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Comparative Study of the Nesting Behavior of the Green Turtle, *Chelonia mydas*, During High- and Low-Density Nesting Periods at Ras Al-Hadd Reserve, Oman

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Abstract. – **The nesting behavior of the green turtle (*Chelonia mydas*) at Ras Al-Hadd, Oman, was conducted under two nesting periods; high-density (peak) nesting (June–October) and low-density (non-peak) nesting (November–May). During these two periods the behavioral nesting phases had both differences and similarities. Based on the number of turtles (200–400/night) during high-density nesting, with limited beach space, nest site selection became very competitive and nesting in the tide zone was more frequent. During low-density nesting (10–20/night), the reverse behavior occurred, with nesting in the tide zone being less frequent and turtles having a greater selectivity in choosing their sites. Sand moisture content may also be a factor in nest building. During non-peak nesting, sand moisture is low because of dry desert winds, causing nest collapse and significantly higher nest abandonments than during high-density nesting when the prevailing wind is from the ocean and sand moisture is adequate. During peak nesting, because of extreme crowding conditions, emerging turtles colliding with nesting turtles caused some of them (ca. 20%) to abort their nesting process. This occurred only if the nesting turtles had not yet oviposited. Stressful procedures were performed on some turtles during nesting: blood sampling from the cervical sinuses and tagging the front flippers. Following these procedures, a significantly higher number of the turtles (17%) remained on the beach and continued their nesting exercise during peak nesting compared to only 2.6% during non-peak. The data indicate that during peak nesting turtles were more stress tolerant than during non-peak nesting. During peak nesting turtles were less disturbed or frightened by human presence, with 54% remaining on the beach and continuing their nesting as compared to 11% during non-peak. Total nesting time was not significantly different between the two nesting periods, but total time was correlated with ascent on beach, digging time, and return to sea. Mound length was correlated with nest chamber depth; length of beaches, slope, and exposure had no influence on nest selection.**

Key Words. – **Reptilia; Testudines; Cheloniidae; *Chelonia mydas*; sea turtle; ecology; behavior; nesting; seasonality; Arabian Sea; Oman**

The nesting behavior of sea turtles under natural conditions has been previously described (Hendrickson, 1958, 1982; Carr and Ogren, 1960; Carr and Hirth, 1962; Bustard and Greenham, 1969; Bustard, 1972; Hirth and Carr, 1970; Tufts, 1972; Schulz, 1975; Ehrenfeld, 1979; Ehrhart, 1982; Chen and Cheng, 1995; Al-Gheilani, 1996; Miller, 1997). Each of these studies reported on different aspects of the nesting process. However, nesting characterization needs more detailed studies, especially for comparing intra-specific populations of different geographical regions relative to the ecological, climatic, and physical characteristics of their nesting beaches. The endangered sea turtle species *Chelonia mydas* was chosen for the present study because of its worldwide distribution and high nesting density in Oman.

The southern sector of the Arabian Peninsula, which includes the coastal region of Oman and Yemen, hosts one of the largest populations of the green turtles in the world (Ross and Barwani, 1982). More than 90% of the nesting green turtles in Oman are found at Ras Al-Hadd Reserve, which has isolated nesting beaches, extending from Ras Al-Hadd village to Ras Ar-Rú-ays (Fig. 1). Ross (1979) estimated about 6000–18,000 green turtles nest at Ras Al-Hadd Reserve each year. In addition, small scattered nesting populations are found on Masirah Island and elsewhere along the coastline of the Arabian Sea. Green turtles are also found in the Arabian Gulf mainly on the offshore islands of Karen and Jana (Miller et al., 1989; Pilcher and Al-Merghani, 1994) and on the coast of the Red Sea (Gasperetti et al., 1993; Al-Merghani et al., 2000).

The mark-recapture program in the Sultanate of Oman started in 1977 and focused on Masirah Island and Ras Al-Hadd National Reserve. More than 40,000 green turtles have been tagged and some have been recaptured during the last 24 yrs as an on-going conservation and management study. An extensive database was also established in Saudi Arabia on green turtles relative to their ecology, reproduction,

