PARTIAL MIGRATION IN THE MEDITERRANEAN STORM PETREL *HYDROBATES PELAGICUS MELITENSIS*

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ABSTRACT

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Studying the migration routes and wintering areas of seabirds is crucial to understanding their ecology and to inform conservation efforts. Here we present results of a tracking study carried out on the little-known Mediterranean Storm Petrel *Hydrobates pelagicus melitensis*. During the 2016 breeding season, Global Location Sensor (GLS) tags were deployed on birds at the largest Mediterranean colony: the islet of Filfla in the Maltese Archipelago. The devices were retrieved the following season, revealing hitherto unknown movements and wintering areas of this species. Most individuals remained in the Mediterranean throughout the year, with birds shifting westwards or remaining in the central Mediterranean during winter. However, one bird left the Mediterranean through the Strait of Gibraltar and wintered in the North Atlantic. Our results from GLS tracking, which are supported by data from ringed and recovered birds, point toward a system of partial migration with high inter-individual variation. This highlights the importance of trans-boundary marine protection for the conservation of vulnerable seabirds.

Key words: Procellariformes, movement, geolocation, wintering, Malta, capture-mark-recovery

INTRODUCTION

The Mediterranean Storm Petrel *Hydrobates pelagicus melitensis* is a small seabird endemic to the Mediterranean basin. It is considered to be a subspecies of European Storm Petrel *H. pelagicus* based on morphological criteria (Lalanne *et al.* 2001), with clear separation confirmed by molecular markers (Cagnon *et al.* 2004). The IUCN lists the entire population of European Storm Petrel as Least Concern (BirdLife International 2018). However, the Mediterranean subspecies accounts for less than a tenth of the total population (BirdLife International 2018), and it is restricted to a few rat-free islands in the Mediterranean basin (Martin *et al.* 2000, Ruffino *et al.* 2009). Half of Mediterranean Storm Petrel nesting pairs are concentrated on the Maltese islet of Filfla (0.06 km^2) in the central Mediterranean, where the population is estimated to be 5 000–8 000 breeding pairs (Sultana *et al.* 2011). Certain Mediterranean colonies are stable after the implementation of conservation actions (Sanz-Aguilar *et al.* 2009), and some islets have recently been colonised after the eradication of rats (Mayol 2018). Population trends, however, are unknown for many other colonies.

The breeding ecology of the Mediterranean Storm Petrel (i.e., birds visiting colonies exclusively at night and nesting in boulder scree and sea caves at sites that are difficult to access) and its small body size make it difficult to study. Therefore, up-to-date population estimates are approximate or rely on high-effort capture-mark-recapture approaches (Bolton *et al.* 2010, Sanz-Aguilar *et al.* 2010). While knowledge about breeding biology is improving in parts of the range, some aspects of the birds' life history, such as annual movements, remain poorly known (Matović *et al.* 2017, Martínez *et al.* 2019).

The Mediterranean Storm Petrel has been described as sedentary, because birds are present in their breeding areas throughout the year (Zotier *et al.* 1999). However, in western Mediterranean colonies, there is little proof of presence during winter (Martínez *et al.* 2019) and little evidence for post-breeding movements westwards into the Atlantic (Cramp & Simmons 1977, Hashmi & Fliege 1994, Brooke 2004). Several authors have mentioned observations of European Storm Petrels in the eastern and southeastern Mediterranean during the winter (Busuttil & Flumm 1998, Shirihai 1999, Kirwan *et al.* 2008), in regions where no breeding has been recorded. Recent stable-isotope analysis on birds from western Mediterranean colonies point to waters overlying the Tunisian Plateau as the main wintering area and suggest post-breeding movements to the southern and eastern areas of the Mediterranean Sea (Martínez *et al.* 2019). However, two long-distance recoveries of Mediterranean Storm Petrels ringed on Filfla were recorded in the eastern Atlantic (Sultana *et al.* 2011), and movements of European Storm Petrels through the Strait of Gibraltar have been observed (Cramp & Simmons 1977). To our knowledge, the non-breeding movements of the Mediterranean Storm Petrel have never been investigated through tracking.

Since the 1990s (Hill 1994), geolocation via the logging of light levels (i.e., calculating locations from day length and the timing of sunrise and sunset) has become a powerful tool to study large-scale movements of various taxa around the globe (Evans & Arnold 2009). Global Location Sensor (GLS) devices have been widely used to track the migratory behaviour of many different bird species, including a variety of seabirds (Phillips *et al.* 2004, Wakefield *et al.* 2009). With technological developments in recent years, the size and weight of GLS devices has been considerably reduced, and small devices can now fit on birds the size of small warblers (Bridge *et al.* 2013, Salewski *et al.* 2013, Adamík *et al.* 2016). While GLS devices have lower accuracy than Global Positioning System (GPS) devices, advances in analytical software have improved location accuracy (Lisovski *et al.* 2012, Lisovski & Hahn 2012).

