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BRIEF REPORT

Spring migration of a Neotropical shorebird, the Rufous-chested Plover, *Charadrius modestus*, between southern Brazil and the sub-Antarctic Falkland/Malvinas Islands

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Abstract

Information about migratory strategies and routes is central to avian ecology and conservation, but frequently lacking for Austral breeding species. Terrestrial Austral migrants wintering in southern Brazil are largely thought to breed in Patagonia and migrate to the region in late winter/spring. Here, we present satellite tracking data from 3 adult Rufous-chested Plovers (*Charadrius modestus*) tagged during the nonbreeding season in southern Brazil and describe the weather conditions during the initiation of their pre-breeding migration. These individuals departed their wintering areas on days of decreasing air pressure and predominantly NE quadrant tailwinds in late August/early September. Unexpectedly, they all performed non-stop flights (mean ± 1 standard deviation = 2,354.6 ± 30.8 km in orthodromes) over the Southwestern Atlantic Ocean to reach breeding sites in the sub-Antarctic Malvinas/Falkland Islands in 3–6 days. These are the first tracking data for this species, and some of the only data from any species using this poorly studied migratory system. Gathering additional information on this route could, therefore, be crucial for management and conservation, as little is known about the sites at which migrants concentrate during the pre-migratory period and because this route can be a potential gateway for emerging pathogens and viruses to sub-Antarctic and Antarctic regions.

Keywords Biologging · Bird migration · Charadriidae · Movement ecology · Rufous-chested Dotterel

Introduction

Bird migration generally involves regular, annually repeated seasonal movements between breeding and wintering areas (Rappole 2013), enabling organisms to exploit spatial and temporal peaks in resources (Dingle 2014; Zhao et al. 2017). Migration, however, is energetically expensive (Hedenström and Alerstam 1997), and different behaviors may be utilized so that birds can either achieve the fastest (time minimization) or most efficient (energy minimization) migrations (Åkesson and Hedenström 2000). As a result, the cost of long-distance migration is thought to select for migrants that can make adaptive decisions about when to migrate based on local weather and habitat conditions (Saino et al. 2010).

In addition to an individual's (re)fueling rate and body condition (Lindström et al. 2019), weather conditions can play a strong role in the decision to leave their wintering grounds or stopover areas (Packmor et al. 2020). Long-distance migrants are predicted to select for favorable winds at departure (Conklin and Battley 2011), and the presence of favorable winds can substantially improve migration efficiency and help minimize migration-associated risks (Vanstellant et al. 2017). Once *en route*, migrants may be able to correct for suboptimal wind conditions encountered (Linscott et al. 2022), but such behaviors require increased energetic expenditures and can lead to in-flight mortality

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events (Loonstra et al. 2019). Winds, thus, represent one of the most important factors influencing avian migrations, especially for species undertaking trans-oceanic flights during which stopovers are impossible (Gill-Jr et al. 2014).

Shorebirds are among the organisms that perform some of the longest migrations in the world (Conklin et al. 2017). Migratory shorebirds play an important role as major reservoirs and potential vectors of pathogens and viruses along migratory routes (Klaassen et al. 2012; Navedo et al. 2021), including the highly pathogenic avian influenza H5N1 (Wille et al. 2019). However, there is a lack of knowledge about the basic biology of many shorebird species (Piersma and Lindström 2004), including the migration route of shorebirds endemic to South America (Piersma et al. 1997). The Rufous-chested Plover, or Dotterel (*Charadrius modestus*, Charadriidae), is a medium-sized Neotropical shorebird that breeds mostly in Chilean and Argentinean Patagonia, but with a small population also breeding on the Falkland/Malvinas Islands. The species has been described as a partial migrant—i.e., part of the population remains resident year-round, while the rest of the population migrates—but population-specific migration strategies and routes are unknown (Wiersma et al. 2020). In southern Brazil, the species occurs during the Austral fall-winter. These individuals are hypothesized to migrate northward to Brazil from breeding sites in southern South America (Kovacs et al. 2006), but concrete evidence on migratory connectivity is currently lacking.

