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Short communication

Insights into the management of sea turtle interesting area through satellite telemetry

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ABSTRACT

Female sea turtles typically lay several clutches during each nesting season and rest in the time between laying clutches (the interesting period) in the waters off the nesting beach. Adequate protection of turtles in the interesting area requires knowledge on their spatial behaviour and was so far hampered by methodological limitations. Satellite telemetry data of exceptionally high quality allowed us to scrutinize interesting area use of four loggerhead sea turtles nesting in the Bay of Laganas (Zakynthos, Greece). We assessed the efficacy of two zones of a marine reserve with distinct levels of protection (boats are excluded from one zone). Most of the obtained locations of three of the four turtles were within the bay, a result consistent with a strategy to minimize energy expenditure. Turtles showed no obvious preference for the highly protected area of the bay. The availability of warmer water in the less protected area may be more crucial than avoidance of boat disturbance.

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1. Introduction

Adult sea turtles are a paradigmatic group of long-distance travellers with often no or little food intake along migratory routes and in the reproductive area (Plotkin, 2003). Moreover, female sea turtles lay several large clutches of nutrient-rich eggs during a reproductive season, which may last up to several months (Miller, 1997). These high energetic 'fixed' costs suggest that strategies for minimizing metabolic expenditures during the reproductive season would be highly beneficial (Hays et al., 1999). Data from time-depth recorder studies in several sea turtle species indicate that animals are indeed inactive and rest predominantly on the seafloor during the reproductive season (Hays et al., 2000; Houghton et al.,

2002). More active dive patterns have also been recorded (Hochscheid et al., 1999; Houghton et al., 2002), which were interpreted as foraging dives, indicating behavioural plasticity in interesting behaviour (Hays et al., 2002b).

While these data have shed light on interesting activity levels, methodological limitations have to date prevented thorough investigations of individual interesting behaviour on a spatial scale. Data collected through visual tracking of marked individuals (Meylan, 1995; Mortimer and Portier, 1989), for instance, is likely to be systematically biased towards locations close to the observer, and turtle behaviour might be affected by the presence of a research vessel necessary for sonic or radio tracking (Tucker et al., 1995). Although the advent of satellite telemetry for wildlife tracking has revolutionised the

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study of long-distance migrations of sea turtles (e.g. Godley et al., 2002; Luschi et al., 1998; Troëng et al., 2005), the frequency and accuracy of locations have been insufficient for investigating small-scale spatial behaviour.

Satellite telemetry data of exceptionally high quality allowed us to investigate individual spatial behaviour of loggerhead sea turtles (*Caretta caretta*) in the Bay of Laganas (52 km²; Zakynthos, Greece; Fig. 1) during the reproductive season. To verify whether turtles minimise energy expenditure, we assessed the extent to which turtles remained within the confined area of the Bay of Laganas.

Data on spatial behaviour during the interesting period not only contributes to testing evolutionary ecology hypotheses, but is required for efficient protection. Because the interesting area hosts a large proportion of adults of a given rookery in a relatively small space during the breeding season and because the resting behaviour of females may make them especially vulnerable to disturbance and injury (e.g. from boat strikes), a high protection priority should be given to these areas. The nesting beaches as well as the Bay of Laganas (Bay of Laganas refers to the marine protected zones, although the actual bay is slightly larger; Fig. 1) were declared a national marine park in 1999, with the main aim to protect loggerhead sea turtles from mass tourism (Dimopoulos, 2001). Turtle-watching tourism is widespread in the waters of Zakynthos, but no turtle-watching from boats is allowed in the highest protected zone of the bay, comprising the waters off the most densely nested beach area (Fig. 1; Dimopoulos, 2001). Against this background, we tested whether turtles show a preference to stay within the highly protected area of the bay to assess how well protection zones in an interesting area can protect the individuals of a rookery in this vulnerable phase.

