuals inside (left) and outside (right) the MPA. Made with R (R Core Team 2020).

As for the identification of the feeding grounds, 4 gannets were found to forage inside AENP MPA, 6 gannets up to 20 km outside the MPA and 3 birds had feeding grounds in the vicinity of Algoa Bay (up to 40 km away from the MPA). The rest of the adults had longer foraging trips and their feeding grounds were offshore. Figure 5 illustrates an example of how the feeding grounds were detected using the Behavioural Change Point Analysis on the tracks.

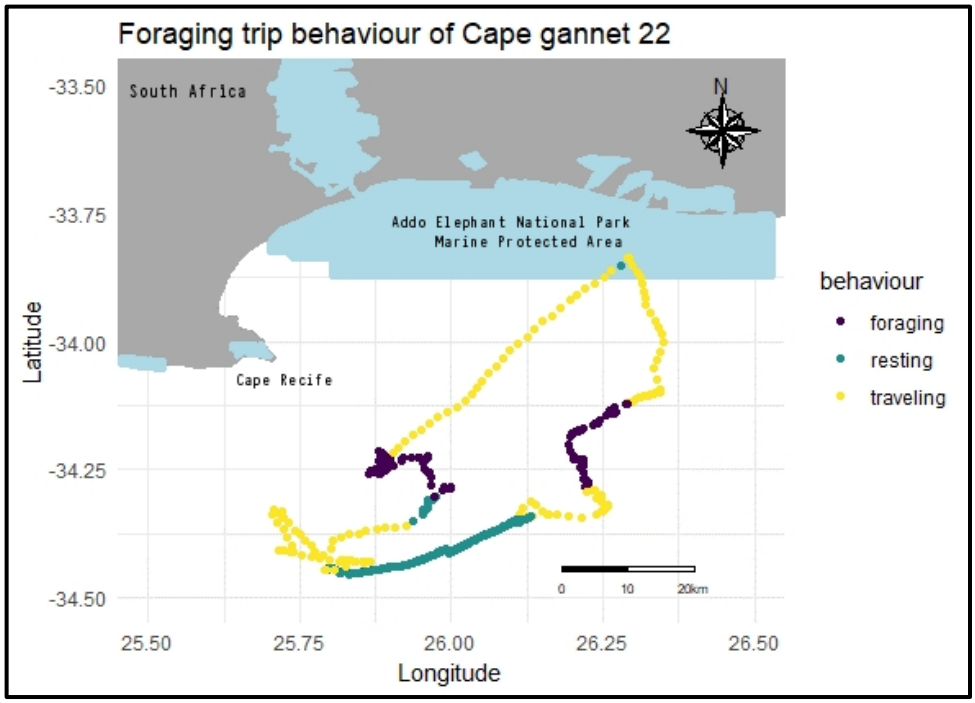

Figure 5 Example of the application of the Behavioural Change Point Analysis on the foraging trip of Cape gannet 22. The foraging points are illustrated in purple, the resting points in green, and the traveling points in yellow. The trip starts and ends at the colony on Bird Island inside the AENP MPA. Made with R (R Core Team 2020).

3.4 Foraging distribution in comparison to previous years

The GPS tracks from the guard phases of the rearing seasons of 2010-2020, collected by previous research on Cape gannets' distribution, were used to illustrate these foraging trips. What was particularly of interest to study, was the potential change in the foraging distribution after the enlargement of the MPA in 2019. In Figure 6, the foraging distribution during the rearing seasons of 2010-2018 is demonstrated in orange, and the foraging distribution from 2019 until 2021 is represented in black. The range is shorter both in longitude and latitude for the years after the MPA enlargement.

