



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

Journal:	<i>Emu - Austral Ornithology</i>
Manuscript ID:	MU13112.R2
Manuscript Type:	Research Paper
Date Submitted by the Author:	n/a
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Keyword:	Atlantic Ocean, migration, seabirds, movement

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

12

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34 **Abstract.** Here we report migration routes and non-breeding areas of Common Terns (*Sterna*
35 *hirundo*) from the Azores archipelago, based on ring recoveries (including live and dead
36 birds) and tracking using geolocators (global location-sensing or GLS loggers). To date, there
37 have been 55 transatlantic ring recoveries of Common Terns from the Azorean population -
38 six from Argentina and 49 from Brazil - reported over 15 different years. The three tracked
39 birds migrated southwards in different months (August, September and November), but were
40 more synchronous on the northbound migration, which in all cases began in April. The birds
41 were tracked to three different areas along the South American coast; the male spent
42 November to April on the north Brazilian coast (13°N-2°S), whereas the two females first
43 spent some time off northeast Brazil (4-16°S; one for a week and the other for three months)
44 and then moved south to the coast off southeast Brazil, Uruguay and northern Argentina (24-
45 39°S). Although the values need to be viewed with caution given our small sample size and
46 the errors associated with geolocation, the tracked terns potentially travelled up to c. 23,194
47 km in total to-and-from the non-breeding grounds, representing an average of about 500
48 km/day. With the exception of Belém (north Brazil) and Lagoa do Peixe (south Brazil), the
49 coastal areas used by the tracked birds coincided with concentrations of ring recoveries,
50 confirming their importance as non-breeding areas for birds from the Azores population.

51

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

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59 **Introduction**

60 Over the last two decades, our knowledge of seabird movements and distribution at sea has
61 been greatly improved by tracking technologies (Burger and Shaffer 2008, Phillips *et al.*
62 2008). In particular, the miniaturization of light-level geolocators (global location sensing or
63 GLS loggers) has provided unprecedented detail on the migration of smaller species such as
64 terns (Egevang *et al.* 2010, Nisbet *et al.* 2011a, Fijn *et al.* 2013, McKnight *et al.* 2013, van der
65 Winden *et al.* 2014).

66 Ring recoveries have shown previously that the North American populations of the
67 Common Tern *Sterna hirundo* spend the non-breeding period along the South American coast
68 (Hays *et al.* 1997, 1999), and recently, Nisbet *et al.* (2011a) used geolocators to track the
69 migration of five birds from a breeding colony in Massachusetts. Analyses of ringing data
70 suggest that Common Terns from the NW European population have a rather different
71 strategy, spending the non-breeding along the West African coast (Wernham *et al.* 2002).
72 Ring recoveries of Azores breeders off Brazil and Argentina (Hays *et al.* 1999, Neves *et al.*
73 2002, Lima *et al.* 2005) indicate that at least some Common Terns from the Azores spend the
74 nonbreeding season on the South American coast, suggesting they use the same areas as birds
75 from North America; however, details of the route and other aspects of migration remain
76 poorly known.

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

83

84 **Methods**

85 *Ring recoveries*

86 Ring recovery data provide snapshots of distribution and can be a good complement to
87 tracking data (e.g. Harris *et al.* 2010). We present details of all the ring recoveries available in
88 the Portuguese Ringing Centre database; these include seven previously published ring
89 recoveries (Hays *et al.* 1999, Neves *et al.* 2002, Lima *et al.* 2005). We use the term
90 “recovery” to include both birds trapped and released, and birds found dead (these are
91 distinguished in Tables S1 and S2). The recoveries were made over a period spanning almost
92 two decades (1993-2013) by different organizations and individuals in Brazil and Argentina.
93 In Brazil, Common Terns have been ringed by over 25 different ringers. Nevertheless, most
94 recoveries of Azorean birds in Brazil were obtained through the ringing program coordinated
95 by P. Lima on the northeast coast of Brazil. Coastal surveys were conducted beforehand,
96 using a single-engine airplane, to identify the sites with higher concentration of terns.
97 Trapping and ringing activities took place in January to April, November and December, for 3
98 to 10 days a year, between 16:00h and 05:00h, using 20 mist nets (12 x 2.5m; 12mm mesh)
99 (Lima *et al.* 2005). In Argentina, terns have only been trapped at one location, Punta Rasa;
100 trapping involved mist netting from 1993 until 2008, and use of cannon nets (16*7m) since
101 2010, in periods of 1-3 days in January to March, November and December each year. No
102 tern ringing was conducted in Punta Rasa in 2009.

