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## Short-term effects of data-loggers on Cory's shearwater (*Calonectris diomedea*)

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**Abstract** We investigated the possible effects of a 12-g data-logger attached to a darvic ring on the performance of Cory's shearwater (*Calonectris diomedea*, 600–850 g) from two different colonies in the western Mediterranean Sea. We compared return rates, current breeding success and body condition between equipped and unequipped birds. Effects on feeding ecology during winter and breeding period was also evaluated through the measurement of stable isotopes of carbon ( $\delta^{13}\text{C}$ ) and nitrogen ( $\delta^{15}\text{N}$ ) in one of the colonies. We found no evidence of negative effects of loggers on demographic parameters analysed or in feeding ecology. Power analyses suggested a high power to detect medium effect size, but a low power to detect small changes. Despite the non-significant results we could only exclude medium to

strong effects of the devices on one of these parameters. We detected some short-term negative effects on body condition for the equipped birds, but these were unlikely to have had important consequences. Results suggest that the use of loggers is an adequate methodology to obtain information from seabirds at sea, but data should be carefully interpreted with regard to potential biases during severe environmental conditions.

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### Introduction

Studies of dispersal and feeding ecology of seabirds have recently benefited from technical advances in tracking equipment and data loggers such as geolocators (Global Locators Service sensors). These devices, placed on the back, the tail or the leg of the bird, are used to automatically record location and activity or to monitor environmental variables such as water temperature, salinity and sea currents (Wilson et al. 1995, 1997, 2002; Tuck et al. 1999; Garthe et al. 1999; González-Solis et al. 2000; Hamer et al. 2001; Hedd et al. 2001). Their use has undoubtedly provided important information on bird migration and activity, but has also been questioned, as individual behaviour might be significantly affected by the extra weight of the device. For example, Wanless et al. (1988a, 1988b) found that common guillemots (*Uria aalge*) and razorbills (*Alca torda*) equipped with radio-transmitters prolonged their foraging trips and reduced the amount of food delivered to chicks due to the extra weight carried. Hedin and Caccamise (1982) showed that these negative effects were present even if the extra weight was only a small percentage of the bird's body mass (see also Caccamise and Hedin 1985). The device size and shape may also affect flight, swimming and diving efficiencies (Sedinger et al. 1990; Gessaman et al. 1991; Wilson and Culik 1992; Bannasch et al. 1994; Bakken et al. 1996; Hull 1997; Taylor et al. 2001; Phillips et al.

2003). If data loggers or tracking equipment affect individual performances, equipped birds are clearly not representative of the group under investigation. Despite these problems, most authors do not adequately assess the impact of devices on equipped birds (but see Calvo and Furness 1992; Murray and Fuller 2000).

As a part of a long-term monitoring program on Cory's shearwater (*Calonectris diomedea*), the present study investigated the effect of geolocators positioned on the leg of birds. A geocator is an electronic device that stores information on light levels. Once recovered, it allows analysis of a bird's movements with about 180 km accuracy, as each location has a unique combination of time of sunrise and photoperiod length (Hill 1994; Ekstrom 2004; Phillips et al. 2004; Afanasyev 2004). When, geolocators are placed on the leg, their mass may displace the gravity centre of the bird. Moreover, although shearwaters use mainly wing for propulsion underwater (Warham 1990), attachment, on darvic rings, of devices such as the one we used may affect the hydrodynamic profile and prey capture efficiency while diving. To investigate possible effects of geolocators on bird performance, we compared return rate, breeding success, body condition and feeding ecology between equipped and unequipped birds. Our analysis, conditional on the retrieval of the device, e.g. the return and the capture of previously equipped birds, is the first study that simultaneously investigated the effect of equipment on bird feeding ecology and fitness components in different breeding locations and under different ecological conditions.

## Materials and methods

### Study area and field procedure

Data were collected during 2001, 2002 and 2003 in two Mediterranean colonies, Pantaleu and Congreso Islands. Pantaleu is a small protected island at the Balearic archipelago 200 m off the SW coast of Mallorca (39°34'N; 2°20'E). The Congreso colony is ca. 700 km further south, and it is part of the Chafarinas archipelago, 4.5 km off the Moroccan Mediterranean coast (35°11'N; 3°46'E). The total breeding numbers in these colonies have been estimated at ca. 200 pairs and a minimum of 800–1000 pairs, respectively (Iguar and Gómez 2000; Genovart 2001). In 2000 in Congreso, 72 breeding shearwaters were measured and ringed with metal bands during the incubation period. Geolocators were deployed on 20 individuals, and 52 were selected as controls. In Pantaleu colony during 2002, 135 breeding individuals were monitored, and geolocators were deployed on 20 shearwaters. We used a geocator embedded in transparent resin, measuring 11×18×22 mm. The device was mounted on a darvic band and placed on the bird's legs; this represents about 12 g of extra weight, which is 1.5–2% of the weight of a Cory's shearwater (range 600–850 g). Breeding success was

