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Breeding biology of the green turtle, *Chelonia mydas* (Reptilia: Cheloniidae), on Wan-An Island, PengHu archipelago. II. Nest site selection

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Abstract Nest site selection of the green turtles on Wan-An Island in the summer of 1996 was determined. Turtles (*Chelonia mydas*) laid on average one clutch for every three emergences. Even though the total track length was 115 m on average, individual lengths varied considerably depending on the nesting beach where the turtles emerged. Limited accessibility, i.e. adequate distance from the nearest village and a well-protected environment, make beaches A and D suitable nesting beaches for green turtles on Wan-An Island. Both total track and nesting track apexes were found clustered in the interface zone, and turtles preferred to reach the vegetation zone once they emerged from the sea. It is suggested that the turtles on Wan-An Island exhibit nest site selection behavior. Based on these results and the high nest site fidelity to their first nesting beach, conservation recommendations are proposed to the county and central governments for the preservation of nesting beaches in their natural state, by prohibiting illegal sand mining and properly controlling turtle watch groups on Wan-An Island.

Introduction

Proper nest site selection is important for the maintenance of sea turtle populations. Nest placement and the characteristics of the sand can influence the survival and sex ratio of hatchlings, and thus the reproductive fitness of the population (Mrosovsky and Yntema 1980; Mortimer 1982; Ackerman et al. 1985; Whitemore and Dutton 1985; Mrosovsky and Provancha 1989; Mrosovsky 1994; Ackerman 1997). Selection patterns, however, vary from one species to another. For example, Stoneburner and Richardson (1981) found that site selection by loggerhead turtles in Florida was related to the sand temperature gradient, while Bjorndal and Bolten (1992) were unable to demonstrate any clear selection pattern among the green turtles at Tortuguero, Costa Rica.

Various hypotheses have been proposed. Some have suggested that the nesting sites are maximally scattered or even selected at random (Mrosovsky 1983; Tucker 1990; Hays et al. 1995). Others have suggested that beach topography, including slope, microhabitats, and submerged rocks (Dodd 1988; Horrock and Scott 1990; Crain et al. 1995; Hays et al. 1995; Mortimer 1995), beach vegetation (Horrock and Scott 1990; Hays and Speakman 1993; Mortimer 1995), light-pollution (Mortimer 1995; Salmon et al. 1996; Witherington and Martin 1996), thermal cues (Stoneburner and Richardson 1981), interspecies competition (Whitmore and Dutton 1985), and human disturbance (Williams-Walls et al. 1983; Murphy 1985; Witherington 1992) can influence nest site selection. On the other hand, it has been argued that the structural properties of the sand, such as compressibility, and the characteristics of the particles are unrelated to nest site selection in green turtles (Mortimer 1990, 1995; Foote and Sprinkel 1994). Gravid green turtles have been found nesting on particles with a wide range of sizes and sorting coefficients (Mortimer 1990).

The nesting ecology of the green turtles on Wan-An Island, PengHu Archipelago, Taiwan, has been studied previously (Chen and Cheng 1995). Post-nesting migration (Cheng and Balazs, in preparation) and the inter-nesting marine habitats (Yang 1996) have also been studied. Nest site selection, however, is still not fully understood although preliminary studies found that more nests were located in the interface zone than on other areas of the beach – an observation which has also been reported for loggerhead turtles in Florida (Hays and Speakman 1993). We formulated a hypothesis that vegetation has a significant influence on nest site selection of the green turtles of Wan-An Island.

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Materials and methods

Description of the study site

The morphology and other beach characteristics have been described previously (Chen and Cheng 1995) and are briefly reviewed here. Wan-An Island is located on the south side of the PengHu Archipelago (Fig. 1). Most of the 5000 residents are fishermen. The average surface water temperature was about 24.7 °C, with little temporal variation during the study period. The annual precipitation is about 1117 mm, mainly in the monsoon and typhoon seasons. The tidal cycle is semi-diurnal, with amplitudes ranging from 0.78 to 1.91 m.