103

104 *Study area*

105 The nine islands of the Azores archipelago hold about 50 colonies of Common Tern. The
106 tracking study was conducted at Praia islet (39°03'N, 27°57'W; 0.12 km²), Graciosa island,
107 Azores archipelago, between 7 and 15 June 2011, and 26 May and 19 June 2012. Praia islet
108 provides breeding habitat for six seabird species including Common Terns and Roseate Terns

109 (*Sterna dougallii*). In the mid-1990s, Praia islet benefited from a habitat restoration program
110 and tern numbers rose sharply, accounting for one third of the Azorean breeding population in
111 2003 (Bried *et al.* 2009). Since then, the islet has remained an important site for terns,
112 including c. 350 Common Tern pairs in 2011 (Neves 2011). Praia islet is one of the few
113 Azorean colonies where a geolocator study could be conducted; the others are Vila islet (off
114 Santa Maria island) and Feno islet (off Terceira island). Unlike most others in the Azores,
115 these colonies are accessible, the nests are located in areas where birds can be trapped, and
116 they normally hold over 100 pairs. However, Vila islet has suffered from problems relating to
117 egg predation by European Starling (*Sturnus vulgaris*) (Neves *et al.* 2011), and rats *Rattus*
118 *rattus* can be a problem at Feno islet (Amaral *et al.* 2010). Therefore we decided to conduct
119 the study at Praia islet.

120

121 *Geolocator deployment*

122 We deployed a total of 29 geolocators (15 Mk10 and 14 Mk18; British Antarctic Survey,
123 Cambridge, UK) on adult breeding Common Terns captured using walk-in treadle traps set
124 over their nests. Birds were measured (wing length, tarsus, head and bill), weighed and ringed
125 (with a metal ring, and a darvic ring to which the geolocator was attached, on opposite legs).
126 A 50- μ l blood sample was collected from the tarsal vein, from which sex was later determined
127 genetically (Fridolfsson and Ellegren 1999). A few turns of self-amalgamating tape were
128 wrapped around the waist of the logger (without obscuring the light sensor), which was then
129 attached using Kevlar[®] thread to the darvic ring; the thread was then covered with a resin
130 (West System[®] G/5 adhesive epoxy) to reduce the likelihood of breakage (see Fig. S1,
131 Supplementary Online Material). The total weight (darvic ring, geolocator and attachment)
132 was 1.7 ± 0.3 g, representing on average 1.2% of bird body mass, which is well below the load
133 threshold (3%) beyond which adverse effects are more likely to occur (Kenward, 2001,

134 Phillips *et al.* 2003). However, note that Nisbet *et al.* (2011a) reported serious injuries after a
135 few days in four of 14 birds fitted with loggers that represented 1.2%-1.6% of body mass.
136 From our visual observations, the birds in our study were doing well up to several days after
137 deployment. We equipped only one individual per pair to limit disturbance; their mates were
138 also marked with a metal and a white darvic ring so that they would be easy to spot the
139 following year. Upon recovery, the birds were weighed and the logger removed. The
140 geolocators were calibrated at a fixed location before and after deployment.

141

142 *Geocator data analysis*

143 Light data were downloaded from the retrieved loggers and processed using BASTrak
144 software (British Antarctic Survey) to estimate the latitude from day length and longitude
145 from the time of local midday relative to Greenwich Mean Time. The geolocators measure
146 light values every minute and store the maximum reading (truncated at an arbitrary value of
147 64) at the end of every 10-min period. During processing, we used a light threshold of 20 and
148 an angle of elevation of the sun of -3.5° , based on known positions obtained during
149 calibration of the loggers before and after deployment. During analysis, we excluded locations
150 derived from curves with apparent interruptions around sunset and sunrise, and also locations
151 around the spring and autumn equinoxes that were clearly inaccurate based on visual
152 examination. Outside the equinox periods, mean accuracy \pm SD has been estimated as $185 \pm$
153 114 km at c. $50\text{-}60^\circ\text{S}$ (Phillips *et al.* 2004), but for terns at lower latitudes, Nisbet *et al.*
154 (2011a) estimated the accuracy of latitude and longitude to be around 340 km and 105 km,
155 respectively. Bird locations at sea were stored in a WGS84 datum and examined using
156 ArcView GIS 10.1 (ESRI). Local movements within the non-breeding sites were not included
157 in the calculation of overall migration distances. For each individual, the dates of departure
158 and return to the breeding area were determined visually: departure date was considered to be
159 the first day when the bird's location was outside the cluster of positions of the previous days

