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

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10 **Migration routes and non-breeding areas of Common Terns *Sterna hirundo***

11 **from the Azores**

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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.

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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 geolocator 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 km^2), 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

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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-µl 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   *Geolocator 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 ± SD has been estimated as 185 ±

153   114 km at c. 50-60°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

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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

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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 4º57'N and 36º18'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.

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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

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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

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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^{-}

305 ^{1} 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).

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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

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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. Szczys 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

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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.

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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.

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514

515   **Supplementary material Figures caption:**

516   **Figure S1:** Leg of a Common Tern (*Sterna hirundo*) showing the Mk10 geolocator deployed

517   on a darvic ring.

518   **Figure S2:** Picture of a Common Tern (*Sterna hirundo*) resighted in Lajes do Pico (Azores)

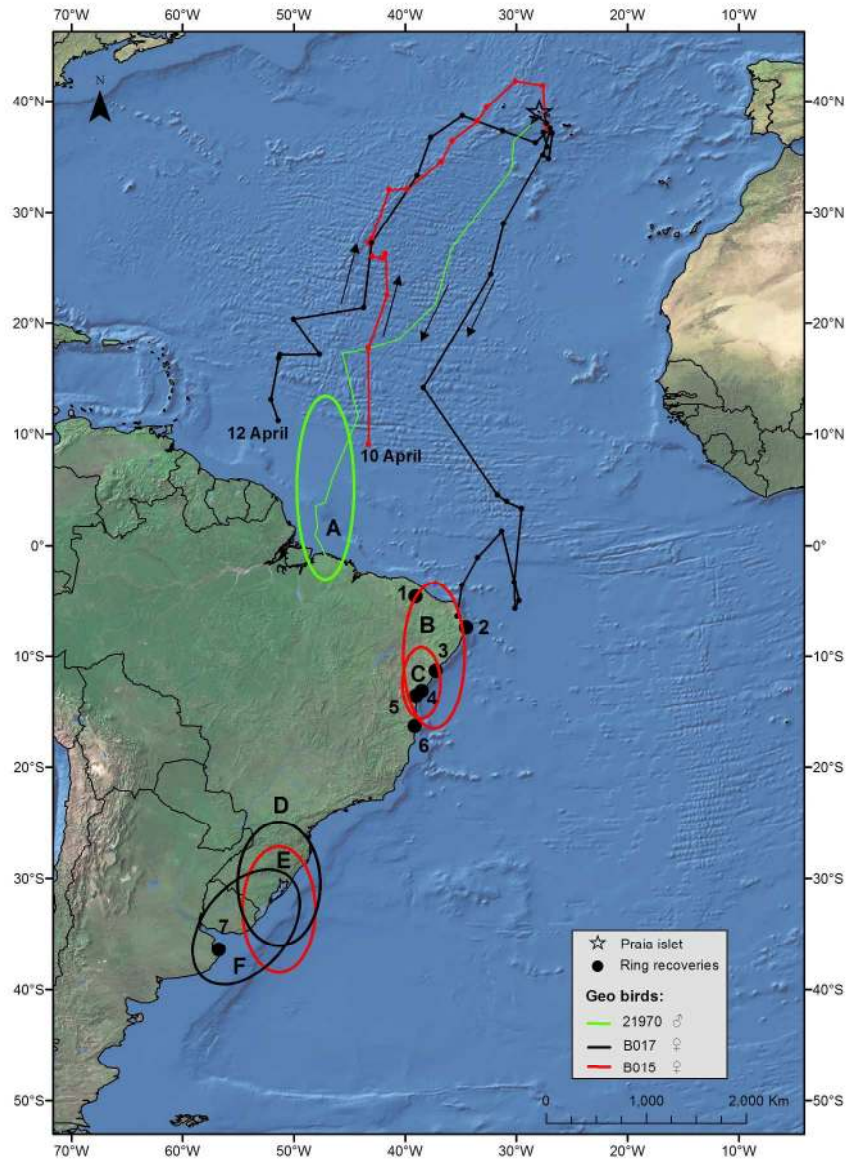519   in August 2011 and originally ringed in Punta Rasa (Argentina). © Ramsés Peréz.

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.

Period	DAY		NIGHT	
	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)	G002588	21/05/1993	0
(07°40'S, 34°50'W)			
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)	G006778	02/02/2003	5
(16°53'S, 39°06'W)			
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)