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Movements of satellite tracked Magellanic penguins (*Spheniscus magellanicus*) in a wintering area in southern Brazil

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A B S T R A C T

Food availability and oceanographic conditions drive the distribution and movement of marine vertebrates. Tracking efforts towards seabirds usually focus on their breeding period, tagging adults in colonies. In this study, we tracked four juvenile and one adult Magellanic penguin (*Spheniscus magellanicus*) with satellite transmitters. These individuals were caught incidentally in gillnets and were tagged at sea, with the exception of the adult that was rehabilitated and released on the beach. The penguins were tracked in their wintering grounds, where behavior and oceanographic characteristics of the area used were determined. All five birds remained along the coast of southern Brazil and Uruguay in neritic waters up to 10 km offshore and 50 m in depth. The four juveniles used a mean area of 1,426 km^2, travelling on average at 7.4 km/h. The high turning angles observed and mean sinuosity of 2.46 indicated that the penguins were foraging. The adult penguin covered an area of 1,033 km^2, at a mean speed of 4.6 km/h, and with low sinuosity (0.43), which is suggestive of either travelling movements or an experienced hunter who needs a few turning angles to forage. The adult travelled 538 km in total, reaching a maximal distance of 465 km. Locations were obtained over a period of 7–10 days, and all five penguins remained in waters of the coastal branch of the Malvinas Current, an area characterized by cold sea surface temperatures (SST, mean = 13.4 °C) and high primary productivity. Salinity values (34.06 PSU) were also typical of the Malvinas Current and were influenced by the La Plata River plume, whose waters are low in salinity and nutrient rich. All five penguins remained near the coast probably because these waters are rich in nutrients, and carry the penguins' main prey, the Argentine anchovy (*Engraulis anchoita*). Regarding conservation concerns involving these penguins, we highlight the current management of the anchovy fisheries and the development of offshore windfarms that could potentially cause major disturbances to the penguins' foraging habitat. The establishment of the Albardão National Park in the nearshore area used by the penguins is highly desirable for the protection of the species and their feeding resources.

1. Introduction

Marine ecosystems are characterized by strong spatiotemporal heterogeneity (Barry and Dayton, 1991), under which marine organisms must cope to survive. Vertebrates living at temperate latitudes have evolved in seasonal environments that shaped their life traits and migration patterns according to the main recurrent large-scale physical and biological characteristics of the ocean (Ballance, 2007; Putman, 2018). Therefore, predators are likely to sense environmental conditions that change with the seasons and modulate their habitat preferences accordingly (Lambert et al., 2017). Due to their high mobility, seabirds breeding at high latitudes may migrate from harsh conditions and food scarcity towards wintering grounds that are frequently far from breeding areas (Alerstam, 1993).

Studies of bird migration, as well as studies covering wintering periods, have benefited from the development of different tracking devices (Williams et al., 2020). Tracking animal movements has been an important tool for understanding the foraging of species that cannot be observed directly. However, most seabird studies are colony-based, i.e., loggers are deployed and recovered at breeding sites, and, depending on the model used, data must be downloaded from the loggers. This approach has improved our understanding of the movements of adults during their breeding period, or only a few months post-breeding, while their distribution during most of the non-breeding period remains

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largely unknown. Similarly, juveniles have been largely neglected in tracking studies (Carneiro et al., 2020). This is the case of the Magellanic penguin (*Spheniscus magellanicus*), which have often been tracked during their breeding period (e.g., Boersma et al., 2002; Boersma and Rebstock, 2009; Raya-Rey et al., 2010; Rosciano et al., 2017).

Magellanic penguins occupy islands along the coast of the South Atlantic and Pacific oceans and coastal sites restricted to temperate zones (Borboroglu and Boersma, 2013). These penguins breed in colonies in the Argentine Patagonia (south of 41°S) (Schiavini et al., 2005; Borboroglu and Boersma, 2013; Hernández-Orts et al., 2017; Hickcox et al., 2019), along the Chilean coast south of 33°S (Simeone et al., 2003), and on the Malvinas/Falkland Islands (~23°S) (Williams and Boersma, 1995; García- Borboroglu et al., 2006; Boersma, 2008; Borboroglu and Boersma, 2013; Stokes et al., 2014; Hickcox et al., 2019).

Post-breeding studies usually last a few months and have demonstrated that Magellanic penguins move northward over the continental shelf (Stokes et al., 1998; Pütz et al., 2000, 2007). More recently, studies using geolocators, which track birds with lower accuracy than satellite tags but for longer periods, have showed that females remained in areas off the La Plata River mouth while males remained in more southern areas across the continental shelf (Yamamoto et al., 2019; Barrionuevo et al., 2020). Penguins departing from colonies in southern Patagonia used the Argentine continental shelf during the wintering period (Dodino et al., 2021).

