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Publisher: Taylor & Francis

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Italian Journal of Zoology

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/tizo20>

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J. G. Cecere^{a b}, C. Catoni^a, I. Maggini^a, S. Imperio^c & G. Gaibani^a

^a Conservation Department of LIPU-BirdLife Italy, Parma, Italy

^b ISPRA - Institute for Environmental Protection and Research, Ozzano dell'Emilia, Italy

^c Ricerca Fauna, Roma, Italy

Version of record first published: 09 Oct 2012.

To cite this article: J. G. Cecere, C. Catoni, I. Maggini, S. Imperio & G. Gaibani (2013): Movement patterns and habitat use during incubation and chick-rearing of Cory's shearwaters (*Calonectris diomedea diomedea*) (Aves: Vertebrata) from Central Mediterranean: influence of seascape and breeding stage, *Italian Journal of Zoology*, 80:1, 82-89

To link to this article: <http://dx.doi.org/10.1080/11250003.2012.710654>

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Movement patterns and habitat use during incubation and chick-rearing of Cory's shearwaters (*Calonectris diomedea diomedea*) (Aves: Vertebrata) from Central Mediterranean: influence of seascape and breeding stage

J. G. CECERE^{1,2*}, C. CATONI¹, I. MAGGINI¹, S. IMPERIO³, & G. GAIBANI¹

¹Conservation Department of LIPU-BirdLife Italy, Parma, Italy, ²ISPRA - Institute for Environmental Protection and Research, Ozzano dell'Emilia, Italy, and ³Ricerca Fauna, Roma, Italy

(Received 23 December 2011; accepted 4 July 2012)

Abstract

We analysed the patterns of movement and habitat use of Cory's shearwaters (*Calonectris diomedea diomedea*) from two colonies in the central Mediterranean Sea: the island of Linosa and the Tremiti Archipelago. The colony of Linosa is placed in a rather pelagic environment, being about 160 km distant from the coasts of both Sicily and Tunisia, while the colony of Tremiti is rather near to the coast of the Adriatic Sea, being only 25 km from the Italian coast. Field work during incubation was carried out at both colonies and throughout chick-rearing only at Linosa. We aimed to test first whether birds from the two colonies differ significantly in habitat use, and secondly whether constraints during incubation and chick-rearing lead birds to explore different habitats. Trip duration was correlated with the farthest distance covered in both colonies and, for Linosa birds, it decreased at the start of chick-rearing but increased later. During incubation the expanse of explored areas did not differ between the colonies, but for Tremiti these were generally characterized by higher average primary production and shallower waters than those for Linosa. Furthermore, during the incubation period Linosa birds explored areas with higher values of primary production and shallower waters than during chick-rearing. Chick-rearing is therefore likely to constrain birds to use sub-optimal areas closer to their colony due to the intense pressures of chick provisioning. Our data indicate that conservation efforts should therefore aim not only to protect the best foraging areas but also to conserve areas closer to the colonies, which will be profitable enough to provide adult birds with sufficient food for chick-rearing.

Keywords: *Calonectris diomedea*, foraging trips, GPS tracking

Introduction

Breeding is generally considered one of the most energy-consuming phase because of the high resource expenditure that it involves (egg production, nest attendance etc) and the constraints that it generates. Pelagic birds are true sea wanderers during most of the year, but during the breeding season are central place foragers that need to return to the colony regularly, to attend their eggs or chicks. Therefore, during the breeding phase, the accessibility of fishing areas is inversely related to the distance from the colony (Orlans & Pearson 1979; [Matthiopoulos 2003](#)), and birds might be constrained to select suboptimal fishing areas closer to the colony over more profitable areas farther away.

