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Each to Their Own: Inter-Specific Differences in Migrations of Masirah Island Turtles

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ABSTRACT. – **We tracked two adult female green turtles (*Chelonia mydas*) from their nesting location on Masirah Island, Oman (lat 20.441°N, long 58.843°E) into the Red Sea. Comparing these tracks with published movements of nesting loggerhead (*Caretta caretta*) and olive ridley (*Lepidochelys olivacea*) turtles, also tracked from Masirah, revealed remarkably different inter-specific patterns of post-nesting dispersal. High-capacity artisanal fisheries, with undescribed levels of sea turtle bycatch, exist within the region, making introduction of effective conservation measures difficult.**

Marine turtles are highly migratory species, often ranging across vast distances during their development and maturation (Musick and Limpus 1997). As adults, they undergo seasonal reproductive migrations from foraging areas often hundreds of kilometers or more from their breeding sites (Plotkin 2003). The predictable return of nesting females to breeding sites over a defined season means this is the most accessible part of their life cycle and the best studied life-history stage (Miller 1997). Flipper tagging of nesting females, often involving thousands of individuals (e.g., Balazs 1980; Limpus et al. 2003; Margaritoulis et al. 2003; Troëng et al. 2005), has provided insights into marine turtle migrations and offered indications of important foraging habitats, but tag recovery rates may be biased because they require the animal to be observed and the observer to report their findings (Godley et al. 2003). Over the last decade, the preferred methodology for gaining insights into the spatial ecology of marine turtles has become satellite telemetry using the Argos network (Godley et al. 2008). Although sample sizes are often constrained for financial reasons, satellite tracked individuals can provide a wealth of unbiased data regarding behavior and migrations, information that may take decades to obtain through traditional methods.

Research on marine turtles started in Oman in the 1970s and verified that four species of turtles nest there (loggerhead [*Caretta caretta*], green [*Chelonia mydas*], olive ridley [*Lepidochelys olivacea*], and hawksbill [*Eretmochelys imbricata*]) and that all four species nest on Masirah Island, situated off the east coast of mainland Oman (Ross and Barwani 1982). The country's main nesting area for green turtles is at Ras Al Hadd and for hawksbills is the Daymaniat Islands. However, Masirah hosts nationally and regionally important populations of these species in addition to a unique olive ridley population and one of the largest nesting aggregations of loggerheads in the world (Baldwin and Kiyumi 1999).

Because of the size of the population and its preference to nest nearer to the island's main town, the loggerheads of Masirah Island received the most effort with regard to flipper tagging, and consequently, several long-distance tag recoveries for this population have been recorded (Baldwin et al. 2003). Two long distance tag recoveries have been recorded from Yemen and Somalia for green turtles tagged at Masirah (Ross 1987), whereas tagging of olive ridleys and hawksbills, which nest in more remote locations and in lower numbers, has not resulted in any tag recaptures (Al Saady et al. 2004).

Satellite telemetry projects undertaken by the authors tracked loggerhead and olive ridley turtles from their nesting sites on Masirah Island to long-term foraging and overwintering areas; revealing novel insights into the preference for oceanic waters by the loggerheads (Rees et al. 2010) and coastal neritic waters by the olive ridleys (Rees et al. 2012).

In this paper, we describe, for the first time, migratory behavior of green turtles that nest on Masirah Island, contextualize the results with the previous studies tracking turtles from the island, and offer insights as to the probable threats facing these populations.

METHODS

We located two green turtles that had emerged to nest on the east coast of Masirah Island, Oman (lat 20.441°N, long 58.843°E) in 2008. Number of nesting green turtles on Masirah Island is low, and these were the only turtles encountered during the field periods. We have no records for their nesting histories. Turtles were detained on their way back to the sea in a wooden corral. Two-part epoxy (Foilfast, SFS Stadler) was used to affix the Kiwisat 101, Argos-linked satellite transmitters

