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## Short communication

## Partial migration in Magellanic penguins

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We studied the migration of Magellanic penguins near the southern tip of the breeding distribution, and for the first time found evidence of partial migration for this species within the same colony. Forty-three percent of the penguins studied stayed within ~ 290 km of the colony (residents), while others went northwards as far as 2000 km. All penguins spent the same amount of time at sea and traveled similar total distances, but residents experienced colder waters (2°C lower) and habitats with lower Chlorophyll-*a* concentrations than migrants. The two habitats are inhabited by different prey items, consequently offering the penguins distinct prey options. We have shown high variability in the non-breeding dispersion behavior of Magellanic penguins within the same colony; nonetheless, further research is required to understand the proximate and ultimate causes, and the consequences, of this behavior.

Keywords: non-breeding dispersion, seabirds, *Spheniscus*

### Introduction

Ornithologists have defined bird migration as the massive dispersion from breeding areas and subsequent return, involving hundreds to thousands of kilometers (Newton 2010). Migration is an adaptive response to fluctuating environments, by which animals overcome the problem of depleted resources by leaving one place to use resources in other more favorable places (Newton 2010). Within some species or populations, individuals have different dispersion behaviors, with some of them migrating through different habitats while others remain as residents within the same habitat. This is known as partial migration (Dingle 1996).

Among penguins, the genus *Spheniscus* generally has a low tendency to migrate over large distances (García-Borboroglu and Boersma 2015). For instance, the African penguin *S. demersus* disperses during the non-breeding stage to a maximum range of 900 km, very close to the coast (20 km on average) (Roberts 2016). The Galapagos penguin *S. mendiculus* moves very close to the colony, not dispersing beyond 200 km. The Humboldt penguin *S. humboldti* does not migrate with a specific pattern (García-Borboroglu and Boersma 2015). In contrast, the Magellanic penguin *S.*



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*magellanicus* has always been considered the most migratory species in the genus (García-Borboroglu and Boersma 2015). It breeds from October to March and spends the rest of the year at sea (Boersma et al. 2013). In recent years, complete migratory trips have been recorded in several colonies, which have been observed to disperse thousands of kilometers northwards (Yamamoto et al. 2019, Barrionuevo et al. 2020, Dodino et al. 2021).

The Magellanic penguin plays a key role in the trophic web and in the South Atlantic Ocean ecosystem, because it is an abundant seabird species, with colonies distributed along the Patagonian coast from Isote Lobos (41.9°S, 65°W) to Isla de los Estados (54°45'S, 64°20'W) (Schiavini et al. 1999, Schiavini et al. 2005, García-Borboroglu et al. 2022, Millones et al. 2022), and because of its role as top predator of fish (Ciancio et al. 2021). Studying the movements of this species during the non-breeding season along its distributional range is key to understanding its migratory behavior. The current study found evidence of variability in the non-breeding dispersion behavior in a Magellanic penguin colony. As far as we know, this is the first study to find partial migration within the same colony for any penguin species.

## Material and methods

During January to March 2020 and 2021 we recorded the migratory trips of 13 penguins, one of which was tracked in both years. Five penguins were tracked in 2020 (three females and two males), and nine in 2021 (five females and four males). These penguins were breeders from Cabo Vírgenes colony (52°21'S, 68°23'W) and were deployed with geolocators. The devices were recovered from October to November within the same year when penguins returned from their migration. Magellanic penguins molt once a year, in March–April, after breeding, and then they depart on their long migration trip (Boersma et al. 2013). In this study, we excluded the pre-molting trip from the data set. Magellanic penguins were selected randomly on the basis that they were breeding at the colony or were known to have bred there in previous years. We measured bill depth and bill length using calipers to determine the sex of individuals (Gandini et al. 1992).

Geolocators were attached to the legs with cable ties, as recommended by Ratcliffe et al. (2014). The tags recorded light intensity once per minute; maximum light level per 5 min period; and saltwater immersion, which was used to determine whether the individual was in (wet) or out (dry) of the water. MK3 geolocators also recorded temperature after 25 min of continuous wet conditions. The geolocators were analyzed following Lisovski et al. (2020) and Barrionuevo et al. (2023).

Calculation of trip duration was based on departure and arrival dates estimated with the geocator wet/dry data. Trip metrics (total distance traveled and maximum distance reached) were calculated using established methods from the R package track2KBA (www.r-project.org, Beal et al. 2021) applied to the most likely track of each individual. Penguins' tracks were divided into migrants and residents according

to the maximum distance they reached. The cutoff distance to establish migrants/residents was set at 600 km. This was based on publications with complete round trip records for this species (Yamamoto et al. 2019, Barrionuevo et al. 2020, Dodino et al. 2021) and on unpublished data from Isla Quiroga colony (mean maximum distance reached was  $1135 \pm 66.9$  km ( $n=52$ ); range = 655 – 2183 km; Barrionuevo and Frere unpubl.). Trip metrics and duration between migrant and resident penguins were compared using t-tests or Wilcoxon test.