This study focuses on the analysis of the patterns of movement and habitat use in a marine colonial bird species, the Cory's Shearwater (*Calonectris diomedea diomedea*), during the periods of incubation and chick-rearing. Cory's shearwaters make self-provisioning trips lasting several days before returning to the nest to incubate (Cramp & Simmons 1997), whereas during chick-rearing they alternate short trips for chick provisioning with longer trips for self-provisioning in what has been called a dual foraging strategy ([Weimerskirch et al. 1994](#); [Magalhaes et al. 2008](#)). This strategy allows birds to balance the constraint of regularly visiting the colony on the one hand with accessing better fishing areas farther from the colony on the other. Food availability is not

*Correspondence: Jacopo G. Cecere, ISPRA - Institute for Environmental Protection and Research, Via Ca' Fornacetta 9, 40064 Ozzano dell'Emilia (BO), Italy. Fax: 0039051/796628. Email: jacopo.cecere@isprambiente.it

distributed evenly, and we might expect that ecomorphological variables of marine habitat such as sea floor depth and primary production might be relevant for determining the profitability of fish resources (Agostini & Bakun 2002). It follows that birds from different colonies will therefore face different sea variables and fish distribution near the colonies, so we might expect them to adopt different strategies during foraging trips.

In this study we compare trip performance and foraging behaviours of Cory's shearwater breeding in two colonies located in very different marine environments. The colony of Linosa is placed in a rather pelagic environment, being about 160 km far from the coasts of both Sicily and Tunisia. The colony of Tremiti, on the other hand, is only 25 km far from the Italian coast in the Adriatic sea which, compared to the strait of Sicily, is quite homogeneous with a rather flat and sandy ground. The main aim of this study was to assess whether trip duration and the characteristics of the areas used by the birds differed between the two colonies under comparison and changed between incubation and chick-rearing. We predict that since chick-rearing requires a more regular nest attendance in order to feed the chick, foraging trips during this period should be shorter and closer to the colony compared to those during incubation. Furthermore, we hypothesize that foraging trips differ between the colonies in both duration and distance covered due to the different seascapes in which the breeding colonies are located.

Although some studies have analysed the movement patterns of breeding Cory's shearwaters (Magalhaes et al. 2008 and Paiva et al. 2010a, 2010d with GPS data; Bartumeus et al. 2010 with PTT data), very few have considered the incubation period (Paiva et al. 2010b, 2010c). Moreover, aside from only one published study which analysed the movements of 13 Cory's shearwaters in the Mediterranean Sea (Dell'Arciccia et al. 2010) and two further studies which used GPS information (Louzao et al. 2009; Bartumeus et al. 2010), the majority of the studies have focused on the subspecies *C. d. borealis* breeding in the Atlantic Ocean (e.g. Paiva et al. 2010d). In the present study, we have concentrated our attention on the Mediterranean subspecies, and have taken into account the whole breeding season. In our study we equipped Cory's shearwaters from two distant colonies in the Mediterranean with light GPS loggers and recorded their movements during trips at different times through the breeding season. We were able to determine the expanse of explored areas, the distance covered and the position of each bird, which allowed us to compare these variables to different environmental features and to investigate whether

there was variation between colonies and different stages of the breeding season.

Materials and methods

The study was carried out during the breeding seasons 2008–2010 in two Italian colonies: the island of Linosa and the Tremiti Archipelago (Figure 1). Linosa, located in the Tunisian Plateau/Gulf of Sidra region (35°51'33" N; 12°51'34"E) between Sicily, Tunisia and Libya, hosts one of the biggest colonies of Cory's Shearwater in the Mediterranean, with an estimated 10,000 breeding pairs (Brichetti & Fracasso 2003). The second colony is located within the Tremiti Archipelago (42°08'19"N; 15°30'52"E), which comprises approximately 400 breeding pairs (Brichetti & Fracasso 2003), one of the biggest breeding colonies of the species in the Adriatic Sea. On Linosa we carried out field work during the incubation (June 2008) and chick-rearing (July–August 2008 and 2009) periods. At the Tremiti Archipelago the fieldwork was carried out on the islet of Capraia only during the incubation period in two seasons (June 2009 and 2010), since the dangerous position of nests located on the cliff did not allow us to work at night when chicks were fed.