160 that corresponded to the breeding area, followed by directed movement away from this area;
161 and arrival date was considered to be the first day the bird returned to the breeding region,
162 preceded by a directed movement towards that area. Non-breeding areas were considered to
163 be the areas used by the birds after leaving the Azores region. We estimated the total distance
164 travelled during the northbound and southbound migrations as the sum of the great-circle
165 distances between the mean of the two daily positions, to allow comparison with previous
166 studies (Egevang *et al.* 2010, Fijn *et al.* 2013, van der Winden *et al.* 2014). Mean travel speed
167 during migrations is defined as the mean of daily distance travelled during those periods. As
168 mentioned above, there is an error associated with both latitude and longitude estimation and
169 so these values are indicative only, and biased upwards. The loggers also recorded saltwater
170 immersion (wet/dry) at 3-s intervals using 2 electrodes, and stored the number of positive
171 tests as a value from 0 (continuously dry) to 200 (continuously wet) at the end of each 10-min
172 period. Saltwater immersion data were combined with the light data recorded by the loggers
173 to determine the amount of time and the proportions of time spent bathing/resting at the sea
174 surface during daylight and darkness. These data were processed using customised functions
175 in R (R Development Core Team, 2008). Wet-dry data do not accurately reflect time spent
176 foraging, as terns pick food items from the sea surface and are usually submerged for less
177 than 3 sec.

178

179 **Results**

180 *Ring recoveries*

181 In the 1990s, Common Terns originally ringed in the Azores were recovered along the South
182 American coast (Hays *et al.* 1999, Lima *et al.* 2005, Neves *et al.* 2002), demonstrating for the
183 first time a regular transatlantic movement. In 1993, Severino Azevedo Junior netted the first
184 Azorean Common Tern to be found in Brazil at Coroa de Avião on the northeast coast, and

185 there have been dozens of subsequent recoveries. Common Terns from the Azores have now
186 been recovered at seven sites on the South American coast between 4°57'N and 36°18'N (see
187 Tables S1 and S2, supplementary online material). Additionally, a Common Tern ringed in
188 Punta Rasa (Argentina) with an orange plastic ring was resighted in the Azores (Lajes do
189 Pico) in August 2011 (see Fig S2, supplementary online material). Of the 55 recoveries, 36
190 were of birds of known age (range: 1-13 years); the most common age classes were juveniles
191 (birds < 1 year old) (28% of the total) and 5-year olds (11%); all other age classes represented
192 8% or less of the total. About 95% of the recoveries were made between November and
193 February; the latest recovery date in any year was 21 May, by which time breeding is well
194 underway in the Azores (this recovery was of a juvenile). There are no demographic studies
195 of terns in the Azores, but ringing studies at three of the main Common Tern breeding sites
196 (Praia, Vila and Feno islets) indicate that first- and second-summer birds very rarely visit
197 colonies (V Neves, personal observation). Thus, it is possible that immature terns may not
198 return to the Azores until ready to breed around the age of three.

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

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

220

221 *Tracking*

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

235 one bird with a geolocator in an area about 200 m away from its nest in 2011. The bird had a
236 single egg that was depredated within 24-h of discovery and therefore we were unable to
237 recover the geolocator.

238 One female (B017), was recaptured on 28 May 2012 at a nest with three eggs, and
239 weighed 128 g (34 g less than 2011). The second female, B015, was recaptured on 11 June
240 2012 on a nest with two eggs and weighed 142 g (the same as 2011). The male (21970) was
241 recaptured on 19 June 2012 on a nest with two eggs (one of them pipping) and weighed 130 g
242 (3 g less than 2011). The decrease in weight (by 20%) of bird B017 between years was similar
243 to that (30g; 18%) of the unequipped mate of an equipped bird at another nest, so does not
244 necessarily represent an adverse effect of the device.