The spatial overlap between migrants and residents during dispersion was calculated by taking into account the density distribution (i.e. calculations of the time spent) (Broennimann et al. 2012). For this analysis, we used data recorded from May to August to avoid transition trips between breeding and overwintering areas.

For the estimated most likely tracks, we extracted Chlorophyll-*a* (Chl-*a*) from weekly satellite data (Chl-*a*: 1080 × 2160 global grid resolution (Behrenfeld and Falkowski 1997) and sea surface temperature (SST) at a one-degree spatial resolution (NOAA OI SST V2 High Resolution Dataset, <https://psl.noaa.gov>). For SST and for log (Chl-*a*) as response variables, mixed models were run with penguin IDs as random factors and dispersion behavior (migratory and resident) as predictor factor, using the R package 'lme4' (www.r-project.org, Bates 2010). This analysis also used data recorded from May to August.

Data analyses were run with R and R-Studio (www.r-project.org), and results are presented as mean ± SD.

## Results

Of the 14 penguins studied, six stayed within approximately 600 km of the colony, while eight went beyond 700 km (Fig. 1, Supporting information). The residents were all females, with the exception of one male in two consecutive years (the only bird with two dispersion trips). This male remained as a resident in both years. Trip duration (t-test:  $t=0.11$ ,  $p=0.91$ ;  $\bar{X}_{migrants} = 165.7 \pm 17.7$  days;  $\bar{X}_{residents} = 166.7 \pm 9.0$  days) and total distances traveled (Wilcoxon test:  $W=35$ ,  $p=0.18$ ;  $\bar{X}_{migrants} = 6317.9 \pm 2080.3$  km;  $\bar{X}_{residents} = 4542.2 \pm 674.7$  km) did not differ between migrants and residents. Migrants traveled further maximum distances than residents (t-test:  $t=-5.02$ ,  $p < 0.001$ ;  $\bar{X}_{migrants} = 1376.9 \pm 497.6$  km;  $\bar{X}_{residents} = 293.1 \pm 192.7$  km) (Supporting information). The overlap between migrants' and residents' areas for the trips from May to August, was 31.43% (Fig. 1C–D).

The SST and Chl-*a* values experienced by the penguins that migrated versus the residents did not include zero in their confidence intervals (Fig. 2; CI 2.5–97.5% for SST: migrants = 8.7–10.4°C, residents = 5.2–9.35°C; CI 2.5–97.5% for Chl-*a*: migrants = 6.489–6.799 mg/L, residents = 5.821–6.612 mg/L). Resident penguins experienced lower SST ( $\bar{X}_{migrants} = 9.6 \pm 2.6^\circ\text{C}$ ;  $\bar{X}_{residents} = 7.2 \pm 1.4^\circ\text{C}$ ) and Chl-*a* concentrations ( $\bar{X}_{migrants} = 914 \pm 511$  mg/L;  $\bar{X}_{residents} = 508 \pm 110$  mg/L) than migrant penguins.

