The 7000-km oceanic journey of a leatherback turtle tracked by satellite

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Abstract

A leatherback turtle nesting on a KwaZulu-Natal beach was tracked by satellite for nearly 7000 km during internesting movements, rapid straight transfers and feeding-related movements in the Southern Ocean. Some parts of the track reveal the ability to maintain a straight course in the absence of cues deriving from the coastline or shallow bottoms. Swimming speed and diving behaviour varied in different segments of the journey. The value of satellite telemetry for planning conservation strategies is emphasized. © 1998 Elsevier Science B.V. All rights reserved.

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1. Introduction

The leatherback, \textit{Dermochelys coriacea}, is a highly pelagic, cosmopolitan turtle whose behaviour has been mostly studied with observations in its nesting areas (see references in Rostal et al., 1996). Recoveries of tagged individuals have shown that this species undertakes long journeys — for instance crossing the Atlantic Ocean — and in some cases reaches cold seas far away from their tropical nesting beaches (Bleakney, 1965; Pritchard, 1976; Bouillon et al., 1988). Satellite tracking techniques have permitted partial reconstructions of straight migration courses as long as 2800 km (Duron-Dufrene, 1987; Morreale et al., 1996) and contributed to the collection of information for the development of conservation strategies, which are urgently required to protect this endangered species (Spotila et al., 1996).

In this paper, we describe the movements of a leatherback tracked for 124 days for

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more than 7000 km. Besides interesting wanderings and straight transfers into new areas, we also recorded movements which appear to reflect feeding activities, as is expected for a predator living on pelagic invertebrates with a low caloric value (Lutcavage and Lutz, 1986; Bjorndal, 1997).

2. Materials and methods

The turtle we tracked was an adult female nesting on the Maputaland Marine Reserve, northern KwaZulu-Natal, South Africa (tag no. EE309, curved carapace length 1630 mm). She was found on the night of Jan. 15, 1996, while laying eggs in the most northern part of the reserve (27°02' S, 32°52'E). After nesting, she was equipped with a Telonics Inc. (Mesa, AZ, USA) ST-14 satellite transmitter linked to the Argos system (Taillade, 1993). The transmitter (platform transmitter terminal, PTT) was held in place on the top of the carapace by a harness made of elastic cord (see Eckert and Eckert, 1986). The turtle was allowed to return to the sea at 02:30 of Jan. 16 (South African standard time; UT + 2).

The fixes obtained were classified by Argos into six classes: 3, 2, 1, 0, A and B. For class 3, 2, and 1, the approximation is less than 150 m, 350 m and 1 km, respectively; the other three classes are of decreasing reliability. All the fixes were plotted on charts constructed on Mercator's projection by means of a computer program (Sailware Cruise, SW & N, Florence, Italy); the route followed by the turtle was reconstructed disregarding those localisations which appeared to be erroneous, for instance when they were inland or seemed to indicate a swimming speed > 10 km/h. This procedure led to discard 6 class A fixes out of 90 (7%) and 22 class B fixes out of 122 (18%). However, the reconstructed course inevitably represents an approximation of the true course. In the following, each part of the course between two successive fixes is called a segment.

Different parts of the turtle's journey varied as regards direction, straightness and speed; according to this, we divided the course into 19 legs, each one consisting in a different number of segments. To compare navigational performance in periods with a different availability of astronomical cues, we have considered the turtle's speed and direction in each segment. Segments were considered diurnal and nocturnal when at least 90% of the relative time interval was at day or night. Day was considered to begin at the end of the morning nautical twilight and to end at the beginning of the evening nautical twilight. For statistical comparisons, data from segments covered in less than 120 min were excluded.

Our ST-14 PTT was provided with a salt-water switch suppressing transmissions underwater, which also serves to determine diving parameters by means of onboard software disregarding submergences of less than 10 s. In each uplink, our PTT transmitted 4 data: three diving parameters (duration of the last dive before transmission, mean dive duration and number of dives in a previous 6-h period) and temperature. An estimation of total dive time per 6-h period was obtained by multiplying the number of submergences by mean dive duration in the same period. Mean dive duration and number of dives were compared between day and night, relying only on those data recorded in periods which were completely diurnal or nocturnal. Differences between
daytime and nighttime diving behaviour were also tested by comparing data on last dive duration, excluding the dives under 60 s (see also Keinath and Musick, 1993). The temperature values obtained are those recorded in the PTT housing immediately after each transmission.

Differences between samples were tested by using the Mann-Whitney U-test.