After chicks fledge, breeding adults undergo a synchronous "catastrophic" moult in March and April, then leave the colony, and return for the following breeding season. The species is a pelagic predator that migrates northward to the subtropical convergence zone (Pütz et al., 2007), coinciding with the migration of one of their main prey species, the Argentine anchovy (*Engraulis anchoita*) (Silva et al., 2015; Yorio et al., 2017; Marques et al., 2018). This anchovy is widely distributed across the continental shelf of South America in the southwestern Atlantic Ocean, from the Cabo de São Tomé, state of Rio de Janeiro in Brazil, to central Patagonia (47°S) in Argentina (Whitehead et al., 1988). Adult Argentine anchovy inhabit waters at depths of 30–150 m off the coast of the municipality of Rio Grande, Brazil, and along the Uruguayan coast, while juveniles occur along the coast at a depth of 30 m (Castello, 1997; Costa et al., 2020). In neritic waters off southern Brazil, a range of gillnet fisheries operate targeting sciaenids and bluefish (*Pomatomus saltatrix*), fish species that, like Magellanic penguins, also feed on Argentine anchovy. This overlap makes the incidental capture of penguins in gillnets a common occurrence (Cardoso et al., 2011; Crawford et al., 2017; Fogliarini et al., 2019), but also provides an opportunity to study healthy individuals at sea (provided they can be extracted from gillnets with no injury), rather than debilitated and then rehabilitated penguins washed ashore (Marques et al., 2018).

Magellanic penguins use the coastal waters of the southwestern Atlantic Ocean that, hydrologically, have a strong influence from freshwater inputs from the Patos Lagoon and the La Plata River. The coastal zone receives abundant freshwater, which affects the dynamics of the continental shelf ecosystem. For instance, oceanographic conditions generated by the plume of the La Plata River affect the arrival of pre-breeding female Magellanic penguins in Patagonia (Rebstock and Boersma, 2018). A weak plume at the end of winter causes females to arrive earlier and in better physical conditions than when there is an extensive plume, while male conditions have not been shown to vary due to these oceanographic events. A weak plume probably increases prey availability and, therefore, the foraging capacity of individual females. This sexual difference can also be noticed in the species' distinct spatial distribution during winter, when males are closer to the 200-m isobath and farther from the coast than females (Barrionuevo et al., 2020).

Studying the distribution and foraging areas of the Magellanic penguin has been recommended as a way to produce information that can be useful for the conservation of the species' declining populations (Boersma et al., 2020). This is particularly relevant due to the incidental capture of penguins in fisheries, in addition to potential fishing of the Argentine anchovy stocks in the future and recent plans for offshore wind farm development in southern Brazil (Bugoni et al., 2022). Thus, the aim of the present study was to characterize and quantify the spatial coverage of penguins at sea, assess the variability of penguin movements, and relate their foraging patterns to oceanographic features in their wintering grounds. Tracking data in the non-breeding season are important for the conservation of this species, especially with the inclusion of juveniles that are only rarely tracked. We also aimed to assess how variability in oceanographic conditions may drive variability in the foraging trips of non-breeding juveniles and in the case of a rehabilitated adult Magellanic penguin over the South America continental shelf. We expected that all tagged penguins would use the productive waters of the Malvinas Current and would forage in inshore waters where ocean productivity is higher than in offshore regions.

2. Methods

2.1. Study site and transmitter deployment

This study was conducted in southern Brazil, where satellite transmitters were attached to Magellanic penguins in July and August 2015. Four juvenile Magellanic penguins (hereafter referred to as MAPE01, MAPE02, MAPE03, and MAPE04) were incidentally captured in gillnets in July 2015, along the coast of the state of Rio Grande do Sul (see description of fishery and incidental capture in Fogliarini et al., 2019). These penguins were probably captured just before net hauling, as they were active and showed no signs of either drowning or injury while being kept aboard for a few minutes. Other individuals were hauled on board dead during the same time by the same boat. Another individual, a debilitated adult found stranded on a beach in southern Brazil (hereafter referred to as RMAPE05), was rehabilitated from April 6 to August 21, 2015 by a marine animal rehabilitation center (*Centro de Recuperação de Animais Marinhos*, CRAM-FURG). After the rehabilitation period, this bird was tagged and released on Hermenegildo beach (municipality of Santa Vitória do Palmar) in the state of Rio Grande do Sul, close to the area where the juveniles were also released into the sea.

The deployed tags were KiwiSat 202 GPS-PTTs (platform transmitter terminals) (Sirtrack, New Zealand). PTT tags weighed ~100 g and measured 80 × 35 × 27 mm, which corresponded to <2% of the mean body mass of the penguins (Williams, 1995). Weighing the birds at sea aboard small boats was not feasible, but the birds appeared to be in good health with good plumage, no external injuries, and some fat deposits under the skin. The devices were attached with waterproof TESA tape to the lower back feathers of the penguins, where the drag of the tags would be minimal (see Bannasch et al., 1994).