The GLS devices that are currently available are waterproof and small enough to tag small storm petrels. We tagged Mediterranean Storm Petrels on Filfla to identify their movements and whereabouts during chick-rearing and outside the breeding period. Additionally, we used the EURING databank to analyse long-distance ring-recovery data of all European Storm Petrels that had been ringed and/or recovered in the Mediterranean, supplementing these with records found in the literature. Here we present the first results of our study, perhaps marking the first step toward identifying marine habitat that is critical to this species.

STUDY AREA AND METHODS

GLS deployment

This study took place on the islet of Filfla, which is in the central Mediterranean, 4.5 km off the southwestern coast of Malta: 35°47′15″N, 14°24′35″E. The colony on Filfla has been visited annually by researchers since 1968 and studied mainly through mist-netting, with varying levels of effort. Birds start arriving at the end of February, the laying period spans April to July, and the chicks fledge between August and mid-October, around 70 days after hatching (Sultana *et al.* 2011). Such asynchronous breeding has also been described from other Mediterranean colonies (Mínguez 1994, LoValvo & Massa 2000). Most Mediterranean Storm Petrel nests on Filfla are situated in a scree slope under boulders and are mostly inaccessible to humans. However, in 2016 we identified accessible nests in three cavities created by bigger boulders. A total of 17 adult birds were caught there by hand on 13 different nests (meaning that both partners were tagged for four nests) during the first two weeks of their chick-rearing period (between 02 June and 01 August 2016). All were fitted with a GLS. Of these 17 birds, seven were ringed upon tagging while the remainder were recaptures that had been ringed in previous years during mist-netting sessions—the oldest tag was from 2012.

The birds were equipped with Intigeo-P50A11-7-SEA GLS tags (Migrate Technology Ltd.). These consisted of a light sensor and a button battery sealed in a compact and streamlined waterproof casing. The tags were equipped with a 7-mm light pipe (45°) to avoid shading by the birds' feathers. The lifespan of the GLS battery, as specified by the provider, was 9–13 months from the manufacturing date. The GLS tags were configured to record the full light-level range once per minute, and the maximum light level was recorded every five minutes (configuration mode 10). Our goal with the GLS tags was to generate the maximum number of positions, to cover the entire non-breeding period. To do this, we decided to record only the light level, foregoing parameters such as the temperature and conductivity, to extend the battery lifespan for as long as possible. Because the tags were deployed on the birds' backs and the species does not dive much, we did not record wet versus dry, which shows when the birds are resting on the water or diving. Before attachment, the GLS tags were calibrated for five days (20–24 May 2016) on the flat roof of an observation hide in a nature reserve in the northern part of Malta, Għadira Bay (35°58′13″N, 14°20′56″E), which is situated 21 km from Filfla.

For deployment, each tag was equipped with two tubes (diameter = 1 mm), one at the front end and one at the rear, through which a thread was passed to create the harness. For the thread, we used soft, flat ribbon that was 1.5 mm wide and made of black braided nylon. We followed a wing-loop backpack-style harness design that has been previously used on Common Swifts *Apus apus* (Åkesson *et al.* 2012). The harness consisted of a 50-cm ribbon that was tied in advance to form three loops, which could be adjusted to individual birds in the field. First, the ribbon was threaded through the front tube, which was centred along the length of the ribbon. The ends of the ribbon were then knotted together to form the first loop (diameter ~ 3 cm), which could be adjusted around the bird's neck. The free ends of the ribbon were then passed through the rear tube in opposite directions, creating two loops that could be adjusted around the wings. In the field, the first loop was placed around the neck and adjusted to the bird's size, with the knot centred at the chest. After that, each wing was passed through a wing loop; these were adjusted by evenly pulling both ends of the ribbon. The position of the loops, the chest knot, and the adjustment were checked before the ribbon ends were knotted on top of the tag. The knots and the tag tubes were then fixed with superglue, and excess ribbon was trimmed to the knot. The overall weight of the GLS tag and the harness was 0.9 g.

The birds were weighed prior to GLS deployment, and the general aspect of each bird was examined in the process of selecting birds to tag. Body mass was used as a proxy for body condition. The body mass of adult birds captured in Filfla during breeding season was 27.8 ± 2.3 g on average, and the median mass was 27 g (n = 447 for the 2012–2014 breeding seasons). Only birds weighing ≥ 27 g were tagged; this kept the tag weight at ~ 3 % of the body mass to minimize possible negative effects (Barron *et al.* 2010, Phillips *et al.* 2003, Vandenabeele *et al.* 2012). The total handling time of each bird was less than 10 minutes, and the birds were released back into the nest immediately after handling.