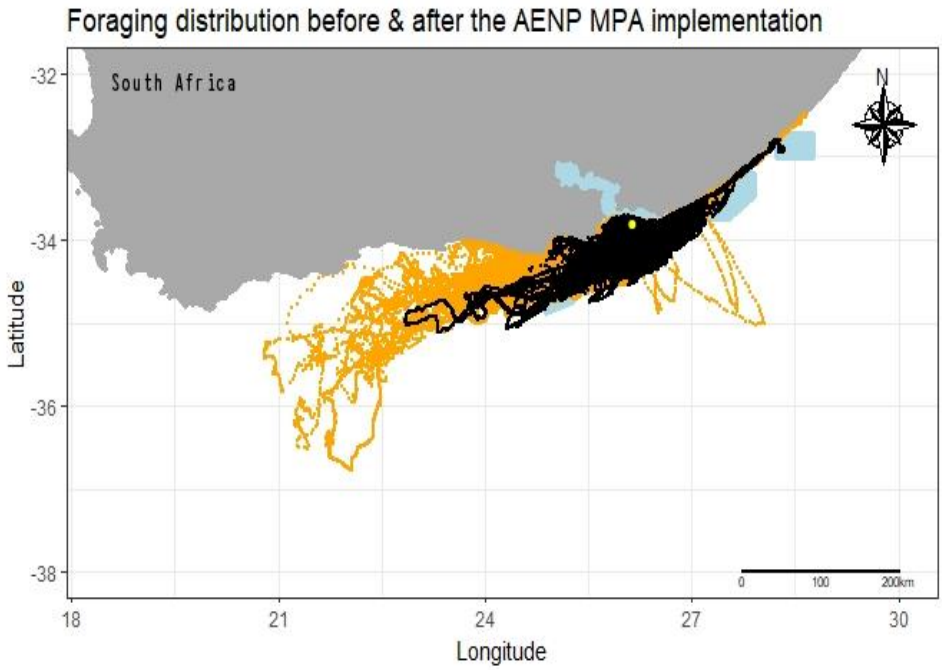

Figure 6 The foraging distribution before and after the implementation of AENP MPA. The points in orange represent the foraging trips during the guard phase of the rearing seasons 2010-2018 (before the MPA enlargement). The points in black represent the foraging trips during the guard phase of the rearing seasons 2019-2021 (after the MPA enlargement). Made with R (R Core Team 2020).

Nevertheless, the illustration of the tracks of each year individually demonstrates a fluctuating distribution of gannets. More particularly, and comparing to the trips of 2021, from 2010 until 2013 the birds had shorter ranges and were closer to the shore. From 2014 the range starts increasing and becomes much greater during 2017 and 2018 than after the MPA implementation.

By comparing the foraging distribution of gannets during the years of the AENP MPA implementation, we can observe a small fluctuation as well. During 2019 and 2020 the gannets made shorter trips to the west than in 2021. Yet, the foraging distribution to the east has decreased from 2020 to 2021 (Figure 7). The range towards the south remains similar for the 3 years.

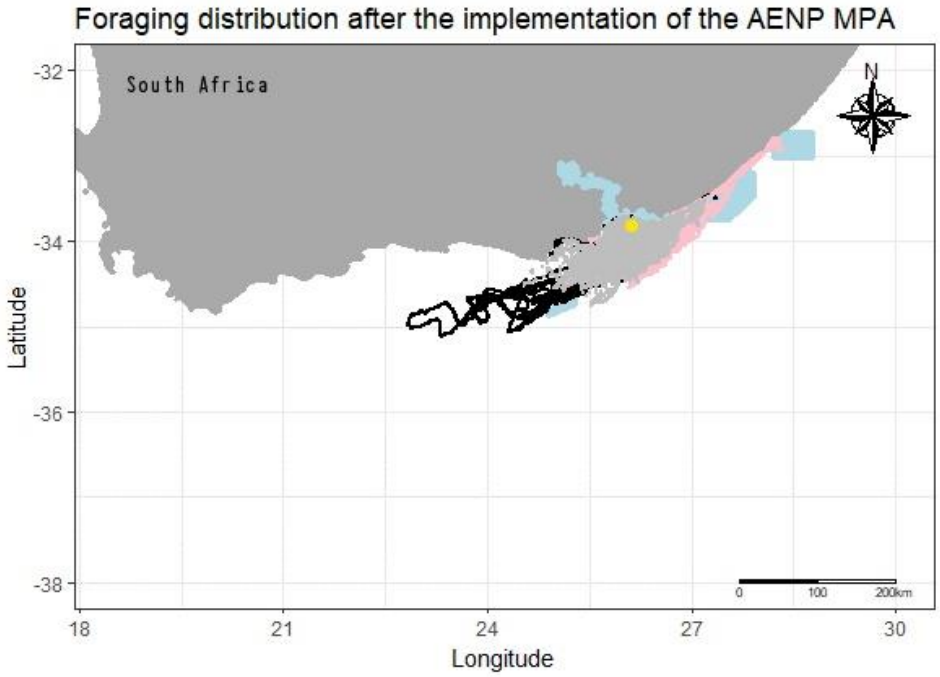

Figure 7 The foraging distribution after the implementation of AENP MPA. The foraging distribution of Cape gannets during the guard phase of the rearing season 2019 (grey), 2020 (pink), and 2021 (black). Made with R (R Core Team 2020).