3. Results

The course followed by the turtle is given in Fig. 1. The reader can evaluate the degree of approximation of the track by looking at Fig. 2, where two parts of the course are magnified and plotted along with all the relative fixes. After release, the turtle wandered in the coastal waters south of the capture site for nine days, swimming in a circuitous route for 404 km (leg 1). On Jan. 25, she left the area in a northern direction but three days later she headed first SSE and then SW (legs 2–4). After Feb. 1, the turtle began to follow a straight course parallel to the coast, which was interrupted between Feb. 2 and 7 by a tight loop (leg 5; Fig. 2A). From Feb. 10, the SW course led the turtle increasingly away from the coast. At the end of leg 7, the turtle stayed for about two

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**Fig. 1**. Reconstructed migratory route of the turtle. Numbers refer to the different legs of the journey (see Section 2). The number of the first two legs has been omitted. Black dots indicate those fixes which separate two subsequent legs; white dot indicates the capture site on Jan. 16. Other explanations in Section 2.
days in the same small area about 330 km south of the mainland (leg 8). From Feb. 21, the course followed a complicated pattern (legs 9–15), which can be comprised in a square with sides of 500 km in length (Fig. 2B). From Mar. 29, the turtle remained in a small area (60 × 100 km) at the NW corner of this square for about 15 days (leg 14), then headed south and later east (legs 15–16). Between Apr. 22 and 29 she described a semicircle (leg 17), but then the emissions did not allow localizations until May 11 (leg 18, dashed segment in Fig. 1). According to the last fixes, the turtle was moving eastward when the transmitter definitely stopped working on 18 May, shortly after the turtle had reached her most southern point (41°48′S).

Between the departure from the nesting beach waters and the last fix 114 days later, the turtle covered at least 6878 km. Disregarding leg 18, whose actual course is unknown, the average speed was 3.2 km/h. However, different legs of the journey were covered at different speeds (Fig. 3A).

No significant differences between night and day speed were found (Table 1). The nighttime navigational performances do not appear to be influenced by the visibility of the moon. We have no data about cloudiness, but we found that the turtle's speed and direction did not change in moonless nights. For instance, on the night of 20–21 Feb., after the sunset of the moon, the turtle covered a segment of 14.42 km at a speed of 2.88
Fig. 3. A. Mean (±SEM) swimming speed and temperature in different legs of the turtle’s journey. Speed in leg 18 has not been calculated (see Section 3). B. Mean (±SEM) duration of dives and number of submergences in the various legs.

km/h heading towards 258°. These values of speed and direction are in the range of those recorded in the same period.

On average, the turtle spent about 93% of her time submerged. The average duration
Table 1
Comparison of the turtle's behaviour during daytime and nighttime (pooled data of the entire route). Mean±SEM of the speed between successive fixes and of three diving parameters are reported.

<table>
<thead>
<tr>
<th></th>
<th>Daytime</th>
<th>Nighttime</th>
<th>Mann-Whitney U-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed between</td>
<td>3.3±0.2 (n = 87)</td>
<td>3.2±0.2 (n = 75)</td>
<td>P = 0.78</td>
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<tr>
<td>successive fixes (km/h)</td>
<td></td>
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<tr>
<td>Mean dive duration (min)</td>
<td>4.0±0.4 (n = 85)</td>
<td>3.2±0.2 (n = 85)</td>
<td>P = 0.80</td>
</tr>
<tr>
<td>Number of dives</td>
<td>127.4±7.3 (n = 85)</td>
<td>126.1±6.2 (n = 85)</td>
<td>P = 0.90</td>
</tr>
<tr>
<td>Duration of last dive (min)</td>
<td>10.0±0.7 (n = 130)</td>
<td>11.8±1.0 (n = 135)</td>
<td>P = 0.48</td>
</tr>
</tbody>
</table>

of the immersions turned out to be proportionally inverse to the average number of dives per 6-h period (Fig. 3B). During the first part of the trip (legs 2–7), the mean dive duration (2.2±0.1 min) was shorter than afterwards (3.9±0.2 min). No consistent relation with the mean speed was found; for instance, during the first small loop the immersion duration was similar to those recorded in the previous and successive segments, covered at higher speed. In several legs a significant diel difference in diving behaviour was found, but a consistent trend related to the features of the leg (e.g. circuitous or linear) is lacking. Moreover, no significant differences were found considering the pooled data (see Table 1).

The mean temperature recorded by the PTT decreased from a value of around 25°C in the first legs to about 15°C at the end of the track (Fig. 3B). This trend is consistent with the seasonal and latitudinal changes.