There are 11 relatively flat sand beaches, all of which are composed of quartz propyrite, coral and shell debris. The beaches range from 67 to 800 m in length and from 20 to 100 m in width and are separated by rocky outcrops. Turtles are known to emerge on 9 of these 11 beaches, all of which are located on the south and west sides of the island (Fig. 1, beaches labeled from A to I). The total length of beach, which the green turtles use for nesting, is about 4 km.

On the beaches, three distinct zones were recognized: the vegetation zone, defined as the supra-littoral vegetation area that backed onto the beach; the open beach zone, defined as the open beach, an area where there was no vegetation coverage; and the interface zone, defined as a corridor extending for 1 m on either side of the vegetation line. The vegetation line itself was defined as the boundary between the vegetation and the open beach. There are two common grasses found on the nesting beaches: *Cynodon dectylon* (L.) Beauv. and *Pennisetum setosum* (Sw.) L.C. Rich. They all belong to the family of Gramineae.

Field surveys

Male turtles have never been observed to emerged over the past 7 years of survey on Wan-An Island, nor have we heard from local residents that they have ever seen male turtles emerge; we assumed in the present study that all emerging turtles were female. Two

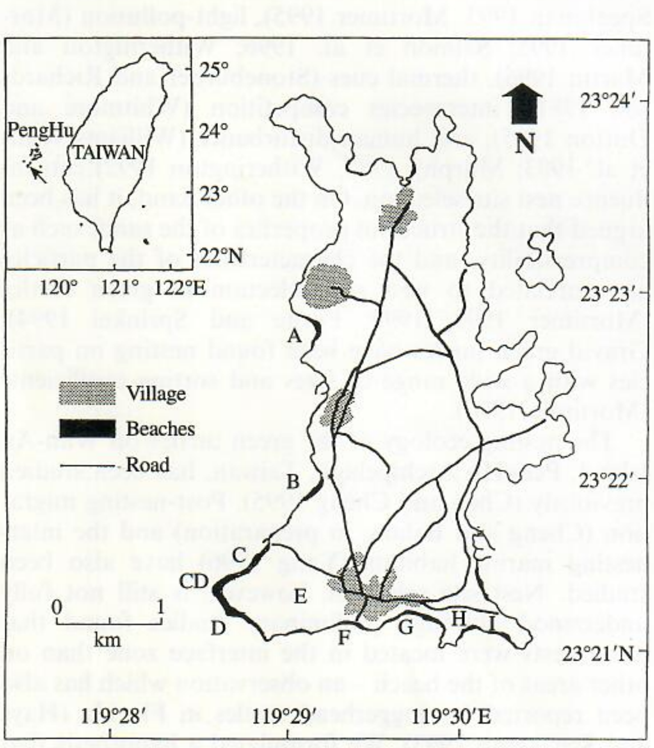

Fig. 1 Map of Wan-An Island, PengHu Archipelago. Beaches surveyed in this study are labeled from A to I

types of surveys were conducted between June and October 1996: intensive nocturnal and morning track counts. During the nocturnal surveys, the beaches labeled from A to I (Fig. 1) were surveyed at least twice each night between 19:00 and 04:00 hrs to search for emergence tracks and turtles, and to determine whether any females had nested, attempted to do, or emerged just as a spawning rehearsal. When turtles were encountered, their morphological characteristics, such as curved carapace (CCL) and straight carapace lengths (SCL) were recorded, and the turtle was tagged. During the morning track count, the beaches were surveyed only once, after daybreak, to search for tracks, nests and digging attempts that may have been overlooked on the previous evening. All tracks were followed, and nest positions were recorded with a GPS personal surveyor (Garmin, GPS 100 SRVY II). Because the accuracy of this GPS surveyor was ±1000 m, a differential GPS (DGPS) was used afterwards to pinpoint locations within 3 to 5 m. For the purpose of this study, two terms were calculated.