3.5 Area of high activity

While inspecting visually the foraging trips, it became apparent that there was high activity in a particular area. The application of a density analysis validated these speculations (Figure 8). A density analysis was also run based on behaviour (Figure 9). The results showed that, indeed, the gannets exhibited high activity offshore Cape Recife and towards Algoa Bay. The behaviour density analysis demonstrated that this area was visited a lot for all three behaviours, but mostly for resting and foraging.

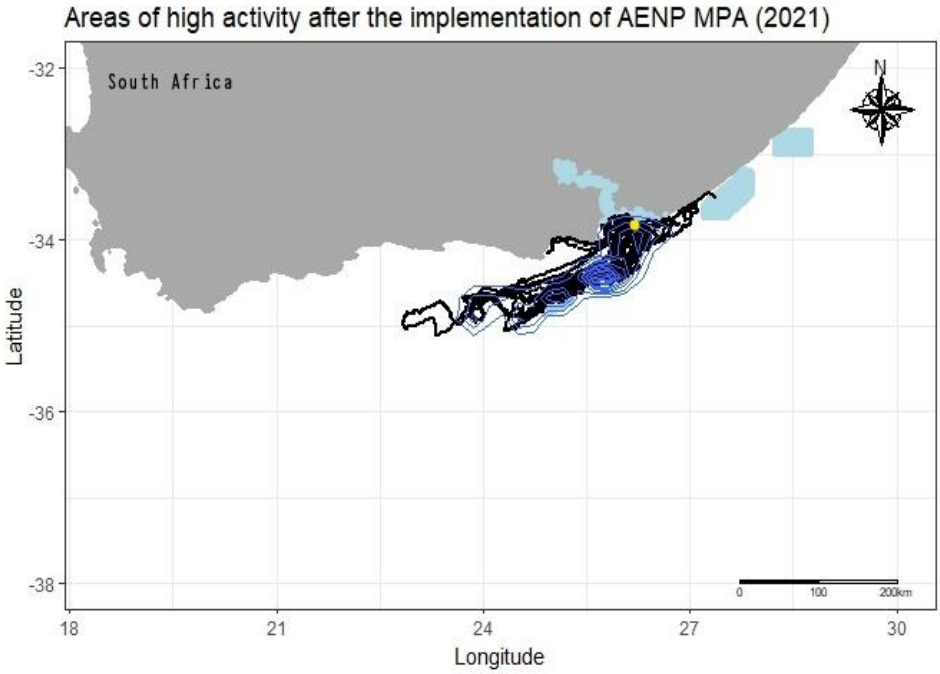

Figure 8 The areas of high activity after the enlargement of AENP MPA in 2021. The black points represent the foraging trips, and the blue lines represent the density of points in the area. Made with R (R Core Team 2020).