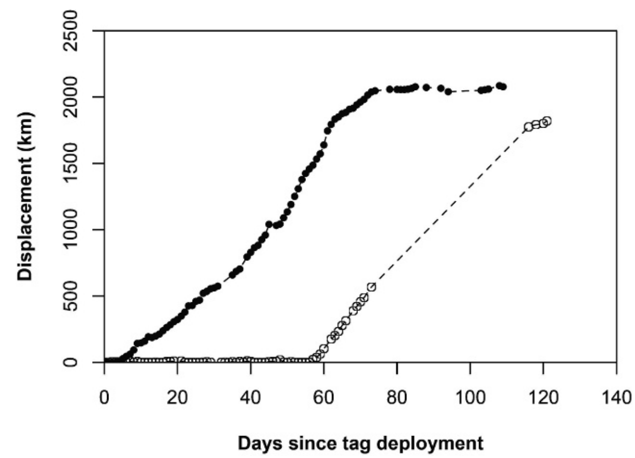

Figure 1. Temporal evolution of displacement from nesting location on Masirah Island, Oman. Turtle 1 (black circles) shows a departure soon after tag deployment, indicating she likely nested no more than once after tag deployment, and an asymptote around 2000 km indicates she settled into a discrete foraging area. Conversely, turtle 2 (white circles) shows extended period in the vicinity of the nesting site, when it probably nested six more times and shows no asymptote, indicating the turtle was still migrating when transmissions ceased.

(Sirtrack Ltd, Havelock North, New Zealand) according to methodology used previously (Godley et al. 2002). Location data were generated by Service Argos (Argos 2012) and were retrieved, compiled, and processed in the Satellite Tracking and Analysis Tool (STAT; Coyne and Godley 2005).

Positional data were filtered within STAT using the following regime: Positions from Argos location classes (LC) 3, 2, 1, A, and B were included as per Witt et al. (2010). From these, position fixes requiring travelling speed greater than 5 km h^{-1} or a turning angle less than 25 degrees were omitted. The filtered locations were then edited to provide a single, best daily location. The best location was obtained by choosing the highest quality LC per day, and if two or more similar LCs existed, the one nearest to 12:00 PM local time was chosen to ensure temporal spread of positions. Distance from shore was generated in STAT using the General Bathymetric Chart of the Oceans (GEBCO; www.gebco.net) dataset. Minimum speed of travel, after departing the nesting area, was calculated between best daily locations using the Spherical Law of Cosines.

Probable nesting events subsequent to transmitter deployment were inferred from convergence of more than one high-quality Argos location being obtained at night, which situated the turtle within 1.5 km of the tagging site. The change from migratory to foraging behavior was identified visually, through the turtle's movements becoming less directed and more tortuous and convoluted and corresponds to the asymptote in displacement from the nesting area. Where distinct foraging areas were identified, we used kernel analysis to define the 75% and 50% use levels, equivalent to estimates of home range and core