Recent advances in biologging technologies have vastly improved our knowledge of movement ecology (Joo et al. 2022). The recent miniaturization of loggers and ability to remotely download data from tracking devices, in particular, has allowed to study the movements of small bodied species, such as shorebirds (e.g., Clark et al. 2010; Lanctot et al. 2016; Chan et al. 2019). In this study, we deployed GPS transmitters on *C. modestus* wintering in southern Brazil to disentangle their spring migration strategy with respect to departure time, wind preference, stopover sites, and routes, with potentially important implications for optimal migration theory. Our study also provides much-needed information for conservation about the connectivity between wintering and breeding areas of this little-known species.

Methods

Study site and GPS deployment

We conducted the study in Lagoa do Peixe National Park (31°15'S; 50°55'W), located on the central coast of the Rio Grande do Sul state in southern Brazil. Lagoa do Peixe National Park is a 36,722-ha protected area and consists of a mosaic of coastal environments adjacent to a 35-km long shallow lagoon that is used by numerous shorebird species as breeding and wintering sites (Bencke et al. 2006). At the site, *C. modestus* feeds mostly on short grasslands maintained by cattle grazing adjacent to saltmarshes, as well as the lagoon's mudflats and shoreline (F.A. Faria, pers. obs. 2021).

Four birds were captured on 27 July, 2021, during the Austral winter. We captured all individuals at night with dip nets and a spotlight. After capture, birds were marked with a unique combination of color bands, metal rings with alphanumeric codes. We weighed unsexed individuals heavy enough to be equipped with the transmitters (e.g., individuals for which transmitters were < 5% of body mass; Kenward 2001). We attached 4-g Pinpoint GPS-Argos transmitters (Lotek UK Ltd.) with a 'leg-loop' harness (adapted from Rappole and Tipton 1991; Sanzenbacher et al. 2000) made of 1-mm diameter polymer cord ('Stretch Magic', Pepperell Braiding Co., USA) and fixed using 1-mm brass crimps (McDuffie et al. 2022). The combination of tag and harness weighed ~ 4.2 g and the entire process of banding, measurement, and tagging lasted ~ 20 min per individual. Body mass of tagged birds varied from 70.4 to 84.5 g. After completion, we kept the tagged individuals in boxes to recover until sunrise, after which they were released and observed for ~ 1 h to ensure that their ability to move and their body posture were unaffected by tag deployment, capture, and handling. The transmitters were chosen because they collect high-accuracy location data (± 10 m) and remotely transmit locations via the Argos system (CLS America 2016). We set the transmitters to collect one position on 1 August and then one position every 3 d from 10 August – 31 October. After that, if the batteries were still working, the transmitters collected one position every 8 d.

Weather data

We downloaded information about average wind speed and direction from 4 d before to 2 d after birds left the wintering area. Data were obtained from a moored buoy linked to the *Sistema de Monitoramento da Costa Brasileira* (www.simcosta.furg.br/). This station collects meteorological data every 30 min and is located ~ 130 km south of the transmitter deployment site.

Data analysis

We filtered data by using GPS-only locations with good cyclic redundancy checks and three-dimensional fixes (Ng et al. 2018). Movement paths were determined by connecting consecutive positions with orthodrome lines. We measured (i) step lengths—the distance between two consecutive positions, (ii) migration distance—the distance between the last position in the nonbreeding range and first location in the breeding range, and (iii) departure interval—the difference in dates between the last position in the nonbreeding range and the first position in the breeding range.

In order to characterize the environment used by the birds during the nonbreeding period, we ground-truthed location estimates *post-hoc*. To describe the weather conditions at departure, data were separated into periods during which no tagged birds departed (hereafter 'pre-departure' or fueling period) and the interval during which the tagged birds left the nonbreeding sites (hereafter initial 'departure period', sensu Lindström et al. 2019). The pre-departure period corresponds to the period 3–6 d (based on the interval of position collection) before departure.

Results

We received data from 3 out of the 4 tagged birds (23–27 positions each), between 1 August and 23 December 2021. One of the tags sent no information, possibly due to equipment failure, dropping out or the death of the individual in a manner that made it impossible for its tag to send positions. Individuals stayed mostly in grassland areas west of Lagoa do Peixe National Park during the pre-departure period. However, all individuals visited rice fields located 8–35 km N/NW of the park in the week(s) before departure from nonbreeding areas and used these rice fields for a total of 3–12 d (Fig. 1a).