2.2. Device settings and data analysis

The devices were programmed to record 10 positions per day, ignoring the first point within about 1 h after release, and avoiding sampling at night when foraging success is much lower as penguins are visual predators (Pütz et al., 1998; Wilson et al., 2004). Positional data were classified according to the quality of the location fix provided by ARGOS (CLS, Toulouse, France). Location data were filtered for biologically unrealistic speeds >25.2 km/h (Culik et al., 1994; Pütz et al., 2002; Wilson et al., 2004), and apparent onshore locations were removed. Locations were obtained over a period of 7–10 days each penguin.

The penguins' behavior parameters, such as maximum distance travelled (km) and total distance travelled (km), were calculated from the remaining daily positions, implemented through the 'rgdal' and 'move' packages on R, respectively (R Core Team, 2016). Maximum distance was calculated as the distance between the first and the farthest points from the tagging location, and total distance was considered as the length of the entire path travelled, since the distance travelled by a

Table 1
Summary of satellite tracking data and behavioral states of five Magellanic penguins (*Spheniscus magellanicus*) during their wintering period in South America continental shelf in 2015. The values represent the total tracking period of the birds.

ID	No. of tracking days	Total dist. Travelled (km)	Max.dist. Travelled (km)	Speed (km/h)	Sinuosity index	Minimum convex polygon (MCP) (km^2)		Kernel density estimator (KDE) (km^2)	
						50%	95%	50%	95%
MAPE01	8	298.8	199.7	8.2	0.75	1680.0	5164.3	771.0	1542.0
MAPE02	10	419.4	117.7	9.1	1.78	974.2	3965.2	983.6	1967.2
MAPE03	10	625.9	84.2	7.5	3.72	1104.9	2928.1	1041.5	2082.9
MAPE04	7	197.6	27.6	4.8	3.58	198.8	441.2	55.9	111.9
RMAPE05	8	465.1	538.7	4.6	0.43	2045.1	5921.4	516.5	1033.0

bird is not linear. Speed (km/h) was calculated considering the total distances covered and the time spent during the whole tracking period.

A Hidden Markov Model (HMM) identified a negligible error in the GPS tracks associated with diving behavior. HMMs were also used to obtain the distance to the next location and turning angles between locations (Boyd et al., 2014; Gurarie et al., 2016). HMMs were assumed to have a true but unknown movement mode at each observed location. Thus, the model was calculated with four true movement modes and one 'Mode 0', which accounted for gaps in the GPS record. A slow sinuous mode (Mode 1), a medium speed sinuous mode (Mode 2), and a fast direct mode (Mode 3) were also included. Together, Modes 1 and 2 were interpreted as indicative of foraging behavior, while Mode 3 was interpreted as travelling behavior. In addition, we calculated the sinuosity index (Benhamou, 2004), which is defined as the ratio of total distance travelled and the maximum distance travelled. The sinuosity index was calculated with the path defined as the ratio of the total distance travelled and the maximum distance travelled in that range. The sinuosity of a path is inversely related to the efficiency of a search path used by an animal to reach its destination along a straight line. The sinuosity of the random search controls the intensity of the local search, allowing the animal to adjust its effort to find food. Hence, this parameter is calculated as the ratio between the distance from the starting point to the target and the length of the path travelled to reach the target. A sinuosity index close to 1 indicates high linearity of the trajectory (probably associated with travel behavior), while sinuosity values > 1 likely indicate foraging.

To estimate a penguin's home range area (km^2), considering the short time interval during which they were tracked, we calculated a minimum convex polygon (MCP) and kernel density estimators (KDE). The MCP estimates an animal's area based on the connection of peripheral location points, while the KDE creates a density estimate based on an animal's use of an area. We used a maximum potential foraging value of 50% and 95% (Seaman and Powell, 1996) for both MCP and KDE calculations of each individual tracked, based on all points recorded during the route (Burgman and Fox, 2003). All home range calculations were conducted with 'home range tools' in ArcGIS™ (ESRI, Inc.). Positions were projected following the UTM coordinate system (Zones 22S and 23S) in the Geographic Information System from ArcGIS™ (ESRI, Inc.).

For the turning angle analysis, an algorithm was used to calculate the Cauchy distribution, with two parameters: mean turning angle, representing the mean direction followed, at cardinal and collateral points (90° angles) of the displacement, and the concentration parameter ($0 < \rho < 1$). Here, the mean turning angle was assumed to be 0 for all true modes, i.e., the mean direction of motion was in a straight line (Boyd et al., 2014). Thus, a change in direction implies that the animal generally has a persistent direction (Edelhoff et al., 2016), so the interpretation can be considered real, i.e., biologically meaningful (Fagan and Calabrese, 2014).