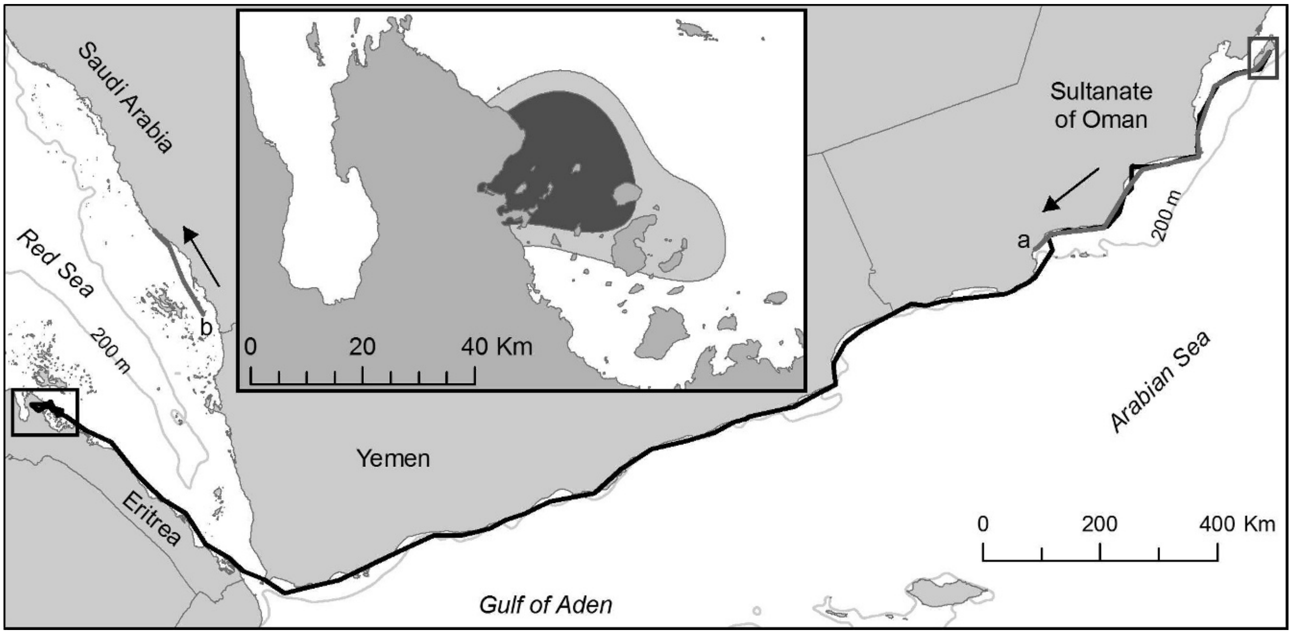

Figure 2. Post-nesting migrations of green turtles nesting on Masirah Island, Oman. Turtle 1 (black line) had settled in a foraging area before transmissions ceased. The inset shows the 50% (dark grey) and 75% (light grey) habitat use for turtle 1, derived from16 daily locations over a period of 31 d. Turtle 2 (two-part grey line) had a long period without data (between locations a [in Oman] and b [in Saudi Arabia] on map) before several signals were received in the Red Sea and showed no indication that a foraging area had been reached. The end points of both tracks are indicated by filled circles. The rectangle to the right of the main map indicates Masirah Island. The 200-m bathymetry contour is displayed for reference.

areas, respectively. A 1-km smoothing factor (h) was used in the fixed kernel density estimator method (Worton 1989) of Hawth's Tools (www.spatialecology.com) for ArcGIS 9.3.1 (ESRI, Redlands, CA).

RESULTS

Green Turtle Departure from Nesting Site. — Neither green turtle had nested during the emergence in which it was equipped with a satellite transmitter. Turtle 1 departed 6 d after transmitter deployment, before which time she probably nested. Turtle 2 remained near the nesting area for 58 d (Fig. 1). Information derived from Argos locations indicated the turtle nested 6 times after receiving the transmitter, with internesting intervals ranging from 10 to 12 d.

Migratory Routes and Parameters. — The two turtles showed remarkably similar migratory behavior. They adopted a largely coastal route from nesting to final location; initially migrating in a southwesterly direction (Fig. 2), although we received no locations between 8 December 2008 and 20 January 2009 for turtle 2. Average speed travelled along the Arabian coast was 1.5 and 1.6 km h^{-1} for turtles 1 and 2, respectively (Table 1). They averaged around 5 km from shore for most of their migrations, hugging the shallow water of the coastline rather than taking a more direct route across the large, open bays of Oman and Yemen (Table 1; Fig. 2). The migratory period for turtle 1 lasted 68 d and was in excess of 64 d for turtle 2 because it had not settled before its transmitter ceased to function.

Final Destinations of Green Turtles. — The tracks of both turtles ended in the Red Sea (Figs. 2, 3) at least 1800 km straight-line distance from origin (Fig. 1). However, because of the geography of the area, with the turtles needing to navigate around the Arabian

Table 1. Carapace size, transmitter activity and migration data for two green turtles tracked from their nesting area on Masirah Island, Oman. CCL: Curved carapace length. Start and End dates of transmitter activity. Coast: distance from coast. Speed and Coast relate to the turtles' westerly migrations along the coast of the Arabian Peninsula; presented as mean ± SD and range. Territories traversed: sovereign state waters the turtles passed through in addition to those of Oman.

ID	CCL cm	Start date	End date	No. days	Speed, km h^{-1}	Coast, km	Territories traversed
1	99.5	26 Aug 2008	13 Dec 2008	109	1.5 ± 0.8, 0.2–4.4, n = 49	5.2 ± 5.4, 0–21, n = 49	Yemen, Eritrea
2	98.0	26 Sep 2008	25 Jan 2009	121[a]	1.6 ± 0.3, 1.3–2.3, n = 13	4.9 ± 4.3, 0–15, n = 14	(Yemen), Saudi Arabia

[a] A period of 43 consecutive days without transmissions during operational life of the tag spanned the time the turtle needed to have passed through Yemeni seas to reach Saudi Arabia (see Fig. 2).

