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G. Dell'ariccia[a]; G. Dell'omo[b]; B. Massa[c]; F. Bonadonna[d]
[a] Anatomy Institute, University of Zurich, Zurich, Switzerland [b] Ornis italica, Rome, Italy [c] Dipartimento SENFIMIZO (Stazione d'Inanellamento), Università di Palermo, Palermo, Italy [d] CNRS - CEFE, Behavioural Ecology Group, Montpellier, France

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First GPS-tracking of Cory's shearwater in the Mediterranean Sea

G. DELL'ARICCIA*[1], G. DELL'OMO[2], B. MASSA[3], & F. BONADONNA[4]

[1]*Anatomy Institute, University of Zurich, Zurich, Switzerland,* [2]*Ornis italica, Rome, Italy,* [3]*Dipartimento SENFIMIZO (Stazione d'Inanellamento), Università di Palermo, Palermo, Italy, and* [4]*CNRS – CEFE, Behavioural Ecology Group, Montpellier, France*

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Abstract
The behaviour and ecology of seabirds such as albatrosses, petrels and shearwaters have been the subject of numerous studies, often employing the most recent technologies to track birds during their foraging trips. Until now, however, large oceanic species have been preferred for tracking studies because of the dimensions and weight of the devices available. New light-weight GPS (Global Positioning System) loggers (< 9 g) were used to track foraging trips of a medium-sized species, the Cory's shearwater, for the first time in the Mediterranean Sea. The tracks obtained showed that Mediterranean Cory's shearwaters alternatively used one of two different fishing areas. Various explanations could account for this difference; one of these could be that the two directions have a different relevance for the birds, being for chick- and self-provisioning. This study provides new hypotheses concerning the behaviour of Cory's shearwaters in the Mediterranean Sea, a different environment compared to previously studied oceans.

Keywords: Calonectris diomedea, *GPS tracking, Mediterranean Sea, feeding behaviour, foraging ecology*

Introduction

The tubenosed seabirds (albatrosses, petrels and shearwaters) are well known for their pelagic and wide-ranging lifestyle. These long-living birds spend most of their life at sea and are tied to small oceanic islands only for breeding. Also during the breeding season, foraging grounds of most species remain pelagic, forcing birds to commute between the breeding island and the open sea, and to cover up to thousands of kilometres during a single foraging trip (i.e. *Diomedea exulans*, Jouventin & Weimerskirch 1990). This highly energy-demanding strategy, called central place foraging (Orians & Pearson 1979), has been deeply investigated using electronic tracking devices, such as the Argos PTT (Platform Transmitter Terminal) or micro GPS loggers (Jouventin & Weimerskirch 1990; Weimerskirch et al. 2002).

Procellariiformes species have been subject of numerous studies to understand their functional ecology in environments with high unpredictability of food resources, especially during the chick-rearing period, when food and energy demand is augmented. Until now such studies have been limited to the larger oceanic species, such as albatrosses, because of the dimensions and weight of the devices (Catard et al. 2000; Weimerskirch et al. 2002; Pinaud et al. 2005). Only recently, the introduction of new, light-weight instruments have allowed tracking of the flight of smaller species (e.g. Cory's shearwaters, *Calonectris diomedea*, with GLS (Global Locating System) loggers: Navarro et al. 2007; Manx shearwater, *Puffinus puffinus*, with GPS loggers: Guilford et al. 2008).

Cory's shearwater is a medium-sized colonial species, breeding on islands across the Mediterranean Sea (*C. d. diomedea* Scopoli, 1769) and offshore the northwest coast of Africa, in the Macaronesian (Azores, Madeira, Canaries, and Selvagem Islands) and Berlenga (*C. d. borealis* Cory, 1881) Islands (del Hoyo et al. 1992). Breeding biology is similar to that of other Procellariiformes species. Cory's shearwaters form long-term pair bonds and biparental care is essential to raise the chick from the single egg laid every year (Warham 1996). Parents usually deliver food at relatively high frequencies, and

*Correspondence: G. Dell'Ariccia, Anatomy Institute, University of Zurich, Winterthurerstrasse 190, CH-8057 Zurich, Switzerland. Email: gaiadellariccia@yahoo.it