GLS retrieval

The GLS tags were retrieved over four visits in 2017 and two visits in 2018. The birds were either recaptured in the nest or with a mist-net placed in the entrance to the cavity. After removing the data logger, the birds were weighed and carefully checked for injuries that may have been caused by the harness (e.g., abrasions or injuries to the feathers, body, and skin). The bird was then immediately released.

A t-test for paired data was carried out on the weight of the birds prior to tagging versus after tag retrieval to test for a statistically significant weight change over the deployment period.

Ethical statement

All birds were handled and tagged by trained bird ringers under the licences of the local authorities (Wild Birds Regulation Unit, Environment and Resources Authority NP 20/16, NP 0121/16, NP0003/18).

Data processing and analysis

The batteries of all GLS tags were flat upon retrieval. The data were downloaded by personnel at Migrate Technology, Ltd., who provided a .lux file that contained light-level values by date. At the end of battery life, the recorded data showed a period of constant high light measurements and were discarded as unreliable. The threshold value (2), elevation angles (between −5.3° and −5.7°), and the equinox range (± 20 d of each equinox) for the mark-up of sunrise and sunset events were defined in the program IntiProc v1.03 (Migrate Technology, Ltd.). All erroneously assigned mark-ups were removed manually. Locations were generated from the remaining events using the R package "GeoLight v2.0" (Lisovski *et al.* 2015). We then used the two-point averages of the locations for further analyses.

The positions obtained were divided into the chick-rearing stage and the non-breeding stage. Knowing the approximate date of egg laying for each nest, the end of the chick-rearing was calculated individually to be between mid-September for the earliest and mid-October for the latest chick fledging, all occurring within 20 days of the autumn equinox. Because the end of the chick-rearing period and, thus, the beginning of the non-breeding period occurred within this window, the end of the chick-rearing stage in the cleaned dataset was established on 02 September (20 days before autumn equinox) and the start of the non-breeding period was 13 October (20 days after autumn equinox). The cut-off for the non-breeding period was established on 28 February, which coincided with the last day of reliable data before the spring equinox.

The tracking data used in this study are available on Movebank (movebank.org, study name "Partial migration in the Mediterranean Storm Petrel (BirdLife Malta)") and are published both in the Movebank Data Repository (Lago *et al.* 2019) and in the Seabird Tracking Database managed by BirdLife International (http://www.seabirdtracking.org/).

To create distribution maps, locations recorded around each equinox (±20 d) and locations more than 250 km inland were removed because the positions calculated could have a maximum error around these cut-off values (Phillips *et al.* 2004). Maps were created using ArcGIS® Desktop 10.6.1 by ESRI® in the Lambert Azimuthal Equal-Area ETRS89 projection. Kernel densities (90 %, 80 %, 70 %, and 50 %) were calculated with the Spatial Analyst Density Tool using the planar method and automatic search radius.

Ring recaptures and recoveries

To compare our tracking results with conventional ring-recovery data, we asked the EURING databank for a database of European Storm Petrels ringed or recovered between 30°N and 45°N (du Feu *et al.* 2009). On 08 January 2018, we obtained 47 813 records for the area requested. These did not include records from the French or Greek ringing schemes. The EURING databank distinguishes between Atlantic and Mediterranean storm petrels, but not all the ringing schemes and data sets in the Mediterranean report the subspecies. Ring recoveries from local literature that were not in the EURING databank were added to the data set. The data set was filtered to remove clearly local movements around the

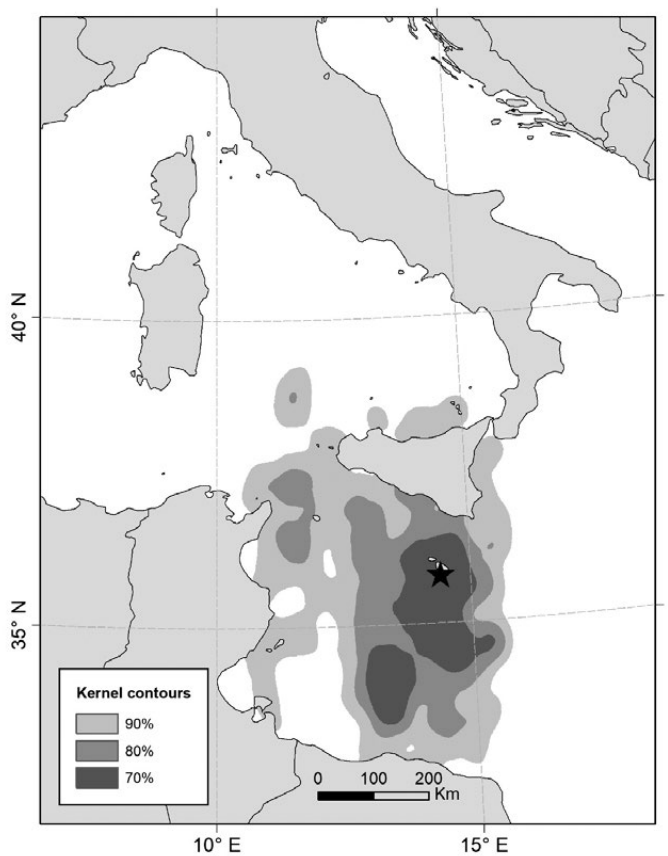

Fig. 1. Kernel activity ranges (90 %, 80 %, and 70 % of the locations derived from GLS tags) of seven Mediterranean Storm Petrels breeding at the Filfla colony during the chick-rearing period, July to September 2016. The star represents the Filfla colony.