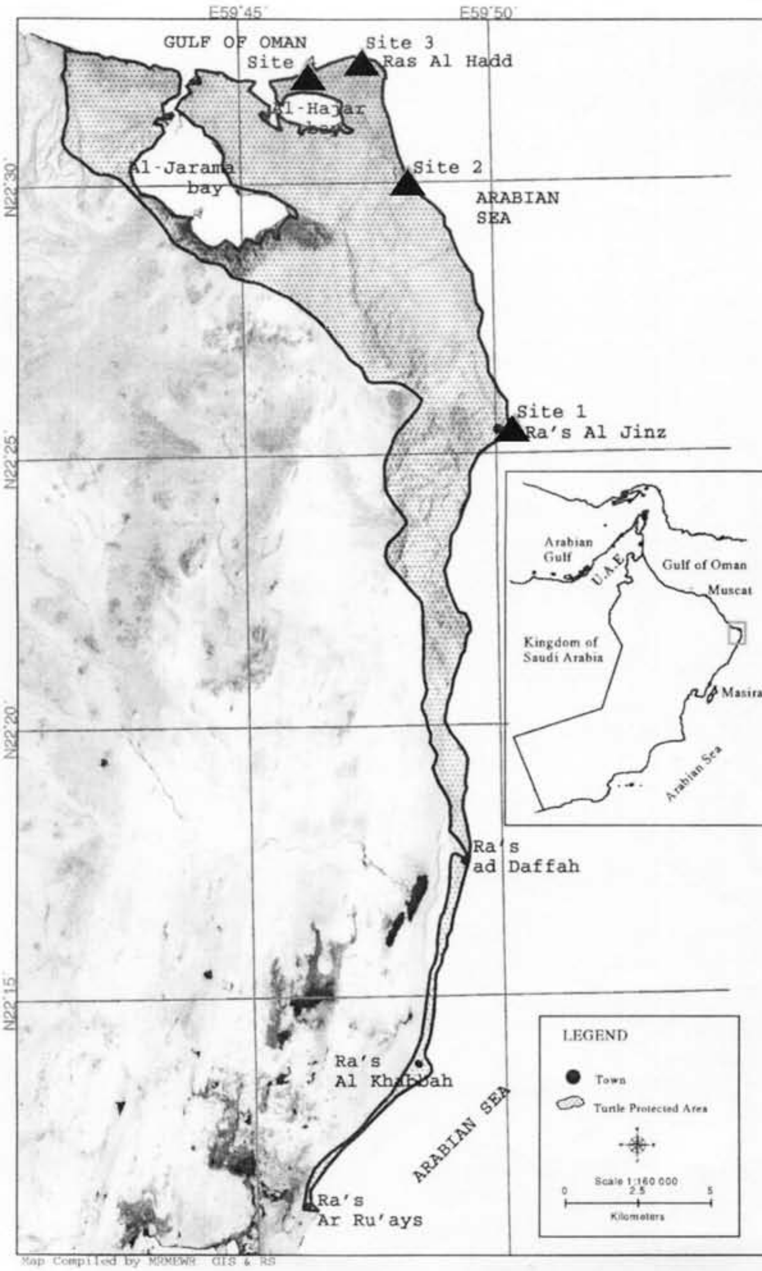

Figure 1. Map showing locations of study sites 1–4 in Ras Al-Hadd Reserve, Oman.

feeding areas, and distribution (Miller et al., 1989; Gasperetti et al., 1993; Al-Merghani et al., 1996; Pilcher, 1999).

A great number of sea turtles traveling from regions of southern Arabia, including Oman, have been observed in the Red Sea and around the Horn of Africa (Hirth and Carr, 1970). In the mark-recapture program of Oman, green turtles have been recovered from feeding areas in Ethiopia, Somalia, Yemen, United Arab Emirates, and Pakistan (Salm, 1991). The major feeding areas for the local population of sea turtles are the Oman coastline and channel of Masirah Island (Ross, 1985; Salm, 1991). Tagged turtles have been recovered from these regions as reported by the Ministry of Regional Municipalities and Environment. The data also revealed that some of these green turtles returned to beaches of Oman for nesting, especially at Ras Al-Hadd. To date, there have been insufficient data to confirm the interaction between demography of nesting turtles and feeding grounds. The tag-recapture program is one tool in the study of this interaction but more extensive work is needed.

The main purpose of this investigation was to compare the nesting behavior of the green turtle at Ras Al-Hadd Reserve during June–October (peak nesting period) when nesting density is high with November–May (non-peak nesting period) when nesting density is low. In addition, measurements of nest parameters were obtained, including the dimensions of body chamber, nest chamber, mound length and width, and morphometric data of the turtles. Time span between different phases of nesting, as well as measurements of nest chambers, were compared between the two nesting periods.

Investigations on the nesting behavior of this species in Oman have been neglected. Green turtle conservation efforts are hampered by a lack of specific information regarding their physiology and behavior during nesting. This study is an initial effort to develop a database useful to both Omani conservationists and biologists. The study should also prove to be a resource in efforts to protect all endangered sea turtles in this region.

METHODS

Study Area. — Ras Al-Hadd Reserve is located where the Gulf of Oman and the Arabian Sea meet (between 22°32'N and 59°45'E and 22°14'N and 59°48'E) (Fig. 1). The first 4 km in the north are located on the Gulf of Oman, while the rest of the Reserve is located on the Arabian Sea. The coastline extends from north of Ras Al-Hadd to Ras Ar-Rú-ays in the south and is characterized by moderate to high-energy wave action and mostly sheltered by rocky hills (Salm and Salm, 1991). Approximately twenty beach areas with different lengths (50 m to 5.3 km long) make up the Reserve. Most of these beaches are protected by rocky hills and are considered ideal nesting grounds for the green turtles.