GPS logger deployment

During incubation one pair partner is away foraging at sea while the other bird broods the single egg for several days, making it very easy to catch the brooding bird by hand. Birds were weighed and the mini-GPS logger (see below) was attached to the back feathers using 3–4 strips of Tesa® marine cloth tape (Tesa SE, Hamburg, Germany) (Wilson & Wilson 1989; Wilson et al. 1997). Birds were ringed and sexed during handlings by using their sex-specific vocalizations or by sex determination of their partner. We recorded just one nest attended by three adults: in this case we tagged just one individual, whose sex was determined by voice. To verify the presence of the focal bird in the nest without further handling, we coloured part of its breast feathers with a non-toxic and scentless animal crayon, and the same was done for its partner. The coloration faded away naturally within a few days of contact with sea water. Total handling time was kept below 10 minutes and birds were returned to their nests immediately afterwards. We monitored all nests once every day: in broad daylight during incubation and at night during chick-rearing. Once a bird with GPS eventually returned to the nest it was recaptured and the GPS logger removed by peeling away the tape from the feathers. After the single egg has hatched

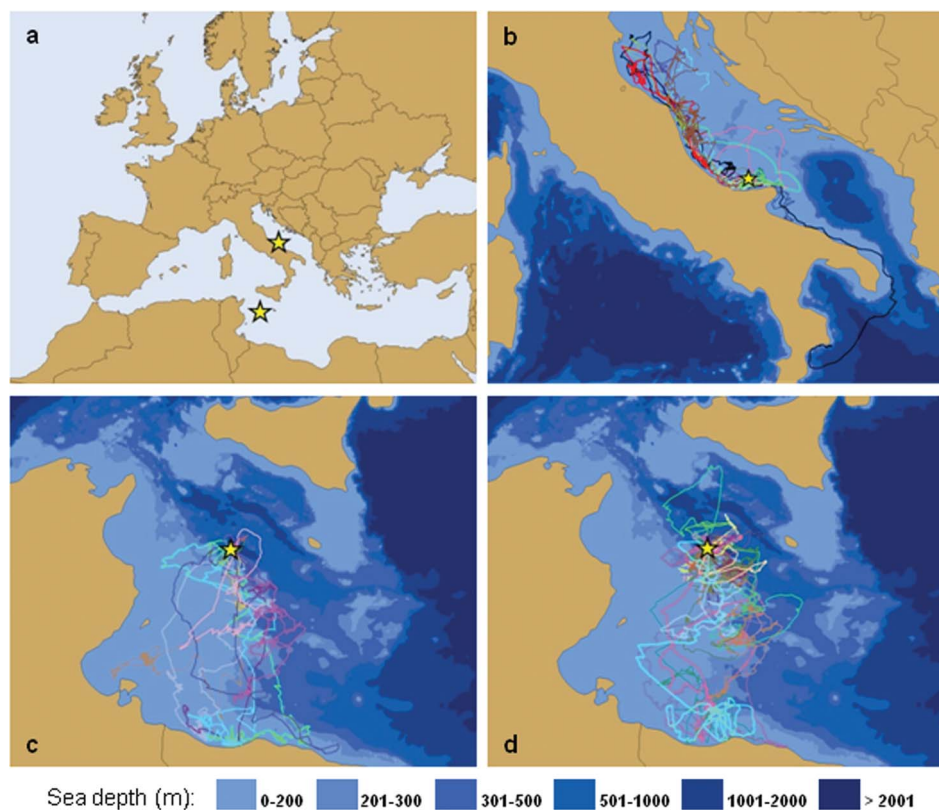


Figure 1. a) position of Tremiti Archipelago (northern star) and Linosa island (southern star); b) 26 individual tracks collected during incubation from birds breeding at Tremiti; c) 14 individual tracks collected during incubation from birds breeding at Linosa, and d) 46 individual tracks collected at the same colony from birds raising a chick. The first sea depth range (0–200 m) represents the neritic domain.

both adults spend the day foraging at sea and leave the chick alone in the nest, returning to the colony only at night. Consequently, during the chick-rearing period adults were caught at night just after they had fed their chick.

