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Living between widely separated areas: Long-term monitoring of Mediterranean loggerhead turtles sheds light on cryptic aspects of females spatial ecology

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ABSTRACT

Over the last decades, satellite tracking techniques have substantially advanced our understanding of sea turtle spatial behaviour, especially for the post-nesting migrations of females. Substantial gaps remains in our knowledge of the turtle behaviour during the remaining inter-reproductive period, that spans over 2–3 years. We report the results of a prolonged tracking experiment on loggerhead turtles nesting along the Ionian Calabria, the main breeding ground in Italy. Argos satellite transmitters were deployed on eight females, a sample representing a substantial fraction of the overall population (20–25 nesting females). All turtles but one were tracked for >300 days (range: 313–1523 days), revealing their spatial behaviour during a complete reproductive cycle and providing novel information on a number of poorly-known aspects of loggerhead spatial ecology: i) the post-nesting migratory strategy resulted in accordance with that of most adult loggerheads tracked so far, as the nine routes of six turtles were directed towards specific sites all located in the Tunisian continental shelf, a main foraging area for Mediterranean turtles; ii) the pre-breeding migratory routes were rather variable, likely deriving from different navigational strategies adopted by migrating turtles, and their temporal pattern indicates that mating occurred away from the nesting area; iii) the 10 inter-nesting movements of four turtles revealed unusual long-distance loops mostly in oceanic waters (median of maximum distance from nesting location: 145.5 km); iv) while at the foraging grounds, four turtles occupied distinct areas during summer and winter, making directed movements between the two sites, seasonal core areas were separated and their size was larger in winter than in summer (median: 498 km^2 vs. 258 km^2); v) individual females displayed an high fidelity to both sites in successive years. These findings further highlight the plasticity in loggerhead spatial behaviour and the importance of the Central Mediterranean and of the Tunisian shelf for loggerhead conservation.

1. Introduction

Measures of effective conservation are particularly challenging for migratory species, both terrestrial (e.g. Piersma and Baker, 2000; (Bolger et al., 2008) and marine (e.g., Palumbi, 2004; Reynolds and Jennings, 2000). Actually, three relevant key facts are known to be critical for successful conservation planning (Wilcove and Wikelski, 2008), even the largest protected areas are currently too small for wide-ranging species; ii) large-scale movements may extend over different countries therefore implying different conservation policies; iii) the detailed knowledge of migratory routes are essential in order to understand demographic connectivity between widely separated areas. Various examples of how movement data of terrestrial or marine animals were used to drive conservation efforts are provided by Hays et al. (2016).

Many animals spend a relevant part of their life moving over widely different spatial and temporal scales (Gurarie et al., 2009). Therefore, the types of movements may differ even dramatically, but three main forms at least are normally recognized (Forman and Godron, 1986; Gurarie et al., 2009) local movement (within a home range, i.e. area daily covered for feeding and other activities), dispersal movement (one-way movement of an individual away from the area of birth or residence), and migration (cyclic movement of animal populations between two different areas/habitats during different seasons).

Our understanding of the spatio-temporal distribution, migratory connectivity and habitat use of wide-ranging species has dramatically increased over the last 30 years, thanks to a variety of technological tools such as satellite telemetry, genetic analyses, remote sensing and biochemical markers (e.g. Hart and Hyrenbach, 2009; Hawkes et al. 2011; Mills, 2013; Hays et al. 2016).

Sea turtles are the only reptiles that undertake large-scale migrations comparable of those of other terrestrial or marine vertebrates

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(Plotkin, 2003; Southwood and Avens, 2010). In most species, wide-ranging movements occur among different developmental habitats during the early life stages (Musick and Limpus, 1997), while adults shuttle between distinct foraging and nesting grounds, often embarking in long-distance migrations on a multi-annual basis (Plotkin, 2003; Godley et al., 2008). Moreover, in some species adult females are known to perform extensive movements also between successive nesting events within the same breeding season, during the so-called internesting period (Godley et al., 2008).

Over the last few decades, satellite tracking techniques have led to substantial advances in the scientific knowledge of sea turtle spatial behaviour, revealing the movement patterns displayed by medium- to large- sized individuals (i.e., from late juveniles to adults), and also to obtain some indications on those of smaller juveniles (Mansfield et al., 2014). The picture provided by satellite tracking findings is still somewhat incomplete, even for the best documented case of adult females. The findings obtained are indeed biased towards the post-nesting migrations, that are typically tracked for some months after departure from the nesting area. What the females do for the rest of the inter-reproductive period, that spans over 2–3 years, is much less documented (Godley et al., 2008). In hard-shelled species, the turtle behaviour during the successive prolonged stay in neritic foraging area(s), as well as during the pre-breeding migrations, has been monitored in a minority of cases, such as in hawksbills (*Eretmochelys imbricata*; Hawkes et al. 2012) and loggerheads (*Caretta caretta*; Zbinden et al. 2008; Marcovaldi et al., 2010). This bias leaves out a most relevant part of the adult cycle, and the available findings thus only provide a sort of snapshot of the spatial behaviour of females throughout their 2–3 years reproductive cycle, limited to the first months after nesting.