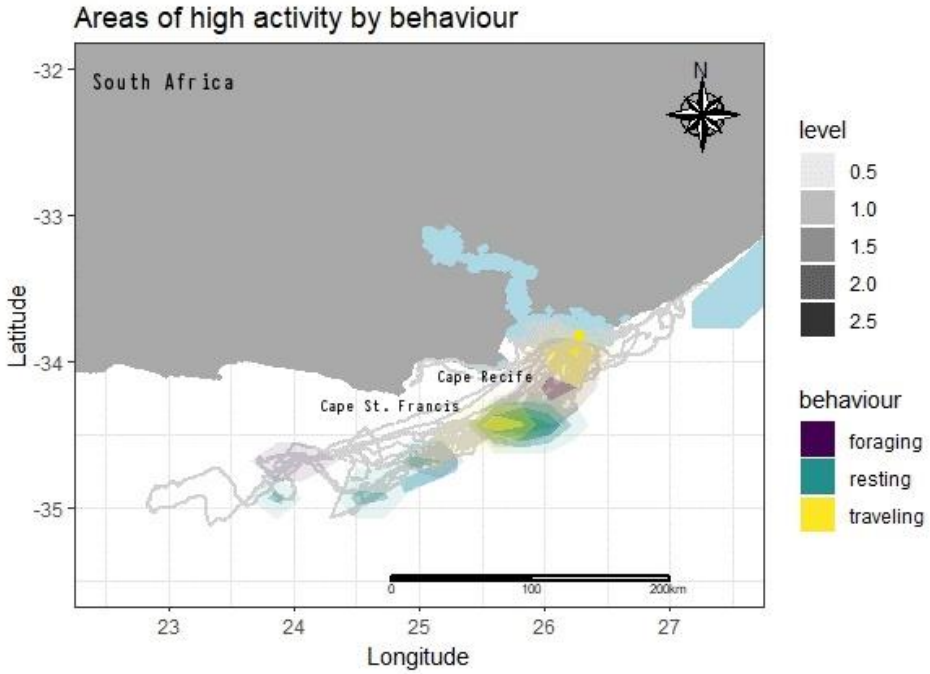

Figure 9 The areas of high activity for each behaviour. The grey points represent the foraging trips. The polygons represent each behaviour (purple for foraging, green for resting, and yellow for traveling) by density. The level represents the intensity of each activity. Made with R (R Core Team 2020).

Density analysis was also applied for the datasets of the previous years (2010-2020), in favour of investigating if this was a repetitive behaviour (Figures 10, 11 & 12). Similarly, except for the trips of 2020, the majority of the points cluster in the broader area offshore Cape Recife and towards Algoa Bay. Some slight variations in the locality appear.

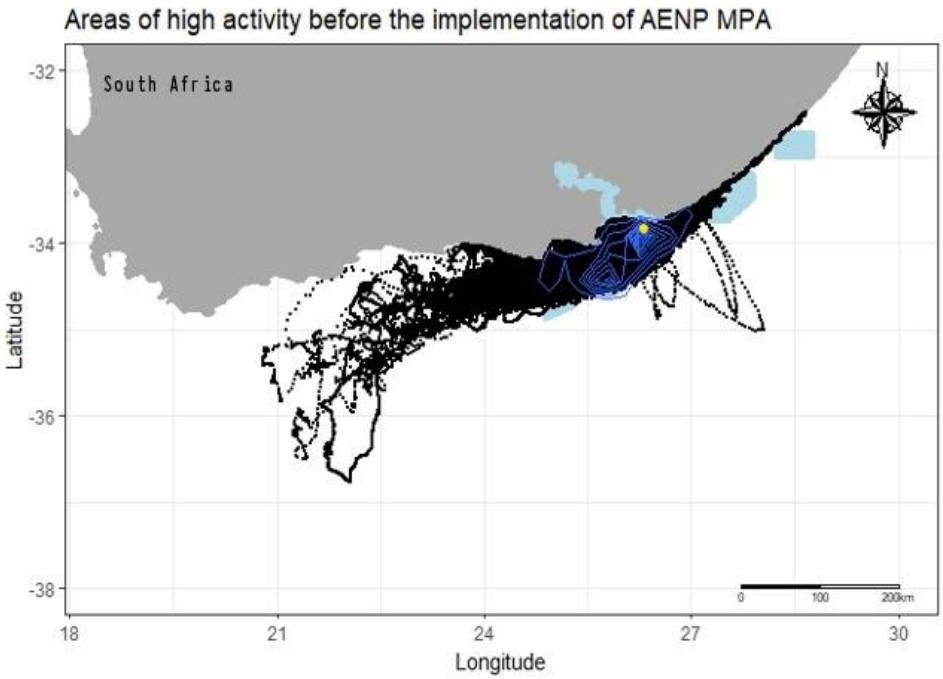

Figure 10 The areas of high activity before the enlargement of the MPA. The black points represent the foraging trips of 2010-2018, and the blue lines represent the density of points in the area. Made with R (R Core Team 2020).