recorded (2000 in Congreso and 2002 in Pantaleu) in two groups: (1) nests where adults were manipulated only for ringing (Congreso  $N=20$ ; Pantaleu  $N=89$ ) and (2) nests where at least one member of the pair was equipped with a geocator (Congreso  $N=18$ ; Pantaleu  $N=15$ ). During the following breeding season (2001 in Congreso, 2003 in Pantaleu) burrows were monitored until all breeders were identified. Adults that returned were recaptured during the incubation period. From these individuals, body measurements were taken and geolocators retrieved. Feeding ecology of adults from Congreso was studied by the analysis of stable isotopes (see below) from feathers and blood samples. For this purpose, during 2001, we collected: (1) the first primary feather, grown after the deployment of geolocators (Monteiro and Furness 1996), that is during summer 2000, and reflecting feeding habits in the breeding area, and (2) the eighth secondary feather, moulted during the wintering period after summer 2000 and reflecting dietary intakes in the wintering areas. The analysis of blood samples helped identify breeding dietary habits 1 year after individuals were equipped (2001).

### Stable isotope analyses

Stable isotope ratios of nitrogen ( $\delta^{15}\text{N}$ ) and carbon ( $\delta^{13}\text{C}$ ) in consumer tissues reflect those in their prey in a predictable manner (DeNiro and Epstein 1978, 1981). In marine ecosystems the measurement of stable isotope ratios in consumers can provide trophic ( $\delta^{15}\text{N}$ ) and in-shore versus offshore foraging information ( $\delta^{13}\text{C}$ ) (Michener and Schell 1994; reviewed by Forero and Hobson 2003). Stable isotope signatures of whole blood represent dietary information integrated over a period of about a month (Hobson and Clark 1992; Hobson 1993). In contrast, grown feathers, being metabolically inert structures, give dietary information corresponding to the time of their growth (Hobson and Clark 1992). We used analyses of the two tissue types to investigate possible changes in diet during current breeding (i.e. through blood analysis and feathers grown after equipment was placed) and during the previous winter (i.e. feather analysis). Stable carbon and nitrogen isotope assays were performed on 1 mg sub-samples of homogenised blood or feather vane material and measured by continuous-flow isotope-ratio mass spectrometry (CFIRMS) using an Europa 20:20 mass spectrometer. All isotope abundances are expressed in  $\delta$ -notation as parts per thousand (‰) deviation from atmospheric AIR ( $\delta^{15}\text{N}$ ) or VPBD ( $\delta^{13}\text{C}$ ) standards. The analytical precision ( $\pm$ SD) of these measurements is estimated to be  $\pm 0.1\%$  and  $\pm 0.3\%$  for carbon and nitrogen, respectively.

### Statistical analyses

Return rate and breeding success of equipped and unequipped birds were compared using a  $\chi^2$ -test. Effects on

body condition of individuals the year of recapture were investigated by combining the five different measures in a body size index in a principal component analysis (PCA). We subsequently used an ANCOVA model with body weight as the dependent variable, body size index (PC1) as covariate and the following fixed factors: colony, sex, presence of geolocator, and their interaction. Two-way ANOVAs were used to test potential effects of geolocators on feeding ecology of individuals from Congreso, including sex and equipment with geolocator as fixed effects and stable isotope values of blood and feathers as dependent variables.

Given the relatively small number of equipped birds, we were interested in the power of the tests and calculated the power to detect an effect on return rates, breeding success and isotope values. Tests on the difference in return rate or breeding success were considered one-tailed as the effect was expected to be negative. In contrast, in the case of isotope values, no directional change was expected, and the tests were considered as two-tailed. For both types of tests we calculated the power to detect small to medium effects. Moreover, we calculated a joint power for the four tests on the effect on demographic parameters (return rate and breeding success in the two colonies). In this way we combined the power of multiple tests. The joint power indicates the probability that at least one out of the four contingency tables would show a significant result under the hypothesis that the device had a negative effect on survival and/or breeding output. The joint power,  $P_{\text{joint}}$ , was derived by first calculating the power,  $P_i$ , for each table separately after  $\alpha$  was corrected for multiple tests. Assuming the tests were independent,  $P_{\text{joint}}$  can be calculated from:  $1 - P_{\text{joint}} = \prod(1 - P_i)$ . Following Jennions and Møller (2003), we estimated the power for each test according to the effect size,  $w$ , a standardised measure of the magnitude of the effect assumed. We considered values of  $w$  of 0.1, 0.3 and 0.5 as small, medium and large effect sizes, respectively. Power curves were traces using the software G-Power (Erdfelder et al. 1996), and were double checked with the appropriate functions in MATLAB 6 (The Math Works).