4. Discussion

Previous recoveries of leatherbacks tagged in Maputaland were from the Western Indian Ocean up to 2500 km away from the nesting beach (Hughes, 1989, 1996). As none of them had occurred south of 30°S, the journey of our leatherback as far away as the Southern Ocean was totally unexpected. The very first part of our recordings shows wandering movements in the waters around the nesting area for a total length of 400 km (leg 1). They are to be interpreted as internesting activity: first, because turtles are assumed to leave the area of nesting beach soon after the last egg-laying of the season and, second, because the wandering movement of our leatherback lasted precisely 9 days, and 9–10 days is the most frequent internesting interval in leatherbacks (e.g. Boulon et al., 1996; Girondot and Fretay, 1996). At the time of the expected egg-laying, we did not get any reliable location on land, but the turtle was nonetheless localized close to shore (1–10 km). We can thus conclude that our leatherback renested before starting her migration.

The successive recordings confirm the pelagic habits of the leatherbacks after completing the nesting cycle. The turtle displayed two different patterns of movement. The first, also reported in previous papers (Duron-Dufrenne, 1987; Morreale et al., 1996), consists in following a straight course for hundreds or thousands of kilometres over open ocean. The second pattern, which is only shown in our track, consists in
slower wandering movements over a limited area; this is to be interpreted as a part of feeding activity. Typical examples of the first pattern are reflected in legs 3, 4, 6, 7, 11 and 16, while legs 5, 8, 10, and 14 are attributable to the second pattern. In other cases, behaviour is intermediate and might result from a mixed activity of feeding and transfer.

The spatial behaviour of our turtle was probably influenced by the Agulhas Current, which permitted the initial rapid movement towards areas suitable for feeding activity. It is probable that the circuitous movements in the 500-km sided square mentioned in the results are related to feeding activity. One should emphasise that this area is in the region of the Subtropical Convergence; this is in accordance with other data on turtle preference for convergence regions (Carr, 1987; Beavers and Cassano, 1996; Lutcavage, 1996). Shortly before the end of emissions, the turtle left this feeding area; this infers movements between different feeding areas in the 2–3 years between two successive nesting cycles.

The straight part of the track confirms the leatherback’s ability to maintain a constant heading without reference to visual landmarks. While moving parallel to the coast, the turtle remained more than 50 km offshore and thus too far for visual guidance. Cues originating from shallow bottoms are also to be excluded, as the turtle always swam in at least 2000 m deep waters. In the case of the leatherbacks which migrate in a corridor between the Pacific coast of Costa Rica and Galapagos waters (Morreale et al., 1996), the Cocos Ridge can be taken into account as a guidepost, but it has been found that the turtles are also able to maintain a straight course over the deep waters beyond the Galapagos. Other turtle species are known to keep straight courses over deep oceanic waters (Balazs, 1994; Balazs et al., 1994). In our case, however, it cannot be excluded that the turtle was helped by the flow of the Agulhas Current.

In all these cases, reliance on one or more biological compasses has to be admitted. Like the green turtle (Luschi et al., 1996), our leatherback seems to be able to keep a constant heading even on moonless nights, so that the usage of a magnetic compass can be postulated. Alternatively, the turtle might have used the wave direction to steer a constant direction, provided that she had calibrated the wave direction with a ‘true’ biological compass at dusk. The navigational performances of the leatherbacks, which also comprise of the return journey to their own nesting beach after 2–3 years spent in the open ocean, suggest a position-fixing ability, whose sensory basis and physiological mechanism are still largely unknown in all sea turtle species (Papi and Luschi, 1996).

The number and duration of the turtle’s submersions varied widely during the different legs of the journey. While covering legs 9–15, which we assume to be mostly devoted to feeding, submersences were particularly prolonged and infrequent (Fig. 3). It is hard, however, to unequivocally relate this diving pattern to feeding activity, especially because a contemporaneous decrease in speed was not always found. Dive durations recorded by Eckert et al. (1989) in leatherbacks during internesting intervals are much longer than those we recorded in the same period (9.9 vs 2.0 min). Our values, on the other hand, are closer to those (2.3 min) reported by Keinath and Musick (1993). In these studies, dive durations varied between night and day, while we did not find any consistent difference.

The leatherback is an endangered species with many populations declining (Spotila et al., 1996) or close to extinction (e.g. Chan and Liew, 1996). Leatherback conservation
policies should focus on the protection of the adults (Spotila et al., 1996), not only while nesting but also during migration and in foraging areas. However, recoveries of tagged turtles do not provide sufficient information about migratory behaviour and routes. For instance, all of the six tag recoveries of the Maputaland leatherbacks occurred in areas completely different from those visited by our turtle. Information from satellite telemetry is thus necessary to extend protective measures to both the migratory corridors (Morreale et al., 1996) and the pelagic feeding areas.

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