We used three types of mini-GPS loggers: one by Earth & Ocean Technologies (Kiel, Germany), weighing 19.4 grams (with a battery of 500 mA), and two different types by Technosmart (Guidonia, Italy), weighing 11.9 and 9.8 grams, with two different batteries (500 and 250 mA respectively). The deployment of lighter GPS loggers allowed us to track lighter birds, despite the shorter life-span of these devices. As recommended by several authors (e.g. Phillips et al. 2003), device weight was always less than 3% of the bird's weight. All GPS loggers were configured to record at the same time both the position and the instantaneous speed of the bird every 10 minutes.

Environmental data

We considered two different variables to characterize marine habitats: sea floor depth and net primary

production. The former has been shown to affect significantly the localization of foraging areas of Cory's shearwaters which generally prefer to feed in neritic habitats and in waters not deeper than 1000 m (Louzao et al. 2009; Bartumeus et al. 2010; Paiva et al. 2010b). Other oceanographic characteristics influencing the feeding behaviour of pelagic birds are chlorophyll-a concentration and sea surface temperature (Wakefield et al. 2009; Paiva et al. 2010b), both of which affect marine phytoplankton productivity. We chose to use the net primary production data (standard VGPM), which are based on monthly MODIS-aqua r2009.1 input data including sea surface temperature, chlorophyll and photosynthetically active radiation values (Behrenfeld & Falkowski 1997). Bathymetry was obtained from the General Bathymetric Chart of the Oceans (GEBCO 08) of the British Oceanographic Data Centre (<http://www.bodc.ac.uk/projects/international/gebco/>) as a 30 arc-second grid (approx. 1 Km). Net primary production data were downloaded by the Ocean Productivity site (<http://www.science.oregonstate.edu/ocean.productivity/index.php>) for a spatial resolution of 10 arc-minutes (approx. 18 km).

Analyses

The area explored by each bird (EA) was computed with the Home Range Tool 1.1 (Rodgers et al. 2007) for ArcGis 9.2 (ESRI®), using the 95% fixed kernel density (Worton 1989). To compare outcomes from different birds we used the same scale to perform fixed kernel analyses by using the same value of smoothing parameter (h) for the calculation of all EAs. To conform with the auto-ecology of Cory's Shearwater, after inspecting several trips (short, medium and long lasting trips) we chose the smoothing factor which computed 95% fixed kernel density which better represented the main EAs while excluding the fast and long directional shiftings ($h = 5000$; cell size = 100) (Figure 2).

We used generalized linear models (GLM) to assess whether sex, date and colony affected trip duration and EA size. Within each EA we calculated the average and the maximum value of primary production and the average sea floor depth. To assess whether birds that explored larger areas reached the most favourable feeding locations, we correlated EA size with the higher value of primary production and the average bathymetry recorded within the EA. Since, some data-set were not Gaussian, we used the Spearman test for all the correlations. The average value of net primary production and average sea floor depth within EAs were compared between trips made by birds from Linosa and Tremiti during incubation, and between birds from Linosa during incubation and chick-rearing periods.

Results

During incubation we tracked 40 birds: 14 from Linosa in 2008 and 26 from Tremiti in 2009 and

2010. During chick-rearing on Linosa we tracked 46 birds: 18 in 2008 and 28 in 2009. We considered only one foraging excursion per bird. All recorded tracks are shown in Figure 1. Both during incubation and chick-rearing birds from Linosa mainly headed south, reaching the Libyan and Tunisian coast. Tremiti birds mainly explored the north-western Adriatic sea, mostly travelling along the Italian coast; a few birds crossed the Adriatic Sea and only one travelled to the south of the colony, after a few days in the northern Adriatic sea.

Incubation

Foraging trips lasted on average 7.53 ± 0.7 days during the incubation period. Table I shows the trip durations and maximum distances travelled by Linosa and Tremiti birds. The duration of foraging trips was correlated to the farthest distance from the breeding site reached during the trip in both colonies (Pearson; Linosa: $r = 0.81$; $p = 0.001$; $n_{ln} = 14$; Tremiti: $r = 0.71$; $p < 0.001$; $n_{tr} = 26$) and was not significantly influenced by date, sex or colony (GLM: $F = 0.95$; $R^2 = 0.63$; date, $p = 0.55$; sex, $p = 0.93$; colony, $p = 0.35$; $n = 37$). The pattern of trip duration during incubation is slightly bimodal for both colonies, and there is a higher tendency of longer trips in Linosa birds (Figure 3a).