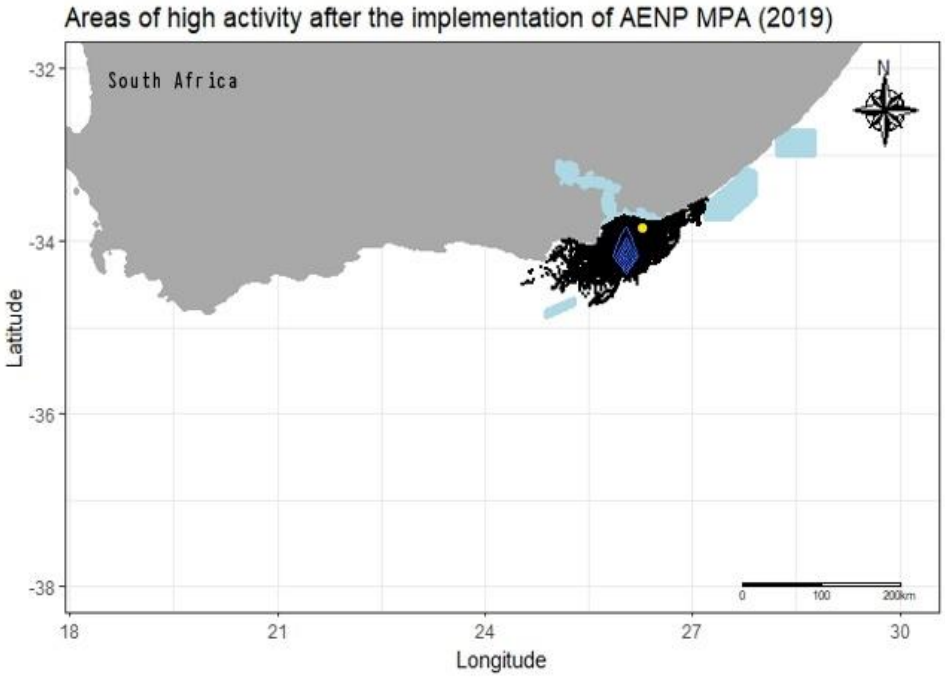

Figure 11 The areas of high activity after the enlargement of the MPA. The black points represent the foraging trips of 2019, and the blue lines represent the density of points in the area. Made with R (R Core Team 2020).

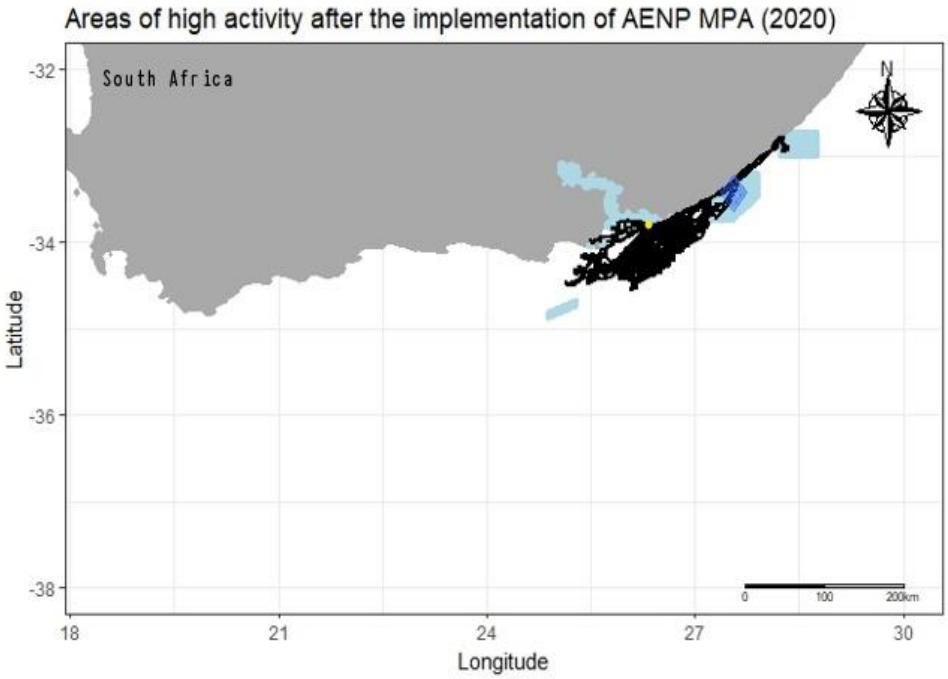

Figure 12 The areas of high activity after the enlargement of the MPA. The black points represent the foraging trips of 2020, and the blue lines represent the density points in the area. Made with R (R Core Team 2020).

4. Discussion

This study provides an assessment of the foraging distribution of Cape gannets breeding on the colony of Bird Island (Algoa Bay) in Eastern Cape, South Africa during the guard phase of the rearing season of 2021. The aim is to compare the foraging distribution of the gannets to the boundaries of the newly established Addo Elephant National Park Marine Protected Area in the interest of providing input for the management of the species and the monitoring of the MPA. A comparison of these results to the foraging trips of 2010-2020 depicts the foraging distribution over the years with an emphasis on the ranges before and after the enlargement of BI MPA to AENP MPA. An area of high activity is identified and proposed to be considered as an MPA after further investigation.

