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Keyword:	Atlantic Ocean, migration, seabirds, movement

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Non-breeding Areas of Common Terns from the Azores

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Migration routes and non-breeding areas of Common Terns *Sterna hirundo* from the Azores

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Abstract. Here we report migration routes and non-breeding areas of Common Terns (*Sterna hirundo*) from the Azores archipelago, based on ring recoveries (including live and dead birds) and tracking using geolocators (global location-sensing or GLS loggers). To date, there have been 55 transatlantic ring recoveries of Common Terns from the Azorean population - six from Argentina and 49 from Brazil - reported over 15 different years. The three tracked birds migrated southwards in different months (August, September and November), but were more synchronous on the northbound migration, which in all cases began in April. The birds were tracked to three different areas along the South American coast; the male spent November to April on the north Brazilian coast (13°N-2°S), whereas the two females first spent some time off northeast Brazil (4-16°S; one for a week and the other for three months) and then moved south to the coast off southeast Brazil, Uruguay and northern Argentina (24-39°S). Although the values need to be viewed with caution given our small sample size and the errors associated with geolocation, the tracked terns potentially travelled up to c. 23,194 km in total to-and-from the non-breeding grounds, representing an average of about 500 km/day. With the exception of Belém (north Brazil) and Lagoa do Peixe (south Brazil), the coastal areas used by the tracked birds coincided with concentrations of ring recoveries, confirming their importance as non-breeding areas for birds from the Azores population.

Additional keywords: at-sea distribution, Argentina, Brazil, geolocation, ring recoveries, nonbreeding season, Patagonian shelf.

Introduction

Over the last two decades, our knowledge of seabird movements and distribution at sea has been greatly improved by tracking technologies (Burger and Shaffer 2008, Phillips *et al.* 2008). In particular, the miniaturization of light-level geolocators (global location sensing or GLS loggers) has provided unprecedented detail on the migration of smaller species such as terns (Egevang *et al.* 2010, Nisbet *et al.* 2011a, Fijn *et al.* 2013, McKnight *et al.* 2013, van der Winden *et al.* 2014).

Ring recoveries have shown previously that the North American populations of the Common Tern *Sterna hirundo* spend the non-breeding period along the South American coast (Hays *et al.* 1997, 1999), and recently, Nisbet *et al.* (2011a) used geolocators to track the migration of five birds from a breeding colony in Massachusetts. Analyses of ringing data suggest that Common Terns from the NW European population have a rather different strategy, spending the non-breeding along the West African coast (Wernham *et al.* 2002). Ring recoveries of Azores breeders off Brazil and Argentina (Hays *et al.* 1999, Neves *et al.* 2002, Lima *et al.* 2005) indicate that at least some Common Terns from the Azores spend the nonbreeding season on the South American coast, suggesting they use the same areas as birds from North America; however, details of the route and other aspects of migration remain poorly known.

More information is needed to ensure protection at the non-breeding grounds of Common Terns from the Azores population, which is substantial (c. 3000 pairs; Neves 2011) and unusual in that the birds breed on remote, oceanic islands. Hence, the purpose of this study was to combine data from ring recoveries and geolocator tracks to determine the distribution, timing of migration, routes and non-breeding areas of birds from the Azorean population.

Methods

Ring recoveries

Ring recovery data provide snapshots of distribution and can be a good complement to tracking data (e.g. Harris *et al.* 2010). We present details of all the ring recoveries available in the Portuguese Ringing Centre database; these include seven previously published ring recoveries (Hays *et al.* 1999, Neves *et al.* 2002, Lima *et al.* 2005). We use the term "recovery" to include both birds trapped and released, and birds found dead (these are distinguished in Tables S1 and S2). The recoveries were made over a period spanning almost two decades (1993-2013) by different organizations and individuals in Brazil and Argentina. In Brazil, Common Terns have been ringed by over 25 different ringers. Nevertheless, most recoveries of Azorean birds in Brazil were obtained through the ringing program coordinated by P. Lima on the northeast coast of Brazil. Coastal surveys were conducted beforehand, using a single-engine airplane, to identify the sites with higher concentration of terns. Trapping and ringing activities took place in January to April, November and December, for 3 to 10 days a year, between 16:00h and 05:00h, using 20 mist nets (12 x 2.5m; 12mm mesh) (Lima *et al.* 2005). In Argentina, terns have only been trapped at one location, Punta Rasa; trapping involved mist netting from 1993 until 2008, and use of cannon nets (16*7m) since 2010, in periods of 1-3 days in January to March, November and December each year. No tern ringing was conducted in Punta Rasa in 2009.