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chicks do not undergo prolonged fasting periods (Hamer & Hill 1993). They are nocturnal on their breeding grounds (but see Bretagnolle 1990 on Selvage Is.), and in late afternoon birds can be observed waiting for darkness at sea in front of their colonies, in flocks of hundreds or thousands of individuals, before coming onshore (Warham 1996; Brooke 2004). At the end of the breeding season, most Mediterranean birds migrate to the southern Atlantic Ocean (Gonzáles-Solís et al. 2007). Recently, Magalhães et al. (2008) demonstrated that Cory's shearwaters in the Azores use a dual-foraging strategy as already described for other Procellariiformes species in the Southern hemisphere oceans (Chaurand & Weimerskirch 1994; Weimerskirch et al. 1994). The species that use this strategy alternate, during the chick-rearing period, short trips (ca. 1–4 days) over coastal waters aiming to provide food to chicks, with long trips (ca.10 days) over pelagic waters aiming to restore the adults' own reserves lost during the short trips (with only minor differences between species; Weimerskirch et al. 1994; Weimerskirch 1998; Magalhães et al. 2008).

The relatively small size of Mediterranean Cory's shearwaters (560–730 g; Massa & Lo Valvo 1986) did not allow detailed study of foraging ecology (i.e. tracking foraging trips using Argos PTTs). Consequently, to date, no studies have been carried out in the Mediterranean Sea. Nevertheless, the oceanographic conditions of this area (i.e. a surface of 2.51 million km^2 and a maximum latitude length of 3700 km) makes this closed sea a particular environment where some Procellariiformes species evolved, and comparisons with oceanic species become of interest. The presence of coasts not very far from the breeding islands has been demonstrated to influence the foraging trips in oceanic species (Magalhães et al. 2008). We can, thus, expect that the relatively short distance between Mediterranean coasts in most directions would probably influence the length of average distances travelled by shearwaters during foraging trips, presumably shortening them with respect to those covered by their homologue oceanic species. Moreover, as a consequence of an average lower primary productivity (http://oceancolor.gsfc.nasa.gov/SeaWiFS/) with respect to the oceanic areas where the majority of previous studies have been carried out, we could also expect different foraging strategies and habits.

Therefore, we followed for the first time the individual foraging movements of Cory's shearwaters in the Mediterranean Sea, using new < 9 g GPS devices, set at high localization frequency. This aimed to understand the behaviour of this species during foraging trips and to identify possible influences of the Mediterranean environment on its habits.

Materials and methods

The study was carried out on the island of Linosa (Pelagian Isles, Sicilian Channel, Italy: 35°52' N, 12°52' E; surface 5.4 km^2), with a breeding colony of Cory's shearwater estimated around 10,000 or more pairs (Massa & Lo Valvo 1986). The birds lay a single egg on a sandy substrate inside burrows and holes created by cracks of effusive lava rocks. The study took place in the area of Mannarazza, where most of the Linosa shearwaters nest, between 28 July and 12 August 2007, during the chick-rearing period. At this time of the breeding season most of the chicks had hatched and were 1–2 weeks old. A total of 22 burrows containing a small chick were selected and the presence of the adults during the night was recorded. We also ringed both adults of each pair. The bird's sex was assigned on the basis of morphologic secondary sexual traits such as weight, and vocal characteristics (Brooke 2004).

For the GPS deployment the birds had to be trapped at least twice: the first time to apply the device and then, when back from their foraging trip, for retrieving it. In order to minimize the stress due to manipulation and trapping, a mechanical trap allowing only one-way access was placed at the entrance of their burrow. The door mechanically closed when an adult entered the burrow, precluding it to exit but still allowing the entrance to the second member of the pair. Ten suitable burrows were equipped with such traps. Every night between 2:00 and 5:00 am (before sunrise) the burrows were checked for trapped birds, the birds caught were weighed, equipped with the GPS data loggers and released, and the trap door left open after the operations. All traps were again set during the day.