2. Materials and methods

The Bay of Laganas (Zakynthos, Greece, ca. 37°43'N 20°53'E; Fig. 1) hosts the largest known rookery of loggerhead sea turtles in the Mediterranean with an average of nearly 1300 clutches per season on approximately 5.5 km of beach (Margaritoulis, 2005). The nesting area is monitored comprehensively by ARCHELON (The Sea Turtle Protection Society of Greece). It consists of six discrete beaches (Fig. 1) with individual females showing fidelity to the bay, but not always to specific beaches (ARCHELON internal reports, unpublished data). Sea turtles nest on Zakynthos from the second half of May till the first half of August (Margaritoulis, 2005).

We stopped turtles on their way back to the sea after they had successfully nested and been measured (CCL: curved carapace length, notch to tip) to attach satellite transmitters (Kiwisat101; 630 g; Sirtrack Ltd., New Zealand) on the second central carapace scute using previously described methods (e.g. Godley et al., 2003).

A total of six turtles ($N = 5$ on Gerakas beach, $N = 1$ on Kalamaki beach; Fig. 1) were equipped with transmitters, three in 2004 and three in 2005 (Table 1). Transmitters were programmed for a 36 s repetition rate and an output power of 1 W. For transmitters attached in 2004 (individuals A, B, and C), on/off duty cycles during the reproductive season were 10:10 h. The transmitters attached in 2005 (individuals D, E, and F) were programmed for emitting continuously during the reproductive season. A surface time counter measured the amount of time that the salt water switch was dry over a 24-h period.

Data were transmitted through the Argos satellite system (www.argos-system.org). We only used fixes of the three most accurate location classes (1–3). According to Argos and con-

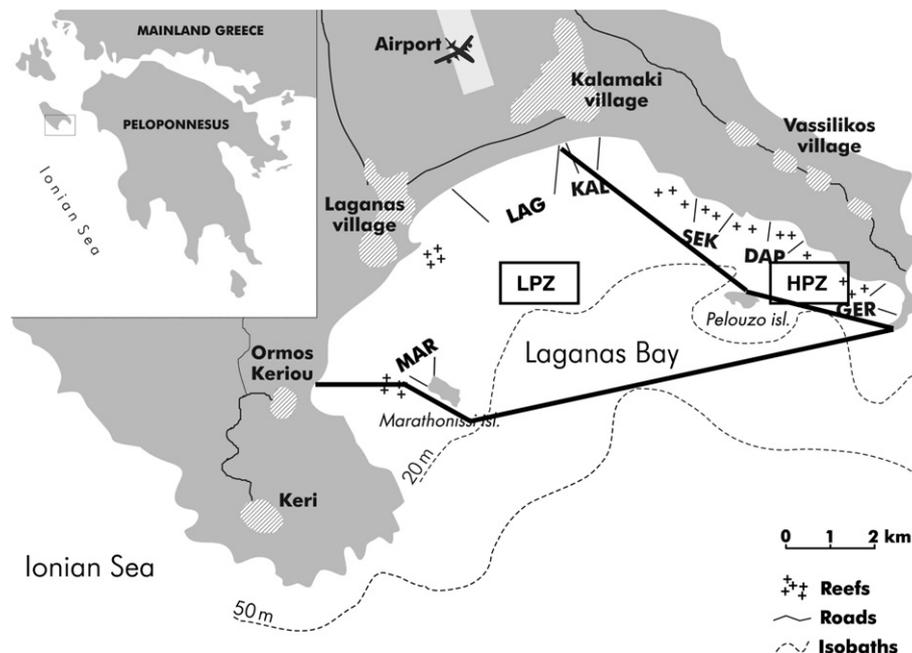


Fig. 1 – Location of the Bay of Laganas (Zakynthos, Greece) showing the marine protected zones and the six nesting beaches (MAR: Marathonissi, LAG: East Laganas, KAL: Kalamaki, SEK: Sekania, DAP: Daphni, GER: Gerakas). In the highly protected zone (HPZ), boat traffic is prohibited; in the less protected zone (LPZ) boats are permitted, travelling up to six knots speed.

