Chelonian Conservation and Biology, 2012, 11(2): 229–234

Nest Location and Clutch Success of the Hawksbill Sea Turtle (*Eretmochelys imbricata*) at Shidvar Island, Iran

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ABSTRACT. – **We investigated nest-site characteristics and clutch success of hawksbill sea turtles (*Eretmochelys imbricata*) nesting on Shidvar Island, Hormozgan Province, in the Islamic Republic of Iran. We found that hawksbills tended to cluster their nests at a specific elevation above sea level, and that emergence success was highest in nests nearest to this preferred elevation, declining at higher and lower elevations. These results suggest that elevation might be an important cue for nest-site selection in this population.**

The hawksbill sea turtle (*Eretmochelys imbricata*) is a circumtropically distributed species inhabiting coastal reefs, bays, estuaries, and lagoons (Witzell 1983). Historically, there has been a high demand for its richly patterned scutes and, to a lesser extent, its meat and eggs, resulting in large population declines through intensive harvesting (Mortimer and Donnelly 2008). Population declines have made the hawksbill the focus of intensive conservation efforts over the past decades, which have included extensive monitoring and protection of nesting beaches worldwide.

For sea turtles, nest location is known to have a significant impact on a turtle's reproductive success, and

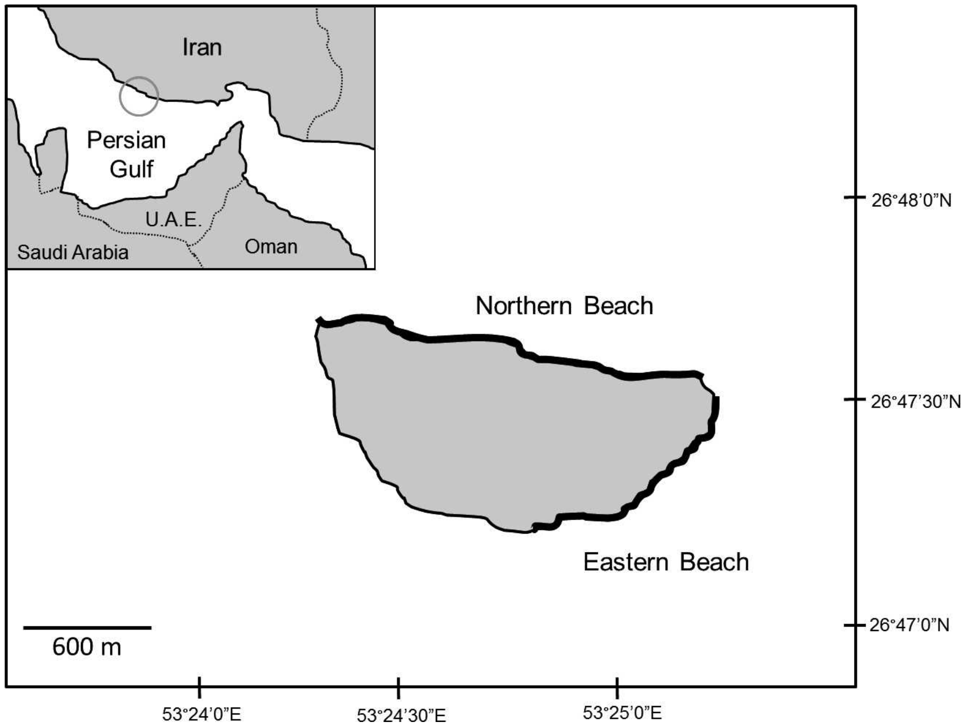

Figure 1. Location of Shidvar Island, Iran, in the Persian Gulf (inset). Hawksbill nesting beaches on the island are indicated by thick black lines.

identification of the proximate cues driving nest-site selection has received considerable attention (for review, see Miller 1997). Such studies have identified several biological, physical, and chemical parameters that are often nonrandomly associated with nest location, including slope and vegetation cover on the beach, salinity, sand particle size, pH, and sand temperature (Horrocks and Scott 1991; Hays et al. 1995; Mortimer 1995; Garmestani et al. 2000; Wood and Bjorndal 2000). Nest location, in turn, has been shown to influence the number and fitness of hatchlings that emerge from the nest (Horrocks and Scott 1991; Janzen and Paukstis 1991; Matsuzawa et al. 2002; Zbinden et al. 2006).

