

SATELLITE TRACKING OF CORY'S SHEARWATER MIGRATION¹DIETRICH RISTOW, PETER BERTHOLD, DEAN HASHMI² AND ULRICH QUERNER

Research Centre for Ornithology of the Max Planck Society, Vogelwarte Radolfzell, D-78315 Möggingen, Germany, e-mail: hashmi@vowa.ornithol.mpg.de

Abstract. Transmitters were attached to four adult male Cory's Shearwaters (*Calonectris diomedea*) caught at their breeding sites off Crete, Greece, in autumn 1998. The birds had left the Mediterranean by the beginning of December. Two were last recorded in the eastern tropical Atlantic in January/February. The other two wintered east of the Mid-Atlantic Ridge, one at about 10°N, the other one in equatorial waters, and could be tracked until return migration in March/April. The seasonal variation in travel speed is in accordance with a conventional pattern of migration with phases of migration and wintering, rather than continuous movement throughout the nonbreeding cycle. The birds left the Mediterranean later and wintered farther north than expected. We suggest that the known longitudinal cline in body size, morphology, and vocalizations of Cory's Shearwater may also be found in migration behavior.

Key words: *Calonectris diomedea*, Cory's Shearwater, eastern tropical Atlantic, Mediterranean, migration, Procellariiformes, satellite tracking.

An important deficiency in our knowledge on seabirds is information about the time between breeding events. In recent studies, satellite tracking (Croxall 1998, Nicholls et al. 1998, Reinke et al. 1998) and geolocation loggers (Tuck et al. 1999) were used to record migration paths of procellariiform seabirds. This paper addresses the migration of Cory's Shearwater (*Calonectris diomedea*). Its breeding range extends from the Azores to the eastern Mediterranean. The waters frequented during reproduction are almost abandoned in winter, when only a very small number of birds remain in the Mediterranean. Observations at sea document that Cory's Shearwaters appear in wide parts of the Atlantic and suggest wintering in the Southern Hemisphere, where some shearwaters regularly penetrate the Indian Ocean (Thibault et al. 1997). A simple spatial and temporal migration scheme drawn from eight ringing recoveries and studies partially based on museum skins (Mougin et al. 1988) appears speculative. This paper provides the first description of the actual route to and partly also from the winter range for a medium size procellariiform seabird.

METHODS

Four adult shearwaters were captured at the end of the breeding season, on 29 and 30 September 1998, in

their colony off Crete. Spacious nest crevices were selected so that the birds would move around freely inside the nest with transmitter and antenna. In the second half of the night, after feeding nestlings, four heavy males were caught in their nest holes. Their weight of 554–569 g was well above the corresponding average (\pm SD) weight of 525 ± 30 g of male adults in the colony. Their minimum age, according to the rings they wore, was 6–14 years. PTT-100 transmitters (Microwave Telemetry Inc., Columbia, Maryland) with mass 22 g and external dimensions of $55 \times 16 \times 18$ mm (antenna 190 mm) were attached in the morning, shortly before the birds were released on an elevated rock from where they returned straight to the sea. The total additional loading resulting from the attachment was less than 4.5% of body mass. For attachment, teflon tape (width 7 mm, provided by Microwave Telemetry Inc.) was tied at its half length by a knot to the metal eye on the front end of the underside of the transmitter. The two tape ends were then led to the left and right of the neck, respectively, crosswise in front of the breast, underneath the wings and up to the two metal eyes at the back end of the underside of the transmitter, threaded through these and tied by a simple knot between them. This way the transmitter was mounted on the back between the wings, as described in Sedinger et al. (1990). A check of free wing beat with unchanged position of the transmitter completed the mounting procedure. To match battery life with the birds' absence from the colony from November to March, the transmitters were programmed to send 1 signal min^{-1} over transmission periods of 12 hr and to switch off during intermittent periods of 4.5 days.