Study area

The nine islands of the Azores archipelago hold about 50 colonies of Common Tern. The tracking study was conducted at Praia islet (39°03'N, 27°57'W; 0.12 km^2), Graciosa island, Azores archipelago, between 7 and 15 June 2011, and 26 May and 19 June 2012. Praia islet provides breeding habitat for six seabird species including Common Terns and Roseate Terns

(*Sterna dougallii*). In the mid-1990s, Praia islet benefited from a habitat restoration program and tern numbers rose sharply, accounting for one third of the Azorean breeding population in 2003 (Bried *et al.* 2009). Since then, the islet has remained an important site for terns, including c. 350 Common Tern pairs in 2011 (Neves 2011). Praia islet is one of the few Azorean colonies where a geolocator study could be conducted; the others are Vila islet (off Santa Maria island) and Feno islet (off Terceira island). Unlike most others in the Azores, these colonies are accessible, the nests are located in areas where birds can be trapped, and they normally hold over 100 pairs. However, Vila islet has suffered from problems relating to egg predation by European Starling (*Sturnus vulgaris*) (Neves *et al.* 2011), and rats *Rattus rattus* can be a problem at Feno islet (Amaral *et al.* 2010). Therefore we decided to conduct the study at Praia islet.

Geolocator deployment

We deployed a total of 29 geolocators (15 Mk10 and 14 Mk18; British Antarctic Survey, Cambridge, UK) on adult breeding Common Terns captured using walk-in treadle traps set over their nests. Birds were measured (wing length, tarsus, head and bill), weighed and ringed (with a metal ring, and a darvic ring to which the geolocator was attached, on opposite legs). A 50-μl blood sample was collected from the tarsal vein, from which sex was later determined genetically (Fridolfsson and Ellegren 1999). A few turns of self-amalgamating tape were wrapped around the waist of the logger (without obscuring the light sensor), which was then attached using Kevlar© thread to the darvic ring; the thread was then covered with a resin (West System® G/5 adhesive epoxy) to reduce the likelihood of breakage (see Fig. S1, Supplementary Online Material). The total weight (darvic ring, geolocator and attachment) was 1.7±0.3 g, representing on average 1.2% of bird body mass, which is well below the load threshold (3%) beyond which adverse effects are more likely to occur (Kenward, 2001, Phillips *et al.* 2003). However, note that Nisbet et al. (2011a) reported serious injuries after a few days in four of 14 birds fitted with loggers that represented 1.2%-1.6% of body mass. From our visual observations, the birds in our study were doing well up to several days after deployment. We equipped only one individual per pair to limit disturbance; their mates were also marked with a metal and a white darvic ring so that they would be easy to spot the following year. Upon recovery, the birds were weighed and the logger removed. The geolocators were calibrated at a fixed location before and after deployment.

Geolocator data analysis

Light data were downloaded from the retrieved loggers and processed using BASTrak software (British Antarctic Survey) to estimate the latitude from day length and longitude from the time of local midday relative to Greenwich Mean Time. The geolocators measure light values every minute and store the maximum reading (truncated at an arbitrary value of 64) at the end of every 10-min period. During processing, we used a light threshold of 20 and an angle of elevation of the sun of -3.5°, based on known positions obtained during calibration of the loggers before and after deployment. During analysis, we excluded locations derived from curves with apparent interruptions around sunset and sunrise, and also locations around the spring and autumn equinoxes that were clearly inaccurate based on visual examination. Outside the equinox periods, mean accuracy ± SD has been estimated as 185 ± 114 km at c. 50-60°S (Phillips *et al.* 2004), but for terns at lower latitudes, Nisbet *et al.* (2011a) estimated the accuracy of latitude and longitude to be around 340 km and 105 km, respectively. Bird locations at sea were stored in a WGS84 datum and examined using ArcView GIS 10.1 (ESRI). Local movements within the non-breeding sites were not included in the calculation of overall migration distances. For each individual, the dates of departure and return to the breeding area were determined visually: departure date was considered to be the first day when the bird's location was outside the cluster of positions of the previous days that corresponded to the breeding area, followed by directed movement away from this area; and arrival date was considered to be the first day the bird returned to the breeding region, preceded by a directed movement towards that area. Non-breeding areas were considered to be the areas used by the birds after leaving the Azores region. We estimated the total distance travelled during the northbound and southbound migrations as the sum of the great-circle distances between the mean of the two daily positions, to allow comparison with previous studies (Egevang *et al.* 2010, Fijn *et al.* 2013, van der Winden *et al.* 2014). Mean travel speed during migrations is defined as the mean of daily distance travelled during those periods. As mentioned above, there is an error associated with both latitude and longitude estimation and so these values are indicative only, and biased upwards. The loggers also recorded saltwater immersion (wet/dry) at 3-s intervals using 2 electrodes, and stored the number of positive tests as a value from 0 (continuously dry) to 200 (continuously wet) at the end of each 10-min period. Saltwater immersion data were combined with the light data recorded by the loggers to determine the amount of time and the proportions of time spent bathing/resting at the sea surface during daylight and darkness. These data were processed using customised functions in R (R Development Core Team, 2008). Wet-dry data do not accurately reflect time spent foraging, as terns pick food items from the sea surface and are usually submerged for less than 3 sec.