Cory's shearwaters were tracked by means of small GPS data loggers (www.technosmart.eu). The loggers (20 × 40 × 6 mm, weight < 4 g) were mounted on one or two rechargeable batteries of 5 g each (total weight: < 1.8% or < 2.7% of body size with one or two batteries, respectively). GPS loggers with one battery recorded the bird position at one fix/20 s; those with two batteries were set to record four fixes/s. Both types could last for about 11 h, and had a precision of ± 4m in 95% of the locations.

The loggers were made waterproof by rolling in a plastic film and then sealed into a latex finger; finally, they were attached to the uppertail coverts, using tape (TESA 6051). The removal of the GPS did not damage the feathers.

All birds but one were weighed before being released with GPS and 12 also after being recovered, which generally occurred after the adult had fed the chick.

The positional data were downloaded from the logger to a computer and plotted with the aid of MapInfo Professional (MapInfo Corporation, Troy, NY, USA). This allowed a detailed analysis of the track for the extraction of parameters such as: length, speed, shape, and direction. For the tracks at four points per second, we also calculated the straightness index (SI) as D/L, in which D is the beeline distance and L is the total path length flown between the same two points. The identification of flight patterns was made combining the MapInfo images of tracks, the straighten index and the flight speed.

Differences related to sex and direction among foraging trips were tested using the Mann–Whitney U test. Correlations between body weight and trip duration were tested using Spearman's Rank test. Differences in body mass changes during foraging trips were analysed using the Wilcoxon signed-rank test. Calculations were done using the software package STATVIEW 5.01 (SAS Institute, Cary, NC, USA).

We also analysed the tracks in relation to wind intensity and direction using a contingency table and the χ^2 test. Daily wind data over the Mediterranean Sea by satellite recording are freely available from: http://podaac.jpl.nasa.gov/DATA_PRODUCT/OVW/index.html (Product 109). In this data set (QuikSCAT Level 3), values of wind speed and direction are provided on an approximately 0.25° × 0.25° global grid (see the website for more details). Wind data have been extracted with MATLAB 7.5.0 R2007b (The MathWorks Inc., Natick, MA, USA).

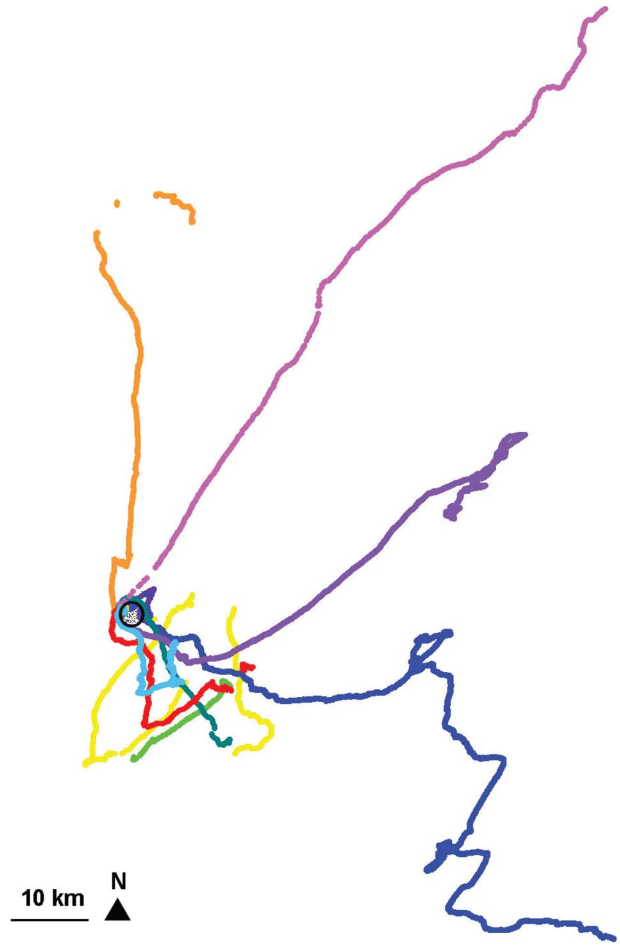

Figure 1. GPS tracks of Cory's shearwaters during foraging trips. Only 4 individuals reached long distances from the colony, covering on average 86.1 ± 12.2 km in 9 h, and flying mostly towards northeast. The other birds rested near the colony, reaching on average a distance of 26.2 ± 3.6 km, in an area southeast with respect to the island, in the same time span. The black circle indicates the island; the colony and departure point for all tracks is in the northwest side of it.