Transmissions were received through the ARGOS satellite system which assigns locations to seven quality classes: classes 3, 2, and 1 (≥ 4 signals per satellite pass) have known accuracies of SD = 0.15, 0.35, and 1 km, respectively, whereas spatial errors of locations classified as 0 and A (3 signals), B (2 signals), or Z (1 signal) have to be determined by the user and are less reliable. Locations of quality 0 or A at known sites prior to deployment indicated a SD of 17.7 km ($n = 13$; range 0–48 km; 50% of the locations within 10 km), locations of quality B or Z had a SD of 177.4 km ($n = 6$; range 11–346 km; 50% within 13 km). In accordance with a study on the spatial error of ARGOS-locations (M. Kaatz, unpubl. data), we treated locations of quality 0 and A as well as B and Z as having comparable quality. We received a total of 260 locations: 7.3% of these were of quality 3, 2 or 1, 49.2% of quality 0 or A, and 43.5% of quality B or Z. To

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² Corresponding author.

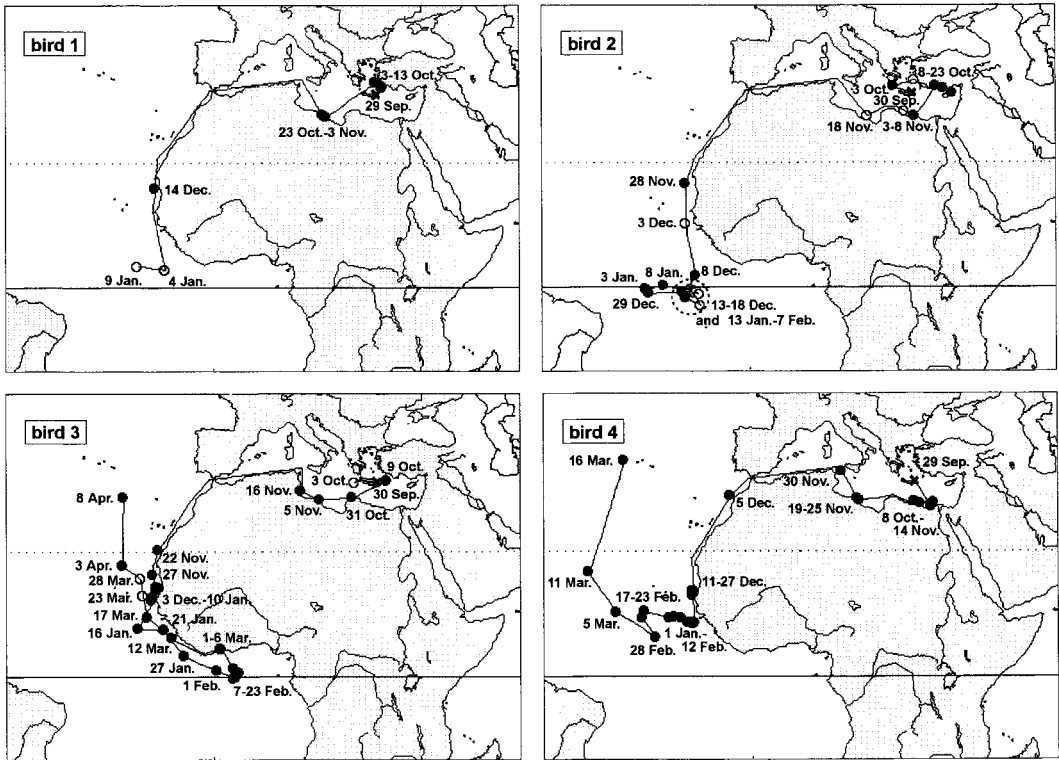


FIGURE 1. Migration paths of four eastern Mediterranean Cory's Shearwaters in winter 1998/1999. Given figures refer to the date of one location or the period of several neighboring locations (which are in one case, bird 2, marked with a stippled circle), respectively. Black dots denote reliable locations, open dots low quality locations (see Methods).

consider B and Z locations matches the aim of this study to examine the broad geographic migration route (Fig. 1) and seasonal changes of travel speed measured on coarse temporal scales (Fig. 2).