## Results

Recapture rates were 61.8% (47 recaptured out of the 72 marked) and 76.3% (103 out of 135) in Congreso and Pantaleu, respectively. Return rates were slightly higher for control than for equipped birds, although differences were not significant (Congreso: non-equipped birds = 67.3%,  $N=52$  vs. equipped birds = 60.0%,  $N=20$ ,  $\chi_1^2=0.34$ ;  $P=0.56$ ; Pantaleu: 78.3%,  $N=115$  vs. 65.0%,  $N=20$ ,  $\chi_1^2=1.66$ ;  $P=0.20$ ). This difference was also true within each sex (Table 1), with the trend more pronounced in females from Pantaleu. Probability of breeding successfully in the year that birds were equipped with geolocators (2000 in Congreso and 2001 in Pantaleu) was higher, but not significantly different in

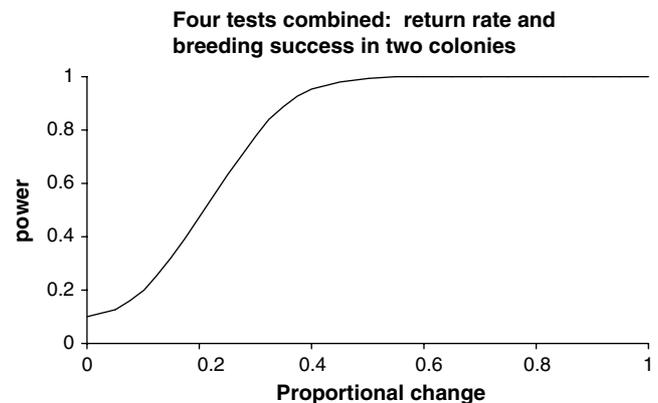
**Table 1** *Calonectris diomedea*. Return rates of males and females of control and carrier individuals (with geolocator)

Site	Individual	Males		Females		$\chi_3^2$	$P$
		Percent	$N$	Percent	$N$		
Congreso	Control	66%	27	68%	25	0.95	0.81
	Carrier	60%	10	60%	10		
Pantaleu	Control	81%	52	76%	63	0.42	0.93
	Carrier	73%	11	56%	9		

nests of unequipped birds than in nests where at least one member of the pair carried a geolocator (Congreso: 80.0%,  $N=20$  vs. 72.2%,  $N=18$ ,  $\chi_1^2=0.31$ ;  $P=0.48$ ; Pantaleu: 64.0%,  $N=89$  vs. 60.0%,  $N=15$ ,  $\chi_1^2=0.09$ ;  $P=0.38$ ). We detected a similar non-significant trend in both colonies during the breeding season following geolocator attachment (Congreso: 73.3%,  $N=15$  vs. 61.5%,  $N=13$ ,  $\chi_1^2=1.28$ ;  $P=0.48$ ; Pantaleu: 64.1%,  $N=92$  vs. 50.0%,  $N=10$ ,  $\chi_1^2=0.77$ ;  $P=0.26$ ).

Although we did not detect significant effects of geolocators on return rates or on breeding success, our small sample sizes precluded us from discarding any negative effect on these parameters as they were always about 10% lower in equipped than in non-equipped birds. We estimated the power of detecting significant differences in both colonies for return rates and breeding success in the year in which the equipment was attached. The result was a combined power of 0.80 to detect small to medium effects ( $w=0.20$ ) in at least one test, which corresponded to a relative change of a maximum of 30% of the observed proportion (Fig. 1). In contrast there was not enough power to detect smaller changes between the two groups. Therefore, if they exist, negative effects on demographic parameters would be small ( $w < 0.20$ ).

After controlling for body size, we detected a significant effect of geolocator on body mass of individuals that returned (Table 2), but no interaction with sex or colony was detected. On average, this effect corresponded to a loss of body mass of 1.6% in individuals



**Fig. 1** *Calonectris diomedea*. Power of the four tests for proportional change between carriers and non-carriers. We detected significant changes >20–30% ( $w < 0.2$ , effect size small to medium) in at least one of four tests (breeding success in the same year and return rate in the next year in Congreso and Pantaleu colonies)

with geolocators (mean body mass in control individuals = 656 g, SD = 67; mean body mass in equipped individuals = 646 g, SD = 73).