One individual left the study area between 28 and 31 August, while the other two individuals left between 6 and 9 September. All birds performed a non-stop flight over the Southwestern Atlantic Ocean of 2,354.6 ± 30.8 km (mean ± 1 standard deviation; Table 1; Fig. 1b), reaching the Falkland/Malvinas Islands no more than 72 h after departure (Fig. 1c). Winds during departure periods were predominantly from the NE quadrant ($\overline{x}$ = 14.7 ± 2.5 knots), while during the pre-departure period, the wind direction was more equally distributed across quadrants (Fig. 2). Birds remained in the breeding area until the tag batteries were drained early in the Austral summer.

Discussion

We provide here the first migratory tracks for Rufous-chested Plovers. These tracks demonstrate that the species is able to perform a non-stop pre-breeding migration over

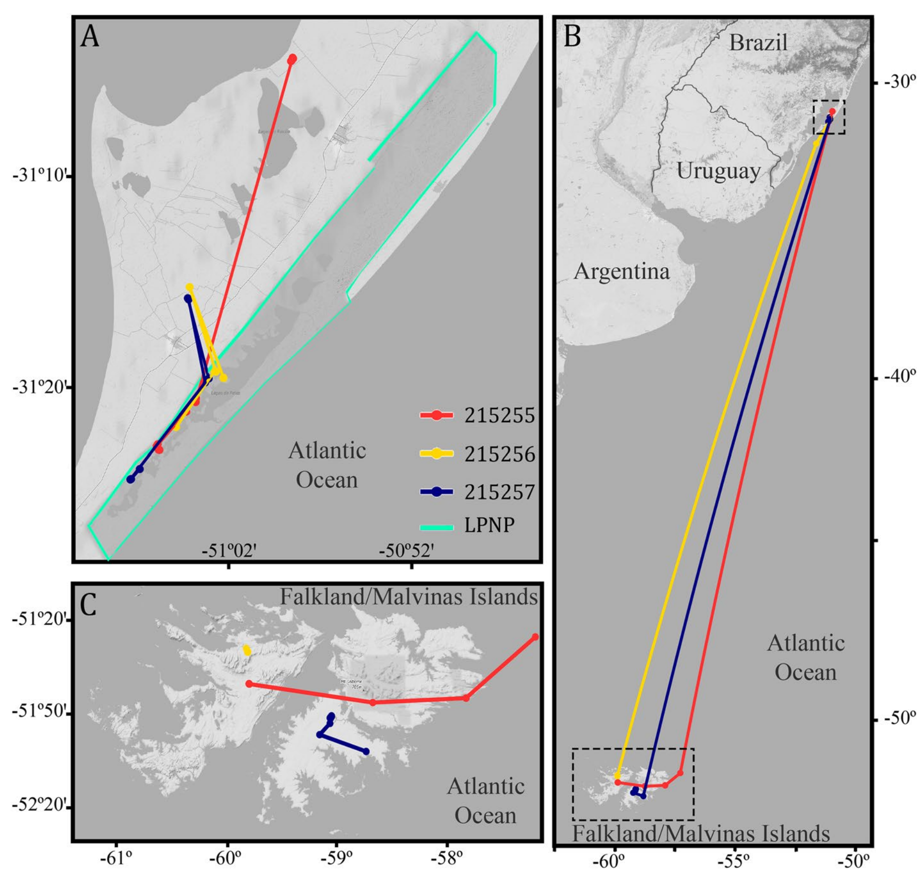

Fig. 1 Movements of Rufous-chested Plovers (*Charadrius modestus*) wintering in southern Brazil during the pre-departure or fueling period (**a**), migratory (**b**), and post-migratory (**c**) periods. Different colors correspond to different individuals and LPNP indicates the borders of Lagoa do Peixe National Park

Table 1 Migration dates and distances of three individual Rufous-chested Plovers, *Charadrius modestus*, from their wintering grounds in southern Brazil to their breeding grounds on Falkland-Malvinas Islands in 2021

Individual	Deployment date	Mean departure date interval ± 1 d	Distance migrated (km)	Number of GPS fixes
215255	27 July 2021	07 September 2021	2323.2	27
215256	27 July 2021	30 August 2021	2355.8	23
215257	27 July 2021	07 September 2021	2384.8	27