The main study area was Ras Al-Jinz, a 1-km beach about 12 km south of the village of Ras Al-Hadd (Fig. 1, Site 1). It is backed by rocky hills from north and south sides of the beach along the shoreline and about 100–150 m from the rocky hills to the tide line. However, the nesting area was limited to 30–40 m from the tide line based on the presence of nest mounds and abandoned body chambers. The beach is divided into northern and southern sectors by a small rocky elevation.

Methodology. — In this investigation, we elaborate on some aspects of nesting behavior and include observations previously unreported. We omitted some observations that have previously been reported. All the observations on nesting behavior were recorded at Ras Al-Jinz. An observer sat a few feet directly behind the turtle with a stopwatch and small flashlight, used occasionally but not directly on the turtle. A video digital camcorder was used to photograph the phases of nesting. The turtles were observed for the entire duration of each phase, although some of these turtles did not complete the entire phase because of unfavorable conditions, such as inadequate sand moisture, artificial lighting, obstacles during digging, or the presence of humans or animals. The study was conducted during June–October 1994, June 1995, December 1999, June 2000, and January 2001. A group of government rangers were also involved in the field observations. The observations on nesting behavior were based on 29 complete nests for peak period and 27 for non-peak period.

In addition, two sets of nesting data were gathered. First, a total of 62 nests were observed from each nesting period to study the number of nesting attempts, abandonments, and nesting success. Secondly, a total of 394 nests from the peak period and 131 from the non-peak period were studied to investigate nest distribution and distance from the high tide line.

At Ras Al-Jinz random areas (100 x 50 m) were selected to examine and count turtle tracks still fresh from the previous night. This size was found to be large enough to assign tracks to individual turtles without confusion. Based on these observations, the number of complete and incomplete nests and their distances from the high tide mark were recorded. The tracks were traced from the high tide mark to the nesting site, or sites, depending on the number of body chambers each turtle made. The tracks were traced from the nest site back to the sea so that a complete record of each turtle was obtained. Abandonments were based on the number of body chambers excavated by each turtle. In this investigation successful nesting signifies that a turtle oviposited its eggs before returning to sea. The actual number of nesting turtles at Ras Al-Jinz was based on direct count by the rangers at the Reserve for the last 10 yrs, and varied over the years between 200–400/night during peak and 10–20/night during non-peak nesting periods.

Turtles preparing to dig their nest chamber were subjected to two procedures associated with ongoing reproductive physiology and population studies. Turtle behavioral response patterns immediately following the procedures were analyzed. The physiology and population study procedures involved: (1) blood collection from the cervical sinuses for monitoring circulating hormone levels, and (2) tagging with metal plates on front flippers for future identification. The research team conducted all blood sampling, whereas tagging was performed by the Reserve Rangers. After the procedures, some turtles returned to sea immediately, while others stayed on the beach and moved about randomly. Tagged and sampled turtles were considered unaffected if nesting resumed within an hour of the two procedures. The research team spent 5 hrs/night on the beach for 21 nights for 88 turtles observed during peak periods, and 36 nights for 76 turtles during non-peak periods.

The response of turtles to the presence of humans without conducting procedures was also evaluated. Direct approach to turtles was made to those seeking a nesting site or actively engaged in digging a body or nesting chamber. Occasionally a flashlight was directed on a turtle to act as a disturbance. Response was recorded as return to sea or continued nesting. In all, 75 (peak) and 53 (non-peak) turtles were observed over 13 and 19 nights, respectively.

During peak period, emerging turtles occasionally collided with those engaged in nesting. The reactions of the emerging and nesting turtles were recorded. In another experiment, turtles were occasionally intentionally disturbed during burying or mound formation by attempting to move them from their site. The reaction of the turtles was recorded.

Body and nest chambers were measured during oviposition and prior to the filling phase. All other measurements were done after nesting had been completed. Flexible fiberglass tape was used to measure the nest dimensions. The curved carapace length (CL) was measured by placing a flexible tape on the mid-line of the carapace from the nuchal scute to the posterior end of the carapace. Curved carapace width (CW) was measured by placing the tape along the surface at its widest point.

Nesting frequency in relation to size of sand particles, beach slope, and beach exposure were studied at sites 1–4 (Fig. 1). Sand samples were collected in August 1995 from the four sites at Ras Al-Hadd. The samples were taken at 10 m from the high tide mark at 60 cm depth. Particle size was determined by passing 50 g of sand through a series of sieves (mesh sizes: 2, 1, 0.5, 0.25, 0.106, and 0.053 mm) on a shaker for 10 min (Stancyk and Ross, 1978). The fractions of sand retained by each sieve were weighed and recorded as a percentage of total sample weight.

Spearman rank correlations were computed for the various activity times and other body measurements. For the differences in measurements between the peak and non-peak periods the Mann-Whitney U-test was used. All the statistical analyses, including the tables, were done using the statistical package SPPSS (version 10.0) with $\alpha = 0.05$.

RESULTS

Nesting Behavior. — In this study, the process of nesting in the green turtle was divided into seven phases: (1) ascent onto the beach, (2) digging body chamber, (3) digging nest chamber, (4) oviposition, (5) filling nest chamber, (6) filling body chamber and mound building, and (7) return to sea.