After controlling for sex (Table 3), geolocators did not affect stable isotope ratios of individuals at any of the times measured, as shown by the lack of differences in  $\delta^{13}\text{C}$  and  $\delta^{15}\text{N}$  values of blood, first primary and eighth secondary feathers between equipped and non-equipped individuals (see means in Table 4). In contrast with previous analyses, we had enough power to detect significant changes in both trophic levels and inshore versus offshore foraging. Considering the values of stable nitrogen isotopes in primary feathers, for example, we were able to detect a difference of 10% in mean isotope values between control and equipped birds with a probability > 90% (Fig. 2). The power curves of other stable isotope values were similar.

## Discussion

We investigated the short-term effects of geolocators on several aspects of the ecology of Cory's shearwater (*Calonectris diomedea*). Analyses of recapture rates showed that the extra weight (1.5–2%) and/or the shape of geolocators had no measurable effects on demographic parameters or diet. In particular, differences in return rates and breeding success between equipped and unequipped birds were not significant (the real difference was < 10% in general), although these parameters were lower in equipped birds.

Low negative effects of geolocators on individuals from Congreso and Pantaleu were supported by the small difference observed in weight between birds with

and without geolocators, which ranks < 2%. Such a rank of variation is still lower than the natural intra-individual variation observed in body mass (up to 10%, authors' unpublished data). In sooty shearwater (*Puffinus griseus*), body mass of adults carrying dummies of satellite transmitters was reduced on average 8.3% at recapture before breeding, but not during the mid-breeding period, and there was no effect on chick condition or on colony attendance (Söhle 2004). Bro et al. (1999) found significant interaction between ecological conditions and the effects of devices in partridges (*Perdix perdix*). A decrease in food availability may deteriorate the body condition of equipped birds to a greater extent. This might produce a negative effect on survival or individual breeding success. For example, in Pantaleu colony we found a 13% decrease in the recapture rate in equipped compared with control birds. However, in another colony of Cory's shearwaters (at Columbretes Islands, 39°54'N; 0°41'E; data not shown) we obtained the opposite result, the percentage of recovery of devices was higher (78%) than the percentage of recovery of control birds (69%).

On the other hand, in one colony (Congreso, Chafarinas Islands), breeding success during the year of recapture (2001), i.e. the season after equipment, was 10% lower for equipped birds. In the season after recovering the device (2002), i.e. two seasons after equipment, this difference dropped to 4% (75.0%,  $N=8$  and 78.5%,  $N=14$ , for experimental and control birds, respectively). Such a low difference in breeding success suggested a subsequent restoration of body condition.

**Table 2** *Calonectris diomedea*. Results of the three-way ANCOVA performed for exploring effects of colony, sex and geolocators (Geo) on body condition of Cory's shearwaters (PCI principal component 1)

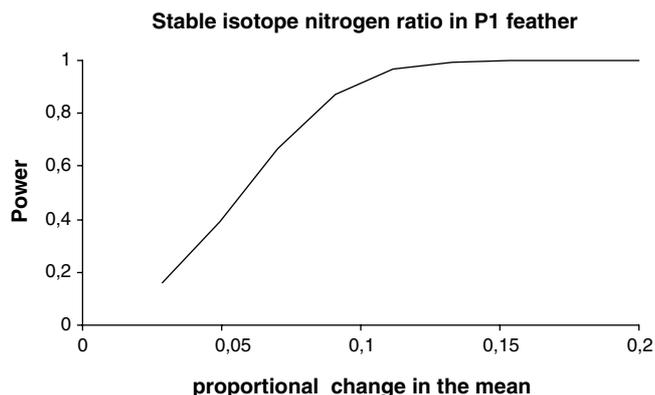
	$F_{(1, 112)}$	$P$
Size index (PCI)	41.3	< 0.001
Colony	1.4	0.24
Sex	0.8	0.37
Geo	5.1	0.03
Colony×Sex	1.5	0.23
Colony×Geo	0.6	0.43
Sex×Geo	0.0	0.91
Colony×Sex×Geo	0.3	0.61

**Table 3** *Calonectris diomedea*. Two-way ANOVA on stable isotopes values in different tissues, controlling for sex and the interaction between sex and geolocator