Results

Ring recoveries

In the 1990s, Common Terns originally ringed in the Azores were recovered along the South American coast (Hays et al. 1999, Lima et al. 2005, Neves et al. 2002), demonstrating for the first time a regular transatlantic movement. In 1993, Severino Azevedo Junior netted the first Azorean Common Tern to be found in Brazil at Coroa de Avião on the northeast coast, and there have been dozens of subsequent recoveries. Common Terns from the Azores have now been recovered at seven sites on the South American coast between 4º57'N and 36º18'N (see Tables S1 and S2, supplementary online material). Additionally, a Common Tern ringed in Punta Rasa (Argentina) with an orange plastic ring was resighted in the Azores (Lajes do Pico) in August 2011 (see Fig S2, supplementary online material). Of the 55 recoveries, 36 were of birds of known age (range: 1-13 years); the most common age classes were juveniles (birds < 1 year old) (28% of the total) and 5-year olds (11%); all other age classes represented 8% or less of the total. About 95% of the recoveries were made between November and February; the latest recovery date in any year was 21 May, by which time breeding is well underway in the Azores (this recovery was of a juvenile). There are no demographic studies of terns in the Azores, but ringing studies at three of the main Common Tern breeding sites (Praia, Vila and Feno islets) indicate that first- and second-summer birds very rarely visit colonies (V Neves, personal observation). Thus, it is possible that immature terns may not return to the Azores until ready to breed around the age of three.

To date, a total of 7834 Common Terns have been ringed at nine principal locations in Brazil (see Table 1). In five of these locations, Azorean terns have not been recovered, probably due to the low number of terns ringed or the timing of ringing. Even though 39% of the terns ringed in Brazil were ringed at Lagoa do Peixe, no Azorean birds has ever been recovered there. This is probably due to timing; the bulk of ringing at this site has been in April and November, months in which there are only two recoveries of Azorean birds in Brazil. Table 2 shows the number of birds ringed per month in Mangue Seco and Caixa Prego, as well as the number of recoveries from the Azores. Over 90% of the Mangue Seco recoveries occurred in December, January and February, and the recovery rates over those months in relation to ringing effort are disproportionately high. In addition, although many birds are ringed there in November, there is only one Azorean bird recovered in that month.

Together, these results suggest that Azorean birds mainly use Mangue Seco in December to February. Similarly, at Caixa Prego, birds were only recovered in January and February; however, that may be an artifact of ringing effort, as fewer birds were ringed in other months. Between 1993 and 2013 a total of 4414 Common Terns were ringed at Punta Rasa (Argentina) and in the same period a total of six birds from the Azores were recovered at that location, representing 0.14% of ringing effort. There is currently no Ringing Centre in Argentina and we couldn't obtain detailed data regarding number of birds ringed in each month. However, given the small number of recoveries of Azorean birds in Argentina it would be difficult to draw any conclusions of seasonal occurrence from ringing effort and recovery rate.

Tracking

In 2012, we observed a minimum of 10 birds (35%) that had been fitted with loggers in 2011; however, we recovered geolocators from only three individuals (10%; two females and one male), including one bird that had moved island (see below). The low recovery rate was due to egg predation by the European starling (*Sturnus vulgaris*), which resulted in nest desertion by the terns. When we first visited the islet in late May 2012, we found that considerable depredation had occurred and the number of eggs/nests relative to the number of terns present was low. On another visit in June, we found that predation was still intense. The nests of at least 4 birds with geolocators were depredated before we could trap the adult. The two Mk18 loggers recovered from females were in good condition upon recovery, but the Mk10 logger from the male had failed due to water ingress; fortunately, the extracted data indicated that it had stopped working only a few days earlier so locations were available for most of the deployment period. The three birds that were retrapped were all nesting with the same mate as in 2011. We visited Praia islet again in 2013, between 19 June and 1 July, but located only one bird with a geolocator in an area about 200 m away from its nest in 2011. The bird had a single egg that was depredated within 24-h of discovery and therefore we were unable to recover the geolocator.

One female (B017), was recaptured on 28 May 2012 at a nest with three eggs, and weighed 128 g (34 g less than 2011). The second female, B015, was recaptured on 11 June 2012 on a nest with two eggs and weighed 142 g (the same as 2011). The male (21970) was recaptured on 19 June 2012 on a nest with two eggs (one of them pipping) and weighed 130 g (3 g less than 2011). The decrease in weight (by 20%) of bird B017 between years was similar to that (30g; 18%) of the unequipped mate of an equipped bird at another nest, so does not necessarily represent an adverse effect of the device.

The two females were recaptured on Praia islet where they were originally marked in 2011, but the male had moved 80 km to a different colony: Feno islet, off the island of Terceira. It is possible that other birds fitted with loggers had emigrated from Praia islet due to the high level of breeding failure caused by the starlings; if so, this would have substantially reduced the resighting rate as there are over 50 Common Tern colonies on the nine islands of the Azores.