The loggerhead is the most common sea turtle in the Mediterranean Sea (Casale and Margaritoulis, 2010). Adults and juveniles occur throughout the entire basin, although nesting beaches are concentrated in the eastern basin, in particular along the Greek, Turkish and Cyprian coasts, for an average of over 7200 documented nests/years (Casale and Margaritoulis, 2010). Recent genetic studies (mtDNA sequences) showed a degree of isolation among the Mediterranean rookeries, indicating the existence of distinct demographic sub-population, as a result of at least two colonisation events from the Atlantic (Clusa et al. 2013). Satellite tracking findings have started to outline an overall picture of the main movement patterns of these turtles, although some biases remains given that most efforts have focused on the adults of the main rookeries in Greece and Cyprus (Luschi and Casale, 2014).

The Ionian coast of Calabria is currently recognized as the most important regular nesting ground of loggerhead turtle in Italy (Mingozzi et al. 2007), accounting for about 50–80% (average 65%) of the total nesting events documented countrywide with a total of 261 nests recorded in the period 2005–2014), that corresponds to a density of 12 to 27 nests/year. Nests are mostly concentrated (about 80% on average) along the southernmost Ionian coastline, the so-called "*Costa dei Gelsomini*" (Mingozzi unpubl data). Such a picture classifies the Ionian Calabrian coast as a marginal nesting ground for Mediterranean loggerhead turtles when compared with the other rookeries, hosting a small percentage of the total breeding events, and being located at the western limits of the Mediterranean regular nesting range of the species. Marginal populations are however relevant for species conservation, as they can significantly contribute to the overall genetic diversity (Lesica and Allendorf, 1995; Eckert et al., 2008) and so information on the movement patterns shown in these cases is most valuable.

In the present paper we report the results of a prolonged tracking experiment on female loggerhead turtles nesting in Southern Italy, which constitutes the first tracking attempt on nesting females in Italy. The study aims to complement the available information on the movements of loggerhead females in the Mediterranean and in particular to: a) identify the spatial and temporal patterns of female migratory routes, both after and before breeding; b) identify foraging and wintering areas where the turtles stay during the non-breeding period; c) assess their fidelity to migratory routes and feeding grounds in subsequent years; d) to compare the movement patterns recorded during inter-nesting and migration with those described elsewhere. Such information is essential to contribute to the conservation planning of this endangered and marginal nesting population.

2. Materials and methods

2.1. Study area

The study area is located along the Ionian coast of Calabria, the southernmost part of the Italian Peninsula (Fig. 1), extending for 40.4 km between Capo Bruzzano (38.040°N, 16.145°E) and Melito di Porto Salvo (37.918°N; 15.788°E). For most part (86.2%, 34.8 km), the coast is constituted by low-lying sandy or sandy-shingly beaches, on average 28.9 ± 11.5 m wide (range: 5–70 m, $n = 346$), that provide an habitat potentially suitable for turtle nesting. The remaining 13.8% (5.5 km) is represented by highly eroded coast.

2.2. Satellite transmitter attachment

During four nesting seasons (years 2009, 2010, 2011, 2013), seven Platform Transmitter Terminals (PTTs) linked to Argos system (www.argos-system.org), were deployed on female loggerheads nesting along the study area. An eighth PTT was deployed on a large female (73 cm curved carapace length) found at night on a beach. Since no indication about nesting attempts was available for this turtle, it will not be considered in this analysis. Details on tracked turtles, transmitter models and deployment locations can be found in Table 1.

Taking into account the wide extent of potential nesting beaches, and therefore the inability to monitor the entire beach length during the night, an opportunistic searching method to locate nesting turtles was set up. Nighttime patrolling activity was concentrated on selected beach sectors only, where (and when) one or more failed nesting attempts were recorded during patrols conducted the previous morning. Night monitoring (from 10:00 p.m. to 04:00 a.m.) was carried out by at least two patrols equipped with night vision scope (Wild Heerbrugg Mod. Big 3), and long range torches (Mag Charger Mod. Rn4019e) which monitored a stretch of about 10–15 km around the selected beach.

Turtles were approached at the end of egg-laying process or after a false crawl, and PTTs were attached to their carapace by using standard gluing methods with epoxy resins (Powerfast Pure 2K, Powers Fasteners, Inc., Brewster, NY). Turtle Zeffiria (2009) was missing a part of the right rear flipper and, after several attempts, could not dig the egg chamber.

2.3. Location data analysis

We obtained the initial Argos data through STAT (Satellite Tracking and Analysis Tool, Coyne and Godley, 2005), available on www.seaturtle.org. The locations obtained from Argos were subjected to a filtering process excluding locations that were considered invalid on the basis of a pre-determined speed threshold. Speed thresholds were determined individually, calculating for each female the maximum speed recorded between high-accuracy localizations (Argos location classes 3, 2 and 1) obtained at least 1 h apart, and then adding a 20% buffer to this value (see also Lambardi et al. 2008). A minimum individual speed threshold of 4 km/h was anyway used.

The turtle reconstructed movements were divided into four successive phases: i) inter-nesting ii) post-reproductive migration, iii) stay at the foraging ground and iv) pre-breeding migration. For pre- and post-breeding migration the Straightness Index (Batschelet, 1981) was calculated as the ratio between the distance from the starting point to the final destination and the actual path length covered to reach the goal.