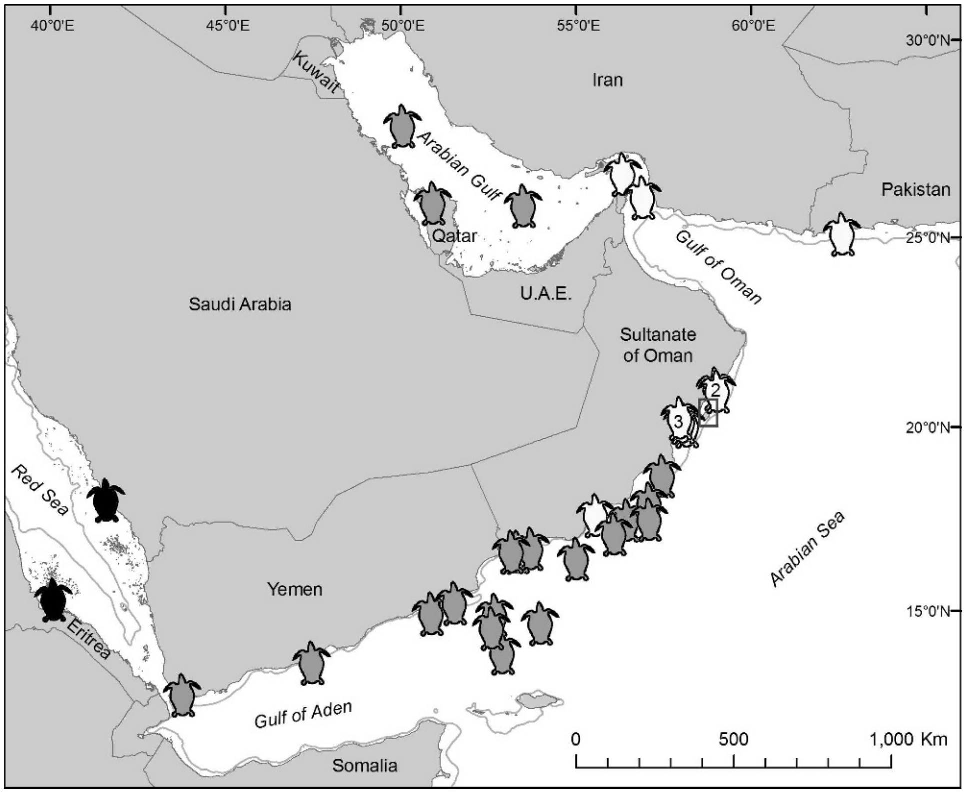

Figure 3. Location of the Masirah Island (tagging site; rectangle) and end locations of green turtles and all previously published satellite tracked turtles from location. Black icons: green turtles ($n = 2$). Grey icons: loggerhead turtles ($n = 20$; Rees et al. 2010). White icons: olive ridley turtles ($n = 9$; Rees et al. 2012). The numerals 3 and 2 on the figure indicate the number of individuals represented by overlapping icons. The 200-m bathymetry contour is displayed for reference.

Peninsula to enter the Red Sea, turtles 1 and 2 had migrated a minimum of 2400 and 2500, km respectively. Turtle 1 had settled into a localized foraging habitat prior to the end of tracking (see inset, Fig. 2), as indicated by a change from directed travel to more convoluted movements for the last 31 d. This was not the case for turtle 2, because the limited tracking data obtained within the Red Sea showed the turtle had not settled in a foraging area but was still undertaking directed movement northwestward along the Saudi Arabian coast (Fig. 2). It is likely that both turtles passed through the coastal waters of Yemen before entering the Red Sea, where turtle 1 moved to the west coast and Eritrea, whereas turtle 2 evidently remained on the Arabian coast and passed into Saudi Arabia.