245 The two females were recaptured on Praia islet where they were originally marked in
246 2011, but the male had moved 80 km to a different colony: Feno islet, off the island of
247 Terceira. It is possible that other birds fitted with loggers had emigrated from Praia islet due
248 to the high level of breeding failure caused by the starlings; if so, this would have
249 substantially reduced the resighting rate as there are over 50 Common Tern colonies on the
250 nine islands of the Azores.

251 Birds departed the breeding grounds between 24 August and 10 November (Table 3).
252 Female B017 left Praia islet on 24 August, flew southwards across the Atlantic for seven days
253 and arrived at NE Brazil by 31 August. She spent the first week of September in this area
254 (area B, see Fig 1 and Table 4) and then quickly moved to southern Brazil (area D, see Fig 1
255 and Table 4); on 8 September she was at 9°S, 36°W (area B, see Fig 1 and Table 4) and by 10
256 September was at 21°S, 41°W, having flown c.1500 km in just two days. Due to proximity to
257 the equinox, there are no reliable locations from 11 September to 3 October for bird B017 in
258 area D (see Fig 1 and Table 4); however, based on the available longitudes, the bird was
259 moving south along the Brazilian coastline. This individual then spent >3 months in area D

260 (see Fig 1 and Table 4) and by early January moved slightly south to an area off southeast
261 Brazil, Uruguay, and northeast Argentina, around the mouth of Rio de la Plata, where it
262 remained until 10 March (area F, see Fig 1 and Table 4). The locations became unreliable due
263 to the spring equinox until 12 April, when the bird was at 11°21'N, 51°43'W (663 km off the
264 north coast of Brazil; see Fig 1), already on its northbound migration. By 20 April, B017 was
265 back at the Azores archipelago, having travelled c. 475 km/day on average during the period
266 12-20 April.

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

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

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

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

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

295

296 *Activity (immersion) data*

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

307

308

309

310 **Discussion**

311 Our study, which is only the second published tracking dataset for this species during the non-
312 breeding period, recorded considerable individual variation in the timing of migration and
313 non-breeding areas used by Common Terns from the Azores archipelago. In particular, the
314 two females in our study started the autumn migration over a month earlier than the male.
315 Although this result should be viewed with caution given the small sample, it suggests that
316 some of the variability in timing of migration might be sex-related, particularly as a similar
317 pattern was evident in Common Terns tracked from a North American colony (Nisbet *et al.*
318 2011a, b), although not in Arctic Terns (*Sterna paradisaea*) from Greenland or The
319 Netherlands (Egevang *et al.* 2010, Fijn *et al.* 2013). Nisbet *et al.* (2011b) suggested that the
320 differences in departure dates were because males perform more post-fledging care than
321 females, and so remain for longer at the breeding grounds. Timing of migration may also be
322 responsive to local environmental conditions, as Common Terns from the Azores departed
323 from their breeding grounds from one week to three months later than their American
324 conspecifics, but returned earlier at the start of the following season (Nisbet *et al.* 2011a, this
325 study). The tracked birds from the Azores also travelled faster than US birds, probably
326 because they had to cross the Atlantic Ocean, whereas the terns from the US migrated in short
327 steps, stopping and feeding along the coast.

328 Following their arrival off South America, the tracked Common Terns did not settle in
329 a restricted area but rather remained mobile, and were dispersed over a wide region. This is
330 the same region used by non-breeding Common Terns from North America (Nisbet *et al.*
331 2011a), and in which all the ring recoveries of non-breeding birds from the Azores have been
332 reported (Hays *et al.* 1999, Neves *et al.* 2002, this study). Hays *et al.* (1999) suggested that
333 Common Terns from the Azores congregated at Mangue Seco (Area 3) during the non-
334 breeding season, a hypothesis corroborated by the large number of subsequent recoveries and

335 by our tracking data. Mangue Seco seems to be particularly important for Azorean terns
336 during the months of December and January. In addition, we identified two other important
337 non-breeding areas for Azores Common Terns on the Brazilian coast; Belém in the north, and
338 Lagoa do Peixe in the southeast, two areas previously known to be important for other tern
339 populations. Hays *et al.* (1997) also suggested that Punta Rasa in Argentina was one of the
340 most important non-breeding areas in South America for the North American populations of
341 Common Terns. Despite the small sample size, our tracking data, as well as the six ring
342 recoveries and the resighting, suggest that this area is important for the Azorean population as
343 well. It is important to note that birds are not restricted just to this site but use a large area that
344 includes Lagoa do Peixe in southern Brazil.