Birds departed the breeding grounds between 24 August and 10 November (Table 3). Female B017 left Praia islet on 24 August, flew southwards across the Atlantic for seven days and arrived at NE Brazil by 31 August. She spent the first week of September in this area (area B, see Fig 1 and Table 4) and then quickly moved to southern Brazil (area D, see Fig 1 and Table 4); on 8 September she was at 9°S, 36°W (area B, see Fig 1 and Table 4) and by 10 September was at 21°S, 41°W, having flown c.1500 km in just two days. Due to proximity to the equinox, there are no reliable locations from 11 September to 3 October for bird B017 in area D (see Fig 1 and Table 4); however, based on the available longitudes, the bird was moving south along the Brazilian coastline. This individual then spent >3 months in area D (see Fig 1 and Table 4) and by early January moved slightly south to an area off southeast Brazil, Uruguay, and northeast Argentina, around the mouth of Rio de la Plata, where it remained until 10 March (area F, see Fig 1 and Table 4). The locations became unreliable due to the spring equinox until 12 April, when the bird was at 11°21'N, 51°43'W (663 km off the north coast of Brazil; see Fig 1), already on its northbound migration. By 20 April, B017 was back at the Azores archipelago, having travelled c. 475 km/day on average during the period 12-20 April.

Female B015 used non-breeding areas similar to female B017, but the timing differed. The southbound migration started later, in mid-late September, and by 4 October the bird was already in area B (see Fig 1 and Table 4) where it remained until 11 November. For several weeks, the movements of B015 were restricted to a smaller area (area C; see Fig 1 and Table 4), before the bird moved between 3 and 7 January to southern Brazil (area E, see Fig 1 and Table 4) where it remained until 10 March. We have no accurate location data between 11 March and 10 April, by which time B015 was already on its northbound migration (1165 km off the north coast of Brazil, at 9°04'N, 43°03'W; see Fig 1). By 18 April, the bird was back at the Azores archipelago, having travelled c. 524 km/day on average during the period 10-18 April.

The male (21970) started its southward migration around 10 November (see Table 3). Its movements contrasted with those of the females; the bird did not reach the non-breeding grounds until 18 November (area A, see Fig 1 and Table 4) and apparently remained in the same area until late April-early May, before starting the northward migration (but note that there are no reliable location data between 23 February and 9 April because of proximity to the equinox). This bird had returned to the Azores by 30 May.

All tracked birds spent the non-breeding period (corresponding to the Northern Hemisphere winter) near river mouths or lagoons; area A (Belém) includes the mouth of Rio

Amazonas, areas B and C include the mouth of Rio São Francisco and Rio Real and areas D-F include the mouth of Rio de la Plata and Lagoa do Peixe, a large lagoon in southern Brazil.

Estimates of travel speeds (above and on Table 3) have to be viewed with caution due to the uncertainties inherent in the geolocation method; thus the values presented are indicative only and biased upwards. The same is true for the estimates of distances travelled during southbound and northbound migrations. Our results indicate that birds could travel up to 11,597 km between the non-breeding areas and the Azores, however, the shortest, direct route is only about 9,000 km. The real value will probably lie in between as it is unlikely that birds will always be able to fly the shortest route due to weather (especially wind) conditions, diversions to feed, possible navigational errors etc.

Activity (immersion) data

During the breeding, post-breeding and pre-breeding periods, the tracked Common Terns spent short amounts of time sitting on the sea surface during daylight (0.1-1.6 $min.day^{-1}$ on average), but up to an hour or more on the water during darkness (5.9-74.6 $min.day^{-1}$ on average) (see Table 5). During the autumn and spring migration, the amount of time that birds rested on the water approximately doubled, but there was considerable variation between days and individuals. When crossing the Atlantic during the autumn and spring migration, terns were very active, never resting for >3 h a night, and on some nights, even flying non-stop. Time spent on the sea surface was highest during the non-breeding period (7.6-134.8 $min.day^{-1}$ on average), with birds occasionally resting on the water for up to a maximum of 10 h during daylight and 6 h during darkness (see Table 5).

Discussion

Our study, which is only the second published tracking dataset for this species during the non-breeding period, recorded considerable individual variation in the timing of migration and non-breeding areas used by Common Terns from the Azores archipelago. In particular, the two females in our study started the autumn migration over a month earlier than the male. Although this result should be viewed with caution given the small sample, it suggests that some of the variability in timing of migration might be sex-related, particularly as a similar pattern was evident in Common Terns tracked from a North American colony (Nisbet *et al.* 2011a, b), although not in Arctic Terns (*Sterna paradisaea*) from Greenland or The Netherlands (Egevang *et al.* 2010, Fijn *et al.* 2013). Nisbet *et al.* (2011b) suggested that the differences in departure dates were because males perform more post-fledging care than females, and so remain for longer at the breeding grounds. Timing of migration may also be responsive to local environmental conditions, as Common Terns from the Azores departed from their breeding grounds from one week to three months later than their American conspecifics, but returned earlier at the start of the following season (Nisbet *et al.* 2011a, this study). The tracked birds from the Azores also travelled faster than US birds, probably because they had to cross the Atlantic Ocean, whereas the terns from the US migrated in short steps, stopping and feeding along the coast.

