

Preliminary results on the foraging ecology of Balearic shearwaters (*Puffinus mauretanicus*) from bird-borne data loggers*

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SUMMARY: A data logger devised and manufactured by our research team in order to study the homing routes of carrier pigeons was subsequently modified to study the homing behaviour and foraging strategies of breeding marine birds. Recent versions of the data logger, equipped with a flight sensor and depth meter or saltwater switch, were used in a study of the foraging strategies of chick-rearing Balearic shearwaters (*Puffinus mauretanicus*) in the framework of the project LIFE-Puffinus financed by the Balearic Government and the EU. Due to low recapture rates (only 3 out of 6 tagged birds were recovered), only preliminary data from a small sample are available. Data loggers have recorded data on the pattern of nest attendance (including departure time to foraging trips and return time) and the diurnal pattern of flight and dive activity (including depth and duration of dives). Despite the small sample size, the results show that our data loggers can successfully be applied to the study of the breeding biology and foraging ecology—including the diving pattern—of Balearic shearwaters and similar species.

Key words: foraging, diving behaviour, breeding biology, Balearic shearwater, *Puffinus mauretanicus*, data logger.

RESUMEN: RESULTADOS PRELIMINARES SOBRE LA ECOLOGÍA TRÓFICA DE LA PARDELA BALEAR *PUFFINUS MAURETANICUS* A PARTIR DE AVES MARCADAS CON DATA-LOGGERS. — Un dispositivo electrónico diseñado y producido por nuestro equipo de investigación con la finalidad de estudiar las rutas de vuelo de palomas mensajeras ha sido adaptado al uso en investigación de la conducta de nidificación y estrategias de alimentación en aves marinas. Versiones mejoradas del aparato, equipado con un sensor de vuelo, y un profundímetro (o bien un sensor de agua marina) se han utilizado para el estudio de las estrategias de alimentación de individuos reproductores de la pardela balear (*Puffinus mauretanicus*), en el marco del proyecto LIFE-Puffinus financiado por el Govern de les Illes Balears y la UE. Disponemos únicamente de datos preliminares, debido al pequeño tamaño de la muestra, ya que sólo se recuperaron tres de los seis aparatos colocados sobre las aves. Los data-loggers han proporcionado información sobre el modelo de permanencia en el nido (incluyendo los horarios de salidas y entradas), la distribución diaria de las actividades de vuelo y buceo, así como la profundidad y duración de las zambullidas. A pesar del pequeño tamaño de la muestra, nuestros resultados sugieren que este tipo de data loggers puede utilizarse en estudios de conducta de nidificación y alimentación de aves de la talla de la pardela balear, incluyendo el estudio del modelo de buceo.

Palabras clave: forrajeo, comportamiento de buceo, biología reproductora, pardela balear, *Puffinus mauretanicus*, data logger.

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INTRODUCTION

Some years ago, our research group devised a data logger which, when positioned on the back of a pigeon, can detect and memorise the direction in which the bird is heading during a homing flight (Papi *et al.*, 1991; Dall'Antonia *et al.*, 1993, 1999; Bonadonna *et al.*, 1997, 2000; Holland *et al.*, 2000). Subsequently, our investigation on carrier pigeons was extended to the homing ability and foraging patterns of marine birds. The instrument was therefore modified in agreement with the new requirements, and new sensors were added (see Dall'Antonia *et al.*, 1995; Benvenuti *et al.*, 2001; Falk *et al.*, 2000; Baccetti *et al.*, 2000).

Recent versions of the device, devoid of the compass and equipped with flight sensors and depth meters (or a water switch), were used to investigate the foraging behaviour of breeding Balearic shearwaters. Mediterranean shearwaters are still considered as a subspecies of the Manx Shearwater (*Puffinus puffinus puffinus*) in most handbooks (Cramp and Simmons, 1977; Glutz and Bauer, 1987; Howard and Moore, 1991). However, the two Mediterranean taxa (*P. p. mauretanicus* and *P. p. yekouan*) have recently been described as two different species (see Heidrich *et al.*, 2000; Mayol-Serra *et al.*, 2000, for references). The Balearic Shearwater (*P. mauretanicus*) is the rarest bird species among the Mediterranean endemic taxa. Three thousand pairs, most of which breed on the island of Formentera, were estimated by Aguilar (1991).