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

352 None of the tracked birds travelled to the West African coast, which is the non-
353 breeding area of the large breeding populations of Common Terns in continental Europe and
354 the UK (Wernham *et al.* 2002). Common Terns from the Azores represent the only population
355 of a non-pelagic bird species that breeds in Europe and spends the Northern Hemisphere
356 winter in South America. Szczyś et al. (2012) found that Common Terns from the Azores
357 were genetically more similar to those from North America than those from mainland Europe.
358 This matches with the migration patterns of the different populations. There have been
359 considerably fewer recoveries of Roseate Terns from the Azores, but they indicate that birds

360 of this species, contrary to the results for the Common Tern, may spend the non-breeding
361 period on either side of the Atlantic. To date there have been 12 recoveries of Roseate Terns
362 from the Azores (Hays *et al.* 2002; Neves, unpublished data); four in Brazil (in the months of
363 November, January, February and March) and eight in Africa (in the months of October,
364 November, January, March, April and June).

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

376 The immersion data show that, overall, Common Terns from the Azores spend less
377 time sitting in the water during the day, and more time in the water during the night than their
378 North American counterparts, whereas their activity patterns are similar during the non-
379 breeding period (Nisbet *et al.* 2011a). During the pre-breeding, breeding and post-breeding
380 periods, Common Terns from the Azores spent much longer in the water (presumably
381 resting), during darkness than daylight. While migrating, the tracked terns rested less during
382 the day (especially during the spring migration) than the North American terns (Nisbet *et al.*
383 2011a), and spent broadly similar periods sitting in the water during darkness.

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

394

395 **Acknowledgments**

396 We are grateful to R. Oliveira and L. Aguiar for transport to Praia islet and to Alexandre and
397 Rita (Octopus) for transport to Feno islet. We also thank L. F. Correia for help with fieldwork
398 in Feno Islet, R. Medeiros for help with Figure 1, and J. Bried for help with lab procedures for
399 sex determination. We thank J. di Costanzo for suggestions on geolocator deployment and for
400 help with archived ring recovery data. We are also very grateful to Janet Silk for providing
401 the R code to analyse the immersion data. Thanks to Biotrack for extracting data from the
402 failed logger. Thanks also to P. Figueiredo from CEMPA for help and clarification with the
403 ring recoveries and to M. Souza from CEMAVE for help with ringing data from Brazil. We
404 are also very grateful to all the many ringers of *S. hirundo* in Brazil who allowed us to use
405 their records and to Ramsés Pérez for allowing us to use his picture (Fig S2). Finally we thank
406 J. Bried, H. Hays, G. Cormons and anonymous referees for many useful comments that have
407 helped improve the manuscript. Fieldwork was conducted under permits n°43/2011 and
408 n°33/2012 issued by SRAM-Açores. This study was funded by grants from the *Fundação*

409 *para a Ciência e a Tecnologia* (SFRH/BPD/26657/2006 & SFRH/BPD/88914/2012) and also
410 received support from MoniAves (2009-2012, SRAM) coordinated by R. S. Santos. IMAR-
411 DOP/UAç is funded by FCT and DRCT Azores (Research Unit No 531 and Associate
412 Laboratory No 9-ISR-Lisbon).