4.1 Foraging distribution

Seabirds are considered to be the sentinels of the ocean, as their distribution and diet can inform us about the distribution of their prey (Cairns 1987; Piatt et al. 2007). In the case of Cape gannets, previous studies have demonstrated how their population health status and distribution were affected after the eastward shift of sardines and anchovies (M Crawford et al. 2007; Coetzee et al. 2008). In fact, the current population of Cape gannets is only 40% of the population of the 1950s (M Crawford et al. 2007; Pichegru et al. 2007; Sherley et al. 2019). The principal reason for the sardine and anchovy shift to the east has been thought to be the increased fishing pressure in the Benguela System on the west coast of Southern Africa and the impact of climate change on the Benguela Current (Coetzee et al. 2008; Crawford et al. 2015). What is more, sardines do not exhibit a selection in their spawning areas. This has resulted in the distribution shift of sardine spawners on the south coast of South Africa, in addition to the west, forming schools that originate from the south (Coetzee et al. 2008). It is possible that the lower levels of fish stock exploitation in the south have contributed to this scenario (Coetzee et al. 2008). The distribution of sardines and anchovies on the south and east coast, though, is also influenced by the environmental conditions, such as the flow of the Agulhas Current and its great variability (Schumann 1987; Masello et al. 2010).

This study is focused on the foraging distribution of 27 adult Cape gannets in December 2021. The westernmost trip was accomplished by one bird that travelled

more than 350 km in search of prey. One bird that travelled 131 km until Amathole Offshore MPA made the easternmost trip. One quarter of the gannets travelled until Tsitsikamma National Park (~240 km from Bird Island) and one quarter of birds restricted their distribution until Cape St. Francis (~140 km from Bird Island). 50% of the gannets remained in the vicinity of Algoa Bay and the broader offshore area, not exceeding the distance of 100 km from the colony.

Taking into consideration that Cape gannets can travel several hundred kilometres in search of prey (Gremillet et al. 2004; Botha & Pistorius 2018), their restriction to the vicinity of Algoa Bay and until Cape St. Francis demonstrates that prey was available relatively close to the colony. The MPA does not have physical boundaries for its species and fish are highly mobile (Green et al. 2015a). The foraging grounds and, consequently, the occurrence of prey outside but relatively close to the MPA may portray positive ecological outcomes. Cape gannets have high metabolic rates and a flight of great energy expenditure (Green et al. 2015b). At the same time, the quality of their prey plays a significant role in the development and quality of their chicks (E Mullers et al. n.d.). As a consequence, during rearing season, Cape gannets are in search of good quality prey as close to the colony as possible.

Seabirds exhibit great plasticity towards the environmental changes, as they live in the constantly alternating oceans (Pichegru et al. 2007). This enables them to adapt to their prey distribution shifts, but also avoid intraspecific competition (Masello et al. 2010). The extended range of 7 birds beyond Cape St. Francis could possibly be explained by intraspecific competition or the fact that larger distances offer the possibility of multiple encounters of prey.

4.2 Foraging behaviour

The foraging behaviour of Cape gannets has been studied before resulting in fascinating results. Previous research has focused on the birds' behaviour during the foraging trip by accounting for isolated dives, foraging bouts, fishing by plunge-diving only the head in the water and hovering around an area in search of prey (Ropert-Coudert et al. 2004). Other studies have turned their attention to the preening of the pair on the nest and estimated that the two parents might be exchanging information on resources (Courbin et al. 2020). Sexual segregation in foraging distribution and behaviour, intraspecific competition (Green et al. 2015b), and distribution outside the breeding season have been studied too (Lewis et al. 2001; Botha et al. 2017).

The former BI MPA has been claimed not to be of substantial use to Cape gannets (Green et al. 2015a). Since the implementation of AENP MPA enlarged BI MPA to a great extent, this research is centred on how the gannets utilize the MPA. The principal interest is to explore if the MPA has offered protection to its

biodiversity to the point that the fish stocks can recover and find refuge and, subsequently, the Cape gannets can reduce their foraging effort.

The classification of the gannet behaviour during the foraging trips was into “foraging”, “resting” and “traveling”. The results demonstrate where the Cape gannets were foraging and how much time they spent on each behaviour. The MPA was directly utilized from 4 gannets for foraging, but 9 more gannets had feeding grounds in the Algoa Bay vicinity and did not forage further than 40 km from the MPA. Even if the number of gannets actively using the MPA for foraging is low, they dedicated more than half of their time to this behaviour. This might be a positive indicator regarding the occurrence of fish prey inside the MPA boundaries. Outside the MPA this proportion was lower, as, naturally, the birds dedicated more time to traveling in favour of reaching further feeding grounds. The large difference in the proportion of time spent resting inside and outside the MPA could be due to the following factors. First, the birds traveling longer distances would need more time to rest. As documented, Cape gannets first forage to feed themselves and rest on the sea surface to digest. Then, they spend the night resting on the sea surface. On their return trip to the colony, they feed again to bring food back to their chick (Adams & Klages 1999). As a result, Cape gannets foraging outside the MPA would spend a considerable amount on resting, both during the night and after feeding. Additionally, the birds foraging inside the MPA had incomplete trips. This means that only the start and the end of the trip are visible in the dataset. The activity in the MPA seems to be towards the end of the foraging trips, and hence, the birds did not spend a lot of time resting as they were on their way to returning to the colony. It is unknown if they exhibited further resting behaviour inside or outside the MPA.