New observations noted for the first six phases are described with brief exposition of previously reported behavior for continuity, phase 7 had no new observations. Throughout the phases of nesting, the turtles paused for rest after a burst of activity, with repeated activity-rest cycles usually lasting between 20–90 sec (AlKindi et al., unpubl. data).

1. *Ascent onto the beach.* After the turtle emerges from the sea it is sluggish and crawls very slowly toward the nesting grounds. Periodically, it stops, exhales and inhales, and then proceeds. Its breathing is very shallow.

2. *Digging body chamber.* Once a turtle begins to dig the body chamber, she will usually continue until she finishes, unless there is a disturbance. Obstacles such as rocks may discourage the turtle from continuing the process, and usually she then abandons the chamber and selects another site.

The front flippers begin to make forceful sweeping motions digging into the sand and throwing showers of sand, which lands posteriorly, laterally, and sometimes on the carapace. The front and rear flippers coordinate in an alternating fashion rather than independent front or rear motions. When the right front flipper is in motion, the same is true for the left rear flipper and vice-versa. Subsequently, the rear flippers begin to push the piling sand toward the rear from the sides with sweeping motions. Thus, the rear flippers prevent sand from piling up by pushing the sand away, making the back half of the chamber, while the front flippers dig the front half.

3. *Digging nest chamber.* When the right hind flipper enters the nest chamber, it scoops with a counter-clockwise motion while the left flipper scoops with a clockwise motion. As each flipper comes out of the nest chamber, the scooped sand is held by the flexed foot to form a cup shape pointing posteriorly. Within 4–5 sec the foot releases the sand ca. 8–10 cm postero-lateral to the nest chamber and immediately it rests its flipper on the released sand. Before the other flipper enters the nest chamber, it flicks the sand antero-laterally, which is held underneath its foot from the previous scoop. This maneuver occurs prior to each time the flipper enters the chamber. This allows very little sand accumulation near the rim of the nest.

After each flicking motion, the posterior body is raised slightly above the nest chamber followed by a slight rotation and tilting of the body toward the opposite flipper which is about to enter the nest chamber, giving it more power in its scooping action. During the rotation, the flipper, which is not involved in digging, acts as a pivotal support pressing on the scoop of sand underneath. During each rotation, the tail and the cloacal chamber are always projected into the nest chamber.

During the early stages of nest chamber excavation, the rear flipper makes a vertical penetration into the sand followed by a sideways semicircular scooping motion. About halfway through the excavation, the nest chamber takes a cylindrical shape. Afterward, the scooping action involves more carving into the sides of the chamber. To accommodate this maneuver, a longer scooping reach by the flippers is accomplished by a slight tilting and rotation toward the side of the flipper to reach its full length as the nest chamber becomes gradually deeper and wider below the halfway mark. At the end of nest digging, the nest chamber takes on a pear shape.

4. *Oviposition.* After completing the digging of the nest, with the tail extending into the nest chamber and the cloacal wall distended, the turtle begins to lay its eggs with periodic secretion of mucous fluid over the eggs. The entire body leans gently toward the nest chamber as the eggs are forced out through the cloacal opening, which appears to be accompanied by waves of contractions in the cloacal chamber area.

Prior to egg laying, any disturbance would cause the digging to stop and the turtle would abort nesting and head toward the sea. Once the turtle begins to lay its eggs (6 or more), any disturbance such as human presence does not affect the process. This behavior occurs mostly during the non-peak nesting period.

5. *Filling nest chamber.* At the beginning, the rear flippers working together make a sweeping motion toward the nest chamber, filling most of it in few sweeps from the lateral sides. This motion continues with periodic vertical and horizontal tamping (patting) with the rear flippers until a mound is built at the site of the nest chamber. Afterward, the front flippers begin to make sweeping motions in a posterior direction, which marks the beginning of filling the body chamber, and the formation of the mound.

6. *Filling body chamber and mound building.* With the head and neck slightly raised above the sand, the front flippers begin to make forceful sweeping motions, sending a shower of sand, at first landing on the posterior rim or slightly beyond the body chamber, with some on the cara-

pace. Simultaneously, the rear flippers gather the sand from each side, pushing it toward the middle, creating a mound, which is continuous with the original mound of the nest chamber. As the turtle begins to crawl slowly forward, the mound, in time, becomes longer. This operation is the longest of all the nesting phases, which continues until the body chamber is filled and the mound is formed. As the front flippers make the back sweeps, they dig into the sand, thus making two depressions, one under each flipper. When these depressions become deeper and beyond the reach of the front flippers, the turtle is forced to move slowly forward so the flippers can establish new contact with the sand surface. The front flipper digging motion causes the collapse of the wall of the body chamber as the sand falls in front and sides of the body chamber. The sand is then thrown toward the rear by the front flippers while the rear flippers continue to add to the length of the mound. Thus, the length of the mound depends on how far the turtle moves from the original nest chamber.