Shidvar Island, in the Islamic Republic of Iran, has been reported as one of the most important hawksbill nesting sites in Iran and was designated a wildlife refuge in 1971 (Davis 1994). However, data on nesting patterns are currently lacking. To remedy this, we investigated 1) spatial patterns in nest locations and 2) the potential influence of several nest-site characteristics on clutch success in this population.

METHODS

Study Site. — Shidvar Island, Hormozgan Province, in the Islamic Republic of Iran, is located in the Persian Gulf (lat 26°48′N, long 53°25′E) and comprises an area of 80 ha. The coastline of the island is 5.5 km long, with 2 sections of beach suitable for sea turtle nesting: the eastern beach (1 km long) and the northern beach (~ 2 km long; Fig. 1). The eastern beach is covered with large coarse pieces of hard coral, resulting in many unsuccessful nesting attempts. It is wider and less steep than the northern beach, and turtles tend to nest along the vegetation border (*Seuda* spp., *Atriplex* sp., and *Cyperus rotundus*). The northern beach is steeper and the vegetation is found in dense patches at the top of sand dunes. Females were never observed crawling over the sand dunes and through the vegetation, and all nests were placed on the seaward side of the dunes.

Data Collection. — Fieldwork was conducted between March and July 2006. During the peak nesting season (5 March 2006 to 31 May 2006), the beach was patrolled between 1500 hrs and sunrise. Morning surveys were conducted to determine whether daytime nesting occurred, but all observed nesting occurred at night. Successful nests were marked with a labeled stick, and data on several nest-site characteristics were collected.

Nest-Site Characteristics. — The slope and distance from the daily high tide line were measured for each nest site. These measures were used to calculate the elevation of each nest site above sea level [elevation = distance × sin (slope); see Atherley 1987]. The presence of vegetation near each nest was also documented. Sand samples were taken at nest depth following hatching, and particle size was measured by shaking a known weight of oven-dried sand through wire mesh sieves (Endecotts, Ponte Vedre, FL). The percentage of the sample with particles < 425 μm in diameter was used as index of particle size (Horrocks and Scott 1991). While females were laying their eggs, 3

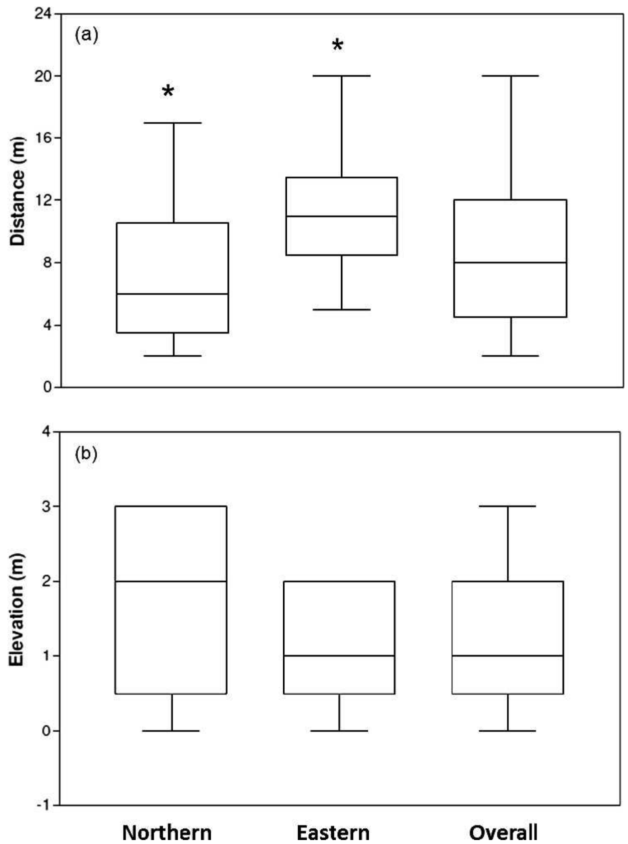

Figure 2. Box plots for (a) distance traveled from the current high tide line and (b) elevation above the high tide line for hawksbill turtles nests at Shidvar Island ($n = 35$). *Indicates comparisons that are significantly different at $p < 0.05$.

sand temperature readings were taken 2 cm below the surface around the nest cavity using a Doric 450 series digital thermometer (Intertechnology Inc, Ontario, Canada). From these readings, a mean temperature for each nest site was calculated.