The minimum travel distance between two locations was determined as the shortest path to be covered at sea surface and was used to calculate the minimum average velocity resulting from day and night movements of several days. This is referred to as "travel speed." In order to avoid temporal scales which are likely to be in conflict with the precision of the data and corresponding to the operational intervals of the transmitters, we used 12-hr locations to calculate travel speeds and describe the travel route. This means that not more than one actual or calculated location is used to characterize a 12-hr transmission period. This was either the only available location, the qualitatively best location if several locations of different quality were achieved, or the temporal and spatial mean of several best quality locations if there were more than one location of the best available class. Different scales of travel speed measurement were defined by the approximate time, t , that had passed between two consecutive 12-hr locations (scale = $t[\text{days}]/5[\text{days}]$). By proceeding this way, we obtained a total of 79 scale-1 paths, 7 scale-2 paths, 2 scale-4 paths, and 1 scale-7 path; 3

of the initial paths referring to the time between attachment and the first 12-hr location were smaller than scale 1 (scale 0.6–0.8) and appear as scale <1 in Figure 2. In a strict sense, direct comparison of travel speeds is only allowed within one scale, because travel speed is a function of scale (Walker et al. 1995).

RESULTS

From the end of October, all birds were recorded over or close to the North African shelf (Fig. 1). Provided that the highest measured travel speed of 27 km hr^{-1} (Fig. 2) was not exceeded, the birds left the Mediterranean between 6 November and 11 December and reached tropical waters off West Africa between 22 November and 13 December. Two birds are known to have wintered in tropical waters east of the Mid-Atlantic Ridge and it is likely that the other two birds which could only be tracked until January (bird 1) and February (bird 2) behaved similarly (Fig. 1). Return migration of the birds which could be tracked started in March. Their final locations were obtained 560 km west off Madeira (bird 3) and near the western Azore Islands (bird 4). The minimum travel distances between initial attachment of transmitters and the final locations are (bird 1–4) 8,490, 13,680, 16,260, and 13,710 km. The corresponding minimum total migra-

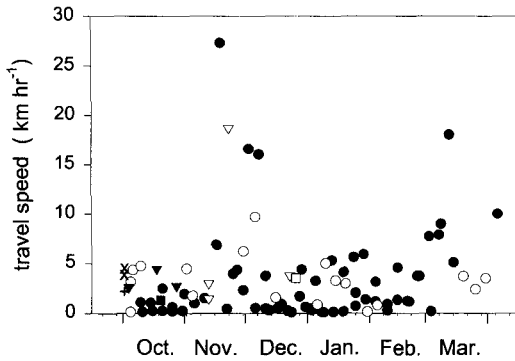


FIGURE 2. Seasonal variation of travel speed measurements of Cory's Shearwaters along the paths shown in Figure 1. Dot = scale 1, triangle = scale 2, square = scale 4. Open signs denote less precise speed measurements, for which at least one of the two points defining a path is a low quality location (see Methods). Scale < 1 measurements are shown as + or x (less precise).

tion paths, connecting the last location with the colony by the shortest at sea distance, were 15,940, 20,770, 20,790, and 18,780 km.

Travel speeds exhibit pronounced seasonal dependence. This is most obvious from scale 1 values, but also supported by values of other scales (Fig. 2). Scale 1 travel speeds > 6 km hr⁻¹ were only reached between 16 November and 10 December and again after the end of February. Scale 1 travel speeds measured during the premigratory phase in autumn (spatially and seasonally defined as being measured in the Mediterranean before 15 November) and in winter (in the tropics between 10 December and 28 February) did not differ significantly (Mann-Whitney *U*-test), whether or not less reliable travel speeds using single B- or single Z-locations were included.

The colony was visited from 3 to 7 April 1999, eight weeks prior to egg laying, when adult breeders and a few prospectors irregularly attend nest burrows at night. Within the subarea where the tracked birds were known to breed ($n = 50$ nests), 26 of the 46 adult male breeders without transmitter could be identified by their rings, but none of the four tracked birds was encountered. The underrepresentation of birds which had been equipped with a transmitter was significant ($P < 0.05$; Fisher's exact test).