The present paper reports preliminary results on the foraging pattern and diving behaviour of chick-rearing Balearic shearwaters, captured at two breeding sites in Mallorca (Balearic Islands). The objective of our study was to check whether our devices can provide reliable data on 1) duration and timing of foraging trips, 2) distance of foraging sites from the colony and 3) number and duration of dives during the foraging activity.

METHODS

The instruments

The instruments used in our tests are modified versions of the logger designed by researchers at the Istituto di Elaborazione dell'Informazione, C.N.R., Pisa, Italy (Dall'Antonia *et al.*, 1993), and used in tests on the homing strategies of pigeons and of

Cory's shearwaters (*Calonectris diomedea*) (Papi *et al.*, 1991; Dall'Antonia *et al.*, 1995, 1999; Bonadonna *et al.*, 1997, 2000; Holland *et al.*, 2000) and on the foraging strategies of marine birds (Benvenuti *et al.*, 1998, 2001, 2002; Baccetti *et al.*, 2000; Dall'Antonia *et al.*, 2000, 2001; Falk *et al.*, 2000, 2001, 2002; Garthe *et al.*, 2000).

Two types of instruments were used. Two birds were fitted with devices equipped with a depth-meter (operating range 0-76 m, resolution 0.3 m) and a flight sensor (a small modified microphone which allowed us to distinguish on graphs between flight activity (continuous high level signals) and surface swimming (low-intensity signals with irregular spikes). The signals from the flight sensors carried by shearwaters are, however, disturbed by a 'noise' related to the fact that these birds alternate wing beating with brief gliding. The analysis of flight activity is therefore less precise than in species which fly by continuous wing beating. The time between successive recordings, which can be pre-selected by the experimenter, was 4 s for the depth meter and 6 s for the flight sensor. This schedule allows continuous recording for 3.5 days. The external width of the streamlined container was 22-33 mm, the height 13-18.5 mm and the total length 80 mm (weight 28 g). Four birds were equipped with a smaller type of data logger, in which the depth meter had been replaced by two short electric wires (water switches) which allowed the underwater activity to be recorded as the number and duration of dives in a temporal sequence. The external width of the streamlined container was 22-26 mm, the height 13-18.5 mm and the total length 62 mm. The instruments weighed 18.5 g.

The birds

The present breeding distribution and population size of the Balearic Shearwater are reported in Mayol-Serra *et al.* (2000). The six birds used for our experiments (all raising a young chick) were captured between 14 and 24 May 1999 at two different colony sites: a large cave on the south-western coast of Mallorca Island, and a cave on an islet near the bay of Palma. Soon after capture, the birds were weighed, equipped with a data logger and released. Four instruments were attached to the back of the birds, following the procedures reported in Benvenuti *et al.* (1998); two instruments were attached to two tufts of back feathers simply using two stripes of waterproof tape.

Data analysis

Data from the recorders were downloaded in the field to a portable computer, and analysed later on in the lab by a specially designed software package (A. Ribolini unpublished). As we noted the time at which each instrument was set to record, an accurate measurement of the diurnal timing of all meaningful events was possible. Data from flight sensors have allowed us to reconstruct the foraging trips as an alternating series of flights and stops of known duration. During the stops, diving activity was computed as number of dives, and for the bird equipped with the depth meter, the dive depth and duration. In order to compensate for small variations of the 0-line reported by the depth sensor, we excluded all dives shallower than 1 m when analysing dive depth.

RESULTS

Nest attendance

Three birds were not recaptured; hence, only data from three devices recovered were available (two devices equipped with a flight sensor and water switch and one device equipped with a flight sensor and depth meter). The three birds exhibited quite a different behaviour. After manipulation, bird 1 left the breeding cave at 03:50 (15 May) and remained out at the sea for at least three days. Bird 2 left the cave at 04:46 (17 May) and remained out at sea for almost two days; it returned to the nest at 22:08 (18 May) and left again at 04:41. Bird 3 spent the subsequent day in the nest, then left at 02:11 (18 May) and remained at sea for two days at least.