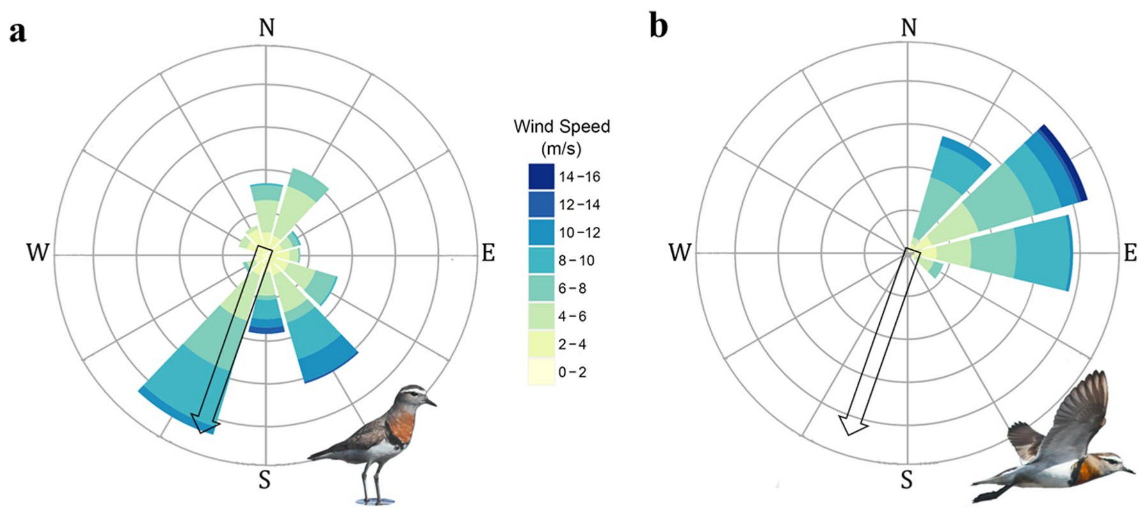

Fig. 2 Wind speed and direction experienced by satellite tracked Rufous-chested Plovers (*Charadrius modestus*) wintering in southern Brazil during pre-departure or fueling (**a**) and migratory departure (**b**) periods. Black arrows indicate departure directions towards Falkland/Malvinas Islands

the Southwestern Atlantic Ocean of more than 2000 km. Unexpectedly, we also demonstrate that at least part of the Brazilian wintering population breeds on sub-Antarctic Falkland/Malvinas Islands rather than mainland Patagonia. Because all tracked individuals carried out similar movements, these results lead us to hypothesize that wintering Rufous-chested Plover may exhibit high levels of migratory connectivity (i.e., belonging to the same breeding population) and that individuals making trans-oceanic flights time their departures from their wintering sites to coincide with favorable wind conditions.

Despite the unexpectedly long flights exhibited by our tracked individuals, it is likely that we underestimated the true durations of their migratory flights, both because of the large intervals between location fixes provided by our tracking devices and because the orthodromic lines we used to estimate their flight paths do not account for the sinuosity of true migratory flights (e.g., Linscott et al. 2022). This demonstrates the capacity of plovers to make non-stop spring migratory flights, day and night, and may reflect a time minimization strategy (Alerstam 2009). Optimal migration theory suggests that this strategy is more commonly adopted during spring migration (Hedenström and Alerstam 1997; Zhao et al. 2017), as early arrival at the breeding grounds can be advantageous for territoriality, mate attraction, and breeding performance (Kokko 1999; Nilsson et al. 2013). This pattern has also been observed in other Charadriidae, such as Grey Plover (*Pluvialis squatarola*; Exo et al. 2019) and Little Ringed Plover (*Charadrius dubius*; Hedenström et al. 2013).