2.3. Oceanographic data

To characterize habitat usage, we overlaid the penguins' tracks with oceanographic data derived from the HYCOM (Hybrid Coordinate Ocean Model) reanalysis project, which provided sea surface temperature - SST (°C), surface elevation - SE (m), and salinity (practical salinity unit - PSU) (https://www.hycom.org/). The reanalysis model provides a spatial resolution of 1/12° (~9 km) at 40 vertical levels with daily temporal resolution. Chlorophyll-*a* concentration – Chlo (mg/m^3) data were used as a proxy for ocean productivity, obtained from the Ocean Color platform's weekly module at a resolution of 4 km (MODIS Aqua level 3, https://oceancolor.gsfc.nasa.gov). Although penguins feed off prey that is several trophic levels above ocean primary producers, chlorophyll-*a* allows the identification of productive areas. Bathymetric data were obtained from GEBCO (General Bathymetric Chart of the Oceans, https://www.gebco.net).

To determine whether these oceanographic parameters influenced the penguins' displacement decision (i.e., whether they moved in a certain direction according to the ocean's physical and biological conditions), oceanographic data were processed considering a time window of one week before tracking commenced. Thus, we related the penguin's use of space with oceanographic features. These data were analyzed only for juveniles, since the adult bird (RMAPE05) was in a rehabilitation center a week before tracking began. The conditions at sea a week before could be tracked by the birds to reach and feed off a given area.

3. Results

Overall, our results demonstrated that the tracked Magellanic penguins remained in the neritic waters of southern Brazil and Uruguay, up to 10 km away from the coast and occupying waters ~50 m deep. The penguins had 95% and 50% MCP areas of 12,968 km^2 and 1,205 km^2,

Table 2
Mean values of oceanographic parameters used by five tracked Magellanic penguins (*Spheniscus magellanicus*) and values obtained a week before the individuals were at the tracking site.

ID	Mean SST (°C)	Mean SST (°C) a week before	Mean chlorophyll *a* mg/m^3	Mean chlorophyll *a* mg/m^3 a week before	Mean salinity (PSU)	Salinity (PSU) a week before	Surface elevation (m)	Surface elevation (m) a week before	Bathymetry (m)
MAPE01	13.10	13.16	7.96	5.86	33.99	34.02	−0.111	−0.001	25
MAPE02	14.03	14.14	7.07	6.32	34.20	34.23	−0.090	−0.030	25
MAPE03	13.28	13.47	9.58	6.25	33.92	33.94	−0.106	−0.010	25
MAPE04	13.18	13.36	6.04	5.24	34.13	34.13	−0.111	−0.010	25
RMAPE05	14.41	–	6.00	–	33.50	–	32	–	25