Following their arrival off South America, the tracked Common Terns did not settle in a restricted area but rather remained mobile, and were dispersed over a wide region. This is the same region used by non-breeding Common Terns from North America (Nisbet *et al.* 2011a), and in which all the ring recoveries of non-breeding birds from the Azores have been reported (Hays *et al.* 1999, Neves *et al.* 2002, this study). Hays *et al.* (1999) suggested that Common Terns from the Azores congregated at Mangue Seco (Area 3) during the non-breeding season, a hypothesis corroborated by the large number of subsequent recoveries and by our tracking data. Mangue Seco seems to be particularly important for Azorean terns during the months of December and January. In addition, we identified two other important non-breeding areas for Azores Common Terns on the Brazilian coast; Belém in the north, and Lagoa do Peixe in the southeast, two areas previously known to be important for other tern populations. Hays *et al.* (1997) also suggested that Punta Rasa in Argentina was one of the most important non-breeding areas in South America for the North American populations of Common Terns. Despite the small sample size, our tracking data, as well as the six ring recoveries and the resighting, suggest that this area is important for the Azorean population as well. It is important to note that birds are not restricted just to this site but use a large area that includes Lagoa do Peixe in southern Brazil.

All tracked individuals spent the non-breeding period in very productive waters. The male used coastal waters at the Amazon river mouth, a productive region where there are extensive marine fisheries (Oliveira *et al.* 2007). The two females spent time on the northern Patagonian Shelf (continental shelf extending from Uruguay to the Strait of Magellan), which is important for numerous other seabird species (Croxall and Good 2002, Phillips *et al.* 2005, Falabella *et al.* 2009, Guilford *et al.* 2009, Catry *et al.* 2011), and also an important area for commercial fisheries (e.g. Csirke 1987).

None of the tracked birds travelled to the West African coast, which is the non-breeding area of the large breeding populations of Common Terns in continental Europe and the UK (Wernham *et al.* 2002). Common Terns from the Azores represent the only population of a non-pelagic bird species that breeds in Europe and spends the Northern Hemisphere winter in South America. Szczys et al. (2012) found that Common Terns from the Azores were genetically more similar to those from North America than those from mainland Europe. This matches with the migration patterns of the different populations. There have been considerably fewer recoveries of Roseate Terns from the Azores, but they indicate that birds of this species, contrary to the results for the Common Tern, may spend the non-breeding period on either side of the Atlantic. To date there have been 12 recoveries of Roseate Terns from the Azores (Hays *et al.* 2002; Neves, unpublished data); four in Brazil (in the months of November, January, February and March) and eight in Africa (in the months of October, November, January, March, April and June).

Our tracked females had arrived back at the Azores in spring before their American counterparts had even left the Brazilian coast (Nisbet *et al.* 2011a). A pattern of relatively slow post-breeding migration, and a much more rapid migration back to the colony in the spring, has been found for many bird species including terns (Egevang *et al.* 2010, Nisbet *et al.* 2011a). Our data seems to indicate that birds from the Azores do not fly faster on the return journey, but more tracking studies are needed given our small sample size. Overall, the tracked birds fly on a more or less direct bearing to the non-breeding grounds, without any apparent need to stop for more than a few hours to refuel during the journey. On the return migration in the spring, birds took a route that was to the west of the southward journey, and again made no stop-over, probably because the trip from the Brazilian coast to the Azores is relatively short (c. 8 days at c. 500 km/day).

The immersion data show that, overall, Common Terns from the Azores spend less time sitting in the water during the day, and more time in the water during the night than their North American counterparts, whereas their activity patterns are similar during the non-breeding period (Nisbet et al. 2011a). During the pre-breeding, breeding and post-breeding periods, Common Terns from the Azores spent much longer in the water (presumably resting), during darkness than daylight. While migrating, the tracked terns rested less during the day (especially during the spring migration) than the North American terns (Nisbet et al. 2011a), and spent broadly similar periods sitting in the water during darkness.

Recoveries and tracking data highlight key areas used by the Azorean population of Common Terns during the non-breeding period. The majority of these offshore areas have been identified as marine Important Bird Areas, but some have not yet been granted formal and effective protection (BirdLife International 2012). In the past, adult Common and Roseate terns have been trapped deliberately by locals to remove their rings in certain places on the north and east coasts of Brazil. Villagers from Quixaba on the north coast no longer take rings and are working to help conserve the terns (Hays 2009), but trapping for rings could still take place elsewhere. In Punta Rasa (Argentina), tourists might cause some disturbance to terns roosting on coastal beaches (Castresana, pers. obs.), but the severity of these impacts remains to be evaluated.

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Figure caption:

Figure 1: Migration routes and non-breeding areas of three Common Terns (*Sterna hirundo*) tracked from the Azores. Numbers as in Tables S1 and S2 (supplementary online material), and letters as in Table 4. The star indicates the breeding colony. Tracks are incomplete for birds that migrated in the periods around the equinoxes. The ellipses encompass all the reliable positions obtained with geolocators during the non-breeding period.

Supplementary material Figures caption:

Figure S1: Leg of a Common Tern (*Sterna hirundo*) showing the Mk10 geolocator deployed on a darvic ring.

Figure S2: Picture of a Common Tern (*Sterna hirundo*) resighted in Lajes do Pico (Azores) in August 2011 and originally ringed in Punta Rasa (Argentina). © Ramsés Peréz.