Results

Overall we equipped 17 Cory's shearwaters with GPS loggers in 21 releases (4 birds were released twice). We recovered 18 devices from which it was possible to reconstruct 13 tracks, 2 of which were at high resolution (four fixes/s; Figure 1). Three birds out of 21 did not return to their nest before our departure from the island. Unfortunately, the tracks were incomplete because in all the loggers the battery elapsed before the birds returned, or because the GPS logger got wet with diving. As a consequence, we discarded four tracks because they lasted less than 1 h. Eventually, we analysed nine tracks from nine different birds (average GPS duration = 8.9 h ± 1.1 SEM. Min 4.3, Max 13; Table I).

For the 18 birds recaptured, the average foraging trip duration was 4.83 ± 0.86 days; the minimum was 1 day, and maximum was 12 days. No differences in trip durations were found between males (M) and females (F) (Mann–Whitney: $U = 24$, $N_F = 8$, $N_M = 9$, $p = 0.25$. For the nine birds with GPS track only, Mann–Whitney: $U = 6.5$, $N_F = 5$, $N_M = 4$, $p = 0.39$). The birds lost, on average, 17.25 ± 7.1 g, but the high variability made this difference insignificant (Wilcoxon signed-ranks test: $T = -1.886$, $N = 12$, $p = 0.59$). The weight variation during foraging trips ranged from +40 to −60 g (Table I), with no differences between sexes (Mann–Whitney: $U = 11$, $N_F = 5$, $N_M = 7$, $p = 0.29$. For birds with GPS track only, Mann–Whitney: $U = 3.5$, $N_F = 4$, $N_M = 4$, $p = 0.19$). There was no significant correlation between trip duration and weight change (Spearman rank correlation: $r_S = -0.297$, $N = 10$, $p = 0.37$. For

Table I. Body measurements, sexes and trip information of tracked Cory's shearwaters. * = tracks recorded at 4 fixes/s. Trel = releasing time (am). Tcol = time before leaving the colony (min). Tflock = time in the flock at sea (min). Values in parenthesis indicate minimum time because of gaps in GPS recording at arrival or departure from the flock. P = track position respect to the island. Dep = direction of departure from the colony. Wdir = wind direction. MD = maximum recorded distance (km). TMD = total time to reach maximum recorded distance (hours). TGPS = GPS duration (hours). AvSp = average speed (km/h). Wi = initial weight (g). Wf = final weight (g). ΔW = weight difference (g). Days = trip duration.

N°	Sex	Trel	Tcol	Tflock	P	Dep	Wdir	MD	TMD	TGPS	AvSp	Wi	Wf	ΔW	Days
1	M	2:00	144	(83)	SSE	SO		24.2	11.17	11.17	19.90	620	560	−60	4
2	F	2:00	119	70	N	O	SE	66.8	10.00	9.88	15.16	450	450	0	7
3	M	4:35	33	120	SE	NE	SO	30.9	5.00	5.07	7.46	637	600	−37	3
4	M	4:25		(8)	SE		S	35.9	11.00	11.01	26.27	625	600	−25	4
5	F	5:00		(44)	NE	NE	SE	104.7	4.33	4.32	25.90	550	525	−25	5
6	F	5:00	17	23	SSE	SO	SE	25.4	9.45	9.45	5.41	525	500	−25	3
7*	F	4:30	16	93	ESE	ENE	SE	109.6	12.00	11.90	15.92	500	540	40	2
8	F	4:30	60	21	SSE	SO	NO	14.6	1.50	5.02	6.94	500			4
9*	M	5:20	15	2	NE	SO	NO	63.3	6.50	13.35	9.40	600	600	0	1

birds with GPS track only, Spearman rank correlation: $r_S = -0.58$, $N = 8$, $p = 0.56$).