Table 1 – Summary of satellite tracking six loggerhead sea turtles in the Bay of Laganas (Zakynthos, Greece) during the reproductive season: Body size (CCL: curved carapace length), transmitter performance (TSR: transmission success rate), median water depth and number/percentages of locations within the bay with respect to protection zone (see Fig. 1)

Turtle	Attachment date	Internesting tracking duration (days)	Number of locations	TSR (mean no. of locations per day)	Median water depth (m)	Number (%) of locations		
						In bay	HPZ	LPZ
A	27.06.2004	44	19	0.43	15.5	16 (84%)	3 (16%)	13 (68%)
B	28.06.2004	25	3	0.12	–	–	–	–
C	29.06.2004	41	19	0.45	6.5	19 (100%)	4 (21%)	15 (79%)
D	16.06.2005	42	43	1.00	54.6	21 (49%)	13 (30%)	8 (19%)
E	19.06.2005	38	20	0.51	6.7	20 (100%)	3 (15%)	17 (85%)
F	21.06.2005	43	11	0.25	–	–	–	–

HPZ: highly protected zone, LPZ: less protected zone.

firm by Hays et al. (2001), the location errors follow a normal distribution with the standard deviation for the three most accurate location classes being less than 1 km. Individuals from which fewer than 12 data points were obtained were excluded. We considered fixes falling on land as belonging to the closest point off the coast. We managed and filtered data with the STAT program of seaturtle.org (Coyné and Godley, 2005). We derived data of sea floor depth from this source. For the calculation of median water depths, we excluded locations on land. Maps were drawn using Maptool (seaturtle.org).

We tested, for each individual separately, for a deviation of observed location distribution between the highly and the less protected area from an expected distribution under no preference (χ^2 -tests; performed in JMP IN®, version 4.04, SAS

Institute). The latter was calculated based on the proportions of area covered by the two zones.

3. Results

All six turtles provided data throughout the reproductive season. Transmission success rate (the average number of fixes of LCs 1, 2, and 3 per day) varied between individuals (mean 0.48 high quality locations per day; Table 1). We excluded two individuals (B and F) (see methods; Table 1). The location points of individuals A and C–E are plotted in Fig. 2. Based on an interesting interval of 10–20 days on Zakynthos (Margaitoulis, 1983) and the fact that loggerhead sea turtles leave the nesting area immediately following deposition of the last