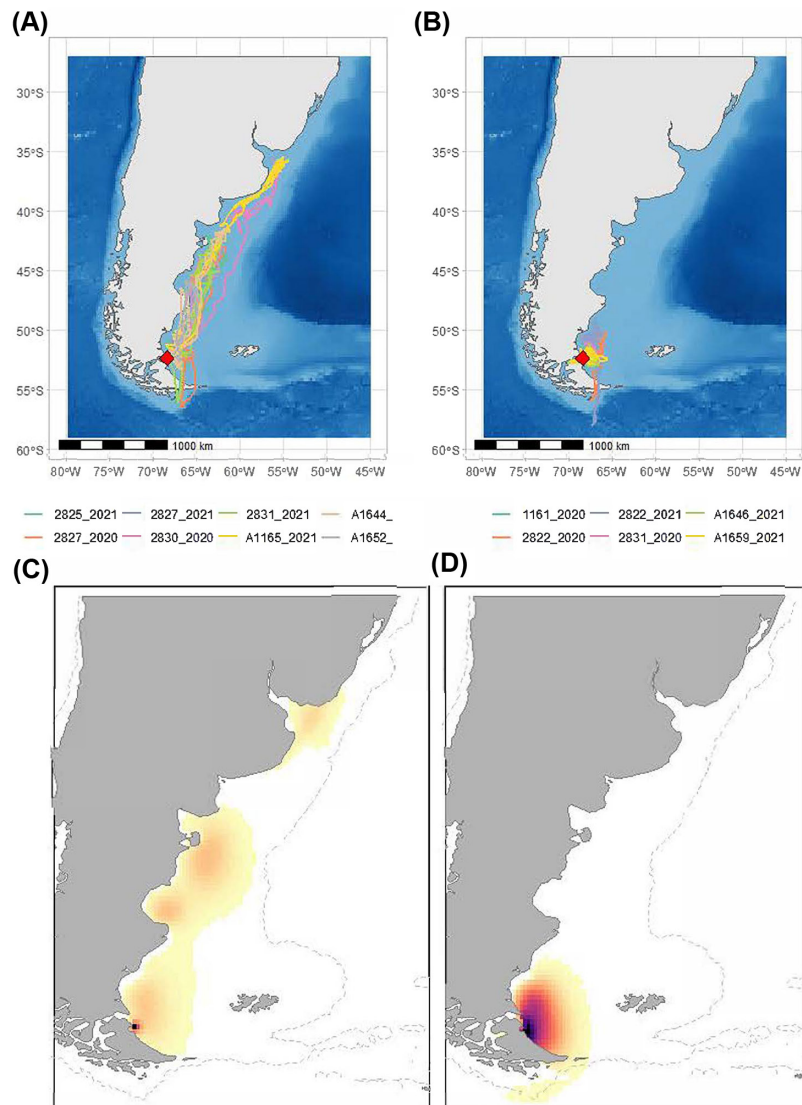


Figure 1: Non-breeding dispersion trips of (A) migrant and (B) resident Magellanic penguins from the Cabo Vírgenes colony (marked with a red diamond). Penguin IDs are specified in the legend. Geolocators were used to track individuals from after molting until their return to the colony. Density points of the May to August dispersion are shown for (C) migrant and (D) resident penguins. Darker colors show more concentrated densities.

## Discussion

We found partial migration within the same colony for the first time in this species, despite many studies having been conducted in recent years on Magellanic penguins that breed in different colonies along the Argentinean coast (five colonies covering all the breeding ranges: Yamamoto et al. 2019, Barrionuevo et al. 2020, Dodino et al. 2021, Barrionuevo et al. 2023). While some individuals migrated long distances, even as far as the Río de la Plata Estuary (2000 km away), others stayed as residents within ~ 290 km of the Cabo Vírgenes colony. Both migrants and residents traveled similar total kilometers and spent the same amount of time at sea, probably because of the constraint imposed by the timing of the breeding season.

Although our sample size was low (14 dispersion trips over two years), 43% of the penguins tracked stayed as residents, suggesting that this behavior is most likely common in this colony. Most penguins that remained near the colony were females (of five individuals, four were females), although 50% of the penguins that undertook the long migration trip were also females. In contrast, of the five males tracked, only one (from whom we had two consecutive migration trips) stayed resident for two consecutive years; all the others undertook the long migration trip. A larger sample size is needed to confirm whether this is a common behavior skewed towards females, and/or to determine individual consistency in this behavior; that is, if individuals that migrate or stay resident normally have the same behavior. In some marine birds, partial migration is biased towards one sex (Pérez et al. 2014,

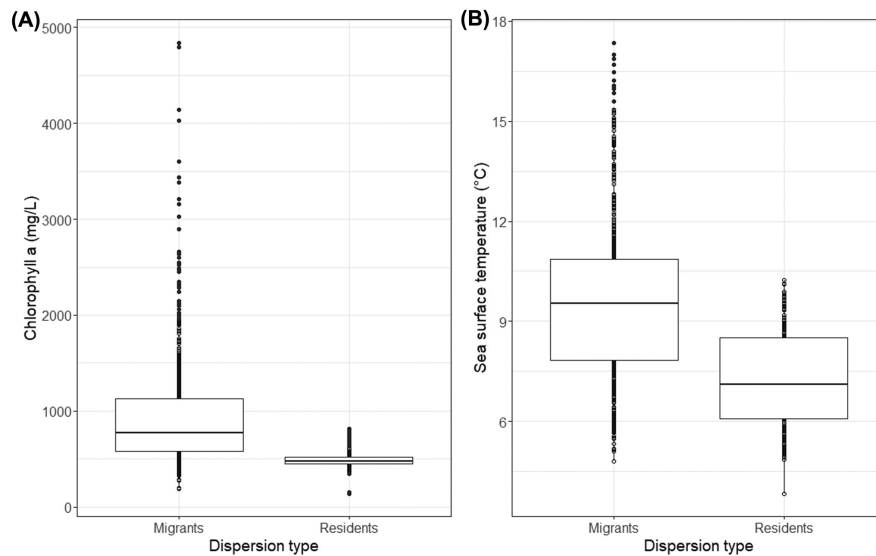


Figure 2: (A) Chlorophyll-*a* and (B) sea surface temperature experienced by Magellanic penguins that migrated and those that stayed near the colony (migrants versus residents). Data from May to August were used.