1. Nesting success (NS) is calculated as:
   NS (%) = (number of nests/number of emergences) × 100.
2. Digging success (DS) is calculated as:
   DS (%) = (number of nests/number of digging attempts) × 100.

Identification of the female turtles

Turtles encountered on the beach were labeled by clipping an Inconel tag on each of the front flippers (National Band and Tag Co., Style 681). The tags were imprinted with the two identification letters "TW", followed by three numerals (e.g. TW001). The return address was printed on the reverse side of each tag.

Determination of the track length, nest position, vegetation line, and spring tide line

The track lengths and directions were determined by walking along the tracks while using the dynamic function of the GPS surveyor. The vegetation line was similarly determined prior to the nesting season with the GPS surveyor, and tracked again in early August to determine the temporal variation in the vegetation line. In the same way, spring tide line was also determined prior to the nesting season by tracking the debris line caused by the spring tide. This debris line was tracked again in mid-August.

The nest position was determined by using the static function of the DGPS, with the machine being placed above the nest for at least 5 min to increase its accuracy. An iron plate (30 cm × 50 cm) was buried by the nest to facilitate site identification by a metal detector (JW Fishers Co., Model Pulse 6×). Other landmarks on the beach were also used to assist identification of the nest location. For the purposes of this study, the following parameters were recorded: the total track length (TTL), the emergence track length (ETL), the return track length (RTL), track apex (TA), and the intra-track width (IW) (Fig. 2).

Statistical analysis

The data were analyzed by a parametric method if the population was distributed normally or had equal variance. Otherwise, the data were analyzed by a non-parametric method. The *t*-test and one-way ANOVA were used to compare the difference between (*t*-test) and among (one-way ANOVA) mean values. Either a linear regression or a correlation analysis method (Sokal and Rohlf 1982) analyzed the relationship between two parameters.

Results

Track characteristics

A total of 11 marked nesting turtles emerged in the season of 1996. A total of 142 tracks and 36 nests were

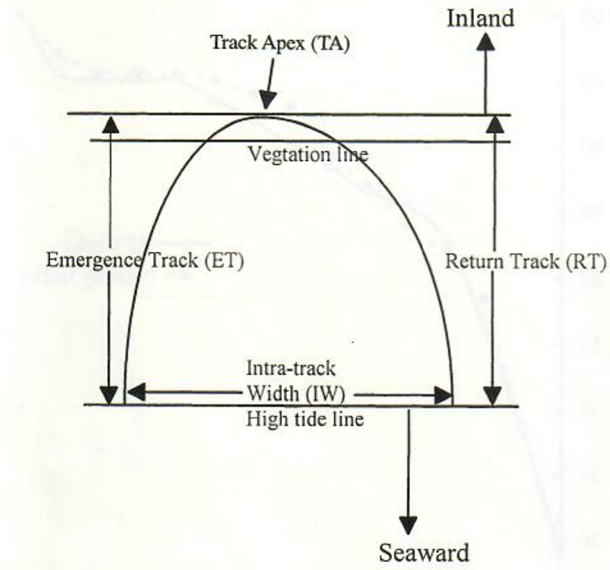

Fig. 2 Terminology of track characteristics

found. Of these tracks 102 (72%) were measured with the GPS, with half of these (51 tracks) being recorded during nesting activities. Two tracks (2% of the total) were located below the spring tide line and considered false crawls. Nesting tracks made up 32% of all measured tracks.

The maximum TTL for each individual turtle ranged from 160 to 490 m, and the minimum ranged from 10 to 95 m. On average, each turtle crawled 115 m on the beach after emerging (Table 1). The number of emergences per individual turtle ranged from 4 to 18, and the number of nests ranged from one to six. On average, each turtle emerged three times for each clutch it laid. Nesting success ranged from 17 to 75% (Table 1). In considering every emergence track of individual marked turtles on all nesting beaches, it was found that female turtles had a higher nest site fidelity to their first nesting beach (71%) than to others (18% on the adjacent beaches and 10% on more distant unknown beaches). This result is similar to findings in previous years (Fig. 3) (Cheng, unpublished data). No significant relationship was found between the straight carapace length (SCL) and the number of nests per individual per season, or between SCL and TTL.