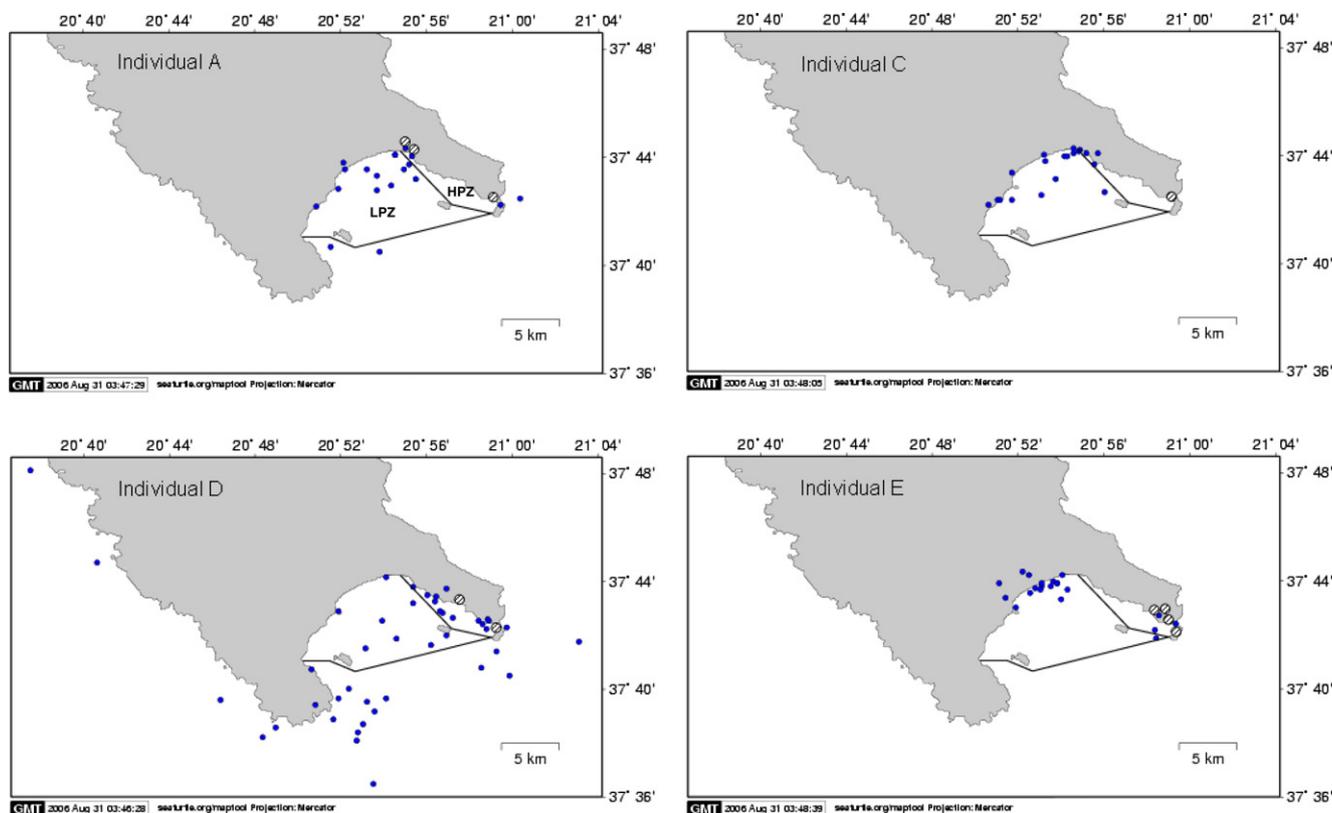


Fig. 2 – Locations (filled circles) of four satellite tracked loggerhead sea turtles during the reproductive season. Locations of observed nestings are indicated with hatched circles. Black lines indicate borders of marine protected zones.

clutch (Schroeder et al., 2003), the four turtles laid each three or four clutches after transmitter attachment. In six instances (additional to the nesting events when transmitters were attached), an ARCHELON team observed turtles with transmitters during night patrols (Fig. 2).

For three of the four turtles (individuals A, C and E), over 80% of locations were situated within the bay with median sea floor depth of 6.5–15.5 m (range of individual medians), whereas for turtle D only 49% of the locations were situated within the bay (Table 1).

For individuals A, C, and E, 79–85% (range of individuals) of the locations received from within the bay were situated within the less protected area (LPZ) and 15–21% within the highly protected area (HPZ; Table 1). The null hypothesis of no preference for either the highly or the less protected area could not be rejected for turtles A, C and E (turtle A: $\chi^2 = 0.65$, $df = 1$, $p = 0.42$, turtle C: $\chi^2 = 1.09$, $df = 1$, $p = 0.30$, turtle E: $\chi^2 = 0.071$, $df = 1$, $p = 0.79$). The distribution of locations of individual D significantly deviated from expectations of no selection ($\chi^2 = 44.41$, $df = 1$, $p < 0.001$), i.e. the data indicate preference to stay in the highly protected zone.

4. Discussion

Our data suggest that loggerhead sea turtles use a spatially restricted area during the reproductive season. This supports the hypothesis of minimizing energy expenditure during this phase. This conclusion is further corroborated through direct behavioural observations in the study area (Schofield et al., 2006). Individual D exhibits a different spatial pattern, but tracking this turtle after the reproductive season indicated what seemed to be atypical behaviour (Zbinden et al., in review).

The finding that turtles did not apparently prefer to stay in a highly protected area suggests that sea turtles may not necessarily adapt behaviour in response to offered marine protection zones, at least not during the reproductive season. We hope that our results alert researchers and managers that detailed interesting area use should be assessed before enforcing management zones. Moreover, we show that the location of nesting is not a good indication of marine residence of individual turtles on a rookery scale. Anecdotal observations of turtles resting off East Laganas beach in the evening before nesting on Sekania beach (Fig. 1) the same night (ARCHELON internal report, unpublished data) support the satellite tracking data in this regard.