Clutch Success. — After hatchling emergence, all nests were excavated. Clutch size was recorded by counting the number of hatched (i.e., only the eggshell remained) and unhatched eggs. Hatching success was defined as the number of hatched eggs divided by the total number of eggs (Miller 1999). Emergence success was defined as the number of hatched eggs minus the number of hatchlings remaining in the nest divided by the total number of eggs. The proportion of dead hatchlings was calculated as the percentage of the clutch that was dead in the nest. Unhatched eggs were opened and were broadly categorized as dead embryos (embryo visible) or undeveloped eggs (no embryo visible).

Data Analysis. — Statistical analyses were conducted using SPSS (version 11.5). To investigate the effects of nest-site characteristics (distance from high tide line, elevation, slope, sand particle size, and temperature) on clutch success (size, hatching success, emergence success) we performed parametric linear correlation analyses. Prior to the analyses, all nest-site variables were

Table 1. Clutch size and success of hawksbill turtle nests at Shidvar Island, the Islamic Republic of Iran. Values reported are means ± SD.

	Northern beach ($n = 24$)	Eastern beach ($n = 11$)
Clutch size	129.5 ± 29.7	111.4 ± 24.6
% Hatching	84.3 ± 22.1	73.3 ± 11.1
% Dead hatchlings	3.6 ± 9.7	2.3 ± 7.9
% Undeveloped eggs[a]	9.1 ± 7.9	19.7 ± 11.8
% Emergence	78.7 ± 30.3	70.5 ± 26.8

[a] Indicates a significant difference at $p < 0.05$.

linearized (Stamps and Eason 1989; Horrocks and Scott 1991). All components of clutch success recorded as percentages were arcsine transformed for analyses (Zar 1998). Values are presented as mean ± SD, and all p values are significant at alpha = 0.05.

RESULTS

We observed 54 nests on Shidvar Island and collected data on the location and nest-site characteristics for 35 of them. Of these 35 nests, 24 nests were placed on the northern beach and 11 were placed on the eastern beach, with most nest sites located less than 1 m from the vegetation ($n = 29$). In total, 37 clutches were deposited on the northern beach and 17 were deposited on the eastern beach.

Nest-Site Characteristics. — Hawksbill nest sites were located between 2 and 20 m above the daily high tide line (10.1 ± 7.3 m SD). There was a significant difference between the 2 beaches ($t = 2.18$, $p = 0.04$), with turtles on the northern beach nesting closer to the high tide line (6.3 ± 6.6 m SD) than those on the eastern beach (11.3 ± 5.6 m SD; Fig. 2a). Most nests ($n = 28$, 80%) were constructed at an elevation of 2 m or less above the high tide line (Fig. 2b). Nests were situated at a slightly higher mean elevation on the northern beach (1.8 ± 1.7 m SD) than on the eastern beach (0.8 ± 1.1 m SD), but this difference was not significant ($t = 1.78$, $p = 0.08$). The mean beach slope across all nest sites was 7.3° ± 4.3° SD. Eighty percent of nests ($n = 28$) were located on beach sections with slopes of 7° or less, with the remaining 7 nests on steeper sections with slopes varying between 8° and 21°. The difference in slope at the nest sites was not significant between beaches ($t = 0.36$, $p > 0.05$), but the slope tended to be steeper on the northern beach (7.7° ± 4.1° SD) than on the eastern beach (5.9° ± 4.2° SD). The sand surface temperature during egg deposition was 32.3°C ± 2.1°C SD for nests on the northern beach and 31.4°C ± 1.2°C SD for nests on the eastern beach, which were not significantly different ($t = 0.64$, $p > 0.05$). The proportion of the sand sample with particles < 425 μm was 69.3% ± 8.8% SD from nests on the northern beach and 11.3% ± 14.3% SD from nests on the eastern beach, and was significantly different between beaches ($t = 1.94$, $p < 0.05$).