Tissue	Isotope ratio	Sex	$P$	Sex×Geo	$P$
Primary feather	$\delta^{15}\text{N}$	$F_{(1, 30)}=2.36$	0.14	$F_{(1, 30)}=2.61$	0.12
	$\delta^{13}\text{C}$	$F_{(1, 30)}=3.18$	0.09	$F_{(1, 30)}=0.05$	0.82
Secondary feather	$\delta^{15}\text{N}$	$F_{(1, 30)}=2.54$	0.12	$F_{(1, 30)}=0.04$	0.84
	$\delta^{13}\text{C}$	$F_{(1, 30)}=0.01$	0.92	$F_{(1, 30)}=0.64$	0.43
Blood	$\delta^{15}\text{N}$	$F_{(1, 21)}=0.25$	0.62	$F_{(1, 30)}=2.58$	0.13
	$\delta^{13}\text{C}$	$F_{(1, 21)}=1.41$	0.25	$F_{(1, 21)}=0.00$	0.95

**Table 4** *Calonectris diomedea*. Mean (%o, SD) of nitrogen and carbon stable isotope ratios in blood and feathers (P1 first primary feather; S8 eighth secondary feather) of individuals carrying (I) or not carrying (0) geolocators (Geo) and results of  $t$ -tests

	Geo	$N$	Mean	SD	$t$	$P$
$\delta^{15}\text{N}$ P1 feather	0	22	11.98	0.92	1.00	0.33
	1	9	11.64	0.72		
$\delta^{13}\text{C}$ P1 feather	0	22	-17.09	0.90	1.08	0.29
	1	9	-17.43	0.53		
$\delta^{15}\text{N}$ S8 feather	0	22	13.69	1.28	0.44	0.67
	1	9	13.91	1.40		
$\delta^{13}\text{C}$ S8 feather	0	22	-15.32	0.99	0.67	0.51
	1	9	-15.62	1.45		
$\delta^{15}\text{N}$ blood	0	16	11.32	0.27	1.25	0.23
	1	6	11.17	0.22		
$\delta^{13}\text{C}$ blood	0	16	-18.01	0.36	0.61	0.55
	1	6	-18.10	0.14		



**Fig. 2** *Calonectris diomedea*. Power of the *t*-test for detecting relative changes in the mean nitrogen isotope ratios in primary feathers (P1). The other power test curves ( $\delta^{13}\text{C}$ : P1, S8 and blood;  $\delta^{15}\text{N}$ : S8 and blood) were similar

Diet and foraging ecology during breeding and wintering periods measured through stable isotopes in individuals from Congreso were not affected by geolocators. These results seemed reliable, because the power to detect small changes in the proportion of stable isotopes between experimental and control groups was high ( $>0.90$ ). However, stable isotope analyses only reveal trophic information and the relative importance of benthic (inshore) versus pelagic (offshore) foods, and do not provide taxonomic details on diets. Currently, we have no way of knowing how diets varied between equipped or unequipped individuals, but the isotope evidence suggests that individuals did not change their trophic position or foraging habits. The power of our analysis indicated that we would be able to detect lower changes in stable isotope values than those between pelagic and more benthic diets (a difference of approximately 2–3‰ in  $\delta^{13}\text{C}$ , Hobson et al. 1994), for example, as would be the case if individuals, due to the geolocators and thus the lower flight and propulsion capacities, would exploit a higher proportion of fishing discards.

Overall we found little evidence of effects of geolocators in Cory's shearwaters. Indubitably, any device attached to a bird must have an effect of some sort, but in our case we suspect that any short-term consequences in the analysed parameters between carriers and non-carriers were not large enough to be detected with our analyses ( $<30\%$  in the relative change of breeding success or return rate in one of two colonies and  $<7\%$  in means of isotopes values).

The use of geolocators seems a viable and economic alternative to satellite tracking (which requires the use of heavier devices and harnesses for the study of large-scale movements). Of course, the low precision might not make them suitable for fine-scale analysis. However, identifying such effects is important, not only in terms of animal welfare (Hawkins 2004), but also in the reliability or interpretation of the information recorded (Ballard et al. 2001; Wilson et al. 2002; Phillips et al. 2003). Although these studies indicate that, if any, the effect of

geolocators on breeding success is expected to be low and short term, we recommend caution, because results may depend on the year, colony or sex. Finally, our work offers guidelines for planning experimental studies with data loggers. Most studies do not use enough devices to get a reasonable power of the analysis when testing for a possible effect of the equipment. If we have shown a method to pool the overall power of multiple tests, we are also alerting researchers to consider the trade-off between numbers of individuals equipped and power of the analysis of interest.

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