Final Destinations of Loggerheads and Olive Ridleys. — We overlaid the final locations of 20 loggerhead turtles (Rees et al. 2010; B. Witherington and E. Possardt, unpubl. data, 2009) and nine olive ridley turtles (Rees et al. 2012) that were tracked from their nesting sites on Masirah, onto the end points of the two green turtle tracks presented here. With one exception, the olive ridleys remained localized around the island or migrated several hundred kilometers north, whereas the majority of loggerheads headed southwest to Yemen, often far distant from the shallow coastal zone. However, three loggerheads also migrated northwestward into the Arabian Gulf (Fig. 3).

DISCUSSION

Both green turtles migrated through coastal habitats with one recorded as settling in a neritic foraging area, which is typical of green turtles (Godley et al. 2008). The minimum travelling speed for turtles that nested on Masirah, mean 37 km d^{-1}, is intermediary between the speeds of oceanic (61 km d^{-1}) and coastal (25 km d^{-1}) migrations of Ascension Island turtles (Hays et al. 2002a) but compares well with coastal migrations of conspecifics from Cyprus (41 km d^{-1}; Godley et al. 2002) and Syria (38 km d^{-1}; Rees et al. 2008) and indicates the turtles may be foraging en route to their ultimate foraging grounds, as suggested in these studies.

A sample size of two from a single nesting season limits the strength of conclusions that can be made; intraseasonal and multiyear spreads of a larger number of tags would better represent the population (Rees et al. 2010; Witt et al. 2011). However, with both turtles apparently taking the same route to the Red Sea, and the two existing tag recoveries coming from the direction of the Red Sea (Ross 1987), we already have firm indications of an important migratory corridor and foraging grounds for this population that warrant further investigation.

Interestingly, the three species tracked so far show distinct divisions in location and habitat preference, with loggerheads having a preference for oceanic waters between Yemen and Oman and olive ridleys remaining in local neritic waters (Fig. 3). The green turtles display the most ''classic'' behavior (neritic foraging habitats), whereas results from loggerhead and olive ridley tracking have highlighted plasticity both within and between populations (Rees et al. 2010, 2012). A telemetry study on hawksbills, the fourth species of marine turtle to nest on Masirah Island, is underway (N. Pilcher, L. Perry, and M. Antonopoulou, unpubl. data, 2012), and information derived from it will add to the growing body of data that should be used to inform conservation management measures of these species breeding on Masirah.

Interaction with fisheries is well documented as a threat for marine megafauna, including turtles (Lewison et al. 2004; Soycan et al. 2008; Wallace et al. 2008; Alfaro-Shigueto et al. 2011). Following coastal migratory routes makes the tracked green turtles more susceptible to fisheries operating in shallow, nearshore waters (Hare 1991; Lutcavage et al. 1997; Hays et al. 2002b). These small-scale fisheries have been shown in other regions to have potentially major impacts on turtle populations and are a cause for concern (Godley et al. 1998; Peckham et al. 2008; Alfaro-Shigueto et al. 2011). Oman's main fisheries have recently changed with the 2009 ban on bottom trawlers (Ministerial Decree 20/2009). This law came into effect in May 2011, at the same time as the government announced subsidies for artisanal fisheries (Oman News Agency 2011), which will likely lead to the increase in the already large number of coastal fishers. Oman's artisanal fisheries target demersal fish species as well as rock lobster and abalone, although pelagic species are also caught, and a small shrimp fishery exists in the Gulf of Masirah (Morgan 2006). Capacity limiting programmes in the region are generally rare (Morgan 2006), and the potential higher number and wide distribution of an expanding artisanal fishery will make management even more difficult than at present. Oman is not alone in encouraging the already large artisanal fisheries sector because many countries in the region are using subsidies to develop this sector (Morgan 2006).

Oman's fishers will not be the sole source of fisheries impact, because turtles tracked from Masirah have migrated into and through eight other sovereign territories, each with their own fisheries polices and wildlife protection laws. There is currently no marine fisheries policy framework for the region, and coordination between countries is weak or nonexistent (Morgan 2006). Therefore, any bycatch reduction and marine turtle conservation measures adopted will be fragmented and of less impact than any multinational initiative covering range states of endangered species. As with other investigations, our results highlight the need for international cooperation to completely protect these migratory species (e.g., Blumenthal et al. 2006), However, autonomous conservation actions, noting in this instance the key role played by Oman, which hosts important turtle foraging areas as well as the breeding locale, will likely have significant beneficial effects on the impacted populations (Moncada et al. 2012).

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