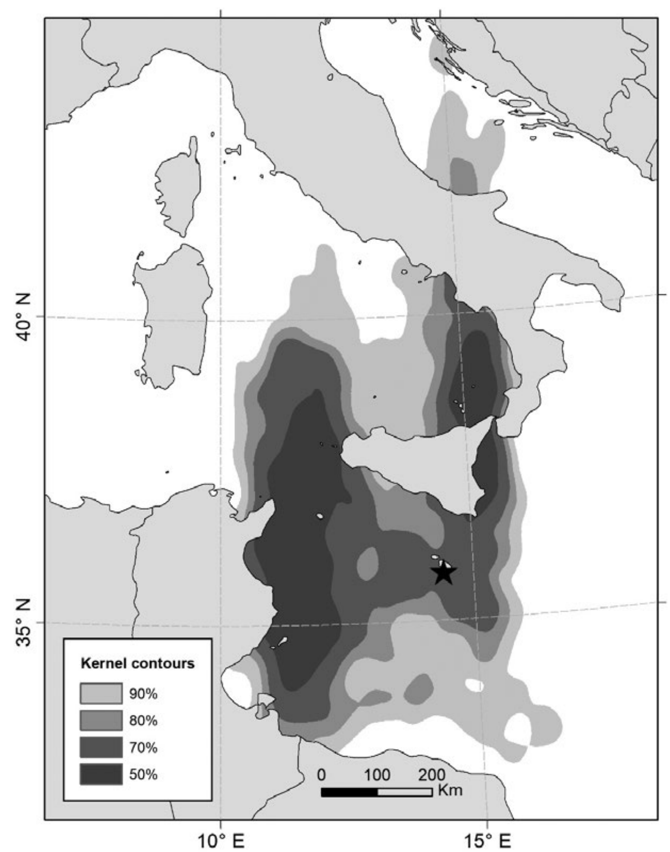

Fig. 2. Kernel activity ranges (90 %, 80 %, 70 %, and 50 %) of locations in the central Mediterranean, derived from seven Mediterranean Storm Petrels breeding at the Filfla colony during the non-breeding period (mid-October 2016 to February 2017). The star represents the Filfla colony.

Mediterranean colonies. Data for any bird recaptured or recovered close to the site of ringing within the Mediterranean was deleted. The cut-off was 25 nautical miles (46.3 km), which is equivalent to the Maltese Fisheries Management Zone. For the birds ringed in the Atlantic, only records of movements between the Atlantic and the Mediterranean were analysed.

RESULTS

GLS retrieval

Of the 17 GLS tags deployed in 2016, we retrieved seven (41 %): six in 2017 and one in 2018. None of the tagged birds recaptured in the following seasons had lost their tag. Tags were retrieved from birds of six different nests, including one nest in which both members of the pair had been tagged. Weights taken before deployment did not differ significantly from the weights upon retrieval (t-test for paired data = 0.44666, $P = 0.6738$). No abrasions, injuries, or scars resulting from tag attachment were found on any individual. Breeding was confirmed for five of the seven GLS-tagged birds; for the remaining two, nest contents were not visible on retrieval or during subsequent visits; therefore, breeding could not be confirmed. The time during which the loggers collected reliable data varied between 232 and 282 days, averaging 257 ± 20 d (standard deviation; see Appendix 1, available on the website). All seven retrieved tags successfully recorded the areas used during chick-rearing and wintering.

After processing the GLS data, 3 600 locations were obtained. Locations recorded within 20 days of the equinox (989 locations) and unrealistic locations (i.e., more than 250 km inland, 22 locations) were excluded, leaving a total of 2 589 validated locations. The data points were split into 660 locations during the chick-rearing period (July–September 2016) and 1 906 locations for the non-breeding period (mid-October 2016–February 2017).

Mediterranean Storm Petrel movements

Areas used during the chick-rearing period

During the expected chick-rearing period in 2016, all seven tagged birds stayed in waters of the central Mediterranean Sea (Fig. 1). The area of general use (90 % kernel contour) covered a wide area up to ~ 400 km from the colony, from the east coast of Sicily to Tunisia and the Libyan coast. The core areas (70 % kernel contour) were situated around Malta and between south of Sicily and the Libyan coast. However, we were unable to confirm the nesting success of the birds, as visits to the colony during the late chick-rearing period were not possible.