Table 2. Pearson's correlation coefficients (r) between nest-site characteristics and clutch success for hawksbills nesting on Shidvar Island, the Islamic Republic of Iran.

	Clutch size	% Emergence	% Hatch	% Undeveloped eggs	% Dead embryos
Elevation	0.03	0.39[a]	0.37[a]	−0.53[a]	0.28
Slope	0.17	0.38[a]	0.41[a]	−0.34[a]	0.23
Temperature	−0.17	−0.31	−0.26	0.11	0.12
Sand size	0.18	−0.13	−0.01	0.01	0.11

[a] Indicates a significant correlation at $p < 0.05$.

Clutch Success. — Mean clutch size ($n = 35$) was 124 ± 28 eggs SD and was not significantly different between beaches. There were no significant differences between the beaches with respect to hatching success, emergence success, or the percentage of dead hatchlings within a clutch (Table 1). However, among the unhatched eggs, there was a significantly greater percentage of undeveloped eggs on the eastern beach ($t = 3.15$, $p = 0.004$).

Clutch size was not correlated with any of the environmental variables that we measured, but hatching and emergence success were positively correlated with linearized elevation ($r = 0.37$ and 0.39, $p < 0.05$, respectively; Table 2). This indicates that success was highest for nests closest to the mean elevation and declined at both higher and lower elevations. The percentage of undeveloped eggs in a nest was negatively correlated with linearized elevation ($r = -0.53$, $p < 0.05$). There were no significant correlations between components of clutch success and sand particle size or temperature (Table 2).

DISCUSSION

Shidvar Island is thought to harbor one of the most important hawksbill nesting areas along the Iranian coast in the Persian Gulf (Mobaraki 2004). Despite this fact, data on nesting numbers, nest-site characteristics, and reproductive output from these areas are virtually nonexistent. Using information gathered from 35 nests, we found that females in this population selected nest sites at elevations that seemed to maximize the hatching (and emergence) success of their clutches. Measures of nest elevation were more normally distributed and had less variance than measures of nest distance from the daily high tide line (Fig. 2a, b). This suggests that hawksbills are more sensitive to elevation than to distance from high tide line when selecting nest sites at our study site. In fact, elevation was not significantly different between the 2 beaches but crawl distance was, suggesting that females altered their distance to select nest sites at a particular elevation.

Females traveled significantly longer distances inland on the eastern beach, which could potentially increase the energetic costs of nesting. Perhaps this is why most hawksbill nesting occurred on the northern beach, where females had to travel less distance inland to deposit nests at the preferred elevation. This beach section is also protected from wave action and wind erosion by its proximity to Lavan Island, and is thus less exposed than the eastern beach, decreasing the costs of moving onto and off of beaches characterized by heavy wave action (Horrocks and Scott 1991). Although it is possible that the greater number of nests on the northern beach might simply due to its longer length, both personal observations and previous work (Mobaraki 2010) suggest that the northern beach comprises more suitable habitat in terms of beach access, slope, and sand characteristics.

Importantly, hatching and emergence success were highest in nests closest to the mean elevation and declined at higher and lower elevations. We also found that the percentage of undeveloped eggs was significantly lower in nest sites located near the preferred elevation. This pattern has been observed in a hawksbill population nesting in Barbados (Horrocks and Scott 1991) and raises the important question of which biotic and abiotic factors related to elevation are influencing clutch success.

It is well known that a particular nest site carries risks related to nesting too near vs. too far from the tide line. For example, nests placed close to the tide line are at increased risk of inundation, and developing embryos are sensitive to chloride (Bustard and Greenham 1968), moisture (Foley et al. 2006), and salinity (McGehee 1990). Conversely, nests placed too far inland can increase hatchlings' risk of predation and disorientation (Fowler 1979; Godfrey and Barreto 1995). In fact, we found that hatchlings originating from nests that were located relatively far from the sea had scorched plastrons and presumably died from heat and dehydration during sea-finding (R. Zare, *pers. obs.*). It is possible that nesting at this particular elevation reflects a trade-off between the selection pressures driving nesting inland and those driving nesting seaward.