Nesting beach

The maximum TTL was found on Beach CD (490 m) and minimum on Beach A (10 m). The emergence frequency was highest on Beach A (31 times) and lowest on Beach F (1 time). The nesting frequency was highest on Beach D (10 nests) and lowest on Beaches C and F (0). The nesting success was highest on Beach B (89%) and lowest on Beaches C and F (0%) (Table 2).

Intra-track width and ratio of emergence track length to return track length

More than 70% of the IWs were less than 25 m (Fig. 4). The peak ratio of ETL to RTL for all tracks was between 1.1 to 1.3. However, if only the nesting tracks were considered, the peak ratio was between 0.3 to 1.9 (Fig. 5).

Relationship between the track apex, nesting success, digging attempts and vegetation line

More than twice as many TAs were found in the vegetation zone as on the open beach (Table 3), and more than 70% of the TAs were located within 10 m of the vegetation line either in the vegetation zone or in the open beach zone. Negative linear relationships existed between the number of nesting track and emergence track apexes, and the distance of these apexes from the vegetation line ($p < 0.05$, in both cases) (Fig. 6). These two relationships were almost identical.

Table 1 *Chelonia mydas*. Body length, emergence frequency, number of clutches, nesting success, maximum, minimum and average total track length (*TTL*) of individual gravid green turtles on the Wan-An Island in the nesting season of 1996 (*CCL* curved carapace length; *SCL* straight carapace length; *TTL* total track length; *n.m.* not measured)

Turtle	Body size (cm)		Emergences per season	Clutches per season	Nesting success (%)	TTL (cm)		
	CCL	SCL				max.	min.	av.
1	111	106	18	3	17	160	10	65
2	99	92	7	3	43	287	37	95
3	109	102	12	4	33	490	35	177
4	120	108	16	5	31	342	38	150
5	108	101.5	12	5	42	321	18	103
6	93	89	5	3	60	222	36	125
7	111	n.m.	11	2	18	324	29	101
8	105	100.5	8	6	75	170	62	100
9	104	99.5	4	2	50	205	95	168
10	97	91	5	2	40	239	21	83
11	100	94	4	1	28	203	49	94
Average	104.6	98.4	9	3	40	269	39	115

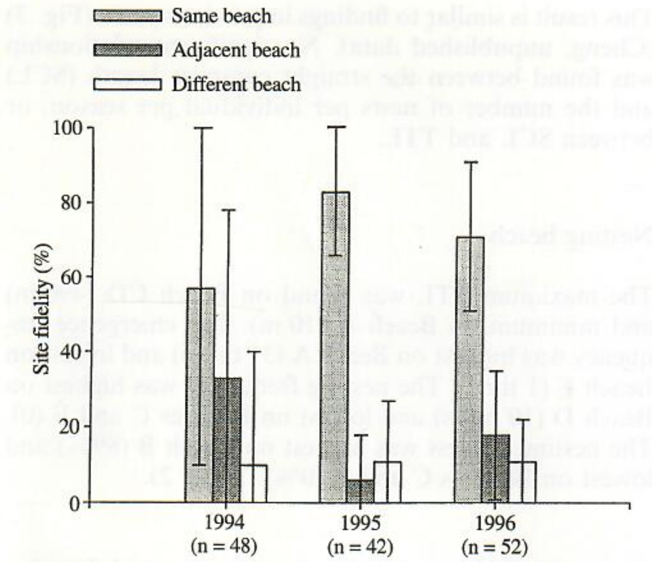

Fig. 3 *Chelonia mydas.* Nest site fidelity of the green turtle to the previous year's nesting beach on Wan-An Island, PengHu Archipelago from 1994 till 1996