Movements and areas used during the non-breeding period

The location data during the non-breeding period from mid-October 2016 to late February 2017 were recorded for all seven birds. Six individuals remained in the Mediterranean throughout this period, mostly in the central Mediterranean up to ~ 600 km from the colony. Although birds were also recorded in Maltese waters during the non-breeding period (90 % kernel contour), the core distribution (70 % kernel contour) shifted to two areas farther away from the

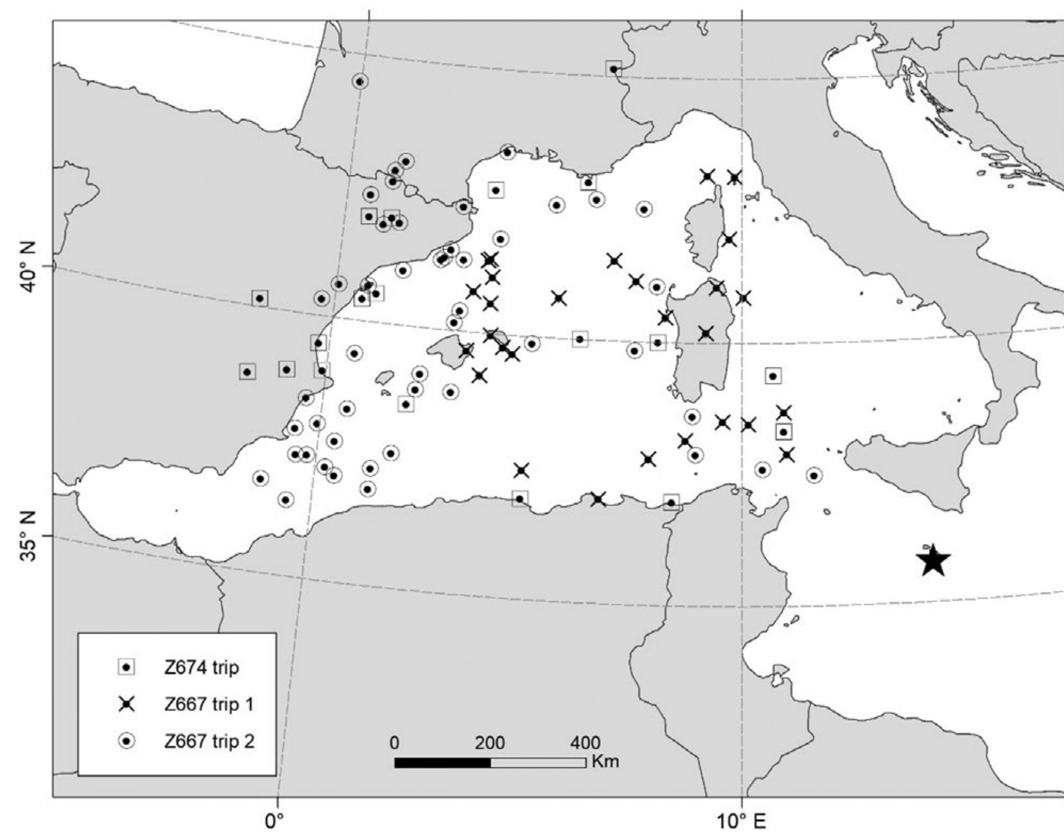

Fig. 3. Non-breeding movements to the western Mediterranean of two Mediterranean Storm Petrels from the Filfla colony: one trip for individual Z674 (December 2016) and two trips for individual Z667 (December 2016, January–February 2017). The star represents the Filfla colony.

colony: one was the channel between Tunisia and Sicily west of Malta, and the other was around the Strait of Messina east and northeast of Sicily (Fig. 2).

While four of the six individuals remained in the central Mediterranean throughout the non-breeding period, two individuals visited the western Mediterranean. In December 2016, the first individual departed the central Mediterranean on 12 December and travelled a counter-clockwise loop, passing Corsica and the Balearic Islands and returning to the central Mediterranean on 20 December (Fig. 3). The second individual made two trips to the western Mediterranean between December 2016 and February 2017 (Fig. 3). The first trip was a 13-d counter-clockwise loop in which the bird left the central Mediterranean on 18 December 2016, passed Corsica and the Balearic Islands, and returned to the central Mediterranean on 30 December 2016. The second trip was a 23-d counter-clockwise loop in which the bird departed the central Mediterranean on 11 January 2017, stayed close to the Spanish coast for ~17 d, and returned to the central Mediterranean on 02 February. This second individual was a member of the pair for which GLS tags were retrieved for both partners, and its partner was one of the four birds that stayed in the central Mediterranean throughout the non-breeding period.

One of the seven individuals stayed in the central Mediterranean after the breeding period, then migrated to the Atlantic Ocean in December (Fig. 4). It left the central Mediterranean on 16 December 2016 and passed the Strait of Gibraltar between 29 and 30 December. It arrived in the Bay of Biscay on 05 January 2017 and stayed until 05 February, after which it moved further northwest into the open Atlantic Ocean.