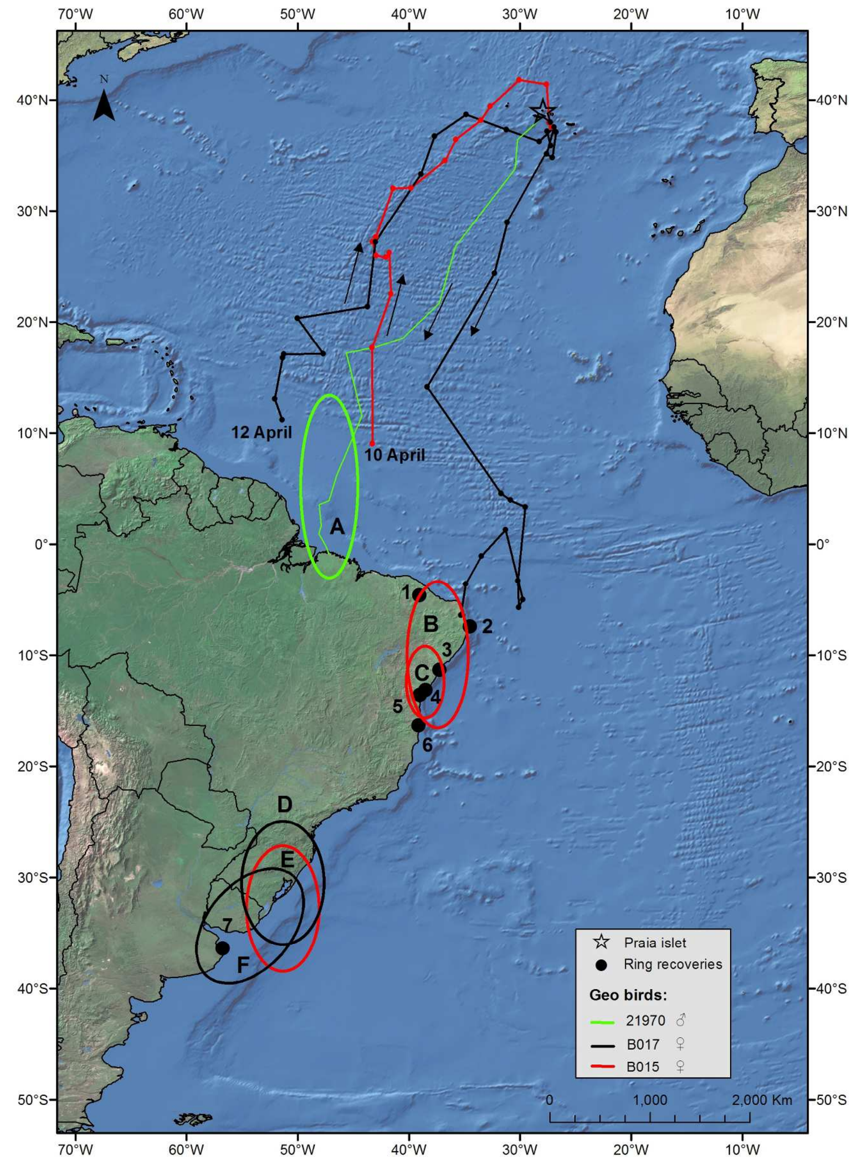

Figure 1: Migration routes and non-breeding areas of three Common Terns (Sterna hirundo) tracked from the Azores. Numbers as in Tables S1 and S2 (supplementary online material), and letters as in Table 2. The star indicates the breeding colony. Tracks are incomplete for birds that migrated in the periods around the equinoxes. The ellipses encompass all the reliable positions obtained with geolocators during the winter.
210x296mm (250 x 250 DPI)

Table 1: Timing of ringing and ringing effort for *Sterna hirundo*, and number of retraps of ringed birds from the Azores, at each ringing site in Brazil. Note that the total number of retraps from North American colonies is unknown, so it is not possible to express the percentage of all retraps that are of Azorean birds.

Site	Latitude	Longitude	Ringing years	Ringing months	Total ringing effort (new birds ringed)	Total retraps of Azorean rings (% of total ringing effort)
Algodoal/Salinas	00°35-00°36'S	47°22'-47°34'W	1983, 1997	April	201	0
Campechá	01°30'S	44°45'W	1994	Nov	2	0
Quixaba*	04°57'S	39°04'W	-	-	0	2
Coroa de Avião	07°40'-08°03'S	34°50'-35°13'W	1987-94, 1996-97, 2001, 2005-07	Jan (3%), Feb (3%), April (6%), May (3%), June (4%), July (1%), Aug (6%), Sept (8%), Oct (32%), Nov (30%) and Dec (4%)	79	1 (1.3%)
Mangue Seco	11°27'-12°40'S	37°21'-38°10'W	1986, 1990, 1995-97, 2000, 2002-03, 2005-09, 2013	Jan (28%), Feb (22%), March (2%) April (<1%), Nov (43%) and Dec (6%)	3932	31 (0.8%)
Caixa Prego	13°08'-13°53'S	38°50'-39°01'W	2000-03, 2007-08	Jan (21%), Feb (54%), April (7%), Nov (6%) and Dec (13%)	452	6 (1.3%)
Corumbal	16°53'-17°56'S	38°39'-39°06'W	1995, 1997, 2003	Feb (72%), July (26%) and Sept (13%)	139	1 (0.7)
Ilha das Garças	20°10'-20°19'S	40°10'-40°19'W	1995, 2012-14	Feb (17%), March (33%), Set (17%), Nov (17%) and Dec (17%)	6	0
Lagoa do Peixe	31°17'S	51°00'W	1985-89, 1990-96, 1998, 1999, 2001-03, 2010, 2012-13	Jan (2%), March (1%), April (67%), May (2%) and Nov (27%)	3022	0
Museu Oceanográfico	32°01'S	52°06'W	2009	March	1	0
TOTAL					7834	41 (0.5%)