Figure 2 shows the duration for each nesting phase. Total nesting time is not significantly different in the two nesting periods, but is moderately correlated with time of digging the nest chamber, with emergence and with ascent on beach and return to sea (r = 0.47, r = 0.42, r = 0.33).

Abnormal Nesting Behavior. — On separate occasions, three turtles demonstrated abnormal behavior by completing all phases of nesting without ovipositing their eggs. They proceeded to cover the nest chamber and the body chamber with a similar pattern to a turtle actually ovipositing her eggs.

At the end of the abnormal nesting operation, two of the three turtles proceeded to dig a new body chamber immediately next to the previous one. Next, the two turtles began to excavate their nest chambers, but this time they laid their eggs, with 96 for turtle 1 and 101 eggs for turtle 2. After this normal nesting operation was completed, they moved immediately to the sea. The third turtle moved to the sea shortly after the first abnormal nesting operation.

Nest Site Selection. — During peak nesting period, turtles emerging from the sea collided with 5% of nesting turtles (n = 101) at Ras Al Jinz. After collision, all emerging turtles were observed to move to another site while 20% of the nesting turtles left their chosen site if they were in the process of digging body or nest chamber. However, if the collision occurred during oviposition, all the turtles remained on their sites continuing their nesting process.

A total of 394 nests were observed during high-density (peak) nesting period (June–October) and 131 during low-density (non-peak) nesting period (November–May). During high-density, the frequency of nest site selection inside the tide zone increased significantly ($p < 0.001$) over the low-density turtles (Fig. 3). However, outside the tide zone (1–5 m), there was a significant ($p < 0.001$) increase in the low-density turtles (Fig. 3). For distances 26–30 m, the percentage of nesting was higher ($p < 0.001$) in high-density period than in low-density period. For the rest of the distances there was no significant difference between the two nesting periods.

In both high-density and low-density periods, over half (52.8 and 55.8%, respectively) nests were beyond 10 m from the tide zone (Fig. 3).

Based on the high number of nesting turtles during the high-density period in a limited space (1 x 0.5 km), nest site selectivity became very competitive, and nesting in the tide zone became very frequent (Fig. 3). During low-density, the reverse conditions occurred; nesting in the tide zone became less frequent and the turtles had a greater selectivity in choosing their nesting sites.

Nests inside the tide zone were completely destroyed as the seawater of high tide washes all the eggs out of the nests

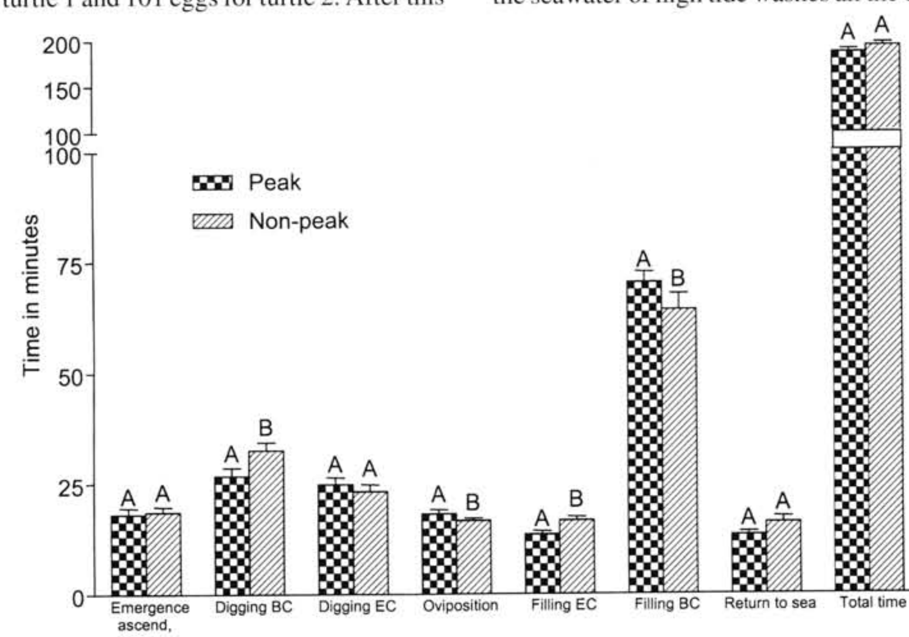

Figure 2. Mean duration of nesting phases in the green turtles at Ras Al-Hadd Reserve-Oman. Different letters on the bars indicate significant differences. BC = body chamber; EC = egg chamber (nest chamber). Sample size for peak period n = 29, for non-peak period n = 27.