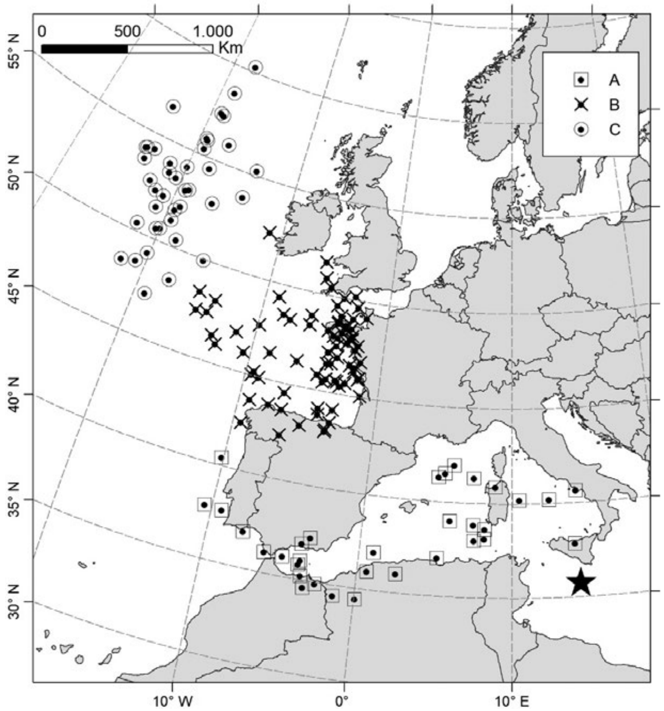

Fig. 4. Movements of one Mediterranean Storm Petrel (Z665) from the Filfla colony during the non-breeding period (October 2016 to March 2017), split into periods of migration into the Atlantic Ocean (A), a stay in the Bay of Biscay (B), and a stay in the North Atlantic (C); return migration is not shown. The star represents the Filfla colony.

The bird performed its return migration around the spring equinox, when the GLS could not record reliable latitude fixes. The longitude data showed a gradual movement eastward starting on 07 March, arriving at a longitude corresponding to the central Mediterranean by 28 March 2017 (Appendix 2, available on the website).

For three individuals, we were able to extract from the GLS data the first occasion that the birds spent inside the nest during the day after their return to the colony in spring: 25 March 2017, 06 April 2017, and 13 April 2017.

Ring recaptures and recoveries

Out of approximately 34 800 Mediterranean Storm Petrels that have been ringed on Filfla over the past five decades, only 12 have been recovered elsewhere; this gives a very low long-distance recovery rate of 0.345 %.

Movements within the Mediterranean basin

A total of 138 individual European Storm Petrels have been ringed and recovered within the Mediterranean more than 25 nautical miles from the site of first capture. There were no records of birds ringed in the western and central Mediterranean that were recovered in the eastern Mediterranean. In the Greek colonies, a low number of European Storm Petrels have been ringed, and there have been no recoveries of foreign birds (D. Portolou pers. comm.). Most recoveries involved movements along the Spanish Mediterranean coast and on the Balearic Islands (n = 118). Eight adult birds ringed in Filfla were recovered between April and August in Sicily and the surrounding waters: one was recovered in the colony of Marettimo Island off the west Sicilian coast, and the other seven

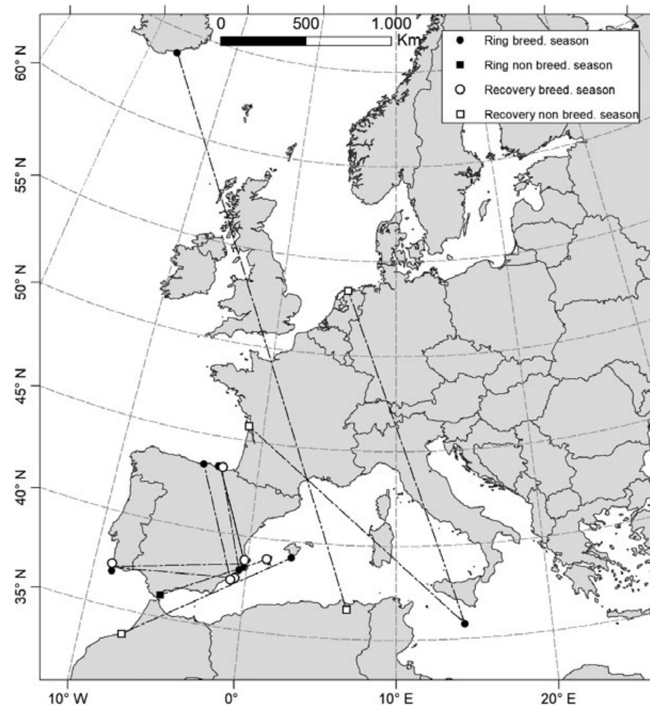

Fig. 5. Ringing and recovery records of European Storm Petrels between Atlantic and Mediterranean basins; ringing and recovery locations are connected by lines.