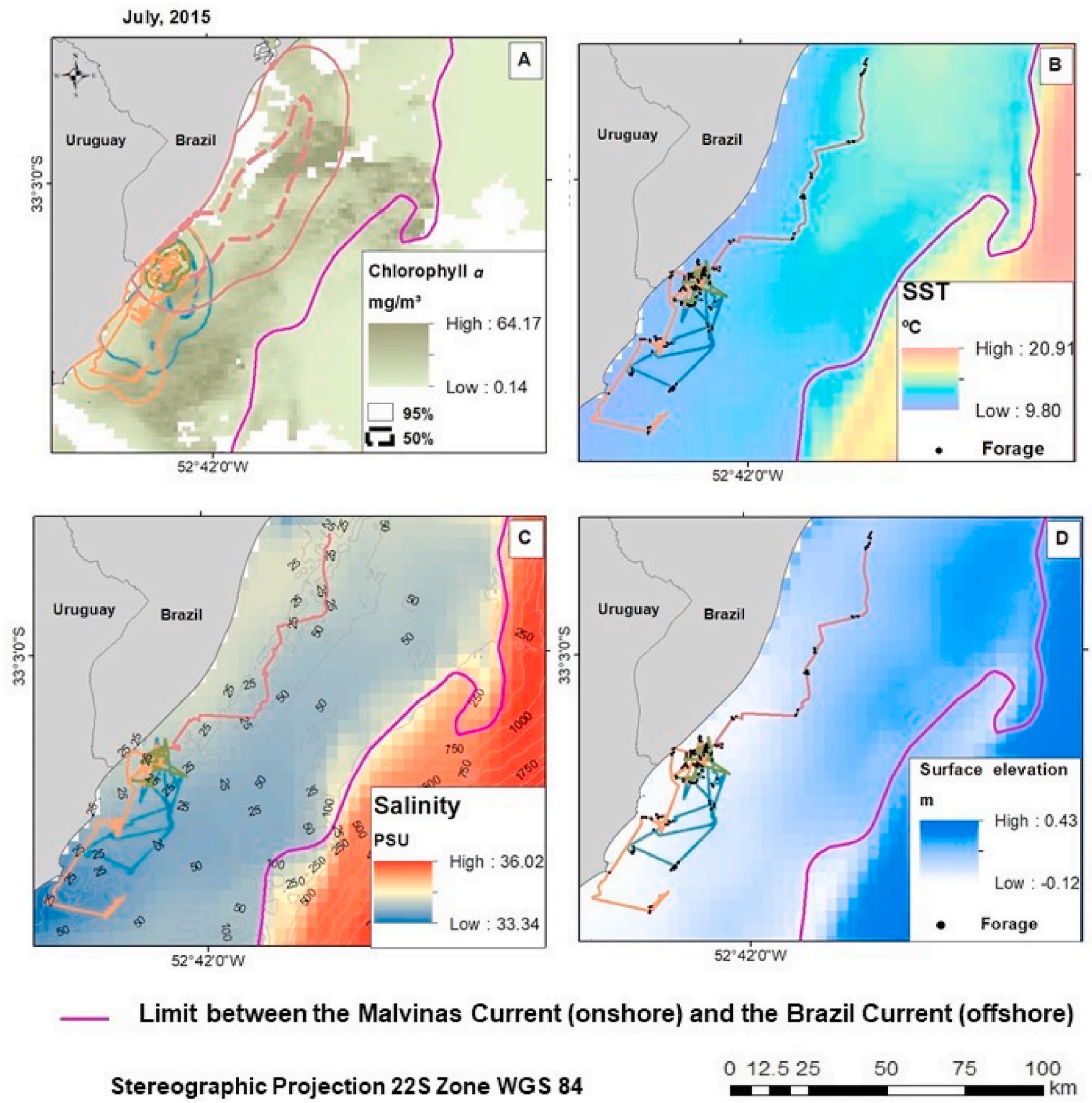

Fig. 1. Mean values of oceanographic parameters obtained during the week of tracking of juveniles Magellanic penguins (*Spheniscus magellanicus*) in July 2015 (n = 4). (**A**) Mean chlorophyll-*a* concentration (mg/m^3) with area of use (MCP); (**B**) Mean sea surface temperature (°C) with the trace line; (**C**) Mean PSU (practical salinity unit) with bathymetry and (**D**) Mean sea surface elevation, with foraging points (black dots, along the tack lines). Each colour represents an individual bird. Note that the limits of currents moved southward reaching the coast from July (Fig. 1) to August (Fig. 2).

respectively, representing a substantial area on the continental shelf. During the period of 7–10 days, penguins showed speeds ranging from 4.6 to 9 km/h (Table 1). The rehabilitated penguin (RMAPE05) moved at wider angles (Fig. 3), i.e., had low sinuosity (0.43), and travelled at a speed of 4.6 km/h over a 95% kernel area of 1,033 km^2; its MCP was 5,921 km^2, with a total distance of 465 km and a maximum distance of 539 km (Fig. 2).

On average, the juvenile penguins travelled a total distance of 386 ± 1 km and a maximum distance of 108 ± 2 km, occupying an area of 990 km^2 (MCP = 50%) and with a kernel density of 50% = 713 km^2 (Table 1; Fig. 1). All penguins remained over the inner continental shelf within the 50-m isobath (Table 2). The HMM shows the locations used by the birds for feeding within this area (Figs. 1 and 2).

The mean value of chlorophyll-*a* concentration, which is often used as a proxy of primary productivity, was 7.66 mg/m^3 (Fig. 1) in the week of tracking, while one week before, it was 5.86 mg/m^3 (Table 2). In August, during the week-long period in which the rehabilitated penguin RMAPE05 was at sea, chlorophyll-*a* averaged 6.00 mg/m^3 (Fig. 2). Oceanographic components such as salinity and surface elevation barely varied during the tracking period and the week prior to tracking. However, these characteristics, in addition to chlorophyll-*a* and SST, were useful to identify the Malvinas Current, which at that time of year drifts northward. These oceanographic features can be identified through SST, characterizing a boundary between currents around 15 °C.

4. Discussion

Despite the limited number of penguins tracked over a relatively short period, this pioneering study in Brazil allowed us to determine foraging movements of penguins and describe oceanographic and physiographic characteristics in the area they inhabit, filling an important gap in the annual cycle of Magellanic penguins (Sequeira et al., 2019). The juvenile penguins tracked behaved similarly to adults in this region (Cardoso et al., 2011; Fogliarini et al., 2019). All five penguins foraged along the coasts of Brazil and Uruguay, remaining in the cold and nutrient-rich waters of the Malvinas Current. Mean SST was 13.4 °C,