Optimal migration theory provides a framework for understanding how birds are able to manage exposure to adverse meteorological conditions and decisions about when to depart based on weather (Gill-Jr et al. 2014; Winkler et al. 2014), as well as minimize *en route* predation risk (Gill-Jr et al. 2005; Ydenberg 2022). Wind conditions largely affect the energetic costs of movement (e.g., Linscott et al. 2022), with cross or headwinds increasing energy expenditure (Nourani and Yamaguchi 2017) and tailwinds potentially increasing flight speed and daily travel distances (Mellone et al. 2012). Wind dynamics in southern Brazil are mainly influenced by the South Atlantic subtropical anticyclone, which results in the dominance of NE winds, except during the passage of cold fronts, when the dominant winds are from the SW quadrant (Grimm 2009). Cold fronts are common during the spring migration period of Rufous-chested Plovers, occurring every 6–10 days (Klein 1998), and could act as crosswinds and discourage migratory departures. Even though our small sample sizes did not allow us to model or statistically test the effect of winds on departures, they suggest that birds likely departed after the passage of cold fronts when winds were out of the NE.

Winds may be particularly important to Rufous-chested Plovers because all the individuals we tracked undertook direct offshore flights across the Southwestern Atlantic Ocean. While unexpected, our results are not entirely unprecedented, as there have been previous reports of Rufous-chested Plovers observed over the open ocean near the Falkland/Malvinas Islands in spring (Prince and Croxall 1996). Offshore flights are also relatively common among other plover species (e.g., Johnson et al. 2006, 2020; Loring et al. 2020), which make departure under ideal conditions, a prerequisite for avoiding unexpected bad weather conditions at sea, where no stopovers for plovers occur. Despite being improbable, the time interval between location estimates provided by our tags preclude us from entirely ruling out the potential that the tagged individuals first flew southward along the coast before flying directly eastward from the Argentine coast to reach the Falkland/Malvinas Islands.

This is the first study to describe the Falkland/Malvinas—Southern Brazil route, but it is likely that other migratory terrestrial breeding birds on the islands share the same flight paths (e.g., Two-banded Plover, *Charadrius falklandicus*). Gathering more knowledge about this potential route could be crucial for conservation practitioners and management actions (Chan et al. 2019), especially in relation to potential coastal areas from which birds may gather to depart for their flights. In addition, this route may be a potential gateway to sub-Antarctic and Antarctic regions for emerging pathogens and diseases, such as avian influenza—a growing concern in South America (Araujo et al. 2018), that arrived on the continent during the 2022 Austral spring and in the Atlantic coast of Uruguay in February 2023 (https://www.montevideo.com.uy/Salud/Confirman-primer-caso-de-influenza-aviar-en-Uruguay-detectaron-la-enfermedad-en-un-cisne-uc845842), nearby to areas where the plovers we tracked spend the winter. Finally, the areas utilized by the individuals we tracked may soon be threatened by coastal development and the construction of offshore and costal wind farms (González et al. 2020; Loring et al. 2020). A number of these farms have already been installed in southern Brazil on shore (Weiss et al. 2018) and proposed for offshore areas as well (Bugoni et al. 2022).

Conclusion

Using satellite transmitters, we were able to describe the pre-breeding migration, timing, and routes of a Neotropical shorebird moving between its wintering areas in southern Brazil and breeding areas on the sub-Antarctic Falkland/Malvinas Islands. Further studies, and an increase in birds tracked (i.e., both from breeding and wintering grounds), would reveal other aspects of the migratory ecology of this species, such as their winter site fidelity, potential for sex-specific differences in migratory ecology, population connectivity, and weather-related movement decisions. Finally, expanding such movement studies to other migratory species could enhance our understanding on the importance of the poorly studied Falkland/Malvinas–South American migratory system, which was only known previously from seabirds (e.g., Olmos 2002), and support conservation and management decisions for shorebirds and landbirds.

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Author Contributions FAF and MR collected the data and designed research. FAF wrote the manuscript. FAF and GTN analyzed data. LB and NS provided methodology and conceptualization support. All authors read, reviewed, and approved the manuscript.

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Data availability Tracking data used for this study had been deposited in https://www.movebank.org/cms/movebank-main and is available under request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval The study had been allowed by Ethics Commitee on Animal Use (CEUA-FURG, Certificate P021/2021); The *Instituto Chico Mendes de Conservação da Biodiversidade* (ICMBio) and CEMAVE/ICMBio allowed the study to be carried out through License SISBIO No. 56070–5, which included banding permits.

Consent for publication Not applicable.

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