* No ringing was ever conducted at this location. The rings are from birds that were killed by fisherman.

Table 2: Total number of *Sterna hirundo* ringed at Mangue Seco (MS, Brazil) and at Caixa Prego (CP, Brazil) in different months, and the number of retraps of ringed birds from the Azores.

Month	Total ringing effort (new birds ringed)		Total retraps of Azorean rings (% of monthly ringing effort)	
	MS	CP	MS	CP
Jan	1083	94	13 (1.2%)	2 (2.1%)
Feb	859	243	5 (0.7%)	4 (1.6%)
March*	62	0	1	0
April*	1	30	1	0
Nov	1698	25	1 (0.1%)	0
Dec	229	60	10 (4.8%)	0
Total	3932	452	31 (0.8%)	6 (1.3%)

* Please note that the Azorean birds retrapped in March and April were not obtained during ringing activities but were found alive by fisherman and later released. Therefore we don't present the "% of monthly ringing effort" for those months.

Table 3. Timing, distance covered and travel speed (mean with range in parentheses) during migration by three Common Terns *Sterna hirundo* tracked from the Azores. Distance values in parentheses correspond to the shortest great-circle routes to the South American coast and then to the non-breeding area, avoiding land.

	B015 (♀)[1]	**B017 (♀)**	**21970 (♂)**[1]
Start of southbound migration	~14-30 Sep	24 Aug	10 Nov
Distance travelled on southbound migration	-	10,686 km (9,010 km)	4,901 km (4,664 km)
Travel speed on southbound migration	-	454 km/day[2] (97-1104 km/day)	613 km/day (43-1270 km/day)
Start of northbound migration	~ 5 Apr[3]	~ 2 Apr[3]	Between 17 Apr and 22 May
Distance travelled on northbound migration	~10,470 km (8,882 km)	~11,597 km (9,137 km)	-
Travel speed on northbound migration	524 km/day[4] (184-1237 km/day)	475 km/day[4] (55-1290 km/day)	-
Arrival to breeding grounds	18 Apr	20 Apr	Between 24 Apr and 30 May

Note: The travel speed and distance values presented are indicative only and biased upwards.

[1] One of the migrations occurred around the equinox.
[2] Refers only to the first half of the migration from the Azores to northwest Brazil.
[3] Estimated from arrival date at the colony
[4] Refers only to the second half of the migration from north Brazil to the Azores.

Table 4: Residency periods in the wintering areas of three Common Terns *Sterna hirundo* tracked from the Azores. Letter codes correspond to the areas in Fig. 1. Timing unknown in some cases because area used around the equinox period when no locations were available.

Non-breeding areas	**B015** (♀)	**B017** (♀)	**21970** (♂)
A – Belém, Brazil (13°N-2°S, 45-49°W)	-	-	18 Nov – 16 Apr
B – NE corner, Brazil (4-16°S, 34-40°W)	4 Oct-11 Nov	1-9 Sep	-
C – Bahia, Brazil (6-15°S, 35-37°W)	12 Nov-3 Jan	-	-
D – Southern Brazil 1 (24-35°S, 49-53°W)	-	mid Sep to Dec	-
E – Southern Brazil 2 (26-38°S, 48-54°W)	7 Jan-10 Mar	-	-
F – Southern Brazil, Uruguay & northern Argentina (28-39°S, 52-58°W)	-	early Jan – 10 Mar	-

Table 5. Mean and range (min. – max.) of time spent sitting at the sea surface in daylight and darkness by three Common Terns *Sterna hirundo*, according to migration phase. The proportions of time spent on the water during daylight and darkness are given in parentheses.