Trapping birds at burrows allowed the frequency of feeding events to be seen. Two types of behaviour were noticed: in about the 50% of burrows ($N = 5$), chicks were fed nearly every day, always at night, and the mean interval between feeds was 1.14 days, with a maximum of 3 days in only one occasion. In the other 50% of burrows ($N = 6$), chicks were fed irregularly, with intervals ranging between 1 and 6 days, and a mean interval of 2.48 days.

Even if tracks were incomplete, all loggers recorded the beginning of the birds' trip. After being released with GPS loggers near their burrows, Cory's shearwaters remained on land for some time (from 15 min to 2 h 24 min) before moving out to sea (mean ± SEM = 47.4 ± 14.9 min, Table I). Once at sea, all the birds stopped in front of the colony, and remained there from 20 min up to 2 h (54.4 ± 13.5 min, Table I) before leaving for the foraging trip. The only exception was one bird that spent only 2 min there, but probably it was due to the late time of release, 5:39 a.m. The locations of the tracked birds were grouped in a limited area of 460 m^2, between 125 and 900 m from the coast, northwest of the colony. All tracked animals left this area for the foraging trip between 3:20 and 7:00 (Figure 2).

The incomplete recorded tracks did not allow us a detailed analysis of foraging trips and precise identification of foraging areas. However, the tracks revealed the existence of two different routes followed by the shearwaters: northeast and southeast of Linosa Island. Only one bird flew eastwards but, because of the distance reached and the fast departure from the colony, it was included in the NE group. The distance from the colony reached by the birds after 9 h (when the batteries were exhausted) differed significantly depending on the direction followed. Shearwaters that flew NE ($N = 4$) were recorded at 86.1 ± 12.2 km from the colony, while those that flew SE ($N = 5$) were only at 26.2 ± 3.6 km (Mann–Whitney: $U = 0$, $p < 0.01$). There was no statistical difference in the trip duration between the birds that followed these two directions (Mann–Whitney: $U = 10$, $p > 0.99$), nor in the longevity of GPS batteries (Mann–Whitney: $U = 8$, $p = 0.62$).

Comparing the difference in weight measures before and after foraging trips showed that after the northwards trips, there was on average no difference in body weight before and after the trip (average weight difference: 3.8 ± 13.4 g. Max 40, Min –25; Table I). On the contrary, from the southward trips, birds showed a decrease in body weight (average weight difference: –31.8 ± 3.9 g. Max –25, Min –40; Table I). This different weight change between birds flying in the two directions is significant (Mann–Whitney: $U = 1.0$, $N_{NE} = 4$, $N_{SE} = 4$, $p < 0.05$). Since the difference in weight between males and females is strong, we repeated the analysis and confirmed the previous result, using the proportional weight decrease (Mann–Whitney: $U = 1.0$, $p < 0.05$).

We obtained two GPS recordings (one male and one female from different burrows) at four fixes per second allowing a detailed analysis of shearwaters' flight. We identified three different patterns in the flight. The first was characterized by a relatively straight flight (SI value higher than 0.8) and high speed (26–38 km/h. Max 48), hereafter referred to as flight. The second pattern characterized by a tortuous path (SI value between 0.2 and 0.6) and very low speed (0–4 km/h), when most likely the birds floated on the sea surface, hereafter referred to as floating (Figure 3a). The third was a mixed