Table 2 *Chelonia mydas.* Emergence frequency, number of clutches, nesting success, maximum, minimum and average total track length (*TTL*) of gravid green turtles on individual beaches of Wan-An Island in the nesting season of 1996

Beach	Emergences per season	Clutches per season	Nesting success (%)	TTL (m) max.	TTL (m) min.	TTL (m) av.
A	31	9	29	287	10	66
B	9	8	89	222	36	109
C	3	0	0	160	73	114
CD	17	3	18	490	36	173
D	20	10	50	324	31	136
E	9	1	11	203	18	68
F	1	0	0	119	119	119
G	6	2	33	324	46	132
H	2	1	50	239	95	167
I	4	2	50	205	27	151
Average	10	4	33	257	49	124

As Fig. 7 shows, digging success was highest between 10 to 12.5 m and 15 to 17.5 m inland from the vegetation line. It is curious that no TAs were found between 12.5 to 15 m inland from the vegetation line. On the open beach, high digging success was found between 5 to 7.5 m from the vegetation line (Fig. 7). Digging success was higher in the vegetation zone than on the open beach ($p < 0.05$) (Table 3).

More nests were found in the interface zone than in the other areas. The digging success, however, was highest in the vegetation zone (75%), followed by the interface zone (60%), and lowest on the open beach (23%) (Table 3). Conversely, number of digging attempts was highest on the open beach (35 times) and lowest in the vegetation zone (16 times) (Table 3).

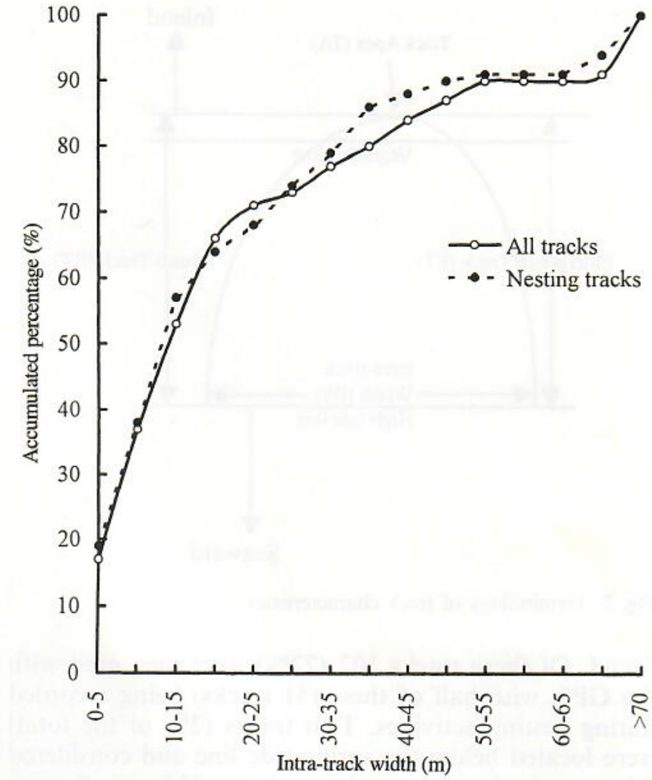

Fig. 4 *Chelonia mydas.* Accumulated percentage of intra-track width for total emergences and successful digging attempts of the green turtles on Wan-An Island, PengHu Archipelago in the nesting season of 1996