The EA size was positively correlated to trip duration (Pearson: $r = 0.64$; $p < 0.001$; $n = 40$) and was not influenced either by date, sex or colony (GLM: $F = 0.93$; $R^2 = 0.62$; date, $p = 0.63$; sex, $p = 0.35$; colony, $p = 0.86$; $n = 37$). EA size did not differ between birds from Tremiti and Linosa (T-test: $t = 0.63$; $p = 0.54$). EA size correlated positively with maximum within-EA primary production in birds

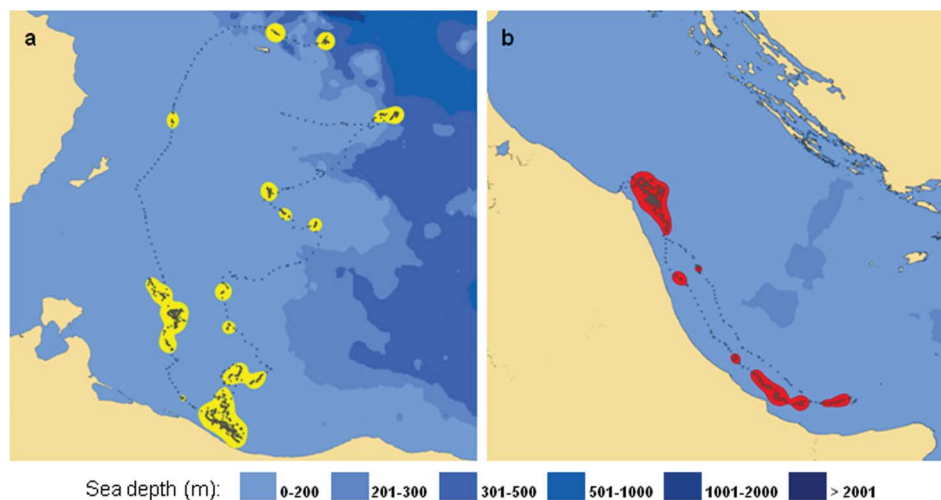


Figure 2. Explored areas of one individual breeding on Linosa island (a) and one from Tremiti Archipelago (b). The area explored by each bird was examined under ArcGis 9.2 using the 95% fixed kernel density.

Table I. Trip information of breeding Cory's shearwaters from the two studied colonies (Linosa and Tremiti). Trip duration refers to the number of consecutive days spent away from the colony, not considering the departure night; Maximum distance refers to the distance between the colony and the farthest localization from the colony attained by tagged individuals. For each tracked bird only one foraging trip was considered.

	Tremiti incubation	Linosa incubation	Linosa chick-rearing
Average trip duration (day)	7.04 ± 0.79	8.43 ± 1.53	3.89 ± 0.6
Minimum trip duration (day)	1	1	1
Maximum trip duration (day)	16	18	17
Maximum distance (km)	424.4	392	368.7
Tracked birds	26	14	46