	DAY		*NIGHT*	
Period	Mean time on water (min d^{-1})	Range	Mean time on water (min d^{-1})	Range
Breeding				
B015	0.2 (<0.1%)	0-1.1	10.8 (1.2%)	0.4-80.7
B017	1.1 (0.2%)	0-17.6	25.0 (2.7%)	1.7-192.7
21970	0.3 (<0.1%)	0-1.2	5.9 (0.6%)	0-20.0
Post-breeding				
B015	0.1 (<0.1%)	0-0.6	13.1 (1.6%)	0.8-67.9
B017	0.5 (0.1%)	0-3.3	40.4 (4.6%)	5.7-220.2
21970	0.7 (0.1%)	0-15.1	25.7 (2.9%)	0.9-248.2
Autumn migration				
B015	3.4 (0.5%)	0-63.0	42.7 (5.7%)	1.4-143.3
B017	25.8 (3.7%)	0-113.3	78.9 (9.9%)	17.8-113.3
21970	4.9 (0.6%)	0-29.7	76.0 (10.1%)	0.8-184.4
Non-breeding				
B015	7.6 (1.2%)	0-113.2	123.8 (15.6%)	0.9-359.0
B017	106.2 (14.6%)	0-623.6	134.8 (15.0%)	0-430.7
21970	25.1 (3.4%)	0-177.6	66.7 (7.8%)	0.6-311.6
Spring migration				
B015	0.4 (0.1%)	0-1.4	71.2 (8.8%)	15.8-154.5
B017	3.5 (0.5%)	0-9.9	143.0 (17.1%)	0-276.8
21970	-	-	-	-
Pre-breeding				
B015	1.6 (0.3%)	0-7.4	74.6 (8.8%)	1.2-289.9
B017	1.5 (0.3%)	0-7.4	68.8 (8.1%)	1.4-164.8
21970	-	-	-	-

Table S1: Recoveries in Brazil and Argentina of Common Terns *Sterna hirundo* ringed in the Azores as chicks or breeding adults. Recoveries ordered by increasing latitude. Number codes for the different sites correspond to those shown in Fig 2.

Site	Ring	Date recapture	Age (yrs, months)
1 - Brazil (Quixaba)	G007153[1]	17/01/2002	0
(04°57'S, 39°04'W)	G007228[1]	17/01/2002	0
2 - Brazil (Coroa de Avião) (07°40'S, 34°50'W)	G002588	21/05/1993	0
3 - Brazil (Mangue Seco)	G006801[2]	19/04/1998	0
(11°27'S, 37°21'W)	G006840	31/12/1997	0
	G006873	27/12/1997	0
	G006925	23/02/1998	0
	G005070[1,3]	13/02/1996	1
	G006702	23/02/1998	1
	G011941	04/12/2007	2
	G011116	27/01/2001	>2
	G011435	10/01/2002	>2
	G002722[4]	30/12/1996	3
	G011930	28/11/2008	3
	G011084	11/01/2002	>3
	G003913[4]	15/02/1996	3
	G008671	11/01/2010	3
	G011084[5]	11/01/2002	>3
		26/01/2003	>4
	G006896	09/01/2002	4
	G010738	04/12/2007	4
	G007343	04/12/2007	5
	G008769	11/01/2010	5
	G002998[1]	28/12/1997	>5
	G002318[4]	29/12/1996	6
	G006527	27/01/2003	6
	G011712	04/12/2007	>7
	G002587	27/01/2001	8
	G003558	08/02/2000	8
	G006874	04/12/2007	10
	G002667	27/01/2003	11
	G002505[2]	01/03/2002	11
	G003130	11/01/2002	12
	G005493	26/01/2003	12
4 & 5 - Brazil (Caixa Prego)	G007311	04/02/2003	0
(13°08'-13°53'S	G007332	04/02/2003	0
38°50'-39°01'W)	G007239	26/01/2002	0
	G011698	24/01/2002	>2
	G006590	05/02/2003	>6
	G002527	04/02/2003	12
6 – Brazil (Corumbal) (16°53'S, 39°06'W)	G006778	02/02/2003	5
7 - Argentina (Punta Rasa)	G011704	16/01/2002	>2
(36°18'S, 56°46'W)	G008696	15/02/2012	5
	G003966[6]	14/02/1999	5
	G011978	15/02/2012	7
	G002698[6]	11/11/2001	8
	G011085	12/12/2013	>16

[1]Found dead [2]Birds captured alive by fisherman and released. [3]From Lima *et al.* 2004 [4]From Hays *et al.* 1999 [5]Bird recovered in two different years [6]From Neves *et al.* 2002

Table S2: Common Terns *Sterna hirundo* ringed in Brazil during the wintering period and later recovered breeding in the Azores. Table presents data for ringing. Site number code corresponds to that shown in Fig 2.

Site	Ring	Date of ringing
3 - Brazil (Mangue Seco) (11°27', 37°21')	H-50217	27/01/2003
	H-50133[1]	27/01/2003
	H-35381[2]	28/12/1996
	H-69077	11/02/2009
	H-55981	24/11/2009
	H-56115	16/11/2007
	H-40901[1]	24/02/2000
	9822-16445[1]	18/02/1998
	J-08146	21/02/2002

[1] Found dead
[2] From Hays *et al.* 1999

Figure S1: Leg of a Common Tern (Sterna hirundo) showing the Mk10 geolocator deployed on a darvic ring.
722x541mm (72 x 72 DPI)

Figure S2: Picture of a Common Tern (Sterna hirundo) resighted in Lajes do Pico (Azores) in August 2011 and originally ringed in Punta Rasa (Argentina). © Ramsés Peréz.
225x178mm (72 x 72 DPI)