Deakin et al. 2019). For instance, *Morus bassanus* males migrate further than females even though they are smaller (Deakin et al. 2019), while *Calonectris diomedea* males are usually more resident than females, independently of body size or age (Pérez et al. 2014).

From May to August, penguins experienced different SST and Chl-*a* according to their dispersion behaviors. The differences in SST and the different areas used by migrants and residents are evidence that individuals of the same colony are consuming different prey species during winter. Magellanic penguins that stayed resident might be consuming Fuegian sprat *Sprattus fuegensis*, whose mean habitat temperature is 7.5°C (range: 5–10°C; Allegra et al. 2019, Madirolas et al. 2000), while penguins that migrated long distances might be consuming Argentine anchovy *Engraulis anchoita* (mean temperature: 12.5°C and range: 8.6–16°C, Hansen et al. 2001). Fuegian sprat is a highly caloric prey (Ciancio et al. 2008) and, in the surroundings of the colony Cabo Vírgenes, it is the most common prey in penguin diet during the breeding period in spring and summer (Frete et al. 1996, Ciancio et al. 2021). Fuegian sprat is also present in winter in the Beagle Channel (Diez et al. 2017) and in autumn off the coast of Tierra del Fuego (García Alonso et al. 2020). In fact, the area off the coast of Santa Cruz and Tierra del Fuego is a major stock and nursery ground for this species (Buratti et al. 2020). We propose that this stock might enable penguins to stay near the colony in winter, but might not be enough to feed all the penguins, thus forcing part of the colony to migrate. However, resident penguins experienced water temperatures 2°C colder than migrants during dispersion, which might have consequences in the higher metabolic cost associated with thermoregulation (Ciancio et al. 2016). A balance between the consumption of a highly caloric prey

and the cost of using colder waters in the south might be the key to understanding the decision to be a migrant or a resident. On the other hand, we have found a lower concentration of Chl-*a* between the area of the residents and that of the migrant penguins. Chl-*a* concentrations determine the movement behaviors of several marine birds whose diet relies on fish (Gulka et al. 2023), but this does not necessarily mean that lower Chl-*a* habitats have lower quality. During winter the area of the residents is subject to lower photosynthetic activity, which might be reflected in the satellite data. This does not necessarily mean that in those areas Fuegian sprats, or other prey species that penguins might be consuming, are not abundant and might be consuming zooplankton.

Further studies are needed to understand the proximate and ultimate causes of partial migration in this species (Chapman et al. 2011), and to determine whether this behavior is obligate and fixed within individuals (Berthold 2001); or facultative, varying within individuals according to environmental conditions (Cristol et al. 1999). The advantages of this Magellanic penguin behavior are unclear, although a meta-analysis of flying birds has shown that resident birds have higher fitness return than migrants (Buchan et al. 2020). Resident Magellanic penguins face colder sea conditions and most likely low food availability by staying in southern waters, but migrants have to cover long distances with the corresponding energetic cost of transport (Alerstam et al. 2003, Newton 2010) and associated risks (Gandini et al. 1994, Crawford et al. 2017). The partial migration found in the current study shows the high variability in Magellanic penguin migratory behavior, possibly driven by the supply of prey and environmental characteristics of the area interacting with individual penguin conditions. The high variability in the oceanographic habitats and trophic niches that this species



experiences within the same colony, but also among colonies (Barrionuevo et al. 2023), may provide evidence of the possibility that this species is adapting in a changing world.

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## Author contributions

**Melina Barrionuevo:** Conceptualization (equal); Data curation (lead); Formal analysis (lead); Investigation (equal); Methodology (equal); Software (lead); Writing – original draft (lead). **Esteban Frere:** Conceptualization (equal); Funding acquisition (lead); Investigation (equal); Methodology (equal); Project administration (lead); Writing – review and editing (equal).

## Transparent peer review

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## Data availability statement

Data are available from the Dryad Digital Repository: <https://doi.org/10.5061/dryad.n5tb2rc26> (Barrionuevo and Frere 2023).

## Supporting information

The Supporting information associated with this article is available with the online version.

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