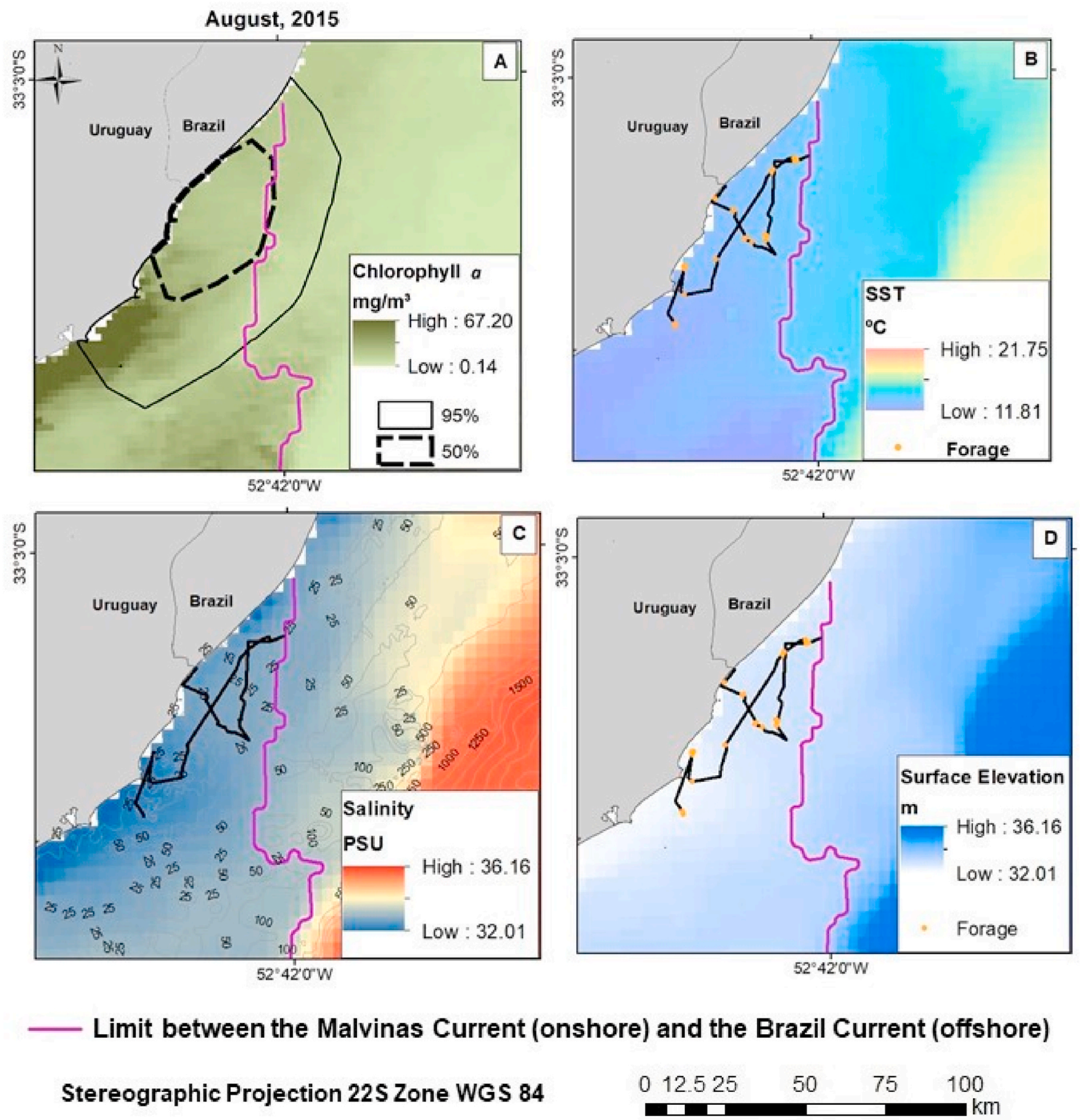

Fig. 2. Mean values of oceanographic parameters obtained during the week of tracking of an adult Magellanic penguin (*Spheniscus magellanicus*) in August 2015 (black lines). (**A**) Mean chlorophyll-*a* concentration (mg/m^3) with area of use (MCP – black lines); (**B**) Average sea surface temperature (°C); (**C**) Mean PSU (practical salinity unit) with bathymetry isolines indicated; and (**D**) Mean sea surface elevation with the black track line and foraging points along the track (pale dots). Note that the limits of currents moved southward reaching the coast from July (Fig. 1) to August (Fig. 2).

similar to the 13.5 °C found a week before tracking. However, based on the tracking points of the rehabilitated penguin in August, a higher SST was registered, with a mean value of 14.4 °C. Salinity during tracking and the week before was, in both cases, 34 PSU. In August, salinity was 33.5 (Table 2). Surface elevation oscillated slightly, appearing to have no relation with the displacement of penguins.

The high turning angles during the movement of juveniles demonstrate that the tracking is biologically real (Fagan and Calabrese, 2014), i.e., truly characterizing the penguins' movements, which indicates that they were feeding normally despite the stress resulting from previously having been captured in fishing nets (Edelhoff et al., 2016). The HMM also showed the foraging behavior of penguins on the inner continental shelf, which is an area known for its intense use based on an at sea count onboard vessels (Costa et al., 2020). Only the rehabilitated penguin had a uniform direction, with low and infrequent turning angles (sinuosity of only 0.4 compared to 3.3 of the juveniles), indicative of travelling rather than foraging, probably because it was fed several months in captivity and, thus, there was no strong need to search for prey.