Apart from providing insights into interesting biology, this study shows that current satellite tracking technology can render adequate spatial information of marine turtles during the reproductive season. Two lines of evidence suggest that the relatively high frequency of high accuracy fixes was not solely a result of exceptional surfacing behaviour during the reproductive season of turtles in this rookery. Consistent with other studies (Hays et al., 1999; Plotkin, 1998), average transmission success rate was lower during the reproductive season than during the post-nesting migration for all four individuals included in our analysis (Table 1, mean transmission success rate during migration, turtle A: 1.1, turtle C: 0.88, turtle D: 2.29, turtle E: 0.82). Moreover, the average amount of time the salt water switch was dry

over a 24-h period was lower during the reproductive season than during post-nesting migration for all individuals (turtle A: 67 min vs. 76 min, turtle C: 78 min vs. 90 min, turtle D: 61 min vs. 90 min, turtle E 49 min vs. 63 min). Compared to other studies, the transmitters we deployed had a high repetition rate, which may explain the relatively high frequency of accurate fixes. However, satellite tracking studies suffer from notoriously small sample sizes due to the high cost per individual. Recently developed GPS-based transmitters for marine turtles (Yasuda and Arai, 2005) are a promising tool to study interesting spatial behaviour and related questions.

Two factors are of potential concern for interpreting spatial behaviour during the reproductive season based on satellite telemetry data. Firstly, a positive correlation has been found between dive duration and resting depth in marine turtles (Hays et al., 2000; Houghton et al., 2002; Minamikawa et al., 2000), suggesting that transmission success rate may be dependent on bathymetry. The amount of locations from the relatively deep waters outside the bay may therefore be underestimated compared to the amount of locations from the shallow waters of the protected zones. However, this potential bias would not have affected the distribution of locations among the two protected areas within the bay, given that they are both in similarly shallow waters (Fig. 1). Secondly, surfacing behaviour has been shown to change according to the time to nesting events (Hays et al., 1991; Houghton et al., 2002). A qualitative analysis of our data in that respect revealed however that amount of time at the surface was spread rather equally over the reproductive season.

One could expect presence of boats to be a main factor responsible for the distribution of turtles in the bay, but our data do not support this, although the density of boats intending to watch turtles in the less protected area is often considerable. Two non-exclusive explanations seem plausible for this counter-intuitive result. Firstly, disturbance by boats is just one factor characterizing the quality of an interesting habitat as perceived by the turtle. Other factors probably include the availability of resting surfaces at a specific depth or water temperature. The latter is likely of importance because the length of the interesting interval is affected by water temperature (Hays et al., 2002a; Sato et al., 1998). Temperature varies amongst areas of the bay with generally warmest temperatures in the northernmost shore-region (belonging to the less protected zone; pers. obs.). An increase in temperature by just 1 °C is predicted to decrease the duration between nestings by approximately one day (Hays et al., 2002a). From an energetic point of view it would therefore be advantageous for turtles to stay in the northern, warm zone, as long as the energy loss from reaction to disturbances is compensated by the thermal metabolic gain. Only a rigorous habitat selection model taking into account as many of the environmental (including anthropogenic) factors as possible could answer the question as to which factors affect the interesting habitat choice. A second possible explanation of the observed pattern is that the presence of boat does not deter turtles. Although habituation to humans would be adaptive in the context of energy saving in the interesting area, a possible habituation to boats may have detrimental effects outside

the bay, where boat speed is not restricted, potentially increasing casualties. That the hypothesis of habituation to human presence in the Bay of Laganas may be plausible is indicated by a trend towards greater habituation to humans with ongoing protection of marine habitats in Hawaiian green sea turtles (*Chelonia mydas*; Balazs, 1995). More research is clearly needed to understand both interesting habitat selection and the alarming possibility of habituation to boats to adequately protect these animals during the reproductive season, a critical time of their life.

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