DISCUSSION

The tracked birds left the Mediterranean comparatively late and wintered farther north than expected. The migration of Cory's Shearwater in autumn through the Strait of Gibraltar has been documented in detail (Telleria 1980, Hashmi 1996). It happens mainly between the middle of October and the middle of November, and there is no indication for substantial variation between years. A comparison of our recorded dates of the last location in the Mediterranean and the normal passage of the Mediterranean population leaving the Strait (Hashmi 1996) indicates that the four birds were late to

extremely late migrants, as they were probably among the latest 35% (bird 1), 3% (bird 2 and 3), and 1% (bird 4) to leave. According to Thibault (1993), the population east of Italy contributes less than 10% of the Mediterranean population; if fledglings, immatures, prospectors, and females are subtracted, male breeders make up perhaps $\frac{1}{5}$ of this percentage. Mougin et al. (1988) assumed that Mediterranean Cory's Shearwaters typically migrate to the Benguela Current, whereas birds from Atlantic colonies are in the southwest Atlantic in winter. Support is given to the claim that Mediterranean Cory's Shearwaters remain in the eastern part of the winter range, but wintering took place in waters which were farther north. In agreement with the paths of the tracked individuals, there are two Atlantic records of chicks banded at the colony off Crete and recovered in Senegal within two months after fledging: one at 14°40'N, 17°24'W on 5 November and the other at 14°26'N, 17°01'W on 2 December. Considering other results, e.g., the occurrence of a small number of the Atlantic subspecies *borealis* off South Africa (Harrison et al. 1997), the behavior appears to be less deterministic than indicated by Mougin et al. (1988).

One hypothesis which may account for the late autumn migration and northerly wintering is that the eastern Mediterranean population is extreme in their migratory traits. It is reasonable to suggest a longitudinal cline not only for body size and vocalizations (Massa and Lo Valvo 1986, Randi et al. 1989), but also for the temporal course of migration and the winter range. However, the apparent absence of the birds which carried a transmitter at the beginning of April from the colony indicates the possibility of a delayed arrival caused by the additional weight of the transmitter or the way it was attached. Other studies have already pointed out that the attachment of devices may affect behavior (Wanless et al. 1988, Falk and Møller 1995).

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EFFECTS OF SAMPLING DESIGN ON AGE RATIOS OF MIGRANTS CAPTURED AT STOPOVER SITES¹

JEFFREY F. KELLY AND DEBORAH M. FINCH

USDA, Forest Service, Rocky Mountain Research Station, 2205 Columbia SE, Albuquerque, NM 87106,
e-mail: jfkelly@fs.fed.us

Abstract. Age classes of migrant songbirds often differ in migration timing. This difference creates the potential for age-ratios recorded at stopover sites to vary with the amount and distribution of sampling effort used. To test for these biases, we sub-sampled migrant capture data from the Middle Rio Grande Valley of New Mexico. We created data sets that reflected the age ratios of migrants that would have been captured with stratified and concentrated designs at four levels of mist-netting effort. Analysis of these data indicate that age-ratios of Neotropical migrants varied significantly with sampling design, but not with sampling effort. More after-hatch-year Neotropical migrants were captured with stratified than with concentrated sampling designs. Age-ratio of temperate migrants did not vary with either amount of sampling effort or sampling design. Sampling design is an important consideration in the interpretation of age ratios among stop-

over sites, and standardization of sampling among sites could improve our understanding of differential migration of age classes.

Key words: age-ratio, Neotropical migrant, sampling design, stopover biology, temperate migrant.

Recent studies of songbird migration have documented strong influences of age class on autumn stopover biology, particularly the tendency for age classes to differ in the timing of autumn migration (Woodrey and Chandler 1997, Woodrey and Moore 1997). Regardless of the mechanisms that generate differences in timing of passage of age classes, this difference creates the potential for age ratios recorded at banding stations to vary as a function of the amount and distribution of sampling effort.

Numerous authors have compared age ratios among stopover sites to better understand migration biology (Johnson 1973, Ralph 1981). Recently, Woodrey and Chandler (1997) used age ratios to demonstrate differ-

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