Even though we found no differences in hatching success between beaches, we did find a significant difference between the percentages of undeveloped embryos, suggesting that some component related to embryonic development differs significantly between the beaches. One possible explanation for this is that sand particle size was significantly larger on the eastern beach. In several studies of loggerheads and green turtles, hatching success decreased as a function of increasing sand grain size, likely due to the much lower water content in the sand (Schwartz 1982; Ackerman 1997; Foley et al. 2006). Sand grain size affects both gas and water flux (Ackerman 1980), and the low diffusive conductance of respiratory gases through beach sand can produce a hypoxic environment for developing embryos (Ackerman 1977). However, studies in the leatherback sea turtle, at least, have revealed mixed results. In some cases high oxygen partial pressures were recorded in nests, suggesting that hypoxia does not contribute to the low hatching success seen in many leatherback clutches (Wallace et al. 2004). In other cases, late-stage embryonic mortality was highest in nests with low pO_2 and high pCO_2 concentrations (Garrett et al. 2010). Hawksbills, like leatherbacks, produce very large clutches (100–250 eggs), and oxygen might also be limiting to the developing embryos since they develop farther from the atmospheric source of oxygen within these larger clutches. However, hawksbill nests are significantly shallower than leatherback nests, so availability of respiratory gases should be less of a factor for hawksbill embryonic development than it is for leatherback embryos. On the other hand, the shallow depth of hawksbill nests might make embryos more susceptible to the low water content associated with coarser sand and surface evaporation. It remains to be seen which biotic and abiotic conditions in nests are important influences on the developmental environment and clutch success of hawksbill nests at Shidvar Island.

Most hawksbill nests in Shidvar Island were placed less than 1 m from the vegetation, suggesting a preference for nesting near vegetated sites. This preference has previously been documented in other hawksbill populations (Horrocks and Scott 1991; Mortimer 1995; Kamel and Mrosovsky 2005, 2006). A common explanation for this is that nest sites with vegetation are often less compacted than those without and thus have higher emergence success than nonvegetated sites (Horrocks and Scott 1991). However, we found no differences between sites with vegetation and sites without, although the number of nonvegetated nest sites in our sample was quite small ($n = 6$).

In summary, the environmental variable that appears to have the greatest influence on nest placement and clutch success at Shidvar Island is elevation. However, the dynamics of sandy beaches need to be studied over a more extensive period of time before this can be confirmed. We envision several other research directions that must be explored to understand the factors driving nest-site choice at Shidvar Island. First, we would like to determine the conditions underlying the higher percentage of undeveloped eggs on the eastern beach. This might be because of differences in moisture, gas exchange, or some other environmental variable potentially correlated with sand size. Alternatively, this pattern might be a result of differences in the reproductive output among females nesting at the 2 beaches. If certain females consistently choose a certain beach, then the differences between beaches might be driven by differences among females. Thus, a second research direction would be to increase knowledge of individual differences in patterns of nest-site choice (Kamel and Mrosovsky 2005, 2006) to shed more light on this matter. Finally, it would be valuable to understand what specific nest-site characteristics contribute to increased hatching success at the preferred elevation. Elevation has been shown to be an important cue in this and previous studies (Horrocks and Scott 1991; Wood and Bjorndal 2000), yet the underlying cause of this pattern remains unknown.

ACKNOWLEDGMENTS

This study was conducted with research permits granted by the Department of the Environment in Tehran, Iran. We thank Karen Bjorndal and Matthew Godfrey for their helpful comments on this manuscript. We also thank M. Mohseni, head of the Department of the Environment in Hormozgan Province for support that enabled us to study hawksbills on Shidvar Island.

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Received: 7 March 2012

Revised and Accepted: 7 May 2012

Handling Editor: Bryan P. Wallace