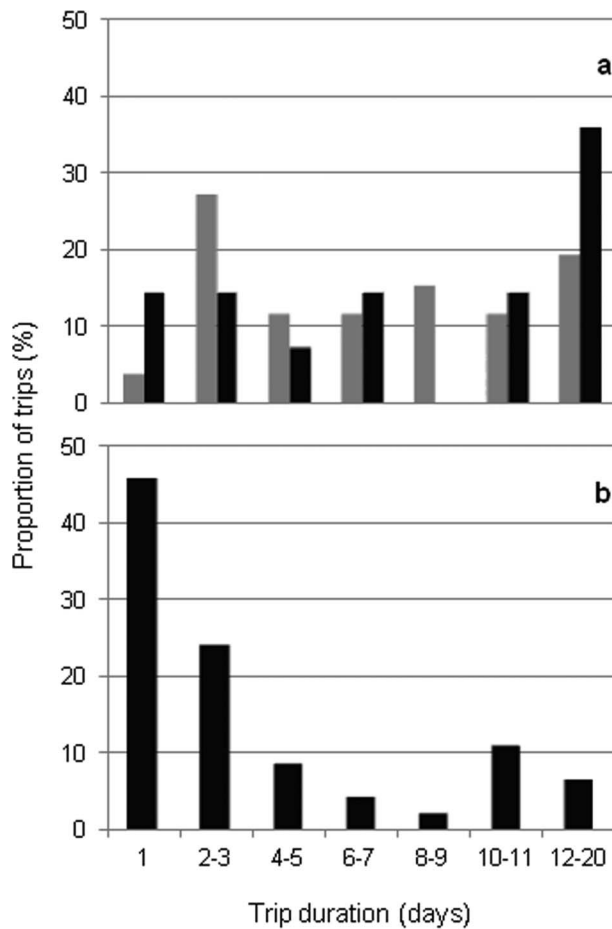


Figure 3. a) Proportion of trips of different durations from birds breeding at Tremiti (grey) and Linosa colony (black) during incubation; b) proportion of trips of different durations from adults raising chicks at Linosa colony.

from Tremiti (Table II). Sea depth within the EAs was not related to EA size in either of the studied colonies (Table II).

The average primary production recorded within the EAs of Tremiti birds was significantly higher than within the EAs of Linosa birds (Mann-Whitney: $U = 6$; $p < 0.001$), while the average sea depth within the EAs of Tremiti birds was significantly lower than

Table II. Results of Spearman correlations between the size of the Explored Area (EA) of each bird and the values of the two considered environmental variables within-EA. Significant results are shown in bold.

	Prim. Prod. Max	Bathymetry
Explored Area size		
Tremiti incubation	$p < 0.001$ $r = -0.66$; $n = 26$	$p = 0.55$ $r = -0.12$; $n = 25$
Linosa Incubation	$p = 0.36$ $r = 0.20$; $n = 14$	$p = 0.34$ $r = 0.23$; $n = 14$
Linosa chick-rearing	$p = 0.23$ $r = -0.19$; $n = 44$	$p < 0.001$ $r = 0.56$; $n = 46$

within the EAs of Linosa birds (T-test: $t = -3.6$; $p = 0.003$) (Figure 4).

Chick-rearing

Trip durations and maximum distances travelled during the chick-rearing period are reported in Table I. As with incubation, the duration of trips positively correlated to the recorded maximum distance (Pearson: $r = 0.83$; $p < 0.001$; $n = 46$). Additionally, trip duration increased significantly with the number of days from hatching (GLM: $F = 4.27$; $df = 21$; $R^2 = 0.61$; date, $p < 0.001$; sex, $p = 0.41$; sampling year, $p = 0.3$). The pattern of trip duration in Linosa birds is slightly bimodal also during chick-rearing period, with a much higher proportion of short trips than during incubation (Figure 3).

The EA size was positively correlated with trip duration (Spearman: $r = 0.79$; $p < 0.001$; $n = 46$) and it was significantly influenced by date (GLM: $F = 3.51$; $df = 21$; $R^2 = 0.76$; date, $p < 0.01$; sex, $p = 0.31$; year, $p = 0.18$). As opposed to the incubation period, sea depth within the EAs was positively related to EA size (the larger the EA, the higher, i.e. less negative, the bathymetry value), while the maximum value of primary production was not (Table II).

Birds from Linosa made shorter trips during the chick-rearing period than during incubation (Mann-Whitney: $U = 162.5$; $p < 0.01$; $n_{inc} = 14$;