Diving activity

Departures from the nest to foraging trips occurred before sunrise (02:11–04:46). Diving activity started between 05:20 and 07:59 and the last dive occurred between 19:03 and 20:39, on different days and in different birds. Figure 1, which reports the distribution of the dives during the day, shows that the birds were active from sunrise to about sunset (pooled data: 165 dives performed by the bird equipped with the depth meter and 334 dives performed by the two birds equipped with the water switch). Diving activity peaked in the morning, in the early afternoon and before sunset.

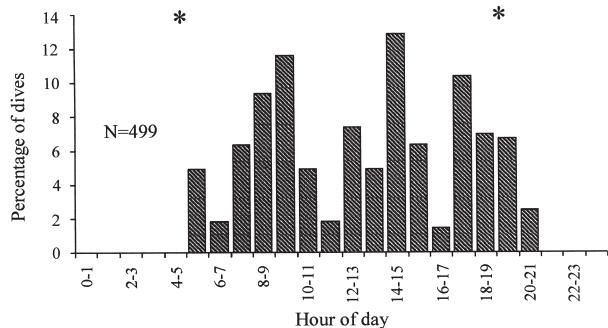


FIG. 1. – The pattern of diving activity is shown as percentages of dives performed during the various 1-hour intervals. Asterisks indicate sunrise and sunset times. Further explanations in text.

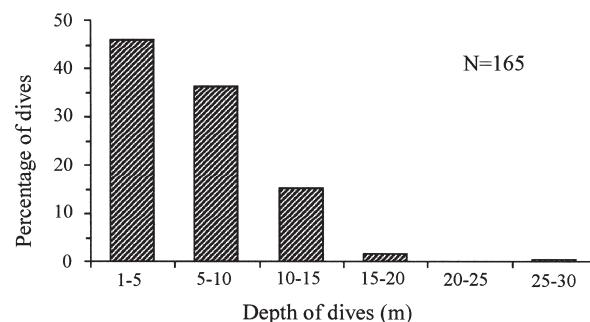


FIG. 2. – Depth preference of the bird equipped with a depth meter is reported. Bars indicate the percentage of dives performed within the various depth intervals.

Data on dive depth, which are available from one bird only (165 dives) are shown in Figure 2. The great majority of the dives were within a depth of 10 m (mean depth: $5.6 \text{ m} \pm 4.1 \text{ SD}$; median depth: 5.0 m). Occasionally, the bird carried out deeper dives up to the depth of 26 m.

Data on the duration of dives are reported in Figure 3. Mean duration of the dives was $17.6 \pm 11.4 \text{ s}$ (median duration = 16.0 s); the maximum recorded duration was 66 s (depth: 26 m). Dives were accomplished in short bouts followed by flight activity or

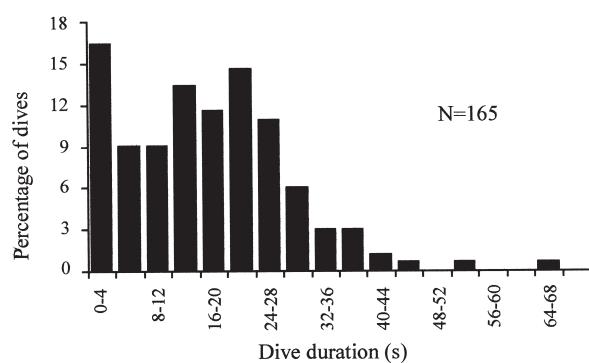


FIG. 3. – The duration of the 165 dives performed by the bird equipped with a depth meter is reported. Bars indicate the percentage of dives performed within the various 4-sec. intervals.

periods of rest on the sea surface. The great majority of the dives were V-shaped, with a non-stop up and down movement at a mean vertical velocity of about 1m/s.

Flight activity

All devices were equipped with flight sensors which detect the duration of each single flight performed by the tagged birds. In the case of Balearic shearwaters, however, the signals from the flight sensors were disturbed by the fact that these birds alternate wing beating with brief gliding. Analysis of flight activity is therefore less precise than in the bird species in which flights are performed by continuous wing beating with highly predictable wing frequency and air speed (see Pennycuick, 1990). From our data, it turns out that the birds were flying for 6.8 ± 2.3 hours each day (mean value from pooled data recorded for the three birds).