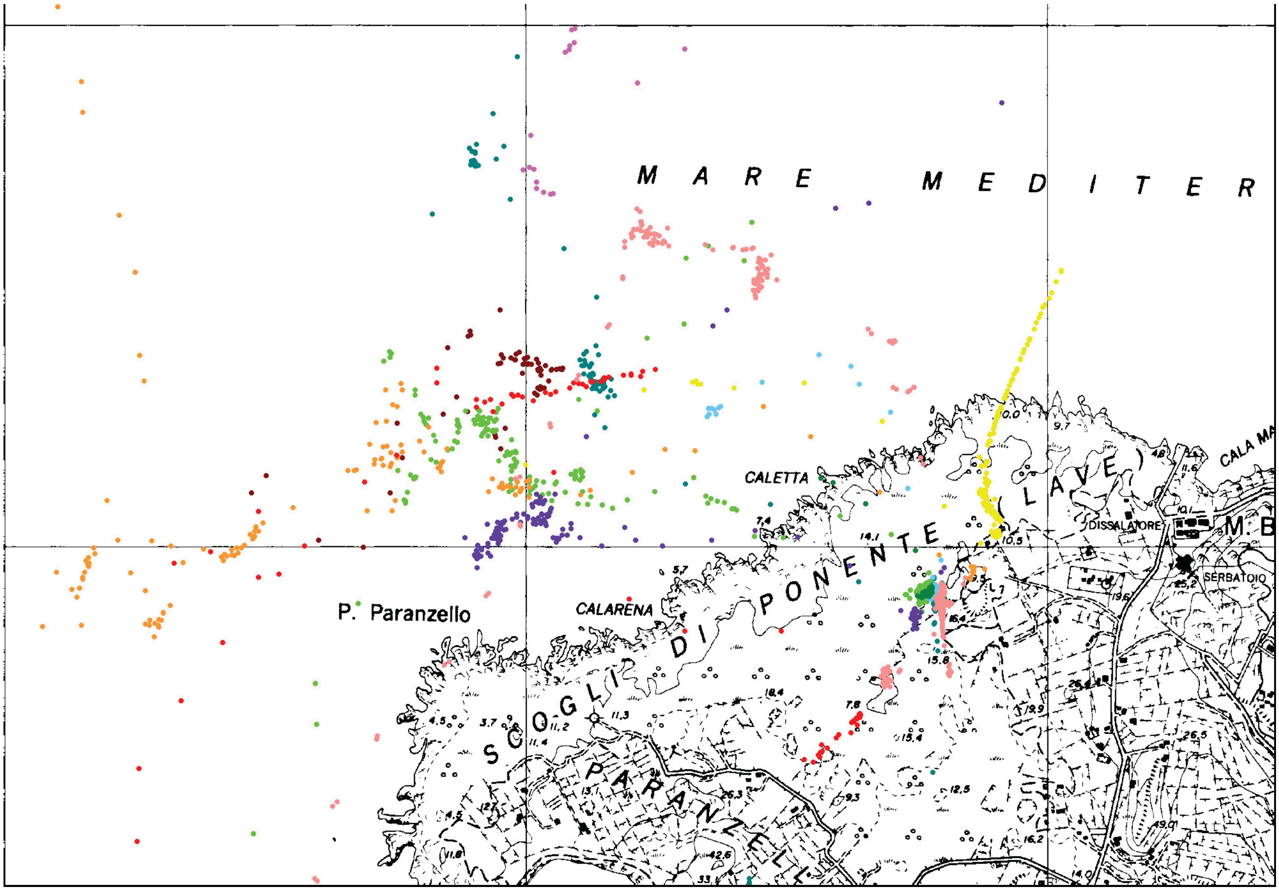

Figure 2. GPS tracks of Cory's shearwaters stopping in front of the colony after release. All the birds stopped in the same circumscribed area from 20 min up to 2 h before leaving for the foraging trips, probably to preen their feathers. Tracks have been recorded during different nights, therefore it is not possible to confirm if the birds stopped in group or not. Grid size, 1 km.

pattern when the bird alternated very often episodes of flight at a moderate speed of about 20 km/h, likely indicative of food searching activity, and floating in a circumscribed area (Figure 3b), hereafter referred to as mixed pattern. In this last case the SI value was between 0.03 and 0.1, indicating that the birds were mostly flying around the same point.

In the part of the trip that we recorded, the two birds behaved differently. The female had longer flights and less sitting, reaching a maximum distance of 109.6 km east–south–east from the colony during the recorded 12 h. The male stopped more frequently alternating shorter flights, flying up to 63.6 km northeast from the colony in about 13 h. If we consider the percentage of time spent in the three activities, the male spent 24.4% in flight, 35.2% floating, and 40.4% in mixed pattern; while the female spent 35.1% of time flying, 20.5% floating, and 44.4% in mixed pattern.