413

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506

507 **Figure caption:**

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

513

514

515 **Supplementary material Figures caption:**

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

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

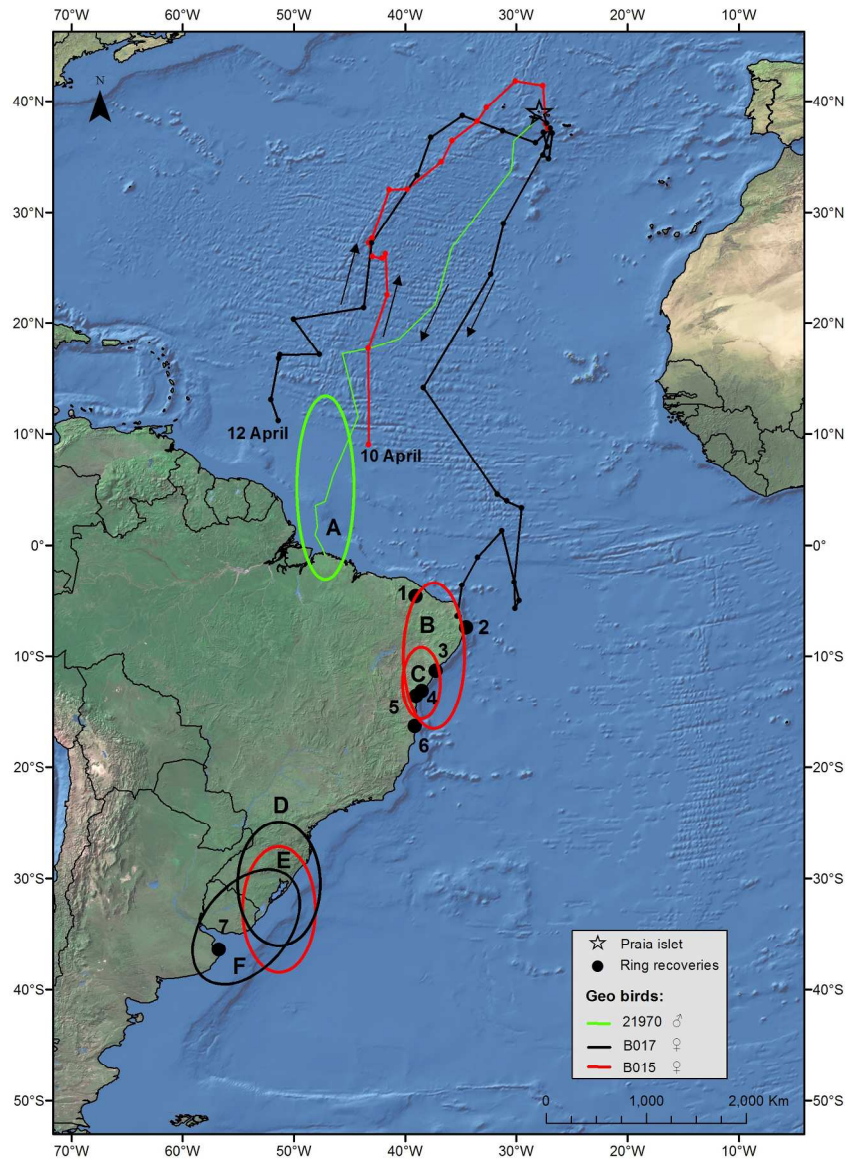


Figure 1: Migration routes and non-breeding areas of three Common Terns (*Sterna hirundo*) tracked from the Azores. Numbers as in Tables S1 and S2 (supplementary online material), and letters as in Table 2. The star indicates the breeding colony. Tracks are incomplete for birds that migrated in the periods 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)
Algoal/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.

Period	<i>DAY</i>		<i>NIGHT</i>	
	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) (04°57'S, 39°04'W)	G007153 ¹	17/01/2002	0
	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) (11°27'S, 37°21'W)	G006801 ²	19/04/1998	0
	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) (13°08'-13°53'S 38°50'-39°01'W)	G007311	04/02/2003	0
	G007332	04/02/2003	0
	G007239	26/01/2002	0
	G011698	24/01/2002	>2
	G006590	05/02/2003	>6
6 - Brazil (Corumbal) (16°53'S, 39°06'W)	G002527	04/02/2003	12
	G006778	02/02/2003	5
7 - Argentina (Punta Rasa) (36°18'S, 56°46'W)	G011704	16/01/2002	>2
	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

¹Found dead ²Birds captured alive by fisherman and released. ³From Lima *et al.* 2004 ⁴From Hays *et al.* 1999 ⁵Bird recovered in two different years ⁶From 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 Pérez.
225x178mm (72 x 72 DPI)

Only