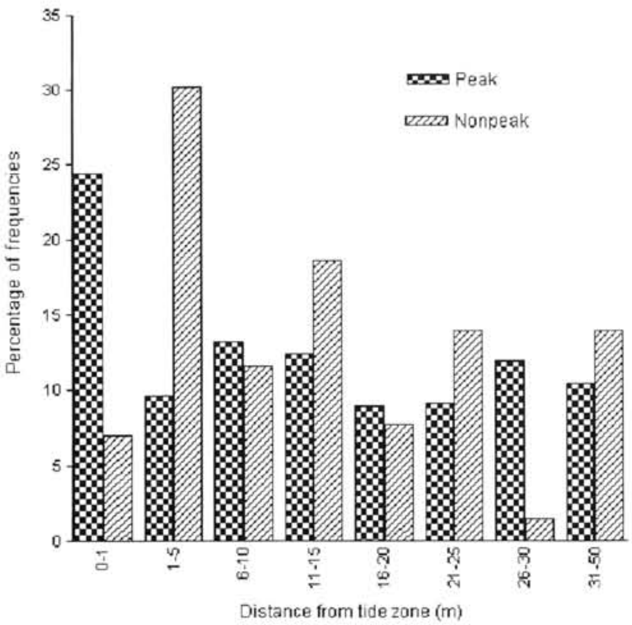

Figure 3. Percentage of nesting site distribution during peak and non-peak periods relative to low tide line. Based on total of 394 and 131 nests during peak and non-peak, respectively.

within a few hours after oviposition. The exposed eggs were either washed into the sea or eaten by predators such as foxes and shore birds.

With the dramatic increase in the number of nesting turtles during the high-density period, the incidents of digging out previous nests was 2.3% (n = 29) but none was observed during non-peak period (n = 27). Whenever this occurred, exposed eggs were either eaten by predators or dried up.

We analyzed the number of nesting attempts and whether the turtles had nesting success or not. A random sample of 62 turtles was used during each peak and non-peak period. Overall, nesting success was 52% and 19% for peak and non-peak periods, respectively. The difference was highly significant ($p < 0.01$). The percentages of turtles that made more than one attempt and nested successfully were 32% for peak and 23% for non-peak periods and the difference was not significant. However, the percentage of turtles that nested on the first attempt successfully was 19% for peak compared to only 6% for non-peak and the difference was highly significant ($p < 0.01$).

Abandonment of nest site before completion was common especially during the low-density season when the sand was dry and dry northern winds were continuous. The number of trials increased when the sand was dry. In all cases, the turtle tried to dig the nest chamber but the dry sand from the sides kept re-entering the chamber. After a nest collapse, the turtle either went back to sea or started a new nest, which involved digging new body and nest chambers. Between 1–7 trials were observed as turtles tried to dig nest chambers, in rare cases up to 9 trials. In most cases, the turtle continued digging and would not abandon the nest until there was repeated sand re-entry into the nest chamber.

Nesting Disturbance. — Two procedures, blood collection and tagging, were performed on turtles prior to nesting. Following the procedures, turtles either continued their nesting or immediately returned to the sea. During peak period, 17% (n = 88) of turtles resumed their nesting compared to only 2.6% (n = 76) during non-peak period.

In another experiment, nesting turtle response to human presence depended upon the period. During peak, while selecting a nest site or digging a body or nest chamber, 54% (n = 75) of turtles continued as if undisturbed, while during non-peak only 11% (n = 53) continued nesting.

After the eggs have been oviposited and filling phase had already begun, all observed turtles (n = 81) continued their nesting regardless of the magnitude of disturbance or any physical manipulation inflicted on them, such as moving the turtles from the nesting site to another location. Based on 5 turtles, it was noted that if the turtles were moved while engaged in filling or mound formation, they continued their nesting activity by engaging in the same natural movements in the new location. This behavior occurred during peak and non-peak periods.

Nest and Body Parameters. — Table 1 demonstrates wide variation between minimum and maximum values for the nest parameters. The data from peak and non-peak periods were combined, as the difference in measurements were not significant between the two periods. The body chamber depth is correlated with body chamber length and width (r = 0.51, r = 31). Mound length is correlated with nest chamber depth based on 29 nests during peak and 27 during non-peak periods (r = 0.41). The mound is frequently constructed in a straight line from the nest chamber but occasionally obstructions in the path would force the turtles to change direction either right or left depending on the size and location of the obstacle.

Based on 53 healthy green turtles, the ranges and means for body measurements were: CL 101.7 ± 0.65 cm (range

Table 1. Summary statistics for different nesting parameters at Ras Al-Hadd Reserve, Oman. Measurements from peak and non-peak periods were combined as there were no significant differences between the periods.

Nest Parameters (cm)	n	Minimum	Maximum	Mean	S.E.	Std. Dev.
Body chamber wall depth	44	10.0	83.0	51.4	2.2	14.4
Body chamber length	50	110.0	275.0	181.3	4.5	32.0
Body chamber width	50	110.0	299.0	172.9	6.3	44.5
Mound length	32	150.0	500.0	314.2	17.3	97.8
Mound width	32	100.0	212.0	159.8	4.8	27.4
Body chamber center point depth	29	27.0	85.0	47.9	2.4	12.8
Nest chamber depth	31	35.0	60.0	46.0	1.2	6.8
Nest chamber width	31	17.0	33.0	21.7	0.8	4.6

Table 2. Percent sand particle size (mm) distribution at four study sites, Ras Al-Hadd Reserve, Oman.