No relationship was detected between wind direction and the directions taken by Cory's shearwaters or the region they flew in search for food; nor there was any with the directions of departure from the colony (Chi-square test: $\chi^2_{12} = 10$, $p = 0.62$) (Table I).

Discussion

This is the first study that made use of GPS loggers to follow the foraging trips of Cory's shearwaters over the Mediterranean Sea.

Our recordings showed that, after leaving the colony, all the birds settled at sea right in front of the colony before departing for their foraging trips. All the tracked birds spent at least 20 min in the same circumscribed area, before leaving at sunrise. Resting at sea is common among seabirds that preen their feathers before flying away on their trips (Bonadonna, personal observation in Gannets with GPS loggers and in Guillemots with route recorders). It would be interesting to investigate whether this is a group behaviour, and whether birds form

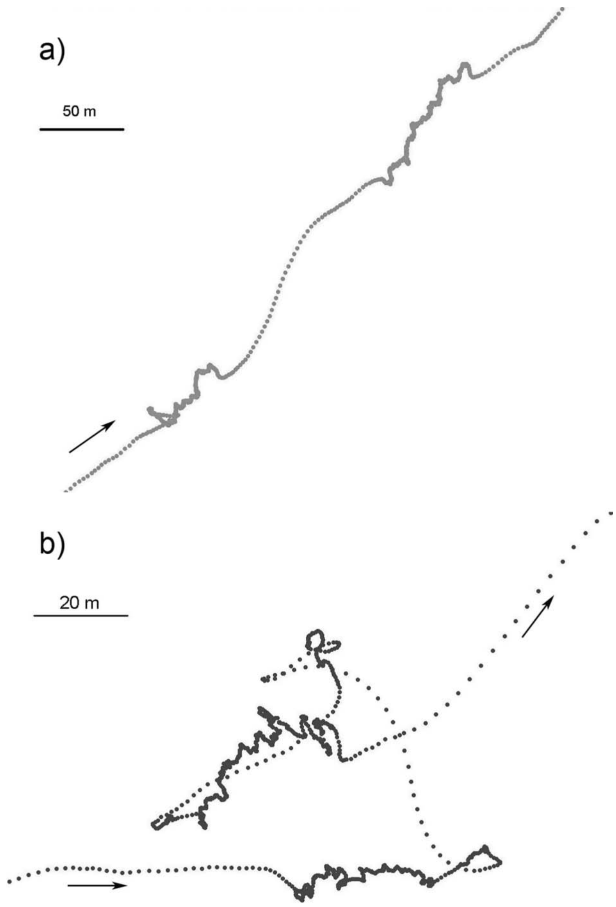

Figure 3. GPS tracks showing a Cory's shearwater (**a**) alternating floating, when fixes appear as a continuous line, and flight, when fixes are more distant due to higher speed. (**b**) Searching behaviour, in which the bird alternated floating and flight around the same small area, as indication of food search.

rafts like they do at sunset, as it seems from the image of fixes (Figure 2), or if it is only seemingly in a group: they stop at the same site in front of the colony, but not at the same moment. This could be verified by putting more than two GPS loggers per night as we did or by observing the flock at sea during the night.

In many Procellariiformes species, such as Blue petrels (*Halobaena caerulea*), during the chick-rearing period, two different kinds of foraging trips have been identified. Blue petrels increase their body weight performing long trips over pelagic waters, and lose their weight performing short foraging trips over coastal waters. Adult birds use short trips to provide food for their chicks, while they need long trips to restore their body condition (Chaurand & Weimerskirch 1994; Weimerskirch et al. 1994). Recently, such behaviour has also been recorded in Cory's shearwaters breeding in the Azores (Magalhães et al. 2008). Our data failed to note such behaviour in the Mediterranean Cory's shearwater; the foraging trips observed had different durations, but without a regular alternation.

We recorded Cory's shearwaters flying mainly in two opposite directions: southeast or northeast with respect to the island. It is interesting to note that in about 9 h of GPS recording birds flying SE remained close to the colony (mean distance 26.2 km). On the contrary, shearwaters flying NE, at the end of similar GPS recording time, were at 86.1 km distant from Linosa. These same birds, 2 or 3 h after the departure, were already 50 km from the island, suggesting a fast move towards areas farther than those reached by birds flying SE.