were recovered along the east Sicilian coast, in the Ionian Sea. Two other adults ringed in Filfla were recovered in Tunisian waters. In addition, there is one record from Spain to Morocco, one record from Spain to Italy, three records from Italy to Spain, and five records (four juveniles and one adult) from Marettimo (Italy) to Filfla (see Appendix 3, available on the website). As many as 137 of the 138 records correspond to recoveries that were clearly during the breeding season (March to mid-October), while only one bird was recovered at the end of or outside the breeding season: it was ringed in Malta and recovered in Tunisia at the end of September.

Movements between Mediterranean and Atlantic basins

Five birds ringed in the Mediterranean were recovered in the Atlantic (Fig. 5), including two birds ringed as adults on Filfla during the breeding season and recovered dead on the French Atlantic coast and Dutch North Sea coast during the non-breeding season; two juveniles ringed in Alicante and recovered in Faro and Biscay as adults during the breeding season; and one juvenile ringed in Mallorca and recovered on the Atlantic coast of Morocco in winter. The EURING databank also contains six birds ringed in the Atlantic that were later recovered in the western Mediterranean (Fig. 5). However, it remains unclear to which population these birds belonged, as most of them were captured with mist-nets in breeding colonies or in coastal locations along the Atlantic without evidence of breeding (Appendix 3).

DISCUSSION

To our knowledge, our study is the first to provide data on the whereabouts of the Mediterranean Storm Petrel throughout chick-rearing, migration, and wintering periods using tracking devices. We showed that GLS devices can be successfully attached to this very small seabird via a wing-loop backpack-style harness system. The negative impact of this type of attachment is low, as shown by the recapturing of birds after one to two years without significant changes in body mass, with no visible harmful effects of the attachment, and with breeding in the recovery year confirmed for some individuals. However, our findings must be treated with caution, as harness attachments for tracking devices are known to have highly negative impacts among a variety of seabird species, such as Northern Fulmar *Fulmarus glacialis* (Falk & Møller 1995, Mallory & Gilbert 2008), Great Skua *Stercorarius skua* (Thaxter *et al.* 2016), and various albatross and petrel species (Nicholls *et al.* 2002, Phillips *et al.* 2003). The fact that storm petrels forage mainly on the sea surface and do not perform deep dives might explain why the attachment method works for this species. Nonetheless, we carefully considered alternative attachment methods prior to tagging. We believe that the species is too small to attach currently available GLS devices by way of a ring on the tibiotarsus or on the tarso-metatarsus. Furthermore, our trials with a leg-loop backpack-style harness failed because the loops slipped off the birds' smooth legs. An attachment method that has worked for the slightly larger Leach's Storm Petrel *Oceanodroma leucorhoa* involved suturing the tag onto the back of the birds (Pollet *et al.* 2014). We would have had difficulty in obtaining a permit to use this method, and it would have required a trained veterinarian on site.

The relatively low return rate (7 of 17 devices) could indicate a negative impact of the tagging on some individuals. However, we think that this low return rate can be mainly explained by the difficulties in accessing the island, which resulted in few visits for tag recovery. Additionally, access to most of the nests was restricted, and the birds showed rather low site fidelity owing to the ephemeral character of their nesting habitat—the rocks and boulders of the scree slope where the colony on Filfla is located often move from one season to the next due to winter storms. In fact, one of the nests where both partners were tagged in 2016 was not found in the following season, but one of the tagged birds was recaptured in a mist-net in 2017. Furthermore, we cannot exclude the possibility that some of the tagged storm petrels were predated by the local population of Yellow-legged Gulls *Larus michahellis* (Borg *et al.*1995, Sultana *et al.* 2011, BM pers. obs.). In a Mediterranean Storm Petrel colony in Spain with high predation by Yellow-legged Gulls, Sanz-Aguilar *et al.* (2010) estimated annual survival rates of 0.72–0.76. We recommend a study to detail possible negative effects of the attachment method on the return rate by establishing an adequate number of untagged pairs as a control group. Ideally the sample size of nests for tagging and monitoring and the number of visits for tag recovery should be increased in future studies.

During the assumed chick-rearing period, adult breeders remained in the central Mediterranean near the colony. This is supported by records of birds ringed in Filfla and recovered during the breeding season mainly in waters south and southeast of Sicily, several of them found dead or shot at sea in the 1970s (Sultana & Gauci 1977). The 90 % kernel activity ranges (Fig. 1) indicated the maximum distance from the colony (365 km) reported for the species during the breeding period (Oppel *et al.* 2018).