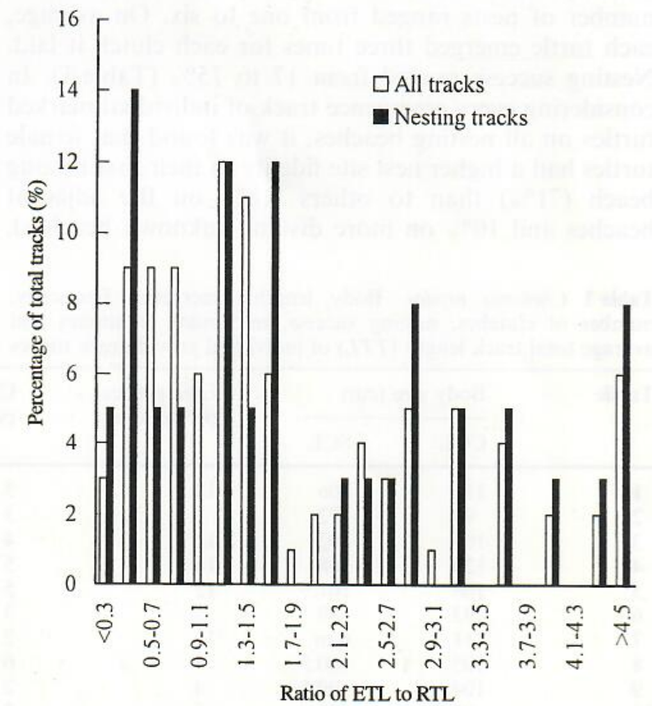

Fig. 5 *Chelonia mydas.* Distribution of the ratio of emergence track length (*ETL*) to return track length (*RTL*) of the green turtles on Wan-An Island, PengHu Archipelago in the season of 1996

Table 3 *Chelonia mydas*. Number of total track apexes, number of nests, digging attempts, nesting success and emergence-specific digging attempts of gravid green turtles in different zones on the beaches of Wan-An Island in the season of 1996

	Vegetation zone	Interface zone	Open beach zone
Number of track apexes	60	25	17
Number of nests	12	16	8
Digging attempts	16	21	35
Digging success (%)	75	60	23
Digging attempts/emergence	0.27	1.1	2.1

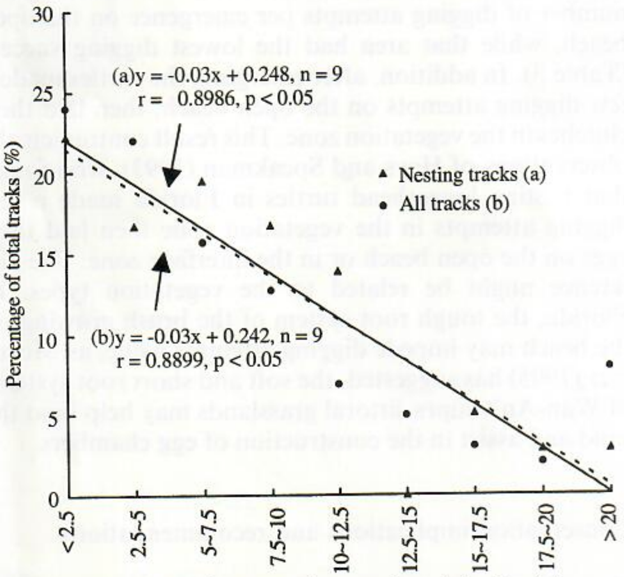

Fig. 6 *Chelonia mydas*. Relationship between the distance of the apex from the vegetation line and the percentage of (*a*) emergence track and (*b*) nesting track apexes at that distance