The small sample size and the incomplete tracks, unfortunately, prevent us from drawing decisive explanations for the use of different foraging areas, but our results do however give the possibility of formulating some hypothesis to be verified in future studies. Various causes could account for the alternative use of the two foraging areas, such as different physical conditions of the birds or different individual experience. We showed that the direction of the wind did not influence the chosen foraging direction, but other meteorological factors could explain the difference. However, it is important to note that we also recorded Cory's shearwaters leaving for foraging trips in the two directions during the same day.

Detailed data on the primary productivity hot-spots and prey availability are missing with a sufficient resolution for the period at issue. A change in the prey distribution could be another explanation for the use of two distinct foraging areas. Again, the fact that we recorded tracks in both directions during the same day is evidence that probably more than a single factor could play a role at the same time.

Another hypothesis to be verified could be that the trips in the different directions have a different relevance for the birds. Comparing the weight changes during the foraging trips revealed that the birds flying SE decreased their body mass during the foraging trip, while those flying NE increased it. As stated before, we did not observe an alternation of long and short trips, but this does not exclude the possibility that Mediterranean Cory's shearwaters use two different foraging areas, one for chick-rearing and another for self-provisioning. Linosa Island is surrounded by coasts at distances varying between 130 and 200 km; these distances are very short with respect to those that this same species or other Procellariiformes have to cover over open oceans to reach foraging grounds. The presence of coasts not very far from the breeding islands has been demonstrated to influence the direction of long trips in oceanic species (Magalhães et al. 2008), so it could be possible that the presence of coasts in all directions has an influence on flying behaviour in a small sea, like the Mediterranean.

It could be interesting to investigate if there are differences in prey caught for self- and chick-nutrition. Different prey could also mean different areas where they can be caught. It is possible that, as in oceanic petrels, adults reduce flying effort, exploiting their reserves by finding enough food for the chicks close to the island. When they need to restore their body condition, they go for more profitable foraging areas that do not require longer trips in terms of duration but only a change in flying direction. The variation in the distribution and abundance of pelagic prey resources around the different breeding sites has been shown to be the cause of the spatial and temporal variability in the foraging strategy of the individual species of Procellariiformes (Baduini & Hyrenbach 2003). Therefore, prey availability and exploitation deserves further investigation.

Our data showed that half of the chicks were fed every night by at least one of the parents, partially confirming the high frequency of food delivery already found for this species in Selvagem Grande, where 79% of chicks were fed every night (Hamer & Hill 1993). At the same time, our findings showed that the other 50% of chicks were fed more irregularly and chicks had to face longer fasting periods, up to six consecutive nights. This finding also corresponds to the data recorded in the Linosa colony in a previous study (Massa & Lo Valvo 1986), and could be another consequence of the different ecological conditions of shearwaters that breed in the Mediterranean Sea that would be worthy of more studies.

Navarro et al. (2008) found that the increase of the wing load caused by an additional weight of the logger on Cory's shearwaters' back resulted in longer foraging trips. This could also be true for our tracked birds and needs more investigations, even if our loggers represented only 2–3% of body weight, while the additional weight used by the other authors was of about 8%.

High-resolution tracks showed that Cory's shearwaters fly differently in different flights. Sometimes they alternated short flights with long resting spells, and at other times they flew for longer distances with less and shorter pauses. This could be linked to different kinds of trips, to sex or simply to individual variation or meteorological conditions. Unfortunately, the small sample prevented a more detailed analysis, but other studies found that these birds travel faster and more directly during long trips than during short ones (Magalhães et al. 2008), making this another interesting topic for future investigation.

In conclusion, the importance of this study lies with the fact that this is the first of its kind to investigate the foraging behaviour of Cory's shearwaters in the Mediterranean Sea. Furthermore, the use of light-weight GPS loggers allowed us to follow this species during foraging trips over open waters. Even if the lack of complete tracks prevented us from obtaining conclusive results, our data contribute to create new hypotheses on the behaviour of this species in the Mediterranean environment and constitute the basis for new studies aimed to elucidate and verify them.

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