The area used by the juveniles tracked had similar chlorophyll-*a* values to those of the Malvinas Current (Telesca et al., 2018), as well as salinity values that were also characteristic of this region in August (Piola and Matano, 2019). In addition, the average water temperature observed (13.4 °C) is indicative of Malvinas Current waters (Vigan et al., 2000). Based on counts onboard vessels and acoustic estimations of anchovy shoals, sea surface temperature and anchovy density are important factors affecting the presence and density of penguins on the SW Atlantic continental shelf (Costa et al., 2020), where there are spawning grounds for the Argentine anchovy during winter.

Juveniles can reach up to 250 km from the coast (Stokes et al., 2014), but in our study, no individual travelled more than 50 km from the coast, where the water reaches depths of about 50 m, a finding similar to another study that used geolocators (Yamamoto et al., 2019). Such areas

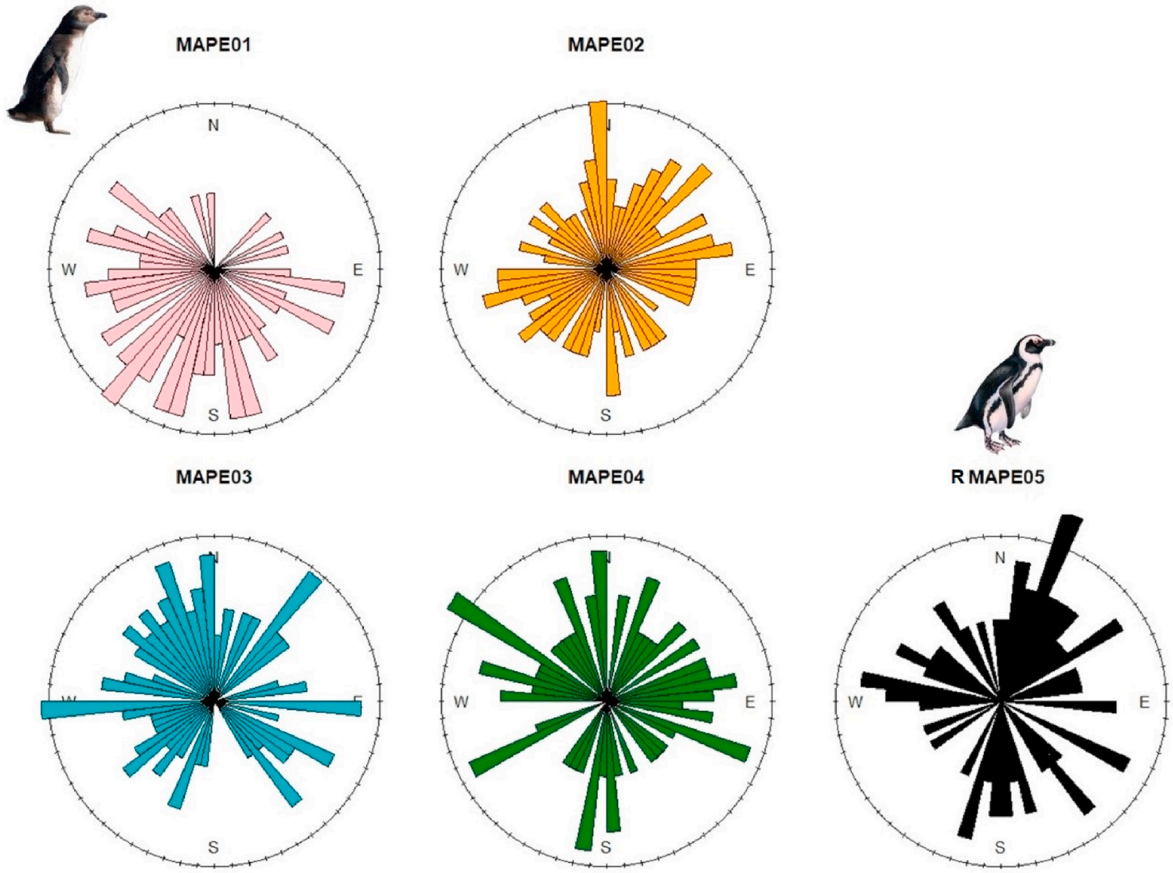

Fig. 3. Turning angles of the five tracked Magellanic penguins (*Spheniscus magellanicus*) in 2015 along the coast of southern Brazil and Uruguay. MAPE01 to MAPE04 are juveniles, while RMAPE05 is an adult.

are also indicative of Argentine anchovy concentration, the penguins' key prey (Costa et al., 2016).

Magellanic penguins migrate preferentially to the north, along the coast of South America, even those in colonies in the southern Pacific Ocean, reaching an average distance of 600–2,000 km from their colony of origin (Stokes et al., 1998; Pütz et al., 2000; 2007; Skewgar et al., 2014; Yamamoto et al., 2019). Females have been observed to move farther north from the colony than males that remained on the Argentine Shelf (Yamamoto et al., 2019; Barrionuevo et al., 2020). Incidental capture in fisheries during the nonbreeding period is the main threat to the conservation of the species (Crawford et al., 2017; Gownaris and Boersma, 2019), contributing to the skewed sex ratio in colonies, as females are more severely affected in wintering grounds (Fogliarini et al., 2019).