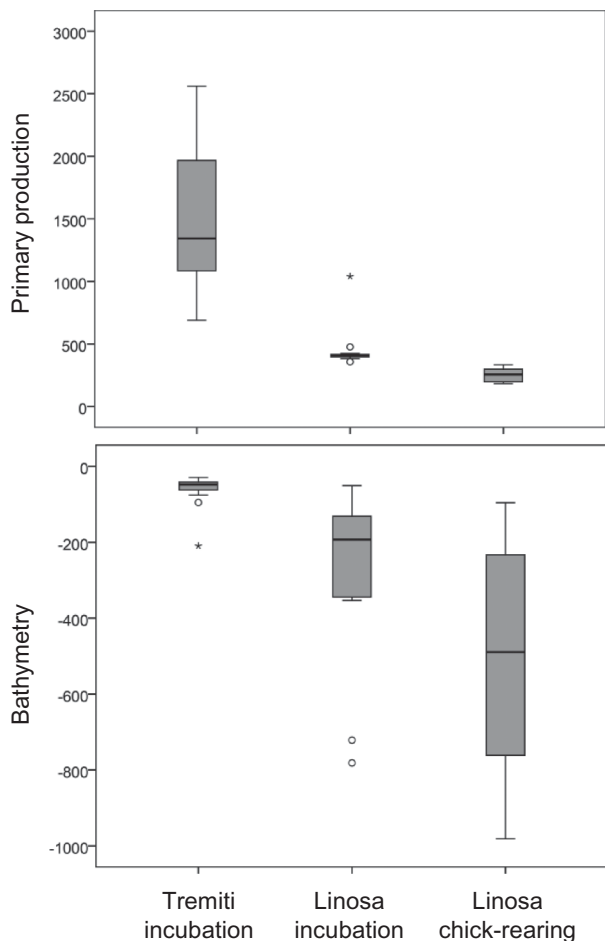


Figure 4. Box-plots (median, interquartile range, cases with values within 3 box lengths, outliers) of average (monthly) primary productivity and bathymetry recorded within Explored Areas (95% fixed kernel density contour) of both Linosa and Tremiti birds during incubation and Linosa birds during chick-rearing.

$n_{\text{chick}} = 46$); as a consequence, EAs are larger during incubation, but the difference is only close to significance (Mann-Whitney: $U = 220$; $p = 0.07$). On average, during incubation, birds reached areas with higher values of primary production (Mann-Whitney: $U < 0.01$; $p < 0.001$) and shallower waters (T-test: $t = 3,13$; $p = 0.004$) (Figure 4).

Discussion

In this study, based on 86 tracked birds, we characterized the movement patterns and EA sizes of Cory's shearwaters breeding in the Mediterranean Sea in two distant colonies, during both the incubation and chick-rearing periods. By linking GPS tracking positions to sea characteristics obtained from remote sensing databases we have been able to show that individual EAs are affected by sea characteristics such as bathymetry and primary

production, although with large differences between the two colonies and breeding phases. The sea features encountered in the EAs differed strongly between birds from the two colonies, not only because the intrinsic differences in seascapes between the Adriatic Sea and the Strait of Sicily, but also because birds from the two colonies actually selected areas with different sea features, indicating a certain degree of plasticity in the habitat use of Cory's shearwaters from different Mediterranean colonies.

Foraging movements

During the incubation period birds spent on average 7.5 days at sea, while their partner remained in the nest brooding the single egg. Trip duration did not differ significantly between colonies, although the proportion of long trips (more than 12 days) was higher in Linosa. Trip duration of Mediterranean birds during incubation was similar to that of birds breeding in the Atlantic Ocean (Paiva et al. 2010c), whereas the maximum distances covered by Atlantic birds were much higher (at least four times) during both the incubation and chick-rearing periods (Paiva et al. 2010c). This is probably due to the geographic characteristics of the central Mediterranean Basin, which is relatively narrowly enclosed between the Italian (with Sicily) and Balkan peninsulas to the north and Africa to the south, with a maximum distance from any coast no farther than 400 km. In such a relatively small area both pelagic and coastal environments are relatively near to the colonies, and thus birds have neither the need, nor the space, to travel long distances to exploit areas having different ecological conditions. Nevertheless, Mediterranean birds spent a similar amount of time in foraging excursions during incubation than Atlantic birds. This occurrence could be due either to a different distribution of prey, more scattered or less abundant in the Mediterranean, and/or to a life history trait of the species.