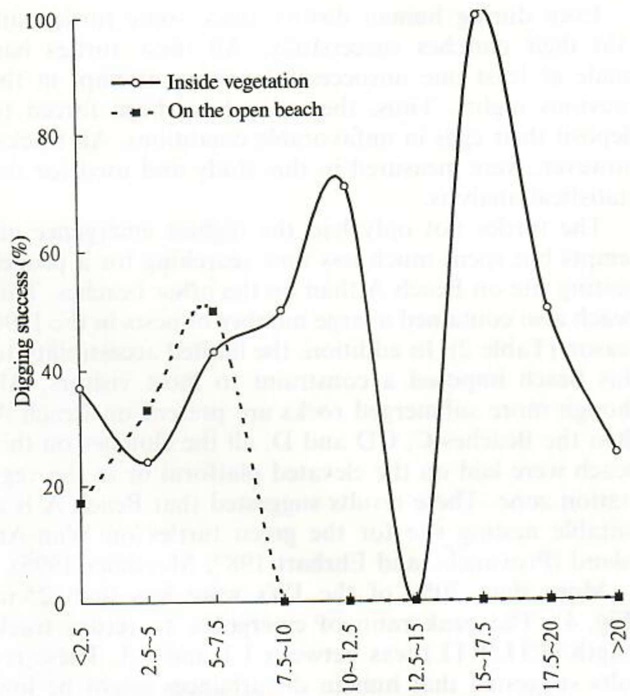

Fig. 7 Relationship between the digging success and the distance between the track apex and the vegetation line

Discussion

General nesting behavior

In this study, we found that the turtles lay on average one clutch for every three emergences (Table 1). Some of these emergences can probably be explained as unsuccessful searches for suitable nesting sites, while others ended in abortive digging attempts (see Table 3). It is also possible that interference by humans or other animals, the encounter of digging impediments, or unsatisfactory thermal cues might have been involved (Mortimer 1990; Salmon et al. 1996; Witherington and Martin 1996). No relationship between body length and TTL was found in this study. This suggests that some turtles might exhibit nest site selection behavior. The lack of relationship between body length and the number of nests per individual was similar to observations by Hays and Speakman (1993).

Each turtle crawled on average 115 m after each emergence, but individual total track length varied considerably, depending on the nesting beach where the turtle merged. Beach A is the smallest beach; the turtles spent much less time searching for a nest site than on the other beaches. Conversely, the turtles spent the most time on Beach CD which has the longest distance between the spring tide line and the vegetation zone (Table 2).

The fact that Beach F had no nest at all and only one emergence might be related to the presence of a nearby village, to which it is connected by a paved road (Fig. 1). An increase of human access to a beach will frighten turtles away and induce them to nest on beaches that would otherwise be less desirable (EXPOSE Memorial Park Management Foundation 1984; Murphy 1985; Witherington and Martin 1996). However, we do not have a good explanation for the absence of nests on Beach C. This beach is as large as Beach D and is similarly protected. Even more curiously, Beach C was one of the more heavily used beaches by turtles in the summer of 1997 (Cheng, unpublished data). Beaches D and A, on the other hand, which had the highest number of nests and emergences, respectively, are not readily accessible to humans. Beach D is some distance from the nearest village, and an unpaved road that used to provide access to Beach A was washed away in a typhoon 3 years ago, so that this beach can only be reached via a small dirt track. As well as being screened by supralittoral, brush-covered dunes (Beach D) or hills (Beach A), the tomb-sites scattered around the entrance of both beaches are a further deterrent to nocturnal visitors.

Even during human disturbances, some turtles still laid their clutches successfully. All these turtles had made at least one unsuccessful nesting attempt in the previous nights. Thus, they may have been forced to deposit their eggs in unfavorable conditions. All tracks, however, were measured in this study and used for the statistical analysis.

The turtles not only had the highest emergence attempts but spent much less time searching for a proper nesting site on Beach A than on the other beaches. This beach also contained a large number of nests in the 1996 season (Table 2). In addition, the limited accessibility to this beach imposed a constraint to most visitors. Although more submerged rocks are present on Beach A than the Beaches C, CD and D, all the clutches on this beach were laid on the elevated platform or in the vegetation zone. These results suggested that Beach A is a suitable nesting site for the green turtles on Wan-An Island (Provancha and Ehrhart 1987; Mortimer 1995).

More than 70% of the IWs were less than 25 m (Fig. 4). The peak ratio of emergence to return track length (ETL:RTL) was between 1.1 and 1.3. These results suggested that human disturbances might be low on the island, allowing most of the emergence and return tracks to be close to straight lines. The peak ratio of the nesting TTL to RTL, on the other hand, varied a great deal ranging from 0.3 to 1.9. This could mean that some turtles take more time finding a suitable nest site, while others take a detour on their return journey to the sea. Nesting turtles are known to take such detours when they experience human disturbances, such as videos or flash photos, during the camouflage phase or during the return journey itself (Johnson et al. 1995, 1996; Witherington and Martin 1996). A few nesting females did experience such disturbances on Wan-An Island in the season of 1996.