In August, adult Magellanic penguins start migrating southward back to their colonies (Boersma, 2012; Rebstock and Boersma, 2018). As previously suggested, migration route and travel rate may be determined by the seasonal movements of their main prey (Stokes et al., 1998), adult Argentine anchovies, wich remain in shallow waters near the coast with SSTs of 9.5–18.5 °C (Castello, 1997). The areas used by the penguins have strong thermal gradients (Bakun, 1997), and are environmental interfaces where high productivity and biological activity occur in winter and spring, which are the peak breeding seasons of anchovies in southern Brazil (Castello, 1997). Since the penguins' main prey moves with the Malvinas Current, the relationship between penguins and similar waters may be directly associated with the movement of the anchovies and only indirectly due to the physical oceanographic conditions, taking into consideration that the present study refers to only two weeks of data. The short tracking period could also explain the limited variation in environmental variables.

After being released on the beach, the rehabilitated penguin first moved north and then south, looking more like it was moving from one place to another rather than foraging, which would be expected. For example, post-released green sea turtles (*Chelonia mydas*) survived and behaved normally (Robinson et al., 2017). Although studies of penguins rehabilitated after oil spills showed that some penguins released did not breed subsequently, and those that did had limited breeding success, penguins are considered easier to rehabilitate than other seabirds (Wolfaardt et al., 2009). Subsequent sightings of rehabilitated oiled Magellanic penguins a few years after release suggest that the species is able to survive for long periods and swim long distances after rehabilitation and release into the wild (Ruoppolo et al., 2012; Goldsworthy et al., 2000). Penguins incidentally captured in gillnets, but carefully and quickly released, do not tend to show unusual abnormal behavior right after capture, as demonstrated in the current study. Thus, proper post-release handling is essential for the survival of penguins captured alive in gillnets.

A thorough understanding of the relationships of predator and prey distributions is essential for understanding food web structure and ecosystem interactions (Phillips et al., 2009). The way in which large marine predators, such as seabirds, use space at individual and population levels is indicative of the interactions between the large-scale spatial dynamics of marine predators and lower trophic levels (González-Solís et al., 2007). As penguins are considered sentinels of the marine environment, studies on their foraging behavior and at sea distribution during a whole annual cycle can provide insights into regional ocean productivity (Boersma, 2008; Rosciano et al., 2017) and improve our understanding on the effectiveness of mitigation for incidental capture, as well as the establishment of marine protected areas, and ecosystem-wide management of forage fish stocks.

The southern Brazilian coast, where penguins stayed for the entire tracking period, represents an important migratory corridor, with key sites for stopping and energetic refueling of visiting and resident bird species from the Northern and Southern Hemispheres. This study demonstrates the importance of this area for the conservation of the species and the area used by other marine organisms. There is currently a proposal to establish a national marine park in this region, adjacent to the area of Albardão (33°12′8′′S and 52°42′21′′W), along the Uruguayan offshore border covering isobaths of 50 m (ICMBIO, 2021). This area has been officially highlighted as a priority area for conservation since 2004, according to Decree 5092 and MMA Ordinance 126/2004 (Brasil, 2004; MMA, 2004). Additionally, neritic areas along the Brazilian coast under strong winds, including the southernmost region of Brazil, have been proposed for the development of offshore wind farms, with potential negative impacts on penguins, caused by habitat alterations through structures for turbines fixed on the seabed (Bugoni et al., 2022). However, similar to the national park, wind farms could have positive impact, by creating areas of exclusions for fishing, which could benefit penguins and other marine animals.

5. Conclusion

The migratory movements of satellite tracked Magellanic penguins along the Brazilian coast occurred in waters with characteristics similar to those of its key prey species, the Argentine anchovy, with combined effects of cold waters of the Malvinas Current and coastal-enriched waters. Our tracking study provided information with relatively high temporal resolution, data which are often difficult to gather. The findings indicate that the environmental variables chlorophyll-*a*, sea surface elevation, and salinity do not seem to influence penguin movements. Thus, this study emphasizes the importance of tracking birds during their non-breeding season, as well as juveniles. Remote tracking of marine animals in winter is relevant to the understanding of the association between area usage and local environmental variables. In addition, this study also intends to serve as a reference for future work focused on actions and strategies for the conservation of Magellanic penguins outside their breeding period. The area used by the tracked penguins is a priority area for Marine Spatial Planning, which Brazil is committed to implementing by 2030, as a signatory of the 2017 UN Conference for the Oceans, through the Interministerial Commission on Marine Resources (CIRM). The legal framework is related specifically to strategies for the conservation of seabirds and coastal birds in Brazil, highlighting the National Plans of Action for the Conservation of Threatened Species.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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