Foraging trips lasted longer during incubation than during chick-rearing, and in the latter period trip duration was positively correlated to date and thus to chick age (since hatching is largely synchronized within the colony), as demonstrated already for Cory's shearwaters breeding in the Azores (Hamer et al. 1999; Ramos et al. 2003). This is easily explained by the need to feed the young chick regularly and often, and suggests that the position and size of EAs change significantly over the whole breeding period. However, this scenario is complicated by the fact that adults from Linosa alternated short and long trips during chick-rearing. Such a pattern has been already observed in the Atlantic populations

(Magalhaes et al. 2008) and a dual foraging strategy has been proposed, in which birds alternate short trips to obtain food for the chick with long trips used for self-provisioning (Weimerskirck et al. 1994; Stahl & Sagar 2000; Terauds & Gales 2006). We therefore suggest that to thoroughly investigate EAs and ecological needs of a pelagic bird species it is necessary to track birds during the whole breeding season, in order not to miss feeding areas which are relevant during a particular breeding phase.

In general, adults from both Tremiti and Linosa left their colonies with a clear preferential direction, probably heading towards known profitable foraging areas, as this ability has been demonstrated for other seabird species (see Weimerskirck 2007 and references therein). Birds from Tremiti mainly headed north-west, flying along the Italian Adriatic coast. This enabled the adults to quickly reach the coastal area of the northern Adriatic Sea, a region characterized by high values of primary production and a well-known spawning area for small pelagic fish (Azzali et al. 2002), one of the main food resources of Cory's shearwaters (Granadeiro et al. 1998). During short trips birds from Tremiti usually remained near the colony, between the archipelago and the mainland coast west and south of the islands.

Adults from Linosa headed mainly south during both incubation and chick-rearing, with only a few individuals heading north or east. Short trips were made to explore the area between the colony and Lampedusa island, while long trips were made to reach Libyan and Tunisian waters which host one of the largest spawning populations of anchovy (*Engraulis encrasicolus*) in the Mediterranean Sea (Schismenou et al. 2008).

Habitat use

Both during incubation and chick-rearing birds made long trips to exploit larger areas and not just to reach the most distant locations. Birds from the Tremiti Archipelago, for example, explored areas characterized by higher values of primary production by increasing the size of EAs. Compared to Tremiti, birds from Linosa explored areas with much lower primary production, although here too an increase in primary production and a decrease in sea depth with increasing trip length was noted, suggesting that birds were seeking better fishing areas with increasing trip length. This possibly indicates that during chick-rearing birds were forced to fish in sub-optimal areas closer to the colony in order to feed their chick often enough. This conjecture is also strengthened by the fact that, during the chick-rearing period, birds with larger EAs (corresponding to longer trips,

presumably for self-provisioning) managed to reach shallower waters in areas close to those used during incubation. On the whole these data suggest a certain plasticity within Cory's shearwaters regarding bathymetry and primary production of areas exploited for fishing (see also Paiva et al. 2010b), which could also imply differences in the food resource exploited both between the two colonies and within the same colony during the incubation and chick-rearing periods.

Conservation remarks

The results obtained in the present study highlight the importance of such long studies for effective conservation programs. Despite areas close to breeding colonies should be sub-optimal in terms of resources, they are necessary during the period of chick-rearing while the areas exploited during long trips are fundamental for the maintenance of adult body condition. Leaving either of these two areas out of conservation programs would drastically reduce the effectiveness of protection actions. It is essential to remark that seabirds are wide ranging, often crossing jurisdictional boundaries during foraging: birds from Linosa visited Tunisian and Libyan waters both during incubation and chick-rearing. In this context, an approach based on the protection of specific areas (e.g. Marine Protect Areas or Special Protect Areas designated under the European Union Directive on the Conservation of Wild Birds) should be necessarily accompanied by a sustainable transcontinental governance of fish activity and marine resource management.

Acknowledgements

We are extremely grateful to Bruno Massa and Pierandrea Brichetti who introduced us respectively to Linosa island and the Tremiti Archipelago. We thank Pedro Geraldes and all volunteers for their help during the fieldwork, and Nigel Richards who provided helpful comments on an earlier draft of this manuscript. Studies carried out on Linosa in 2008 were funded by the Italian Ministry of the Environment and those carried out on Linosa in 2009 and on the Tremiti islands were funded by LIPU UK, and for this we are particularly grateful to all British donors and to David Lingard.

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