4.3 Foraging distribution in comparison to previous years

There seems to be a fluctuation in the foraging distribution of Cape gannets throughout the years. As the oceanic environment in the Agulhas Bank is alternating at a constant rate, it promotes variability in the distribution of its resources. What is more, it has been reported that the biomass of the small pelagic fish stocks has been also fluctuating (: DEFF (Department of Environment 2020). The decline in both sardine and anchovy stocks for almost the past 20 years in combination with their variable distribution affected by the Agulhas Current and the fishing pressure, has possibly caused the range fluctuation in Cape gannets as well.

The illustration of the trips showed an increase in the foraging range of Cape gannets towards the west in 2021 compared to 2019 and 2020. Since the MPA was

established in 2019, the gannets appear to stay in the vicinity of Algoa Bay and not exceed Cape St. Francis in the west with the exception of 25% of our results in 2021. Before the enlargement of the MPA, the birds also showed variable distribution over the years 2010-2018. Notwithstanding, if we compare the foraging ranges before and after the enlargement of the MPA we can observe a reduction in the distribution since 2019. The foraging trips are restricted a lot towards the south. The west and east distributions may vary, but there is a noticeable reduction in the distances travelled. Thus, we could speculate that the enlargement of the MPA might have contributed to the reduction of the foraging effort of Cape gannets. Long-term monitoring would be needed to support these early results.

4.4 Area of high activity

Multiple studies have provided evidence of high species richness (Whitfield & Pattrick 2015), nutrient availability, and high activity in the area offshore Cape Recife (Goschen & Schumann 1988; Sink et al. 2011; Moseley et al. 2012; Coetzee et al. 2019; Kirkman et al. 2021). In particular, Cape gannets, African penguins (*Spheniscus demersus*), and Cape fur seals (*Arctocephalus pusillus pusillus*) have been documented to make use of this area as feeding ground (Moseley et al. 2012; Green et al. 2015a; Botha et al. 2020; Carpenter-Kling et al. 2022). Additionally, that part of the Agulhas Bank has been recognised to have high productivity (Grantham et al. 2011; Jacobs et al. 2022). It coincides with the slope of the continental shelf, and it has been identified as an area of high priority for conservation (Sink et al. 2011). After the evaluation of multiple scenarios, it becomes perceptible that the shelf and shelf edge offshore Cape Recife are very important for protecting biodiversity and avoiding bycatch.

This analysis supports this evidence. In fact, 15 out of 27 gannets were using the area offshore Cape Recife and towards Algoa Bay for foraging, resting, and traveling. As the behaviour analysis did not account for isolated dives and foraging by plunge-diving the head while resting on the sea surface, the foraging activity in this area might be higher than demonstrated in these results.

As the predictability of marine resources is challenging to determine, foraging site fidelity might be a good indicator of foraging success and therefore prey availability (Schneider n.d.; Weimerskirch 2007; Sommerfeld et al. 2015). In fact, seabirds, and consequently Cape gannets, are considered to visit areas of prey availability depending on their previous experience, environmental conditions, and information exchange with their conspecifics (Russell et al. 1992; Weimerskirch 2007; Courbin et al. 2020). From the management perspective, it is advantageous to recognise areas of high activity (Botha et al. 2020). These locations are profitable to the individuals and promote their survival and breeding success (Weimerskirch 2007; Botha et al. 2020). This becomes particularly important when multiple

species are involved, especially threatened or endangered, taking advantage of the resource abundance. On the other hand, the profitability of the fishing industry and how it is connected to these locations should be considered (Grantham et al. 2011). Hence, it is vital to monitor this site and apply the most sustainable management solution. The area offshore Cape Recife and towards Algoa Bay could be considered to be an additional MPA. Further studies would need to be conducted to support this idea, but it seems that it is a location where biodiversity thrives and it is worthy of protection.

4.5 Research limitations

The main limitations of this project were the battery failure of 12 GPS devices and the heterogeneity of the gannets' movements related to each behaviour.