	Percent Sand Particle Size (mm) Distribution						
Location	>2	2-1	1-0.5	0.5-0.25	0.25-0.101	0.101-0.053	<0.053
Site 1	1.93	7.84	85.61	4.24	0.11	0	0
Site 2	0.15	2.43	44.01	26.80	25.76	0.44	0
Site 3	1.36	5.14	59.04	27.48	5.60	0.70	0.14
Site 4	1.56	4.26	66.95	20.15	6.06	0.17	0.04

92–113 cm); CW 91.9 ± 0.60 cm (range 83–100 cm); and body weight 113.8 ± 2.16 kg (range 85–145 kg). Spearman correlation coefficient revealed a highly significant correlation between CL and CW ($r = 0.77$, $p < 0.0001$), CL and body weight ($r = 0.76$, $p < 0.0001$), and CW and body weight ($r = 0.76$, $p < 0.0001$).

Beach Parameters. — The nesting turtles in the four sites during the peak period showed no preference to beach slope and sand particles as hundreds of turtles invaded these beaches, with continuous changes in the nesting populations of the four sites every night. Field observations confirmed that there is a lack of consistency as to the turtles' preference for a certain site. For example, site 3 may have had 50–75 nesting turtles while site 2 may have had as many as 200–400 turtles in a given night and the reverse could occur the following night. Lack of consistency in number of turtles on these beaches was found throughout the nesting season.

Sand particles in sites 1–4 (Table 2) were fairly consistent especially in sites 1, 3, and 4. An area in site 3 had finer sand particles than in the rest of the sites and nesting here was very rare during both periods. Most of the sand particles varied between 0.5–1.0 mm.

Sheltered beaches with hills in the background were found in sites 1 and 2 where the majority of the nesting turtles were found. Beach slope varied between 1.5 and 2.5 m in the four sites.

DISCUSSION

At Ras Al-Hadd Reserve, the nesting season is year-round. Because of the extended nesting season, there are continuous changes in the nesting population throughout the year. Based on the dynamics of the population structure, the green turtles in this region have developed an important behavioral strategy by nesting in great numbers during June–October, which is an ideal nesting time. The number of turtles decreases significantly during the rest of the year as nesting becomes less favorable.

The nesting season for green turtles in other regions occurs either during most of the year or is restricted to a few months of the year (Hirth and Carr, 1970; Hirth, 1971). Nesting period in the southern sector of the Arabian Peninsula is nearly year-round with a peak (high-density) in summer or fall depending on location (Hirth and Carr, 1970; Ross and Barwani, 1982; Miller et al., 1989). The year-round breeding in green turtles in Oman and adjacent regions may be related to the warm waters of this region throughout the year (Miller et al., 1989).

The southwest monsoon (May–September) generates clockwise water surface movement along the Arabian coastline breaking down into unstable gyres. This causes upwelling as water falls below 20ºC with a significant increase in inorganic nutrients. This results in food production including sea grasses and algae, the major food for green turtles (Ross, 1985). During the northeast monsoon (October–May), a reversal of airflow takes place with less intense counterclockwise gyres. During this period, the nutrient levels fall, followed by a reduction in availability of aquatic plants. Thus, the increase in nesting turtles at Ras Al Hadd coincides with the increase in food production during the southwest monsoon.

An additional factor is the effect of wind direction. Change in wind direction during the southwest monsoon causes dramatic changes in beach configuration. The sand on the tide line in one beach moves via wave action northward to the adjacent beach. This sand translocation occurs throughout the 72 km stretch of Ras Al-Hadd Reserve. The reverse condition occurs during the northeast monsoon. The beach dynamics may play some role in nest selection during peak nesting period. During the southwest monsoon, nesting strips on beaches become narrower because of beach loss. Under these conditions, the struggle for nesting space becomes more competitive, with some possible impact on nesting behavior.

Although there were some significant differences relative to the duration of time of each nesting phase, the total nesting time during high and low density was not significantly different. Travel time from sea to nest site and back to sea, and digging the nest chamber are positively correlated with total nesting time. This implies that total nesting time can be mainly influenced by these three phases. Travel time from the sea to the nest site and back to sea can be influenced by many factors such as degree of crowding, obstacles, and beach dynamics, while nest chamber excavation can be prolonged by inadequate sand moisture.

In this investigation, new information on nesting behavior was reported and more elaboration on aspects of previous studies presented. The new observations include details of the scooping motions of the turtles; specifically, the synchronized rotation counterclockwise by the right rear flipper and clockwise by the left rear flipper for digging and carving the nest into a final pear-shaped chamber. These maneuverability patterns are not only important in shaping the chamber vertically and horizontally but also in preventing frequent nest collapse.

After the turtle finished burying its eggs, it created a trailing mound extending forward from the egg chamber. Future investigation on the significance of such elaborate mound building by the green turtle would be of interest, not only as a nest camouflage, as previously reported (Al-Gheilani, 1996), but also for possible association with temperature regulation and gas exchange during incubation.