Most birds in our study remained in the central Mediterranean throughout the non-breeding period, to some extent supporting suggestions that Mediterranean populations are sedentary (Hashmi & Fliege 1994, Brooke 2004) or short-distance migrants (Martínez *et al.* 2019) and contrasting with the long-distance trans-equatorial migrations observed in Atlantic populations (Fowler 2002). Moreover, our results also support the hypothesis by Matović *et al.* (2017) that Mediterranean Storm Petrels remain in the Mediterranean Sea. Their findings are based on recaptures recorded in the EURING databank and on the fact that the survival rates of storm petrels of each subspecies (Atlantic and Mediterranean) correlate with the environmental conditions in their respective sea basin. Soldatini *et al.* (2014) found evidence, through capture-mark-recapture models, that environmental conditions in the Mediterranean affect adult survival of these storm petrels during the non-breeding period. One of the two core areas identified as a wintering area for the Filfla population—the Tunisian waters—is the location of the only recovery during the non-breeding season of a bird ringed in Filfla. This area had also been identified by Martínez *et al.* (2019) through stable-isotope analysis of wing feathers.

Our study also points toward high inter-individual variation in migratory behaviour of the Mediterranean Storm Petrel. Two birds, respectively, performed one and two loop-shaped migrations into the western Mediterranean during the non-breeding season, while one bird exhibited a long-distance migration, leaving the Mediterranean to spend part of the non-breeding period in the Bay of Biscay and vicinity. Movements out of the Mediterranean basin are further confirmed by four records of European Storm Petrels ringed in Mediterranean colonies but retrieved on the Atlantic coast. This evidence of migratory behaviour could contradict the conclusion of Martínez *et al.* (2019) that migration toward the Atlantic should be reflected in the stable-isotope analysis of S8 and P10 feathers. However, this might not be the case if the birds show a non-suspended moult of primary feathers (PP) and have finalised the moult before starting their migration west into the Atlantic; this is an alternative hypothesis of Martínez *et al*. (2019). Of the GLS-tagged birds from Malta that migrated, all three left the central Mediterranean in December. We argue that by that time, they most likely would have finalised their PP moult, in accordance with the timing and progress of moult reported by Sultana *et al.* (2011).

Interestingly, none of the tagged birds in our study moved east, and there were no ring recoveries from eastern Mediterranean countries in the EURING databank; we acknowledge the limitation of drawing conclusions from small sample sizes. Therefore, further work with an increased sample size should gather information on the overall proportion of sedentary versus migratory birds within the Mediterranean population, an analysis that might reveal additional migration routes and wintering grounds. Other important questions remain to be answered, such as whether the migratory disposition depends on age, sex, or population; if there is an intra-individual plasticity in the decision to migrate or to stay; and whether this decision is affected by climatic factors. Better knowledge here could improve the selection of relevant environmental covariates when modelling adult survival from capture-mark-recapture data (Matović *et al.* 2017). The Matović study revealed a correlation between adult survival and the Western Mediterranean Oscillation index, indicating that Mediterranean Storm Petrels from Benidorm may overwinter in the eastern Mediterranean. Despite this suggestion, none of the tagged birds in our study wintered in the eastern Mediterranean, and the two tagged birds observed to move to the western Mediterranean agree with findings by Soldatini *et al.* (2014) that birds of Marettimo (the neighbouring colony closest to Malta) might winter in the Alboran Sea. Apart from further monitoring and tagging work at Filfla, future work should include colonies situated in Spain (Mediterranean coast and Balearic Islands) and Italy (Marettimo), which might be easier to access. In light of a rapidly changing climate and with increased sea surface temperatures (SST) occurring in the various sub-basins of the Mediterranean at different rates (Shaltout & Omstedt 2014), it will be interesting to monitor possible shifts in the wintering areas of the storm petrels, especially because low productivity, which is linked to high SST and low chlorophyll concentration, has been shown to negatively affect adult survival (Soldatini *et al.* 2014).

To date, the designation of marine protected areas (MPAs) for small storm petrel species has mainly focused on the colonies themselves and directly adjacent coastal waters (BirdLife International 2010, Meirinho *et al.* 2014, Metzger *et al.* 2015). Important Bird and Biodiversity Areas (IBAs) are used as the scientific basis for designating MPAs in the European Union. The identification of marine IBAs has generally relied on tracking data from larger seabird species (BirdLife International 2010), whereas offshore marine IBAs for small storm petrels have been identified by modelling a relatively low number of observations from vessel-based line-transect counts; these small species tend to be under-detected and therefore under-represented due to their size. Furthermore, visual identification of subspecies of European Storm Petrel is impossible, which prevents researchers from defining the source population of observed birds. By providing a method that enables GLS-tagging of small storm petrels, we hope to contribute to an improved understanding of the at-sea distribution and movements of the birds throughout the year. Such information might lead to better-informed marine spatial planning and the designation of MPAs for the Mediterranean Storm Petrel and similarly small species.

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