The battery failure failed data extrapolation from one GPS device and in the incomplete tracks of 11 gannet trips. Two of the incomplete trips were removed from the dataset because of the inadequate information they were sharing. The remaining 9 incomplete foraging trips were representing part of the total tracks. The calculation of the duration of the trips was corrected when necessary, using the deployment and retrieval time from the fieldtrip notes. Unavoidably, the total, maximum, and mean distances are not complete for the gannets with ID numbers 11-20. The reason why those trips remained in the dataset, was because they were demonstrating foraging activity inside or close to the AENP MPA and, therefore, considered valuable.

The heterogeneity of the gannets' movements resulted in a variety of autocorrelation and velocity values. The "bcpa" package would cluster GPS points together depending on these values and a behaviour would be assigned, depending on them. Nonetheless, as the values were different for each bird, different values were assigned to different behaviours for each gannet individually. Concomitantly, after visual inspection of the results, some points that evidently belonged to a behaviour were represented as part of a different behaviour. As a result, the behaviours needed to be reclassified manually once again, to represent the feeding grounds correctly. Apart from this limitation, the "bcpa" package was thought to be the most appropriate for the behavioural classification.

5. Conclusion

This study provides an update on the foraging distribution of Cape gannets during the guard phase of the rearing season in 2021 on Bird Island (Algoa Bay) in relation to Addo Elephant National Park Marine Protected Area. The distribution of the birds overall was restricted to the vicinity of the MPA, even though only a small number of gannets actively foraged inside the MPA boundaries, and a number of birds travelled beyond the vicinity of the MPA. This research supports that the enlargement of the MPA has had a positive effect on gannets, because of the high percentage of time spent foraging when inside the MPA and the proximity of the foraging grounds to the MPA when outside of it. Foraging ranges from previous years demonstrate a fluctuation in the trip length. Despite that, there seems to be a reduction in the distribution since the enlargement of the MPA. Last, there is an area of high activity offshore Cape Recife and towards Algoa Bay, and its further monitoring and potential implementation as a new MPA is proposed. Future research would be valuable to further support the advantage of gannets as a result of the AENP MPA and the value of a new MPA. Hopefully, this study can provide insights into the management of Cape gannets, the monitoring of AENP MPA, and contribute to the "Algoa Bay Project".

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Popular science summary

Cape gannet is a large seabird that is endemic to South Africa and Namibia. Their population is in decline since the 1950s and they are now listed as Vulnerable in the IUCN Red List. They have colonies on six islands, three in Namibia, two on the west coast of South Africa and one on the southeast coast of South Africa. The latter population is the only one that is not in decline and consists of approximately 90 000 breeding pairs. Cape gannets feed predominantly on sardine and anchovy, two pelagic fish that have been heavily exploited by the fishing industry and are also in decline. The eastward shift of sardine led the gannets alter their distribution and move towards Bird Island (Algoa Bay).

Marine Protected Areas are regions in the ocean that are protected and managed sustainably for the benefit of people and nature. The Addo Elephant National Park Marine Protected Area was proclaimed in 2019, enlarging the former Bird Island MPA. It is located in Algoa Bay, within the influence of the Agulhas Current, a warm current coming from the Indian Ocean that affects the richness and distribution of many marine species.

The purpose of this project was to assess the distribution of Cape gannets in relation to AENP MPA, while foraging during the early period of chick rearing in December 2021. 30 adult Cape gannets were tagged with GPS devices to record their foraging trips. After the device retrieval, the data was analysed, the distance and duration of the trips were calculated, and their behaviour was classified into "foraging", "resting" and "traveling". The results were also compared to the foraging trips of 2010-2020.

The results for the trips of 27 gannets showed that in 2021 they remained relatively close to the MPA. Seven gannets were flying beyond the vicinity of the MPA, but also 4 of them were foraging directly inside the boundaries of the MPA and 9 more were foraging up to 40 km away from them. In comparison to previous years, there seems to be a reduction of the gannet range during the breeding season since the enlargement of the MPA. However, the distribution is changing over the years. Hence, Cape gannets might have an advantage from the enlargement of the MPA, although future studies will need to be conducted to support this speculation. Last, the oceanic area offshore Cape Recife and towards Algoa Bay was used by more than half of the tagged gannets. The scientific literature supports that this area supports a lot of species and is considered valuable for other predators too. After

future detailed study and monitoring of the area, it could be proposed as a new MPA, in order to protect the biodiversity that it holds.

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