During excavation of the nest chamber, abandonment is less frequent during the high-density period, starting in June. Frequently, the air is saturated with moisture attributed mainly to the southwest monsoon winds making the sand damp and firm, ideal for nest excavation without collapse. However, during this period, the dramatic increase in the number of nesting turtles on the beach may play a major factor as the turtles compete for nest sites under crowded conditions. In November, the winds blow from the desert northwest and cause drying of the sand, thus nest collapse becomes more frequent, and consequently, nest abandonments are significantly increased.

The data revealed that while 52% of turtles during the peak period successfully nested after one or several attempts, only 19% nested successfully during the non-peak period. This implies that sand moisture may be the major factor affecting nest construction. In all, 19% of the turtles nested successfully in their first attempt during the peak period, compared to 6% during non-peak. The percentages of turtles that had more than one attempt, but eventually successfully completed their nesting, was 32% during the peak period and 23% during the non-peak period.

During the high-density period egg mortality increased because of the high frequency of nest building in the tide zone, with eggs washing away, and also the increase in incidence of re-digging previous nests, exposing eggs to predators. However, the incidence of re-digging was surprisingly low during the period of this investigation.

The extended nesting season is perhaps a reproductive strategy for survival in this species, at least in the populations of the Gulf region. The long nesting season enables the green turtles to have a higher nesting success and increases the chance of a higher emergence rate (AlKindi et al., unpubl. data). Also, the long nesting season is another means to ensure the proper sex ratio (Miller, 1985) as sand temperature changes during the long span of nesting season.

Of the four sites studied, there are indications that sand particle size and well-sheltered beaches may play a role in nest site selection. For example, during peak period, hundreds of turtles nested predominately in sites 1 and 2 with lesser numbers in 3 and 4 without any apparent preference. However, in one area of site 4, the sand particles are very fine and nesting in that area was rare. Nesting is observed year-round at sites 1 and 2, but during non-peak period, the well-sheltered site 1 with less human activity is used more frequently than site 2. At sites 3 and 4, nesting is rare during the non-peak period and seldom year-round as these sites are not well sheltered. We suggest that the green turtles are opportunistic in their choice of nest site selection; they choose the best available site without any particular preference.

Green turtles usually nest on beaches with vegetation (Bustard, 1972; Wang and Cheng, 1999). However, the beaches at Ras Al-Hadd have very little vegetation, and the green turtles nest anywhere without any apparent preference. Perhaps green turtles and sea turtles in general have adapted to different sets of ecological and physical conditions throughout the world. This adaptability is of value for species survival.

At Ras Al-Hadd Reserve, the incidence of re-digging old nests by other turtles is low during the high-density period even though there are large numbers of nesting turtles in a small area. Our observations indicate that the turtles are discouraged from nesting on or near an inclination such as previously-made nesting mounds.

Reactions of the green turtles to stress varied between peak and non-peak periods. For example, performing two stressful procedures, blood sampling and tagging, affected the turtles differently during the two periods. The number of turtles that remained on the beach after the procedures was significantly higher during peak than non-peak periods.

During peak period, some emerging turtles occasionally collided with nesting turtles that had already started the nesting process. The emerging turtles would usually leave for other sites after the collision. Some of the nesting turtles aborted nesting, especially if they had not oviposited their eggs. Manipulation of turtles during filling or mound formation did not disturb or discourage the turtles from continuing their nesting. In addition, when the turtles were physically moved from their nests to other sites while they were engaged in filling or mound formation, they continued the same motions as if unmoved from the actual nest.

It appears that the degree of stress or reaction to disturbance may depend on the number of nesting turtles on the beach. When a large number of turtles are present, they seem to have high tolerance for disturbance, especially after they have oviposited their eggs. They appear less cautious and fearful of their surroundings, as the majority of them were not disturbed by human presence. During low-density period, they were more cautious, with a lower tolerance for human presence or degree of stress.

Overall, it is difficult to state with certainty the causes that altered the behavior of the green turtle during its year-round nesting season. However, based on field observations during peak period, the turtles seem to develop a strong urgency to nest. We also noticed during peak period that a few turtles nested early in the evening, occasionally 20–30 min before sunset. During non-peak, we did not witness such behavior. Early nesting may be influenced by crowding.

The green turtle populations in the Arabian Gulf and the Arabian Sea are fairly protected at the present time, but this cannot be guaranteed in the future. Currently, most of the nesting beaches in this region are well isolated with little coastal development. Commercial fishing is becoming increasingly intensive and it is expected to inevitably affect the turtle populations in this region. Fortunately, adult and/or egg harvests are very minimal because they do not constitute a highly desired source of food. In addition, the Government conservation regulations are playing a major role in protecting the populations of sea turtles. Ras Al-Hadd Reserve is one of the largest nesting grounds in the world for the green turtles. Its favorable conditions make it one of the most strategic locations for nesting turtles in the southern sector of the Arabian Peninsula. Conservation and management programs are urgently needed to maintain already established green turtle populations and promote an increase in their numbers in this region.

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