More than 70% of the track apexes were located within 10 m of the vegetation line. Both the numbers of nests and track apexes decreased with the distance from the vegetation line (Fig. 6). In addition, more track apexes were found in the vegetation zone than on the open beach (Table 3). These findings are similar to those of Whitmore and Dutton (1985). Taken together they suggest that the green turtles prefer nesting and/or searching for their nest sites in the vegetation zone, which in turn supports our hypothesis that vegetation has a significant effect on nest site selection behavior.

The turtles might prefer nesting in the vegetation zone because the egg chambers are more prone to collapse on the open beach (Mortimer 1990, 1995). In addition, nests on the open beach are more susceptible to destruction (by the wave wash) (Mrosovsky 1983). In general, they prefer to reach the vegetation zone once emerged from the sea. This conclusion also supports our tentative hypothesis.

Within the vegetation zone, digging success was highest between 10 to 12.5 m and 15 to 17.5 m from the vegetation line (Fig. 7). At these distances behind the beach, the vegetation zone is mostly grass, and the damp beach sand is interwoven by grass roots which may make the substrate well suited for construction of the egg chamber. When the vegetation includes larger plants, with roots penetrating deeper into the sand, digging attempts could be impeded. In addition, the turtle may be inhibited from crawling too far inland and as a result too distant from the spring tide line (Hays and Speakman 1993). The highest number of nests found in the interface zone might be due simply to the high number of digging attempts in this region (Table 3). No nest was found between 12.5 and 15 m inside the vegetation line. This might be due to no turtle nesting in this area in the season of 1996.

On Wan-An Island, female turtles made the highest number of digging attempts per emergence on the open beach, while that area had the lowest digging success (Table 3). In addition, after emerging, the turtles made a few digging attempts on the open beach, then laid their clutches in the vegetation zone. This result contradicts the observations of Hays and Speakman (1993), who found that nesting loggerhead turtles in Florida made a few digging attempts in the vegetation zone then laid their eggs on the open beach or in the interface zone. The difference might be related to the vegetation types. In Florida, the tough root system of the brush growing on the beach may impede digging attempts while, as Mortimer (1995) has suggested, the soft and short root systems of Wan-An's supra-littoral grasslands may help bind the sand and assist in the construction of egg chambers.

Conservation implications and recommendations

Green turtles are known to have a high nest site fidelity (Carr and Hirth 1962; Carr and Carr 1972; Mortimer and Carr 1987). Similar results were observed in the present study; the turtles tended to return to their first nesting beach (Fig. 3). Both total track and nesting track apexes were found to cluster in the interface zone and decreased with the distance from the vegetation line (Fig. 6). The turtles also preferred to reach the vegetation zone, laid more nests and had greater digging success there compared to the open beach (Table 3). Furthermore, the highest digging success zone was much wider in the vegetation zone than on the open beach (Fig. 7). Refuge beaches for nesting green turtles on Wan-An Island were established by the Council of Agriculture, ROC in December 1994 (Cheng 1995). All the results presented in this study argue for the importance of beach protection, including the vegetation zone, to the nesting green turtles. We therefore recommend to both the Central and PengHu County governments that (1) nesting beaches, and especially the vegetation zones, should be preserved in their natural state, (2) illegal sand mining must be prevented, and (3) organized and unorganized turtle watch groups need proper control. All these measures are essential if suitable nesting sites are to be provided for the green turtles on Wan-An Isalnd. A well-protected nesting beach not only attracts more female turtles to lay their clutches there, but should also ensure more hatchlings and, thus, increase the reproductive fitness of the population.

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