DISCUSSION

Response of the birds to experimental manipulation

The use of bird-borne devices requires an evaluation of possible negative bird reactions and consequent disturbance of marked bird behaviour (Wilson *et al.*, 1986; Wanless *et al.*, 1988; Calvo and Furness, 1992). Severe experimental manipulations may alter the normal sequence of events related to nest attendance and foraging behaviour. In addition, we have to consider the effects of increased wing loading and drag during both swimming and flight. Actually, we cannot rule out the possibility that the devices had an effect on the behaviour of the marked birds. However, the following facts make us confident that the data reported by our instruments are not drastically different from natural behaviour: 1) the weight of our devices was about 4-5% of the birds' body mass, a percentage which should not significantly alter their behaviour (see references in Benvenuti, 1993; Benvenuti *et al.*, 2001); 2) the foraging behaviour of the birds with the heaviest type of logger (equipped with a depth meter) was similar to that of the two birds tagged with a lighter type (equipped with a water switch); 3) the weight of the devices, with respect to the birds' body mass was similar to that in other successful studies of marine bird foraging ecology (Croll *et al.*, 1992; Benvenuti *et al.*, 1998, 2001); and 4) the low recapture rate of

tagged birds (50%) was plausibly not due to nest abandoning after the experimental manipulation, but to raw sea conditions, which prevented us from performing routine recapture attempts.

Frequency and duration of foraging trips

Only one complete foraging trip was accomplished during the time the birds were carrying the devices; this trip lasted 2 days. The other two birds had been out at sea for two and three days, when the devices stopped recording data. Due to the small sample size it is not possible to establish the actual duration of foraging trips and to ascertain whether these seabirds use the strategy of performing alternating series of short (one-two day trips) and long trips, as reported for some species of chick-rearing pelagic seabirds (Weimerskirch *et al.*, 1994).

Diving activity

Shearwaters of the genus *Puffinus* mostly forage by surface seizing, pursuit plunging and pursuit diving, which involves underwater 'flying' movements. Progression underwater is efficient; when they are travelling fast, the wings—only about half extended—provide the main thrust (Warham, 1990). Dives are usually not very deep, with much prey captured within the top 2-3 m. Deeper dives (10-30 m) have however been reported for the short-tailed shearwater *Puffinus tenuirostris* (Bester and Klomp, 1997; Weimerskirch and Cherel, 1998), the flesh-footed shearwater *P. carneipes* (13 m) (Oka, 1994) and the sooty shearwater *P. griseus* (67 m) (Weimerskirch and Sagar, 1996). As for the Balearic shearwater, detailed information on the diving behaviour is not available, apart from simple observations on the time spent underwater by foraging birds (Rebassa *et al.*, 1998). Our data show that the Balearic shearwater can perform 26 m deep dives lasting over 60 s, which is much longer than the duration (ca. 30 s) reported by Rebassa *et al.* (1998). It is worth noting that our dive data refer to a single bird, so it is not possible to establish whether the foraging behaviour of our experimental bird is representative of the whole population.

The foraging activity of tagged birds started at sunrise and shortly after sunset. No nocturnal dives were recorded. However, we cannot exclude the possibility that nocturnal dives were performed in full moon conditions (we worked under poor moonlight conditions).

Flight activity

As reported in the results, the analysis of flight activity in Balearic shearwaters is less precise than in the bird species in which flights are performed by continuous wing beating with constant beat frequency. From our data it turns out that the foraging birds flew for about 7 hrs each day. This flight duration actually enables the birds to reach the waters of mainland Spain, which have been reported as important feeding areas (Gutiérrez and Figuerola, 1995).

CONCLUSIONS

Despite a small sample size, our results show that our devices can be profitably used in investigations of the foraging ecology of breeding Balearic shearwaters and other species of similar size. The use of compass loggers (see Benvenuti *et al.*, 1998, 2001, Dall'Antonia *et al.* 2001, Falk *et al.* 2001) in future tests, in addition to the types of device used in the present study, can provide information on the actual location of feeding areas. Because the duration of the trips may be up to three or more days, it will be necessary to extend the life span of the devices by using longer sampling intervals in future studies. The results of future studies can also be optimised by using less stressful procedures for capturing the birds (infra-red lamps instead of common torches), quicker experimental manipulations (e.g. attachment of the devices to the birds' back) and a very limited number of pre-test visits to the breeding colony.

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